DETAILED CHARACTERIZATION OF INDOOR AND PERSONAL PARTICULATE MATTER CONCENTRATIONS

FINAL REPORT
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ABSTRACT

A study entitled "Detailed Characterization of Indoor and Personal Particulate Matter Concentrations" was conducted to characterize indoor and personal exposures to $PM_{2.5}$, its major components, and to specific-size ranges for households located in the Los Angeles, CA (LA) metropolitan area. This study is a continuation of our efforts to characterize exposures to particles and their constituents. It complements our CARB-US EPA-funded study characterizing the PM exposures of individuals with chronic obstructive pulmonary disease (COPD) living in LA (Chang and Suh, 2003) and was conducted with co-funding from the US EPA to allow a more comprehensive indoor characterization study to be performed.

In this study, $PM_{2.5}$, black carbon (BC), nitrate (NO_3^-), and size-resolved particle volume concentrations were measured continuously inside and outside 17 LA homes. In addition, 24-h personal PM_{10}, $PM_{2.5}$, BC, NO_3^- exposures were measured for one individual living in each household. Daily time-activity and housing characteristics data were also collected for each household, while a house dust sample was collected in each home on one of the monitoring days. Data from our study provided novel and important information about the composition and size distribution of PM in LA homes, as it – for the first time – combined measurements of PM size and composition with data on air exchange rates, ventilation conditions, and activity patterns.

Mean 20-minute outdoor $PM_{2.5}$ (32.1$\pm$33.1 ug/m^3), BC (2.3$\pm$2.0 ug/m^3) and NO_3^- (12.0$\pm$10.6 ug/m^3) concentrations were higher than their corresponding indoor levels (17.9$\pm$18.7, 1.9$\pm$1.7, 3.5$\pm$6.1 ug/m^3, respectively). Diurnal variation in 20-minute indoor concentrations was found for all particulate species, which was generally related to diurnal variability outdoors. Nighttime F_{INF} values estimated using indoor/outdoor ratios and regression techniques showed patterns consistent with particle theory. F_{INF} values were highest for BC, which was expected given its non-reactive nature and its size (~0.1-0.5 um). Correspondingly, F_{INF} values were lowest for fine particle NO_3^-, a highly reactive pollutant that in LA may consist primarily of particles larger than 1.0 um. Nighttime F_{INF} for $PM_{2.5}$ fell between those for BC and NO_3^-. Correspondingly, the estimated value of ***P*** obtained using mass balance models was also highest for BC and lowest for NO_3^- (0.18±0.13), with the estimate for $PM_{2.5}$ again roughly equidistant between those for BC and NO_3^- (0.42±0.11). Estimated values for ***P*** were consistent with winter and were lower than summer estimates from our Boston study, with the low value likely resulting from the large contribution of NO_3^- to $PM_{2.5}$ in LA. Estimated values of ***P*** and ***k*** using dynamic models were generally imprecise, providing further evidence that the separate effects of ***P*** and ***k*** could not be estimated under "real-world" conditions.

24-h $PM_{2.5}$, NO_3^- and BC were highest outdoors (mean=28.8, 10.8, and 1.7 ug/m^3, respectively), with personal (17.7, 3.8, 1.8 ug/m^3, respectively) and indoor (17.6, 3.0, 1.6 ug/m^3, respectively) levels comparable. Personal $PM_{2.5}$, NO_3^- and BC exposures were significantly associated with indoor and outdoor levels. Slopes of the indoor-outdoor longitudinal regressions were comparable to those found using 20-minute data, suggesting that estimates of the effective penetration efficiencies for $PM_{2.5}$, NO_3^- and BC are stable. The slopes and intercepts for personal-outdoor regressions for all particulate species were similar to those for the indoor-outdoor associations, suggesting that personal exposures to ambient particles occur primarily indoors and that indoor concentrations are on average equivalent measures of personal particulate exposures.

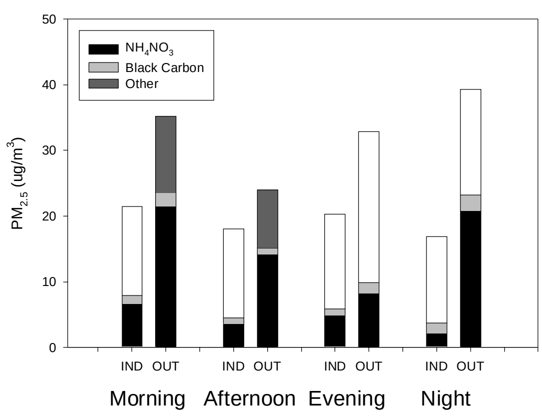
EXECUTIVE SUMMARY

Background. A study was conducted to characterize exposures to $PM_{2.5}$ and its major components for households in Los Angeles, CA. This study tested hypotheses that: (1) diurnal profiles of indoor $PM_{2.5}$, black carbon (BC) and nitrate (NO_3^-) are a function of outdoor levels, air exchange rates (AERs) and home activities; (2) penetration efficiencies and deposition rates are a function of AERs; (3) indoor concentrations are associated with personal particulate exposures; and (4) penetration efficiencies and deposition rates are similar for Los Angeles and Boston homes. Our study addresses a critical research question concerning the ability of stationary ambient monitoring (SAM) site measurements to estimate particulate exposures. It does so by improving our understanding of the fate and transport of ambient particles indoors, where exposures primarily occur. Importantly, our study provides among the first information about the composition and size distribution of PM indoors for Los Angeles homes.

Methods. $PM_{2.5}$, BC, NO_3^-, and particle volume concentrations were measured continuously inside and outside 17 Los Angeles homes. 24-h personal PM ($PM_{2.5}$, BC, NO_3^-) exposures were also measured for one individual living in each household each day, as were activity pattern and home activity information. One house dust sample was also collected in each home. Measurements were made for each home for seven days, with homes monitored consecutively from July 28, 2001 to February 25, 2002. The seven-day monitoring period for each home included at least two weekend days. Data were analyzed using a variety of techniques, selected based on the research question and the underlying data structure, and included descriptive summaries, correlation coefficients, generalized linear and mixed models, and micro-environmental exposure models.

Results. Mean 20-minute outdoor $PM_{2.5}$ (32.1$\pm$33.1 ug/m^3), BC (2.3$\pm$2.0 ug/m^3) and NO_3^- (12.0$\pm$10.6 ug/m^3) levels were higher than their corresponding indoor levels (17.9$\pm$18.7, 1.9$\pm$1.7, 3.5$\pm$6.1 ug/m^3, respectively), with differences greatest for NO_3^-. Indoor and outdoor concentrations varied diurnally and were significantly associated for all species. NO_3^- comprised a large fraction of outdoor $PM_{2.5}$, while both NO_3^- and BC comprised only small fractions of indoor $PM_{2.5}$ (Figure A1).

Figure A1: Composition of Indoor and Outdoor $PM_{2.5}$

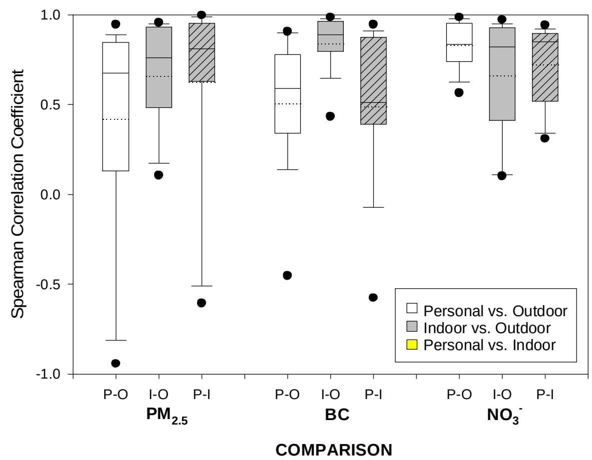


* NO_3^- in form of NH_4NO_3. Contributions of NO_3^- and BC determined based on its average ratio with $PM_{2.5}$ multiplied by the mean $PM_{2.5}$ concentration.

Nighttime F_{INF} values for each of the measured species were consistent with particle theory. F_{INF} was highest for BC, which was not surprising given its non-reactive nature and its typical size (~0.1-0.5 um). Correspondingly, F_{INF} was lowest for fine particle NO_3^-, a highly reactive pollutant that in LA. Nighttime F_{INF} for $PM_{2.5}$ fell between those for BC and NO_3^-, which can be attributed to the fact that both BC and NO_3^- are major components of $PM_{2.5}$ in Los Angeles. Nighttime F_{INF} values for the particle size intervals were consistent with those for $PM_{2.5}$ and its components, where F_{INF} values were highest for $PV_{0.02-0.1}$ and $PV_{0.1-0.5}$ and were lowest for $PV_{0.7-2.5}$ and $PV_{2.5-10}$. Consistent estimates were found using steady state models of nighttime periods. P was highest for BC and was lowest and statistically insignificant (0.18±0.13) for NO_3^-. The estimated P for $PM_{2.5}$ (0.42±0.11) was consistent with those for the size-resolved particles. The value of P was highest for particles between 0.08 and 0.4 um and was lowest for particles between 2.5 and 10 um. Estimated values for P were consistent with winter estimates and were lower than summer estimates from our Boston study, which is likely due to the fact that the highly volatile NO_3^- comprises a substantially large fraction of $PM_{2.5}$ in Los Angeles. Estimates of P and k obtained using the dynamic mass balance model could not be obtained, as for each time period and size, numerous *P* and *k* pairs resulted in similar model error. Precision of the estimates was greatest for post-indoor source time periods for *k* and for non-source, varying outdoor concentration periods for *P*. During these time periods, it is likely that either deposition or penetration, respectively, were the dominant influence on indoor PM levels. For any single time period, however, simultaneous, precise estimates for both *P* and *k* were not obtained.

Similar to 20-min and 6-hr levels, 24-h mean $PM_{2.5}$, NO_3^- and BC were highest outdoors (28.8, 10.8, and 1.7 ug/m^3, respectively), with mean personal (17.7, 3.8, 1.8 ug/m^3, respectively) and indoor (17.6, 3.0, 1.6 ug/m^3, respectively) levels comparable. Personal PM exposures were significantly associated with outdoor and especially indoor levels (Figure 2A). Using time-weighted estimates, indoor exposures comprised the largest fraction of personal PM exposures. Indoor exposures, particularly of BC, however, were comprised of a large fraction of PM originating outdoors, as evidenced by the slopes of the personal-outdoor and indoor-outdoor comparisons. Slopes of the indoor-outdoor longitudinal regressions for the PM species were comparable to those found using 20-minute data, suggesting that estimates of the effective penetration efficiencies for $PM_{2.5}$, NO_3^- and BC are stable. In addition, the slopes of the personal- and indoor-outdoor longitudinal regressions for $PM_{2.5}$ and NO_3^- were low, with the slope highest for indoor-outdoor $PM_{2.5}$ (0.42±0.04). This low value is likely due to the fact that the volatile NO_3^- comprises a large fraction of $PM_{2.5}$ in Los Angeles. Personal- and indoor-outdoor slopes for BC were higher, with values of 0.88±0.12 and 0.83±0.04, respectively. Similar slopes and intercepts for personal-outdoor and indoor-outdoor regressions were found for all species, suggesting that personal exposures to ambient PM occur primarily indoors and that indoor concentrations are on average equivalent measures of personal PM exposures. Air exchange rates were significant modifiers of the personal-outdoor and indoor-outdoor associations for NO_3^- but not for the other PM measures. Indoor-outdoor results for the 24-h and 6-h analyses agreed well.

Figure A2. Distribution of Individual-Specific Correlation Coefficients for 24-h Personal (P), Indoor (I) and Outdoor (O) $PM_{2.5}$, BC, and NO_3^- Comparisons



*BC concentrations estimated from reflectance measurements and their relationship to continuous indoor and outdoor BC. Dotted line shows mean concentrations.

Conclusions. $PM_{2.5}$, BC, NO_3^-, and particle volume concentrations varied diurnally, generally with corresponding diurnal variability in outdoor levels. Home ventilation was an important predictor of the indoor-outdoor association. Estimates of *P* differed substantially by particle species, with values highest for BC and $PV_{0.1\text{-}0.5}$ and lowest for NO_3^- and $PV_{2.5\text{-}10}$. Results suggest that $PM_{2.5}$ components and particle size groups may behave differently from total $PM_{2.5}$, with these differences greatest for reactive pollutants such as NO_3^-. Dynamic models were unable to estimate *P* and *k* precisely, with model errors similar for multiple *P* and *k* pairs.

Recommendations. Further research should be conducted to (1) characterize hourly indoor and personal $PM_{2.5}$, EC, and NO_3^- exposures in other cities and for other populations, (2) characterize spatial variability in air exchange rates within homes, (3) conduct controlled indoor particulate studies to estimate indoor particle source emissions, penetration efficiencies and decay rates for $PM_{2.5}$, its major components, and size resolved particle concentrations for a range of air exchange rates, homes, and indoor and outdoor levels, (4) clarify issues related to processing of aethalometer data, particularly as related to tape changes and monitor comparisons, and (5) characterize the effects of house characteristics and activities on the dynamics of indoor $PM_{2.5}$ and its components.

BODY OF REPORT

1.0 INTRODUCTION

The U.S. Environmental Protection Agency (US EPA) revised the National Ambient Air Quality Standard (NAAQS) for particulate matter to regulate particles with an aerodynamic diameter less than 2.5 microns ($PM_{2.5}$) and to effectively lower the allowable concentration of particulate matter in the United States. This revision was prompted primarily by results from epidemiological studies, which found associations between ambient particulate concentrations and a variety of adverse health indicators, including increased mortality, hospital admissions, blood inflammation markers, and reduced lung function (Pope 2000; EPA 2003). During the EPA revision process and the ensuing debate over the appropriate standard, numerous questions were raised about the validity of the epidemiological study findings. These questions highlighted the need for research to address these outstanding questions. In a report by the National Research Council, the research questions were listed as ten research priorities (NRC 1998). Included in their top ten research priorities was the need to improve our understanding of the relationship between personal particulate matter (PM) exposures and corresponding ambient concentrations.

Our ability to link ambient PM concentrations to personal exposures will be greatly enhanced through an improved understanding of the fate and transport of ambient particles in indoor environments, since exposures to ambient particles occur primarily indoors, where people spend more than 85% of their time. Three primary factors are known to affect the fate and transport of ambient particles indoors – natural air exchange through the building shell, the particle penetration efficiency through the building shell (P) and the particle deposition rate (k). Of these three factors, air exchange through the building shell is the best understood, as air exchange rates have been characterized under a variety of conditions for numerous homes located throughout the U.S. Typical air exchange rates in U.S. homes are lower than one exchange per hour, with rates varying widely by season, geographical location, and home.

For P and k, less is known about their levels. Estimates of both P and k have varied widely by study, perhaps as a consequence of the coupled nature of P and k, which make their effects difficult to separate. To date, this separation has been best achieved under controlled conditions in unoccupied test homes using a multi-stage approach that allows k and P to be determined independently (Chao et al., 2003; Vette et al., 2001; Thatcher et al., 2002, 2003). In the most sophisticated of these studies, for example, Thatcher et al. (2003) estimated k and P for two California residences using a three-stage design that created distinct periods in which either particle decay or particle infiltration predominated. k was estimated dynamically using data from the first stage, in which particles were allowed to decay after deliberate elevation of indoor particle concentrations. The second stage was a transition period, in which homes were pressurized using window-mounted HEPA filters to prevent entry of outdoor particles and to allow indoor particles to decay completely. In the third stage, P was estimated as home pressurization was terminated and particles were allowed to re-infiltrate the home. Using this design, k and P were found to range broadly with particle size in both homes, with k increasing from 0.1 to 5 hr^{-1} and P decreasing from 1.0 to 0.3 as particle size increased from 0.1 to 10 um. For P, estimates differed by home, especially for particles larger than 1.5 um, with the observed differences attributed to home age. Even with this home variation, the estimated values for both homes and their dependence on particle size are consistent with previous studies, likely due to the fact that estimates have ranged broadly by study. For 0.2 um particles, for example, estimates for *k* have varied by a factor of 100, as estimated values have ranged between approximately 0.01 and 1.0 hr^{-1} (Thatcher and Layton, 1995; Abt ***et al.***, 2000; Long ***et al.***, 2001; Vette ***et al.***, 2001; Thatcher ***et al.***, 2002; Thatcher ***et al.***, 2003). This broad range has been attributed to a variety of factors, including differences in home characteristics, airflow and temperature patterns, particle composition, and study design. Although the impact of these factors on estimates of ***P*** and ***k*** is not well understood, their impacts on ***P*** and ***k*** suggest that the generalizability of ***P*** and ***k*** estimates from any one study is low and that estimates from controlled studies in test homes are not relevant to real-world settings, where homes are occupied and ventilation and activity conditions change rapidly.

Under real-life conditions, estimation of ***P*** and ***k*** has been more challenging. Studies of particulate matter have tried to differentiate ***P*** and ***k*** using steady state models and data from non-source periods, since conditions in occupied homes do not generally allow particle decay or penetration to predominate, making independent estimation of ***P*** and ***k*** impossible. Long et al. (2001), for example, estimated ***P*** and ***k*** for 17 particle size intervals using steady state models and 6-h averaged nighttime data from 16 Boston area homes. Across all homes, ***P*** was found to be lowest for the ultra-fine (0.68 for $PV_{0.02\text{-}0.03}$) and coarse (0.28 for $PV_{4\text{-}5}$) particle sizes and highest for accumulation mode particles (0.86-0.89 for $PV_{0.04\text{-}0.3}$). Furthermore, penetration efficiencies were highest and more variable for all particle sizes in the summer as compared to winter months. Deposition rates showed the opposite particle size-specific pattern, with rates highest for the ultra-fine and coarse size categories, but did not vary by season. Size-specific differences in penetration efficiencies and deposition rates were consistent with known particle behavior and theory, while seasonal differences in penetration efficiencies were attributed to corresponding seasonal differences in air exchange rates (AER). Since estimates of ***P*** and ***k*** were study-wide, however, the specific effects of AERs, ventilation conditions and home on ***P*** and ***k*** could not be determined. Additionally, the use of 6-h data, as necessitated by the reliance on steady state models, ignores the fact that AERs vary temporally, adding to uncertainty in the estimates.

Our study continues efforts to characterize ***P*** and ***k*** and factors affecting their levels for particles in occupied homes. As part of this effort, $PM_{2.5}$, black carbon (BC), nitrate (NO_3^-) and size-resolved particle volume concentrations were measured continuously inside and immediately outside 17 Los Angeles area homes. In addition, 24-h personal PM (PM_{10}, $PM_{2.5}$, BC and NO_3^-) exposures were measured for one individual living in each household. Time-activity and housing characteristics information and house dust samples were also collected for each of the monitored households for each monitoring day. The study represents a continuation of our efforts to characterize outdoor, indoor and personal exposures to particles and their constituents. It complements our CARB-U.S. EPA-funded study characterizing the PM exposures of individuals with chronic obstructive pulmonary disease (COPD) living in Los Angeles (Chang and Suh, 2003). In addition, the study was conducted with co-funding from the U.S. EPA, which included moneys to perform an indoor characterization study in Boston. These EPA funds were added to those from CARB, so that a more comprehensive indoor characterization study could be performed in Los Angeles. Data from our study provides among the first information about the composition and size distribution of PM indoors in Los Angeles homes, as it – for the first time – combined measurements of PM size and composition with measurements of most factors known to affect their levels, including air exchange rates, ventilation conditions, and activity patterns.

2.0 PROJECT OBJECTIVES

The primary objectives of the study were to characterize the diurnal variation in indoor PM levels and to examine the impact of housing and activity factors to indoor levels. Specifically, the study was designed and carried out to test four primary hypotheses, that:

- Diurnal profiles of indoor $PM_{2.5}$, black carbon and nitrate are a function of outdoor concentrations, air exchange rates and indoor source emissions
- Penetration efficiencies and deposition rates are a function of air exchange rates
- Indoor concentrations are strongly associated with personal exposures for particles
- Penetration efficiencies and deposition rates are similar for Los Angeles and Boston homes

To test these hypotheses, numerous continuous and integrated particulate measurements were made and housing characteristics and activity information was obtained for one week in each of seventeen homes. These measurements were used to:

- characterize the diurnal variation in indoor $PM_{2.5}$, BC, and NO_3^- concentrations;
- estimate the contributions of indoor particulate sources, such as cooking, cleaning, and activity, on indoor concentrations;
- determine the impact of outdoor concentrations, home ventilation conditions, air exchange rates, and home activities on indoor particulate levels;
- estimate particle deposition velocities and penetration efficiencies;
- characterize the chemical composition of personal $PM_{2.5}$ exposures;
- estimate the contribution of indoor and outdoor particles to personal exposures,
- investigate the relationship among 24-h indoor, personal, and outdoor PM exposures;
- identify factors that are important predictors of indoor particulate concentrations;
- characterize phthalate concentrations in house dust; and
- compare the results to those obtained in multi-pollutant exposure studies of individuals with COPD living in Los Angeles, CA, Boston, MA and Atlanta, GA and to those from indoor particulate characterization studies conducted in Boston.

3.0 MATERIALS AND METHODS

The study was conducted in three parts. In the first part of the study, continuous or semi-continuous particulate concentrations were measured inside and outside each of 17 homes to characterize the diurnal variability in particulate levels and to identify factors affecting this variability. As part of this effort, continuous air exchange rates were measured and daily housing activities were recorded. In the second part of the study, 24-h personal, indoor, and outdoor particulate exposures were measured for one individual living in each of the 17 homes. For the monitored individual, time-activity information was also obtained using participant completed diaries. These data were used to characterize the relationship between personal exposures and corresponding indoor and outdoor levels. Finally, house dust samples were collected in each home to assess the levels of phthalates present in the dust, in order to address concerns about exposures to potential endocrine disrupting compounds Due to cost limitation, however, only a subset of these samples were analyzed for phthalate concentrations.

Monitoring for Parts 1, 2 and 3 of the study was conducted simultaneously. Measurements made as part of each of the Study Parts were made in each home over a seven-day monitoring period, with monitoring equipment set up and removed from the home on the day preceding and immediately after this period, respectively. The seven-day monitoring period for all homes included at least two weekend days. Homes were monitored sequentially, such that no homes were monitored simultaneously. In all, monitoring was conducted from July 28, 2001 through February 25, 2002.

3.1 Part 1: Continuous Particulate Concentrations

3.1.1 Household Recruitment

A total of 17 households in the Los Angeles (LA) metropolitan area participated in the study. Households were identified primarily through personal contacts, since the participant burden was high, with significant participant involvement required. Sampler operation required significant space and power usage, while questionnaire completion required study participants to monitor and record household activities continuously. Potential participants and households were identified and contacted by Dr. Colome. Non-smoking households were asked to participate in the study, while households with sufficient room to house all of the monitoring equipment and in inland locations were preferentially asked to participate in the study. Other selection criteria included willingness to complete daily activity questionnaires and willingness of one individual in the household to wear a personal monitor. [A description of individuals participating in personal monitoring is included in Section 3.2 or Part 2 of the Methods section.] Households were compensated $400 to cover electricity costs ($150) and their time ($250).

3.1.2 Household Profiles

Households were located throughout Los Angeles Basin, with five of the homes located in coastal areas (Figure 1). As shown on Table 1, monitored homes were one-family homes, with the exception of House 17 that was an attached home. Most homes were located away from major outdoor construction. No homes were located near unpaved roads, restaurants, industrial activity, or near a bus or truck depot. Only one house (House 1) was located near a local burning source. Five homes (Houses 3, 5, 7, 10, 17) were located within 400 meters of a major road. Most of the monitored homes had gas stoves, with two of the homes having electric stoves (Table 2). Homes with stoves primarily had range hoods with a vented exhaust fan. Every home had at least one gas-fueled appliance, such as a stove, heating, water heater or clothes dryer. The houses generally had gas heating with central heat distribution systems. Of those not using gas central heating systems, House 3 had an electric heating system and House 13 used floor heating. Most houses had central air conditioning systems. Three homes were equipped with air cleaners (Houses 1, 12, 17). Floor coverings on first and second stories (where applicable) were mainly carpet. One house used area rugs and two houses had wood covering on the first floors (House 5, House 17). Kitchen floors were covered with vinyl (1 house), tile (4 houses) or wood (12 houses).

Figure 1. Map of Participant Homes

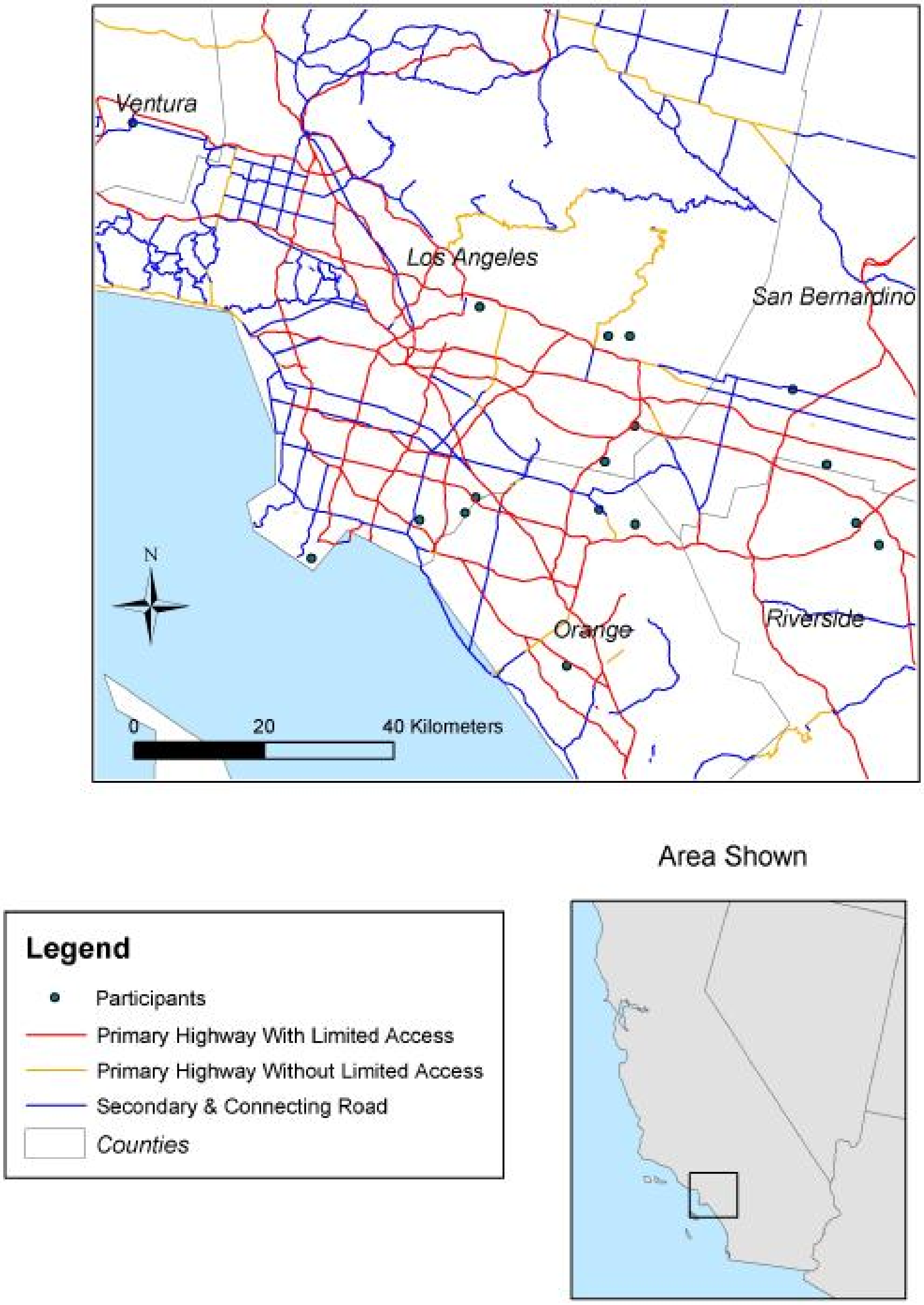


Table 1. Household Profile

House #	Start Date	End Date	City (CA)	Year built	Volume (m^3)[a]	# People	# Pets	Distance from Major Road (m)	Inland?[b]	Potential Sources
1	07/26/01	08/03/01	Irvine	?	471.7	3	2	663	Yes	Busy street, airport, Burning
2	08/18/01	08/27/01	Riverside	1929	420.2	1	1	724	Yes	--
3	08/29/01	09/07/01	Simi Valley	1998	582.5	4	0	253		Attached garage, open field
4	09/09/01	09/17/01	Glendora	1968	469.1	4	1	1699	Yes	Open field
5	09/20/01	09/28/01	Cerritos	1973	744.4	4	0	371		Attached garage
6	10/01/01	10/09/01	Glendora	1962	478.1	4	1	3548		Indoor and outdoor construction, open field, landscaping
7	10/11/01	10/19/01	Diamond Bar	1966	328.1	2	7	82	Yes	Attached garage, landscaping, open field
8	10/22/01	10/30/01	Riverside	1975	475.4	2	0	2239	Yes	Attached garage
9	11/01/01	11/09/01	Fontana	1985	489.8	2	0	2539	Yes	Attached garage
10	11/12/01	11/19/01	Altaloma	1990	536.9	3	0	166	Yes	Attached garage
11	11/28/01	12/06/01	Cypress	1940	426.0	3	1	2446		Attached garage, open field
12	12/09/01	12/16/01	Yorba Linda	1980	634.8	4	1	1743		Attached garage
13	01/07/02	01/15/02	Long Beach	1950	225.8	3	0	966		Home construction, airport, possible night wood burning
14	01/17/02	01/24/02	Pasadena	1914/ 1997	1230.6	6	1	1499	Yes	Home Construction
15	01/28/02	02/05/02	Diamond Bar	1978	811.8	2	0	842	Yes	Attached garage, Home construction
16	02/07/02	02/15/02	San Pedro	1910	442.9	1	0	1502		Home construction, smoker next door
17	02/18/02	02/26/02	Yorba Linda	1976	166.0	1	0	248		--

[a] House volume includes garage. [b] Inland designation determined based on location relative to Pacific Ocean, with coastal homes including homes within 20 miles of Ocean. Simi Valley was determined to be a coastal community based on its climate and air quality.

Table 2. Housing Characteristics

House #	Cooking Appliance	Heating			Cooling		Water Heater	Clothes Dryer	Vacuum Type
		Type	Central	Other	AC	Fans			
1	Gas	Gas	Yes	---	Room	---	Gas	Gas	Canister
2	Gas	Gas	Yes	---	Central	House, Room, Ceiling, Exhaust	Gas	Electric	Upright, Canister
3	Gas	Electric	Yes	Fireplace	Central	Room	?	Gas	Upright
4	Gas	Gas	Yes	---	Central	Ceiling	Gas	Electric	Upright, Canister
5	Gas	Gas	Yes	---	Central	Ceiling	?	Electric	Upright
6	Gas	Gas	Yes	---	Central	Ceiling	Electric	Electric	Upright
7	Electric	Gas	Yes	---	Central	Ceiling	?	?	Upright
8	Gas	Gas	Yes	---	Central	House	?	Gas	Upright
9	Gas	Gas	Yes	---	Central	Room	Gas	Electric	Upright
10	Gas	Gas	Yes	---	Central	Ceiling	?	Gas	Upright
11	Gas	Gas	Yes	---	---	None	Gas	Gas	Upright
12	Gas	Gas	Yes	Fireplace	Central	House	Gas	Gas	Upright
13	Gas	Gas	Floor	Space Heater	---	Ceiling	Gas	Gas	Upright
14	Gas	Gas	Yes	Space Heater	Central	None	Gas	Gas	Canister
15	Electric	Gas	Yes	Fireplace, Space Heater	Central	Exhaust	Gas	Electric	Canister, handheld
16	Gas	Gas	Yes	Fireplace, Space Heater	None	Ceiling	Gas	Gas	Upright
17	Gas	Gas	Yes	---	Central, Room	Ceiling, Room	Gas	Electric	Upright

Data obtained from housing questionnaires administered at the start of the monitoring period. Space heaters were powered by electricity.

3.1.3 Monitoring Plan

Continuous indoor and outdoor size-specific particle volume, $PM_{2.5}$, NO_3^-, and BC concentrations and air exchange rates were measured in most homes. [For several homes, measurements for some pollutants were not made due to space restrictions.] In addition to these air pollutant measurements, detailed information on household activities was obtained using daily household activity diaries that were completed by participants. Technicians visited homes twice each monitoring day, at approximately 8am and 8pm to ensure proper operation of the continuous and semi-continuous equipment, to review activity diaries, and to change integrated samplers (see below Part 2). Technicians shipped and stored all samples (pre- and post-collection) in refrigerated containers. Data for houses 1 to 8 were recorded using Pacific Daylight-Savings Time (PDT), while data for houses 9 to 17 were recorded using Pacific Standard Time (PST).

3.1.4 Air Pollutant Measurements

A variety of continuous or semi-continuous measurements were made inside and outside each home. In the majority of homes, these measurements included indoor and outdoor $PM_{2.5}$, NO_3^-, BC, and size-specific particle count concentrations and indoor air exchange rates (AER). For $PM_{2.5}$ and BC, indoor and outdoor measurements were made independently using two CAMMS and two aethalometers, respectively. For NO_3^- and size-specific particle count concentrations, indoor and outdoor measurements were made using instruments placed on a manifold that alternately sampled indoor and outdoor air. With the exception of $PM_{2.5}$, which provided hourly values, data from all continuous instruments were measured with averaging times between three and ten minutes depending on the particle species.

3.1.4.1 $PM_{2.5}$. One-hour $PM_{2.5}$ concentrations were measured inside and outside each home using the Continuous Aerosol Mass Monitor (CAMM) (Koutrakis et al. 1996). The CAMM measures particulate mass concentrations based on the continuous measurement of pressure drop across a fibrous filter (FlouroporeTM). The monitor combines ambient temperature measurements, short sampling duration, and low face velocity, which together result in minimum volatilization or adsorption artifacts. In addition, because this technique requires a low flow rate (0.3 LPM), the relative humidity of the air sample can be controlled to 40% or less by passing the air sample through a NafionTM diffusion dryer prior to its collection. This is in accordance with the Federal Reference Method (FRM), which requires that particle filter samples be conditioned at a relative humidity of 40% to remove particle-bound water.

3.1.4.1.1 Measurement Method. The CAMM consists of a Well Impactor Ninety Six (WINS) $PM_{2.5}$ size-selective inlet, a slit-nozzle and a round-nozzle virtual impactor, the $PM_{2.5}$ monitoring channel, and a data acquisition and control system. The monitoring channel consists of pressure transducers to measure the pressure drop across the filter and a filter tape transportation system that allows for unassisted particle sampling for several weeks. The principal components of the transportation system include a microprocessor-controlled tape drive, with a low speed, high torque step motor to advance the tape, and a mechanism to release and reseal the filter tape, in-line, each time the filter tape is advanced.

For each one-hour sampling period, a new segment of the filter tape is exposed. Since sudden variations in the composition of ambient air during a one-hour period are infrequent, particles are likely to remain in equilibrium with the sample air during their collection, minimizing adsorption and desorption phenomena. Although the indoor particulate composition may vary more over a one-hour period as compared to that outdoors, the variation in one-hour indoor particulate composition will be substantially less than the variation that occurs over the typically measured 12- or 24-h periods. As a result, adsorption or desorption of particles from the filter tape is still expected to be low.

During each sampling period, sample air enters the $PM_{2.5}$ monitoring channel and is divided into a sample and reference channel, each having flow rates of 0.3 LPM. A high efficiency particle filter is located upstream of the reference channel to remove particles. Air in the sample and reference channels then move through two exposed circular areas (radius=3.2 mm) on the Flourópore^{TM} tape. The pressure drops across both exposed areas are measured using sensitive transducers (full range 0-2” H_2O, Model PX653-02D5V, Omega Engineering Inc., Stamford, CT). The difference between the pressure drops of the sample and reference channels is used to determine the particle mass collected on the filter tape. (The pressure drop measurements for both channels depend on filter characteristics, flow rate, relative humidity and temperature. The pressure drop of the sample channel also depends on the particle mass concentration.) This dual channel design is extremely sensitive, because pressure drop measurements are not affected by changes in flow rate, relative humidity or temperature. Therefore, this monitor requires neither flow nor temperature controls. The latter feature is one of the main advantages of our method, since it allows measurements to be made at ambient temperatures.

3.1.4.1.2 Data Processing. Upon completion of the field study, the CAMM data was processed at the Washington University Air Quality Lab (WUAQL) directed by Dr. Jay Turner. The raw data, downloaded as one-minute intervals during each field study day, was concatenated by house and date into a single file containing both indoor and outdoor data. Incomplete data records (i.e. those records deviating from the standard instrument output format, typically due to data transmission errors) were discarded. Hourly-average mass concentrations were calculated from the valid one-minute records. Instrument parameters and status codes as given by the instrument for each one-minute interval were tallied for each hour and a coding scheme was applied to identify (a) the overall validity of the data, (b) the % of hourly interval with valid data, (c) error flow flags, (d) set-point flow rate flags and (e) set-point active seal flags. Hourly data points were excluded where in (a) the overall validity was set to invalid or (b) where <50% of one-minute records of the hour were valid according to CAMMS Operation Code "00". Under these criteria, no valid outdoor data were obtained for Houses 12, 16 or 17.

After these invalidations, 10 data points with extreme values were additionally excluded based on large deviations from the mean. Specifically, indoor data with values less than four times (-30.28 $\mu g/m^3$) or greater than ten times (100.5 $\mu g/m^3$) the standard deviation from the mean were excluded from the data set. These outliers were generally not preceded or followed by similar values, providing further support that their readings were invalid. These criteria resulted in the voiding of three negative and three positive outliers. Similarly, for outdoor data, one positive and three negative outliers that had values four times the standard deviation above (84.52 $\mu g/m^3$) or below (-46.52 $\mu g/m^3$) the mean were excluded from the dataset. In total, data capture was determined to equal 98% for both indoor (2648 out of 2698 measurements) and outdoor data (1998 out of 2039 measurements). There were fewer outdoor data points overall due to the lack of outdoor data for the three homes mentioned above.

3.1.4.1.3 LOD and Accuracy of the CAMM. Overall, 170 (6.42%) of 2648 valid indoor measurements were below the stated LOD of 3 $\mu g/m^3$ for one-hour measurements, while and 38 (1.9%) of 1998 valid outdoor measurements were below this LOD (prior to correcting the data as described below).

The accuracy of the indoor and outdoor CAMM measurements was determined by comparing 24-hour averaged $PM_{2.5}$ concentrations measured using the CAMM (with ≥18 hours of valid data) with corresponding concentrations measured using the Harvard Impactor (HI). (For the indoor data, results showed that the integrated data of House 17 may be less reliable, thus 4 data points were excluded.) The slopes and R^2 for the indoor (slope: 0.39±0.02, R^2: 0.74) and outdoor (slope: 0.40±0.03, R^2: 0.69) comparisons were similar (Figure 2 and Figure 3). Although the R^2 values indicate good agreement between the CAMM and HI samplers, the slopes suggest that concentrations measured using the CAMM were consistently lower than those measured using the HI samplers. As a result, all CAMM data were corrected based on their observed relationship with HI data (Figure 2 and Figure 3), with corrections performed separately for indoor and outdoor data. Note that the performance of the CAMM (as compared to the HI) was poorer than that previously observed in laboratory and field tests, which showed an R^2 of 0.90 and a slope of 0.94 (±0.02) (Babich *et al.* 2000; Chung *et al.* 2000). Lower R2 values in Los Angeles may result from the large contribution of NO_3^- to $PM_{2.5}$ in LA, which will cause greater loss of $PM_{2.5}$ from the HI filters.

Figure 2. Indoor CAMM vs. HI $PM_{2.5}$ Comparison (n=100)

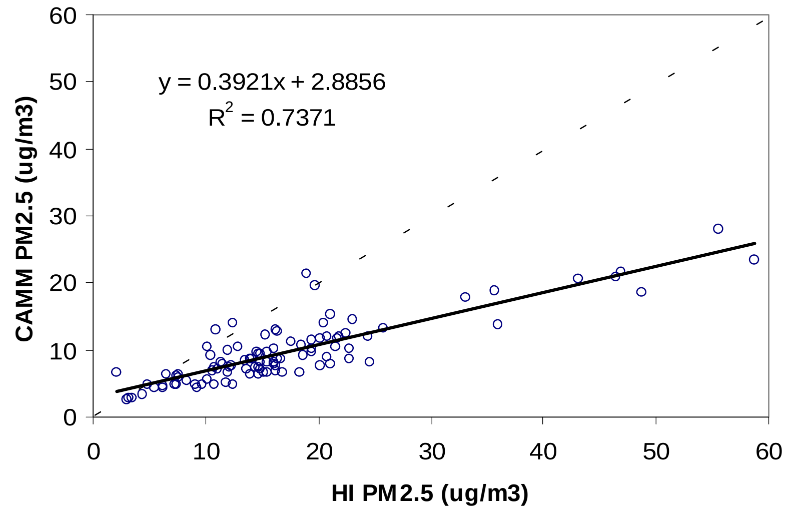
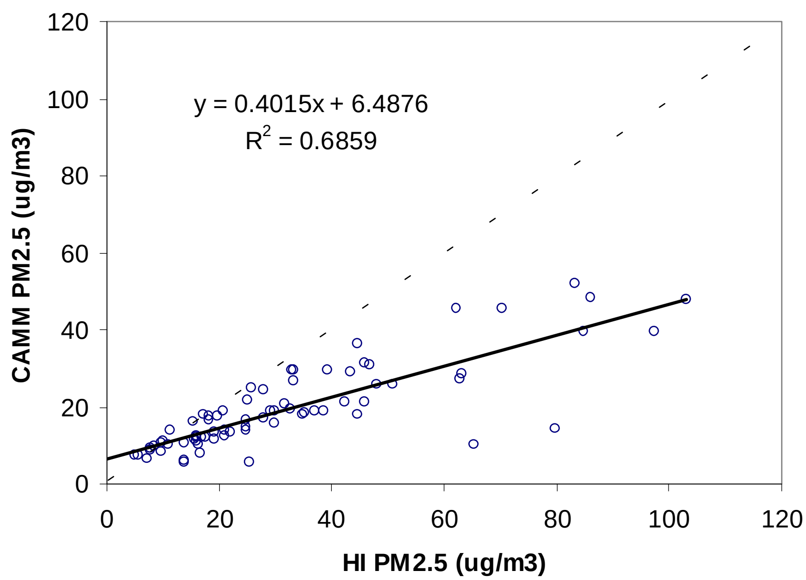


Figure 3. Outdoor CAMM vs. HI $PM_{2.5}$ Comparison (n=74)



3.1.4.2 Black Carbon. Five-minute integrated black carbon measurements were made using two Aethalometers (Magee Scientific), a model AE-16 single-channel model (SN 219) and an AE-20 dual-channel BC/UV model (SN 314). Prior to each sampling session, dynamic zero tests and/or co-location measurements were performed to calibrate the instruments and to ensure their proper operation. For these tests, the outdoor monitor was co-located indoors with the indoor monitor for up to 24 hours. In Houses 1, 5, 7, 10, 13, 15, and 17, the instruments sampled HEPA-filtered air for the 24-hour collocation period to assess the instrument limit of detection. In houses # 2, 3, 4, 6, 8, 9, 11, 12, and 14, the collocated instruments sampled indoor air in order to determine instrument precision. After the collocation period or filtered-air sampling period, the AE-16 (single-channel) model (SN 219) was switched to sample outdoor air. The outdoor instrument continued to sample outdoor air while located indoors.

3.1.4.2.1 Measurement Method. The aethalometer measures light attenuation by particles collected on a pre-fired quartz filter tape at a sample flow rate of 4 LPM. The light source is an incandescent bulb with an effective center wavelength of 820 nm. The filter is changed automatically every 3 to 12 hours. The overall optical attenuation is calculated using the decrease in transmission at the end of the measurement cycle from when the filter was clean. The optical transmission of an unexposed portion of the filter is measured at the end of each cycle to control for drift in the instrument. The change in light attenuation by measurement cycle, which decreases exponentially with filter loading, is reported as a linearized and scaled "attenuation unit." The mean BC concentration during the measurement cycle is then determined from the attenuation units and sample volume data, using an internal, empirically derived conversion factor. The principle of the method is described elsewhere (Hansen and Rosen 1984).

3.1.4.2.2 Data Processing. The aethalometer data was processed at the WUAQL following established standard operating procedures. Briefly, the aethalometer archived raw five-minute data to disk as daily files for each location. Log sheets were used to separate the blanks and co-located aethalometer data from true indoor and outdoor data collection periods. The raw five-minute data was processed using the WUAQL data processor to yield validated five-minute average data records and hourly-average data records. The processor read data records from the input file and formats date and time stamps; screens each record for the BC channel sensor "lamp on" voltage (should not be less than 0.35V), flags for missing data, replicated records with respect to time stamps. This processing resulted in three-digit data validation codes assigned to each 5-minute or 60-minute interval to indicate overall validity and to indicate reason for invalid entries, such as missing records in input file, or for one-hour averaged data, percent of valid data used in obtaining the one-hour concentration. Time series of the indoor/outdoor data were also constructed to screen for spurious data points (one point was removed for indoor data 11/29/01 at 10:50am which had a BC concentration of 11 $\mu g/m^3$).

Only five-minute records were used in this report for further analysis. Prior to accepting this data, aethalometer log sheets were reviewed at HSPH against the data handling log provided by WUAQL. Samples were invalidated based on log sheet comments, such as those indicating a broken manifold, or when data were abnormally low. Data capture, which was determined by calculating the percent of valid samples out of the total samples collected, was high. For 5-minute indoor samples, data capture was 90.5% (31882 out of 35211 total records) while for outdoor samples data capture was 95.5% (31232 out of 32698 valid records). Samples that were invalidated were due primarily to tape advance problems.

3.1.4.2.3 LOD, Precision and Accuracy. WUAQL analyzed the dynamic zero tests and co-located measurement periods. The first hour of data from these tests was removed due to the observation of relatively high BC concentrations, which were likely due to instrument warm-up. Summary statistics of the blank runs at each house are provided in Table 3.

Table 3. Summary statistics for aethalometer dynamic zero tests (units: mg/m^3)[1]

Location	House #	Count	Mean	SD	SE	Min	Max
Outdoor	**3**	202	0.007	0.016	0.0011	-0.038	0.079
	5	221	0.004	0.010	0.0007	-0.015	0.060
	7	244	0.007	0.012	0.0008	-0.079	0.055
	10	223	0.004	0.010	0.0007	-0.044	0.036
	13	278	0.005	0.013	0.0008	-0.056	0.157
	Overall		**0.005**	**0.012**			
Indoor	**3**	201	0.002	0.006	0.0004	-0.025	0.021
	5	221	0.000	0.010	0.0007	-0.072	0.028
	7	247	-0.001	0.012	0.0008	-0.085	0.053
	10	237	0.002	0.010	0.0007	-0.019	0.057
	13	278	0.006	0.014	0.0008	-0.056	0.157
	Overall		**0.002**	**0.010**			

1. Data provided by WUAQL.

Evaluation of the collocated data revealed an instrument bias, where the dual-channel instrument (314) consistently read higher than the single-channel instrument (219), with the ratio of the two instruments variable by house (Figure 4). This bias may be due to an error in the flow-calibration in the single channel instrument 219, which was used to sample outdoor air, since this instrument had recurring flow-leak issues, which could have caused the BC values to be under-reported. [The instrument uses its internal mass-flowmeter measurement and the change in net optical depth on the filter to determine the concentration of black carbon in the sample-air. If the internal flow reading were higher than the actual flow through the filter, then the BC measurement would be proportionally lower.]

In addition to the potential between-instrument bias, there was evidence of a systematic error in each instrument associated with the loading of black carbon on the quartz filter, which is consistent with observations in other studies (La Rosa et al., 2002). After a filter-change event, black carbon concentrations increased by roughly 20%. However, this increase was not consistent, as it varied substantially both within and between homes. As discussed by LaRosa et al. (2002), because the filter loading effect is related to the attenuation of the loaded quartz filter, the artifact introduced by filter changes can be expressed as a function of the net attenuation *q*:

$$C_{obs} = AC_{true}e^{(-Bq)}$$

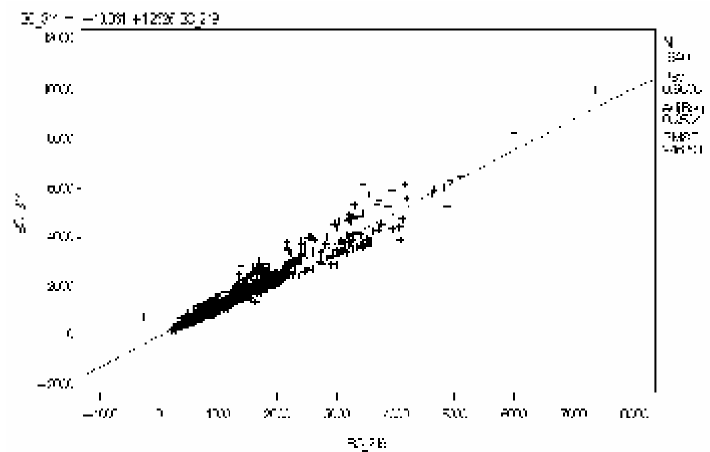
where *A* and *B* are constants, C_{obs} is the measured BC concentration, and C_{true} is the true BC concentration. [This model does not correct for instrument offset, but it corrects both the instrument bias and the filter loading effect.] Because instruments 314 and 219 were collocated, C_{true} for both instruments is identical and the equations for both instruments can be combined:

$$\ln(C_{314}/C_{219}) = \ln(A_{314}/A_{219}) + B_{219}\, q_{219} - B_{314}\, q_{314}$$

Values of B_{314}, B_{219}, and the ratio of C_{314}/C_{219} (but not C_1 or C_2) were obtained by regressing collocated measurements obtained by Instrument 314 against those measured by Instrument 219. The relative between-instrument bias was estimated to equal on average 1.16 (95% CI: 1.150, 1.167) – or a 16% higher reading on Instrument 314. [Attenuation coefficients B_1=0.00273 and B_2=0.00305, $\ln(C_1/C_2)$ = 0.1473 ±0.0071, $p<0.0001$.] The slope of home-specific linear regression of Instrument 314 on Instrument 219 ranged substantially by home, suggesting a bias of ranging between 5 and 32% by home. While consistent with the logarithmic regression results showing an average bias of 16%, home-specific results indicate the bias varies by home.

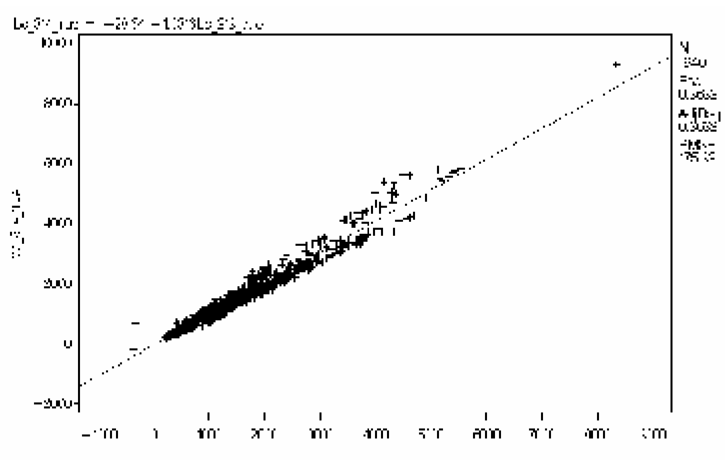
In addition to estimating the between-sampler bias, this equation was used to calculate BC concentrations corrected for the filter-change effect (Figure 5). Correction of the values resulted in a lower RMSE (176 vs. 247 ng/m^3), with a comparable R^2 value (0.95 vs. 0.97). As illustrated by Home 2, the agreement between the two instruments generally improved after correction in which collocated data were collected; however, the magnitude of this improvement varied substantially by home (Figure 6 and Figure 7). In the sampling data set, measurements made by Instrument 219 were adjusted upwards by 16%, since it was thought to have flow leakage problems. This correction did not account for differences across homes or filter changes, and as a result, should be considered a crude correction. Similarly, this value does not correct for potential bias in the accuracy of the instruments.

Figure 4. Uncorrected Instrument 219 vs 314 BC Concentrations: Collocated Tests



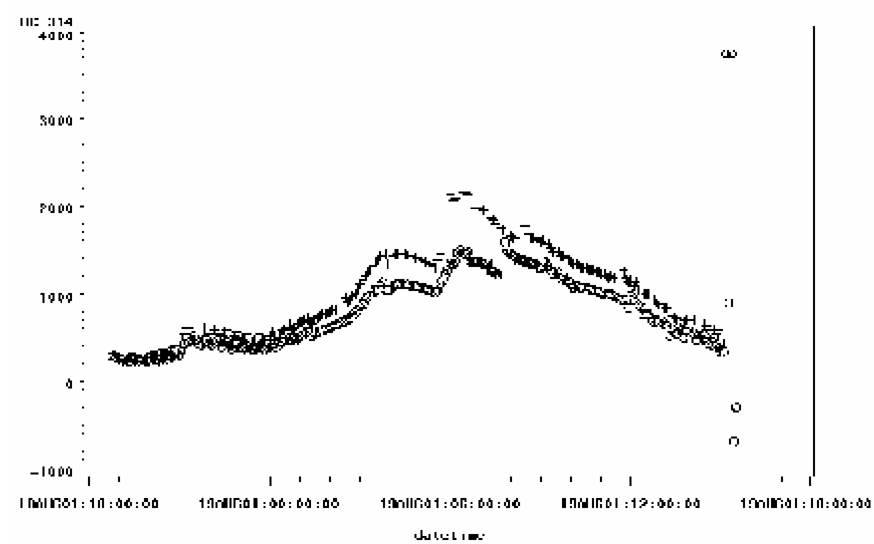
Dotted line indicates regression line. Concentrations in ng/m^3.

Figure 5. Corrected Instrument 219 vs 314 BC Concentrations: Collocated Tests



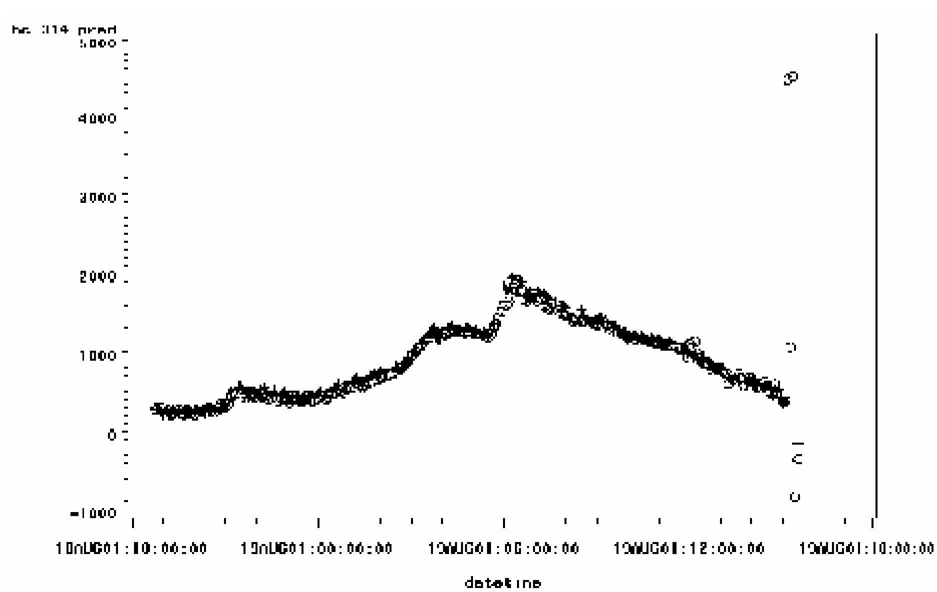
Dotted line indicates regression line. Concentrations in ng/m^3.

Figure 6. Uncorrected Colocated BC Concentrations: House 2*



*Instrument 314 indicated by "+" and Instrument 219 indicated by "o". Concentrations in ng/m^3.

Figure 7. Corrected Colocated BC Concentrations: House 2*



*Instrument 314 indicated by "+" and Instrument 219 indicated by "o". Concentrations in ng/m^3.

3.1.4.3 Sampling Manifold. Continuous NO_3^- and size-specific particle volume concentrations were measured via a sampling manifold (Abt *et al.* 2000). Use of this manifold allowed indoor and outdoor concentrations to be measured alternately over short time periods using only one instrument for each pollutant species. The sampling manifold contained two horizontal arm extensions with electronically-controlled ball valves (Abt *et al.* 2000). One arm extended through the window of the home, while the other arm protruded into the room to sample indoor air. (The mirror image structure was designed to ensure that any particle losses would be identical for both indoor and outdoor air.) The ball valves allowed air to be sampled alternately from either the indoor or outdoor environment. Air was pulled through the manifold at a sampling rate of 41.5 LPM to minimize losses through the system. Indoor air was sampled for 15 minutes, followed by a five minute-period when outdoor air was sampled. The longer indoor air sampling time was needed to capture the variability in indoor concentrations, which was expected to be greater than that outdoors. An important feature of the manifold was that it allowed outdoor air to be equilibrated to indoor temperature conditions prior to sampling, thus accounting for any changes in the size and mass of the outdoor particles that may result from indoor-outdoor temperature differences. Since this equilibration may result in changes in the nitrate phase and reaction equilibrium, this measurement method may affect measurements of outdoor nitrate. Due to the space requirements of the manifold and sampling equipment, the manifold was not used in three of the homes (Houses 9, 11 or 17), for which only indoor size-specific particle count concentrations were measured.

3.1.4.4 Continuous Nitrate. Continuous nitrate concentrations were measured using an automated nitrate monitor placed on the manifold for the determination of both indoor and outdoor concentrations. This monitor is a new method that provides automated measurement of airborne particle nitrate concentrations with a time resolution of ten minutes (Hering and Stolenburg 1998). 24-hour integrated nitrate measurements using HI samplers were collected alongside the continuous measurements both indoors and outdoors on each sampling day; the integrated samplers were placed in the same locations as the CAMMs and integrated PM2.5 samplers.

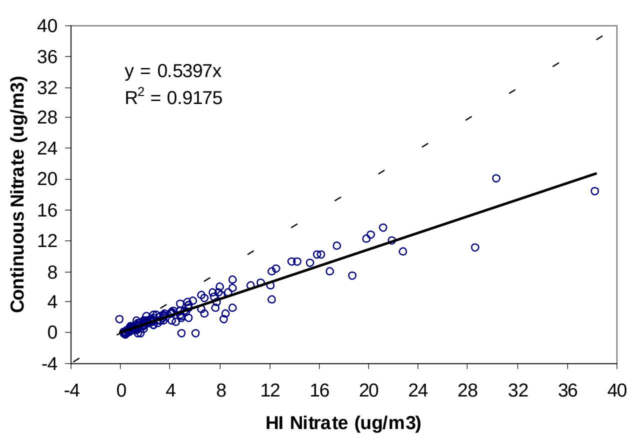
3.1.4.4.1 Measurement Method and Operation. The continuous nitrate monitor is based on the manual method that has been used for over twenty years to measure the size distribution of sulfate aerosols (Hering and Friedlander 1982). In this case, however, the particle collection and analysis have been combined into a single cell, allowing the system to be automated. Particles are humidified prior to impaction to eliminate the rebound of particles from the impaction surface without the use of grease (Winkler 1974; Stein *et al.* 1994). Interference from vapors such as nitric acid is minimized by use of a denuder upstream of the humidifier. Analysis is by flash-vaporization into a nitrogen carrier gas with quantitation by a chemiluminescence NOx analyzer, similar to that described by (Yamamoto and Kosaka 1994). The flow system is configured such that there are no valves on the aerosol sampling line. Field validation procedures include on-line checks of particle collection efficiency, calibration with aqueous standards applied directly to the collection substrate, and determination of blanks by measurements of filtered, ambient air. During this study, the system operated continuously during each nine-day monitoring period, yielding up to 144 measurements per day, each corresponding to an eight-minute sample collection followed by a 90-sec analysis. The inlet for the continuous monitor was placed in the sampling manifold to allow alternate measurements of indoor and outdoor air.

3.1.4.4.2 Data Processing. Continuous nitrate data were downloaded in the field by HSPH and processed by the WUAQL. A standard processing procedure was followed, which included concatenating all house-specific raw data files into a single file, checking for and discarding duplicate records (i.e. records with the same time stamp) as necessary, discarding records without corresponding log sheet entries and flagging each data record. Data records were first flagged according to codes given by the instrument (e.g. power failure or pressure control failure) and/or determined from log sheet or other instrumentation information (e.g. flow rates, hardware failure, manifold disconnected). Taking these flags into account, a second set of flags was assigned to indicate the validity of each data record; records with validity flags of "2" were not considered in further data analyses. Based on this second set of flags, data were invalidated during the initial days of monitoring for House 14, since values were extremely low, suggesting a problem with the instrument during the initial monitoring period. Data capture for indoor and outdoor samples was equal to 88% (4905/5586) and 85% (4770/5586), respectively.

3.1.4.4.3 LOD, Accuracy and Precision. As currently configured, the system has a detection limit of 0.7 $\mu g/m^3$ and a precision of 0.2 $\mu g/m^3$. Of the valid indoor data, 2778 (57%) out of 4905 data records fell below this LOD; of the valid outdoor data, 724 (15%) out of 4770 data records fell below this LOD (prior to correcting data as discussed below).

The accuracy of the continuous nitrate measurements was assessed using 24-hour integrated nitrate concentrations measured using HIs. Continuous data were integrated over 24 hours to correspond to HI measurements. The continuous nitrate monitor was found to perform well both indoors and outdoors, with a slope of 0.54 ± 0.01 and an R^2 of 0.92, when continuous were regressed on corresponding HI measurements (n=131 data pairs) (Figure 8). Results were similar when indoor and outdoor data were examined individually. The high R^2 value indicates strong associations between the methods and is similar to those shown in similar field tests conducted in Riverside, CA as part of the 1997 Southern California Ozone Study. Despite this, the slope was relatively low, indicating that the monitor consistently underestimated nitrate concentrations by a factor of approximately two. In contrast, results from the Riverside instrument comparison found a slope that was not significantly different from one. The lower slope observed in Los Angeles may be due to different sampling designs, where collocation tests in Riverside were performed outdoors, while those in Los Angeles were performed using indoor and outdoor concentrations measured using a continuous NO_3^- monitor placed indoors (see above). As a result of this low slope, all continuous nitrate data was adjusted to HI measurements using the regression equation shown in Figure 8.

Figure 8. Indoor and Outdoor Continuous Nitrate vs. HI Nitrate Comparison (n=131)



3.1.4.5 Continuous Particle Counts (SMPS, APS). Size-specific continuous particle count concentrations were measured using a Scanning Mobility Particle Sizer (SMPS) and an Aerodynamic Particle Sizer (APS), both of which were placed on the manifold for the determination of both indoor and outdoor concentrations.

3.1.4.5.1 Measurement Method. The SMPS consists of an electrostatic classifier (TSI Model 3071A) and a particle detector (TSI Model 3022A Condensation Particle Counter) that measures particle count concentrations from 0.02 and 0.5 um in 46 size channels per decade. The APS sizes and counts particles from 0.7 to 10 um in 37 size channels. The SMPS sizes particles based on their mobility equivalent diameter, while the APS sizes particles based on their aerodynamic diameter. Both the SMPS and APS each sampled in five-minute intervals.

The SMPS and APS sampled at 0.3 and 5 LPM, respectively. The instruments sampled from the same location, with equal tubing length, to ensure that particle losses were equivalent for the sampling methods. The flow rates for the SMPS and APS were adjusted, prior to each sampling run, with the SMPS flow rates adjusted using the manufacturer's calibration as well as independent calibrations made by HSPH. Settings for the APS were based on the manufacturer's specifications alone.

3.1.4.5.2 Data Processing. SMPS and APS data were downloaded by HSPH and processed initially by University of Miami and subsequently by HSPH. Commercial software programs were used to determine raw count concentrations (TSI SMPS v. 2.3 and APS EXTRA v. 1.1). Raw count concentrations were converted to particle number and volume concentrations using SAS V8 statistical software. In addition, APS data were corrected for depositional losses in the sampling manifold based on a regression equation developed from previous laboratory tests (Abt *et al.* 2000). No corrections for loss were made to the SMPS data, which were found to have no significant manifold losses in these laboratory tests.

Size distribution data are reported as particle volume (PV) concentrations in units of $\mu m^3/cm^3$ for 17 particle size ranges as well as for four aggregated particle size ranges: 0.02-0.1 ($PV_{0.02\text{-}0.1}$) and 0.1-0.5 ($PV_{0.1\text{-}0.5}$) microns (um) for SMPS data and 0.7-2.5 ($PV_{0.7\text{-}2.5}$) and 2.5-10 ($PV_{2.5\text{-}10}$) um for APS data. The aggregated size ranges were selected to allow the large data set to be summarized and to allow observations to be made for ultra-fine particles, accumulation-mode particles and coarse-mode particles. Note that no data are reported for the 0.5-0.7 µm size range, since previous studies have demonstrated that neither the SMPS nor the APS accurately measures particle concentrations in this size range (Sioutas *et al.* 1999).

3.1.5 Air Exchange Rates

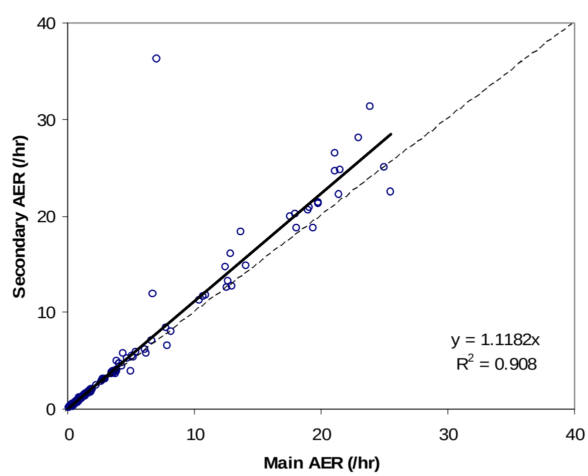
Air exchange rates were measured every three minutes using a constant sulfur hexafluoride (SF_6) source in conjunction with an SF_6 monitor (Bruel & Kjaer, Model 3425), which measured SF_6 concentrations using photo-acoustic infrared spectroscopy (Bruel and Kjaer 1990). SF_6 was released at a controlled rate of six ml per minute from a five-pound cylinder, placed on the same floor of the house but away from the SF_6 monitor; the SF_6 source was placed in the home one day prior to the start of sampling to allow time for equilibration. A main SF_6 monitor was placed in the main room of the home together with the other instruments. Generally on the first day of sampling, a second SF_6 monitor was co-located with the main monitor for QA purposes. After the co-location was complete, the second monitor was placed in a secondary location in the home for further home ventilation characterization.

3.1.5.1 Data Processing. AER data from the SF_6 monitor were processed at HSPH. Air exchange rates for each downloaded file were calculated using three-minute SF_6 measurements, house volume, and the source emission rate. The files were then concatenated into house-specific files for each main and secondary location. The data was flagged according to log sheet information and data processing anomalies. Data records were invalidated when instrument issues questioned the validity of the data, the SF_6 source was noted as missing; duplicate data records due to processing errors were invalidated as necessary. Any data collected within 24-hours of placing the SF_6 source into the home was also invalidated, since 24-hours is required to achieve equilibration of the source before AER can be measured accurately. Data collected by the secondary AER monitor in House 5 was also invalidated, since this secondary monitor was placed in a room closed off from the rest of the house.

3.1.5.2 LOD and Precision. The LOD or the maximum AER that can be measured accurately was calculated for each home based on the amount of SF_6 released into the home over the course of an hour, the home volume and the LOD of the SF_6 monitor of 5 ppb (Bruel and Kjaer 1990; Jelanek 1996). Based on the average home volume and source emission rates of 2-6 ml/min, the LOD was estimated to equal 124.1 (±40.8) hr^{-1}. However, since this value is based on the analytical detection of SF_6 and as a result is extremely large, a more realistic maximum measurable air exchange rate should be closer to 8 exchanges per hour. Of the valid 20-minute AER data, 100% (6528 out of 6528 samples) of main room data and 99.4% (3248 out of 3268 samples) of data from secondary locations fell below the 124.1 hr^{-1} maximum measurable level.

The precision of the SF_6 measurements was assessed using co-located SF_6 monitors. Since SF_6 concentrations were generally collocated before SF_6 equilibrated within the home, precision estimates may be overestimated. Data above the LOD (3 data pairs) as well as data from House 14 were excluded from the precision analyses, leaving 312 20-minute co-located data pairs for comparison. As shown in Figure 9, we found excellent agreement between the co-located instruments, with an R^2 of 0.91 and a slope of 1.12 when one collocated instrument was regressed on the other instrument, indicating that the instruments performed with similar accuracy. The precision of the measurements was estimated to be 47.0% (using 100%*(SD|diff|/mean)/√2) or 21.8% when one outlier (Figure 9) was excluded from the analysis.

Figure 9. 20-minute AER Data: Co-Location of SF_6 Monitors (n=312)



Dotted line indicates 1:1 line; solid line represents the regression line.

3.1.6 House-Activity Diaries

Each household was asked to complete a household activity diary (HAD) each day. HADs were distributed to the study participants by field technicians at the beginning of each of the seven monitoring days. During the morning visits, technicians reviewed the HAD from the previous 24-h monitoring period with the study participants to ensure their proper completion.

HADs were modified versions of diaries used in our Boston indoor source apportionment studies (Abt *et al.* 2000; Long *et al.* 2000), with modifications intended to facilitate their use in Los Angeles area homes (Appendix A). In the HAD, participants were asked to record for 20-minute intervals during the day (6am-12am), in hourly intervals during the night (12am-4am), and in 30-minute intervals during the early morning (5-7am) information about home ventilation conditions (open windows, doors), air conditioner or heat usage, use of kitchen fans, cooking and cleaning activities and other conditions that may affect indoor or outdoor particulate sampling. Participants entered information for each category as either “none” or “any”.

In total, HAD data were collected for 110 subject-days. HAD data were processed into 20-minute, hourly and 24-hour intervals to correspond with the corresponding air pollutant data. Data were characterized for each home and across homes. Information about the amount of time spent performing particle-generating activities, such as cooking and cleaning, were included in data analyses, as were data about home ventilation conditions, such as air conditioner and heating use and open window status.

3.1.7 Data Analyses

Data manipulations and statistical analyses were conducted using Excel 2000, SigmaPlot 2000 Version 6.10 (SPSS Inc.), SAS Release 8.02 (SAS Institute, Cary, NC) and S-PLUS 2000 Professional Release 3 (Mathsoft, Inc.). All valid data were included in the analyses, unless otherwise specified. Data below the limits of detection for each pollutant were flagged, but were included in analyses as the measured concentration for all analyses. Since each home was sampled once, the separate impacts of season and home could not be assessed. As a result, season-specific analyses were not performed. Unless otherwise specified, statistical significance is reported at the 0.05 level.

Units for $PM_{2.5}$, BC measured by the aethalometer and NO_3^- concentrations and exposures are reported in mass concentrations ($\mu g/m^3$). Particle-size resolved data are reported for the 17 particle size bins and the aggregated four particle size bins (0.02-0.1, 0.1-0.5, 0.7-2.5, 2.5-10 μm) as volume concentrations ($\mu m^3/cm^3$). AERs are reported in hr^{-1}. To correspond to particle measurements, which were made in the main activity room, statistical analyses also used AERs measured in the main activity room.

Analyses were conducted on the continuous indoor and outdoor concentration measurements for each particle species as well as continuous air exchange rate measurements. Analyses were performed using data characterization, steady state modeling and dynamic modeling techniques. Data were characterized using multiple averaging periods, depending on the analysis objective. First, particulate concentrations and diurnal profiles were characterized in 20-minute increments to correspond with the measurement cycle of the manifold and the reporting period for the housing activity diaries. Second, data were averaged into 6-hr daytime and nighttime periods to allow indoor and outdoor concentrations to be compared while minimizing the effect of time lags between indoor and outdoor concentrations. Six-hour averaged data were used to estimate values for F_{INF}, P and k using methods based on steady state models. Finally, values for P and k were also estimated using dynamic indoor concentration models based on 5-minute particulate and air exchange rate data. Note that for analyses involving black carbon, results should be interpreted with some caution. As discussed previously, outdoor concentrations were corrected by an average correction factor to account for measurement bias between the indoor and outdoor instruments. This correction did not correct for the effect of tape changes or home-specific variation in the indoor-outdoor instrument bias.

3.1.7.1 Data Characterization. Continuous particulate ($PM_{2.5}$, BC, NO_3^- and size-specific volume) concentrations, air exchange rates, and housing activities were characterized by home and across homes using descriptive statistics, graphical displays, Spearman correlation coefficients and regression models. With the exception of $PM_{2.5}$, which was reported as one-hour averages, other particle measures were reported in 20-minute intervals. All pollutant and AER data were included in the analyses, even those below and above the LOD, respectively. Data graphed as box plots show the concentration distributions, with the dotted line representing the mean concentration, the solid line representing the median concentration, the circles representing the 5th and 95th percentiles, and the ends of the boxes representing the 25th and 75th percentiles. Variability in indoor and outdoor particulate concentrations was assessed using the coefficient of variation (CV) or the standard deviation of the indoor or outdoor concentration divided by its mean, while the difference between indoor and outdoor concentrations was assessed using the mean relative difference, defined as the average outdoor-indoor concentration difference divided by mean outdoor concentration.

3.1.7.2 Steady State Models. In order to examine relationships between indoor and outdoor concentrations and to minimize the effects of time lags between indoor and outdoor levels, continuous data were averaged into four 6-hour intervals, defined *a priori*, as morning (6am-12pm), afternoon (12pm-6pm), evening (6pm-12am) and night (12am-6am). Six-hour intervals that had less than 4.7 hours of valid data were not included in any of the subsequent analyses.

Nighttime (12-6am) data were used to estimate infiltration factors (F_{INF}), P and k (as described in more detail below), since this period was generally the time in which residents were asleep and/or inactive, thus no particle generating sources were generally present. Nighttime periods were further examined to ensure that no sources were present using indoor-outdoor ratios, HAD information and the continuous measurements. This examination identified 25 nights in which (1) source events occurred just prior to midnight, with indoor levels for certain species remaining elevated above outdoor levels past 12am or (2) the indoor time series showed high nighttime concentration spikes that may have been due to unreported indoor activities. These identified "sources" were found to affect $PM_{2.5}$ (n=9), BC (n=1), $PV_{0.02\text{-}0.1}$ (n=9), $PV_{0.1\text{-}0.5}$ (n=7), $PV_{0.7\text{-}2.5}$ (n=5) and $PV_{2.5\text{-}10}$ (n=6).

Steady state models assume that indoor concentrations are in equilibrium with outdoors, such that the concentration of particles entering the home through infiltration from outdoors (PRC_o) or indoor source emissions (Q) equals that exiting the home from exfiltration (RC_i) and decay (kC_i):

$$C_i = \frac{PaC_o + Q}{a + k} \qquad \text{(Equation 1)}$$

where C_i represents the indoor concentration (μg/m^3), P the penetration efficiency (unitless), a the air exchange rate (hr^{-1}), C_o the outdoor concentration (μg/m^3), k the particle decay rate (hr^{-1}) and Q the source emission rate (μg/hr). For simplicity, the decay rate from particle deposition and volatilization processes were assumed to be non-existent, although this assumption is invalid for both $PM_{2.5}$ and NO_3^-.

If both particle generation and resuspension are assumed to be neglible, as should be the case during nighttime, non-source periods, the Q term can be set to zero, thus simplifying Equation 1 to include only P and k as the unmeasured parameters:

$$C_i = \frac{PaC_o}{a+k} \qquad \text{(Equation 2)}$$

During such conditions, F_{INF} is equivalent to the indoor-outdoor ratio:

$$F_{INF} = \frac{C_i}{C_o} = \frac{Pa}{a+k} \qquad \text{(Equation 3)}$$

3.1.7.2.1 Indoor-Outdoor Concentration Ratios. Indoor and outdoor nighttime average data were matched and nightly infiltration factors were calculated based on nightly indoor-outdoor (I/O) ratios. For comparison, I/O ratios for the morning, afternoon and evening time periods were also computed as a method for observing the influence of indoor sources and general activities. Ratios for $PM_{2.5}$ (n=1) and for NO_3^- (n=8) were not included when both indoor and outdoor concentrations were negative (resulting in very large and positive I/O ratios). Ratios were calculated, however, when indoor concentrations (but not outdoor concentrations) were negative, resulting in some negative ratios, primarily for $PM_{2.5}$ and NO_3^-. I/O ratios are summarized by house (with sample size (N), mean, standard deviation (SD)) and are presented graphically as frequency distributions for each particle species. The influence of potential particle generating activities (cooking and cleaning) and home ventilation (as determined by open window and heater use) on daytime indoor/outdoor ratios was examined using generalized linear models, in which data were stratified according to the presence or absence of the activity or home ventilation parameter. Generalized linear models were used instead of ANOVA techniques due to unbalanced sample sizes. Note that the impact of air conditioner use was not examined since air conditioners were used infrequently during the study.

3.1.7.2.2. Regression Models. Regression models of indoor on outdoor concentrations were used to provide quantitative estimates of infiltration factors (F_{INF}) and indoor source contributions. Analyses were initially conducted using six-hour nighttime data. When data from the homes were analyzed together, general linear (mixed) models (PROC MIXED in SAS) were run using a compound symmetry covariance structure, with outdoor concentrations treated as fixed effects and subjects as random effects in order to control for the repeated measures nature of the data set. House-specific regressions were also conducted using simple linear regression techniques (PROC REG in SAS). Results are reported as slopes, intercepts, and corresponding standard errors to provide an estimate of the F_{inf} and indoor source contribution, respectively. R^2 values are also presented for simple regression models as a measure of the goodness of fit, since mixed models are unable to provide such measures. The analyses were restricted to include homes for which at least 4 nighttime data points were available.

Indoor-outdoor regressions using the morning, afternoon and evening 6-hour averaged data were subsequently performed by home and across homes. When data were analyzed by home, the dataset was restricted to include data for homes in which at least 4 samples were available for the 6-hour period of interest. For homes with corresponding nighttime results, comparisons with daytime regression results are made and presented in tables and graphically in box plots.

The impact of home ventilation on nighttime and daytime indoor particulate concentrations was examined statistically using mixed models. Home ventilation was measured using air exchange rates and open window and heater use as categorical variables, since reliable information was not available on the number of minutes that windows were opened or a heater was used. For air exchange rates, data were not examined continuously, since the effect of air exchange rates on the indoor-outdoor concentration relationship is non-linear. For example, air exchange rates between 2 and 10 exchanges/hour are comparable in terms of their impact on effective penetration efficiencies. In contrast, air exchange rates of 0.5 and 1 exchanges/hour are likely to have substantially different implications for effective penetration efficiencies. As a result, the impact of air exchange rates was examined by categorizing data into groups based on tertiles, with "low" indicating AER less than or equal to 0.28 hr^{-1}, "medium" indicating AERs between 0.28 and 0.51 hr^{-1}, and "high" indicating AERs greater than 0.51 hr^{-1}. Open window and heater use were classified as "1" if any open window or heater use occurred or "0" if windows were closed or heaters were not used during the monitoring period. Daytime data were further analyzed to examine whether cooking and cleaning, potential particle generating activities, affected the association between daytime indoor and outdoor particulate levels. [Note that cooking and cleaning did not occur during the night. As a result, their effect on nighttime data could not be examined.] "Cooking" and "cleaning" were classified as "1" if any cooking or cleaning occurred or as "0" if no cooking or cleaning occurred. For the analyses of daytime data, window, heater and activity variables were included in the mixed models as main effects and as interaction terms with outdoor concentrations. All daytime data were included in these analyses. For analyses examining the effect of air exchange rates on daytime concentrations, data were analyzed using mixed models stratified by AER tertiles for only those homes with corresponding nighttime results, in order to allow comparisons between the daytime and nighttime air exchange rate effects. The impacts of cooking, cleaning, heater use and ventilation were examined singly with one activity included in the model at a time and also jointly in multivariate models.

3.1.7.2.3 Penetration and Decay Estimates. Equation 2 was further rearranged to estimate ***P*** and ***k*** using a linear regression model as used previously by Long et al. (2001):

$$\frac{C_o}{C_i} = \frac{k}{P}\left(\frac{1}{a}\right) + \frac{1}{P}. \qquad \text{(Equation 4)}$$

For each species, C_o/C_i was regressed on ***1/a*** using the nighttime average data as described above. The resulting intercepts (***1/P***) and slopes (***k/P***) were used to provide point estimates for ***P*** and ***k***. The delta method was used to estimate the variance ***P*** and ***k*** based on the variance and covariance of the slope and intercept (Morgan, 1992). For ***P***, the variance was calculated as:

$$Var(P) = \left(\frac{-1}{Int^2}\right)^2 * Var(Int) \qquad \text{(Equation 5)}$$

The variance of ***k*** was estimated to equal:

$$Var(k) = \begin{bmatrix} -Slope/Int^2 \\ 1/Int \end{bmatrix}^T * \begin{bmatrix} Var(Int) & Cov(Int, Slope) \\ Cov(Slope, Int) & Var(Slope) \end{bmatrix} * \begin{bmatrix} -Slope/Int^2 \\ 1/Int \end{bmatrix} \quad \text{(Equation 6)}$$

Standard errors were calculated as the square root of the resulting variances. These calculations were conducted in S-PLUS. Model estimates of ***P*** and ***k*** were considered valid only when both the intercept and slope of the regression were significant at the 0.05 level. All estimates of ***P*** and ***k*** are presented in terms of the parameter estimates and their associated standard error. Note that ***P*** and ***k*** were not estimated for NO_3^- due to the fact that the model does not include a term accounting for NO_3^- volatilization.

Since a large dynamic range in air exchange rate is necessary for successful mass balance model performance, data were aggregated across the study homes, to obtain an average estimate for P and k for all homes. Due to the repeated measures nature of the dataset, the regressions were conducted using PROC MIXED in SAS using a first-order autoregressive covariance structure, which tended to give the lowest AIC results.

3.1.7.3 Dynamic Models. A dynamic mass balance model was used together with continuous indoor and outdoor particle volume data and air exchange rate measurements to estimate ***P*** and ***k*** for 17 particle size bins:

$$\frac{dC}{dt} = aPC_{out} - (k+a)C$$

where ***C*** is the indoor concentration (μm^3/cm^3), ***t*** is the time (h), ***a*** is the air exchange rate through the building shell (h^{-1}), ***P*** is the penetration efficiency through the building shell (unitless), C_{out} is the outdoor concentration (μm^3/cm^3) and ***k*** is the deposition rate (h^{-1}). This equation models time-dependent indoor concentration as a function of the infiltration of outdoor particles through the building shell (aPC_{out}) and the decrease of particles indoors through deposition (*kC*) and air exchange (*aC*). The model assumes negligible contributions during the decay period by any indoor sources, such as generation of particles, particle formation due to gas/particle conversion or reaction, particle size change due to coagulation or hygroscopic growth. In addition, the model assumes that particles enter only through the building shell itself, and not through open windows or through central air handling systems. As a result of these model assumptions, only data corresponding to times without central air systems or open windows were used as model inputs. Furthermore, only non-source period data were included in the model runs, with data selected manually, rather than using a censoring algorithm (Allen et al., 2003). Manual selection of data allowed the effect of diverse concentration patterns on estimates of ***P*** and ***k*** to be evaluated. As such, several time periods were selected for analysis, including non-source, nighttime periods (between 12-6am as used for the steady state models) and post-indoor source periods. Post-indoor source periods were identified based on the trend in indoor particulate concentrations, with data selected to include periods of particle decay that followed clear, sharp indoor concentration peaks. Indoor concentration peaks were verified with the housing activity diaries to link selected peaks with indoor events (i.e. cooking, cleaning or other).

The above equation was solved for discrete time steps:

$$C = \frac{aPC_{out}}{(k+a)}\left(1 - e^{-(k+a)\Delta t}\right) + C_{t-\Delta t}e^{-(k+a)\Delta t}$$

to allow its use with our particle volume data, for which the measurement interval was five minutes. Values for the two unknowns in the above equation P and k, along with confidence intervals and significance statistics for the parameter estimates, were estimated for each of the 17 particle size intervals using the NLIN procedure in SAS. Parameters were bounded such that $0 \leq P \leq 1$ and $k \geq 0$. Estimates for P and k were obtained using a time-series approach, where the concentration indoors at the initial time step was based on the initial concentration indoors, the time-dependent concentration outdoors, as well as the time varying air exchange rate. For all subsequent time steps, the modeled concentration from the previous time step was used for the indoor concentration. Estimates for P and k were selected based on the "optimal" model fit, which was defined as the lowest sum of the squares of the differences between the measured and the modeled indoor concentration at each time step. For each time period modeled, individual measurements that accounted for greater than 10% of the total model error were excluded from final model runs for that time period.

Since indoor and outdoor particle volume data were measured in a pre-set alternating pattern through our manifold (see Methods section), 25% of the five-minute indoor and 75% of the five-minute outdoor particle volume concentrations were missing, where one indoor and three outdoor concentrations were not measured each 20-minute interval. As a result, missing indoor and outdoor particle volume concentrations were estimated using a linear interpolation between the previous and subsequent measured time steps. Air exchange rates, which were collected approximately every 3 minutes, were processed to match the 5-minute particle volume intervals.

In order to examine the appropriateness of the methodology, data from selected time periods were analyzed in two steps. Initially, the model was run to allow values for P and k to be estimated simultaneously for each of the 17 particle size intervals. Values for either P or k for each of the particle size intervals were subsequently estimated individually, by fixing P to discrete values between 0.1 and 1 to solve only for k or by fixing k to values between 0.1 and 1 to solve only for P. Model errors were then compared over the range of potential P and k pairs for each particle size range and time period under study. For simplicity, results were reported for three discrete size fractions (0.03-0.04 µm, 0.3-0.4 µm and 3.0-4.0 µm) and for three time periods with different time-varying characteristics, including (1) a nighttime period with relatively steady indoor and outdoor concentrations, (2) a post indoor-event period with prominent indoor decay, and (3) a nighttime period with non-steady outdoor and indoor concentrations. Model results, including P and k estimates and associated model errors, are reported for each time period, particle size interval, and analysis step. Corresponding time-series plots and descriptive statistics of the indoor and outdoor concentrations are also presented to show the data structure being modeled.

3.1.7.4 Comparisons with Previous Studies. Indoor-outdoor regression, mass balance and dynamic decay model results from the current study were compared to findings from our CIAR-sponsored indoor study conducted in Boston, MA (Long *et al.* 2000; Long *et al.* 2001). In this earlier study, data were collected from 10 non-smoking households located throughout metropolitan Boston during the spring/summer and fall/winter of 1998. Each home was monitored for at least six consecutive days during both summer and winter. Monitoring methods used in Boston were similar to those used in LA, including continuous AER measurements using an SF_6 monitor and continuous indoor and outdoor particle volume measurements using the SMPS and APS from a sampling manifold. Continuous $PM_{2.5}$ measurements were collected using indoor and outdoor TEOMs. Previous analyses of these data used averaged nighttime (defined as 1-5am) data and linear mass balance models to estimate ***P*** and *k*.

3.2 Part 2: Personal Particulate Exposures

3.2.1 Participant Recruitment and Profile

One individual living in each of the 17 monitored households were recruited to participate in the personal monitoring component of the study. Participation criteria required simply that individuals be non-smoking, older than 16 years of age, and willing to wear the monitor and complete time/activity diaries for seven consecutive 24-h periods. Eleven women and five men participated in the personal monitoring component of the study. [No individual wore the personal monitor in the first monitored household (House 1).] Ages of the individuals wearing the personal monitor ranged between 28 and 66 years of age.

3.2.2 Monitoring Plan

In each household, personal particulate exposures to PM_{10}, $PM_{2.5}$, BC and NO_3^- were measured for one individual living in the home for each of the seven 24-h periods. Correspondingly, integrated indoor and outdoor $PM_{2.5}$, BC and NO_3^- concentrations were measured over the same seven 24-h periods. The individual who wore the personal monitor also completed a time/activity diary during each 24-h period. Integrated monitoring coincided with the continuous monitoring performed in Part 1 of the study.

3.2.3 Air Pollutant Sampling

Personal, indoor and outdoor measurements of PM_{10} (personal only), $PM_{2.5}$, BC and NO_3^- concentrations were measured over seven 24-h periods. Twenty-four hour indoor and outdoor $PM_{2.5}$ and BC concentrations were measured using 10 LPM Harvard Impactors (HI), which included an inlet, an acceleration nozzle, an oiled impaction plate to remove particles larger than 2.5 µm, and a plastic filter holder with a Teflon membrane filter. Indoor and outdoor nitrate concentrations were measured using modified HIs, which consisted of an impactor to remove particles larger than 2.5 µm, a sodium carbonate (Na_2CO_3)-coated honeycomb denuder to remove the acidic gases – nitric acid (HNO_3), nitrous acid (HONO), and sulfur dioxide (SO_2) – and a Na_2CO_3-coated glass fiber filter in series. Indoor samplers were placed inside the main activity room of the home. Outdoors, they were placed under rain caps in the front or backyard of the home. All inlets for the outdoor samplers were approximately one meter high and were placed at least one meter from vents, windows, and trees.

Personal PM_{10}, $PM_{2.5}$, BC and nitrate exposures were measured simultaneously using our multi-pollutant sampler (Chang *et al.* 1999; Demokritou *et al.* 2001), which used a single personal sampling pump that operated at a flow rate of 5.2 LPM. Flows from the sampling pump were split into three air streams: 0.8 LPM each for the nitrate sampler, 1.8 LPM for the PM_{10} sampler, and 1.8 LPM for the $PM_{2.5}$ sampler. The sampler consists of two impaction-based Personal Exposure Monitors (PEMs) for $PM_{2.5}$ and PM_{10} (Marple *et al.* 1987; Thomas *et al.* 1993), attached to a single elutriator. Since the PEMs were originally designed to be used with flowrates of 4 LPM, the number of nozzle holes was reduced from ten to five for the PM_{10} PEM and to eight for the $PM_{2.5}$ PEM to maintain the same size cut-offs at the lower flow rate. A mini-PEM sampler, which was also attached to the elutriator, was used to collect NO_3^-. The mini-PEM consisted of an inlet-impactor section to remove coarse particles followed by a Na_2CO_3-coated glass honeycomb denuder to collect the acidic gases (HNO_3, HONO, SO_2) and finally by a 12-

mm Na_2CO_3-coated glass fiber filter to collect NO_3^-. Personal monitors were worn on the shoulder strap of a backpack, containing a personal pump and a motion detector. The inlets of the samplers were placed at breathing height. Monitored individuals were asked to wear the sampler throughout each 24-h monitoring period, but were allowed to remove the samplers during stationary activities, such as reading, eating, or sleeping, and during activities where the monitor may be damaged, such as swimming or showering.

3.2.3.1 Laboratory Analysis. Teflon filters used to collect all $PM_{2.5}$ samples were weighed before and after sample collection on an electronic microbalance (Cahn Model C-31). All filters were pre- and post-weighed twice to maximize the sensitivity of the gravimetric determinations. In order to assure consistent values for mass, the filters were equilibrated in a room with controlled temperature (70±5 ^{o}F) and relative humidity (40±5%), both before and after sampling. In order to eliminate the effects of static charge, the Teflon filters were passed over Po^{210} sources (alpha rays), just before each weighing. The Teflon filters used for these samplers were prepared at the Harvard School of Public Health (HSPH) and shipped to the field team in LA, who exposed the samples and returned them to the HSPH laboratory for gravimetric analysis after sampling. All filters were refrigerated during storage and shipment. Mass concentrations were determined from the mass change (corrected for barometric pressure) and the accurately measured total volume of air sampled.

Upon completion of gravimetric analyses, the Teflon filters were analyzed using a reflectometer (EEL Model 43D, Diffusion Systems Ltd, London, UK) to obtain a measure of black carbon concentrations. For nitrate, samples were shipped to and from the field on ice and were stored under refrigerated conditions. Collected filters were extracted into known volumes of solution. Extracts were subsequently analyzed for nitrate using ion chromatography. All ion chromatography results were determined by comparison with known standards. Air concentrations were determined using the measured amounts and the sampled air volume.

3.2.3.2 Data Processing. All integrated data was processed at HSPH. Field data (sampling dates, times, flow rates from log sheets) was merged with lab data (masses of measured species). Data points were voided due to sampling (e.g. pump or battery failures, tube disconnection) or laboratory (e.g. contamination) problems. Samples were invalidated when the sample duration less than 18 or greater than 30 hours (±25% of 24-h target). Likewise, samples with average flow rates ± 20% of the target flow rates for that species were discarded. Data for samples with negative levels or with concentrations below the LOD were flagged, but were left in the data set and subsequent data analyses. Many samples from House 17 were invalidated due to seemingly field operator errors, such as filter ID mix-ups.

3.2.3.3 Blank Corrections and Limits of Detection (LOD). Blank filters were used to correct masses for $PM_{2.5}$ and NO_3^- by subtracting the mean filter blank levels as calculated for each species by sample location (i.e. personal, indoor, outdoor). For $PM_{2.5}$ and nitrate, indoor and outdoor blanks were not statistically different (evaluated using F-tests for either two-sample variances or equal variances, p-values > 0.20), and therefore grouped together to calculate overall blank correction. Overall, 31 indoor/outdoor blanks were collected and 15 personal blanks were collected for each species (generally one blank per house). Field (or method) LODs were estimated as three times the standard deviation (SD) of the field blank filters and target flow rate for each of the measured species. Blanks that were statistical outliers were excluded from the blank correction and LOD calculations; a total of one personal, one indoor and one outdoor $PM_{2.5}$ blank (all from House 17) were excluded from these calculations. BC concentrations were obtained by accounting for blank filter responses; therefore, no additional blanks analyses were possible, such as blank corrections or field LOD determination.

Table 4. Data Completeness: Valid Samples as Compared to Total Collected Samples

Location	Pollutant	Total Collected	Valid n (%)	n ≥ LOD (%)
Outdoor	**$PM_{2.5}$**	115	102 (89%)	102 (100%)
	BC	115	102 (89%)	--
	NO_3^-	109	99 (91%)	99 (100%)
Indoor	**$PM_{2.5}$**	115	105 (91%)	105 (100%)
	BC	115	105 (91%)	--
	NO_3^-	109	102 (94%)	102 (100%)
Personal	**PM_{10}**	105	93 (89%)	92 (99%)
	$PM_{2.5}$	105	90 (86%)	86 (96%)
	BC	105	89 (85%)	--
	NO_3^-	105	94 (90%)	89 (95%)

3.2.3.4 Completeness, Precision and Accuracy. Valid field data were assessed for completeness, precision and accuracy (if the reference measurements were available) for each pollutant. Percent data completeness was calculated as the total number of valid samples divided by the number of collected samples and is presented in Table 4. For all measured species and microenvironments, the percentage of valid samples was generally high, showing that samples were successfully collected and analyzed. However, some values in the table fall below our preset objectives of 90% data completeness. Field technician errors, such as mislabeling of samples, contributed to some sample invalidations, however the majority of invalid samples were due to sampling durations of <18 hours or >30 hours. In many cases the invalid sampling length was due to field scheduling rather than instrument problems, thereby contributing to lower data completeness for all sampling locations. Battery life issues for the personal data, as noted in the previous LA-CARB study (Chang and Suh 2003), led to further duration-related sample invalidations, resulting in slightly lower data completeness for personal sampling as compared to the indoor or outdoor sampling.

Precision and accuracy was determined using co-located duplicate multi-pollutant samplers and multi-pollutant samplers co-located with reference methods, respectively. For each pollutant, agreement between co-located measurements was first determined via regressions, where slopes were forced through zero if the intercept was not significant. Second, relative precision for each species was estimated as the standard deviation of the absolute difference between the co-located samplers, divided by the mean of all measurements, all divided by the square root of two. Third, accuracy for the multi-pollutant sampler measurements was determined using the ratio between the mean multi-pollutant sampler concentrations and the mean corresponding HI (reference method) concentrations.

Precision of the indoor and outdoor HI sampling methods was calculated by co-locating HI's side-by-side in the outdoor sampling location for two 24-hour periods at each home (starting at House 2), resulting in a total of 32 HI co-located sampling days. For all species, two data pairs taken at House 4 and one at House 8 were removed due to field technician errors; for $PM_{2.5}$ and BC only, a further data pair from House 17 was also removed for similar reason. Therefore, the number of data points for precision estimation ranged from 28-29 out of 32 co-located sampling days.

Precision for the multi-pollutant sampler was determined using a similar method as for the HI sampler. Fully configured multi-pollutant samplers were co-located in the outdoor setting for one 24-hour period at each home, starting at House 2; two co-location days were run at House 15, resulting in a total of 17 multi-pollutant co-located sampling days. One data pair for PM_{10}, $PM_{2.5}$ and BC measurements taken at House 17 was removed; no NO_3^- measurements were excluded. Therefore, the number of data pairs for comparison ranged from 16-17 out of 17 co-located sampling days.

3.2.3.4.1 *PM_{10} and $PM_{2.5}$*. For $PM_{2.5}$, a total of 29 valid indoor and outdoor blanks and 14 personal blanks were collected in the study (Table 5). LODs for $PM_{2.5}$ measurements were 14.1 μg and 13.8 μg for indoor/outdoor and personal sampling respectively, which correspond to concentration LODs of 1.0 μg/m^3 and 5.3 μg/m^3 for 24-hour sampling, respectively. These LODs are generally lower than found in the previous CARB-funded study in Los Angeles of individuals with COPD, where the concentration LODs ranged between 2.7 – 10.60 μg/m^3 (Chang and Suh 2003). For PM_{10}, a total of 15 valid personal blanks were collected. The LOD and concentration LOD for PM_{10} samples, 15.3 μg and 5.9 μg/m^3 respectively, were comparable to the LODs for $PM_{2.5}$. All indoor and outdoor field samples were above the LOD; four personal $PM_{2.5}$ and one personal PM_{10} sample fell below the LOD (Table 4).

Table 5. Blank Corrections and Limits of Detection for Integrated Data

Location	Pollutant	Sampler	n	Mean (mg)	LOD (mg)	LOD (mg/m^3)
Outdoor, Indoor	**$PM_{2.5}$** **BC** **NO_3^-**	HI (10 LPM) HI (10 LPM) HI (4 LPM)	29 -- 31	-3.0 (4.7) -- 0.6 (0.3)	14.1 -- 1.0	1.0 -- 0.2
Personal	**PM_{10}** **$PM_{2.5}$** **BC** **NO_3^-**	PEM (1.8 LPM) PEM (1.8 LPM) PEM (1.8 LPM) Mini-PEM (0.8 LPM)	15 14 -- 15	-0.5 (5.1) 2.8 (4.6) -- 0.2 (0.2)	15.3 13.8 -- 0.5	5.9 5.3 -- 0.4

Note that LOD calculated as three times the standard deviation of the field blanks.

The accuracy and precision of the $PM_{2.5}$ HI samplers and the $PM_{2.5}$ and PM_{10} PEMs were determined using co-located samplers as configured during the actual field sampling. The relative precision was found to equal 3.5% for the $PM_{2.5}$ HI, 9.5% for the $PM_{2.5}$ PEM and 3.7% for the PM_{10} PEM, each meeting our data quality objectives of 10% precision. The associations between each of the co-located samplers was also excellent, with R^2 values of 0.98-0.99 and slopes ranging between 0.92 to 1.01, as indicated in Figure 10 through 12.

Using HI as the reference method, the accuracy of the $PM_{2.5}$ PEM was high, with ratios of the mean PEM to the reference HI concentrations equaling 0.92. The association between the $PM_{2.5}$ PEM and the HI measurements was high, with an R^2 value of 0.94 and a slope of 0.94 (Figure 13). The strong association between PEM and HI measurements and high precision of the PEM measurements is similar to and consistent with the results from our previous laboratory and field studies (Chang *et al.* 1999; Demokritou *et al.* 2001), including those from the previous CARB-funded COPD study (Chang and Suh 2003), and further demonstrates that the PEM is able to provide accurate and precise measurements of $PM_{2.5}$ and PM_{10} concentrations despite the use of lower flow rates than originally prescribed for the sampler.

Figure 10. Outdoor HI $PM_{2.5}$ Co-Location (n=28); precision: 3.5%

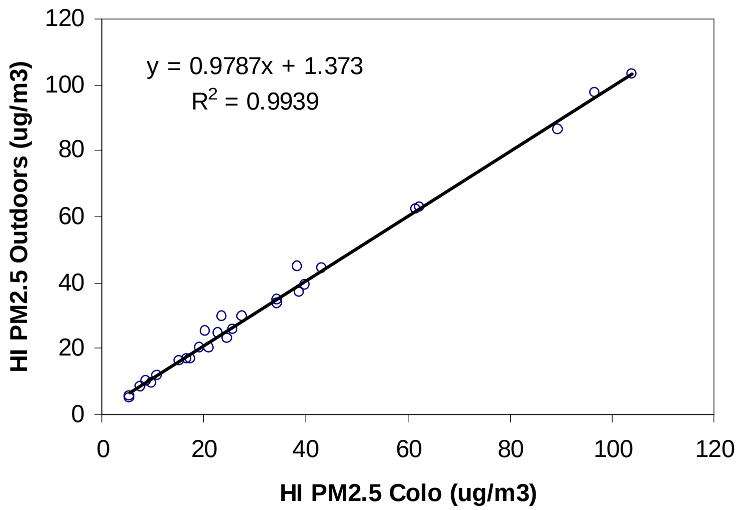


Figure 11. Personal PEM $PM_{2.5}$ Co-Location (n=16); precision: 9.5%

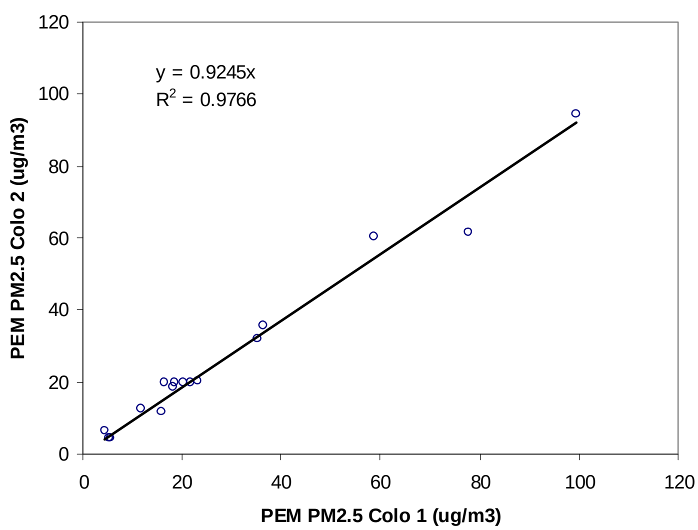


Figure 12. Personal PEM PM_{10} Co-Location (n=16); precision: 3.7%

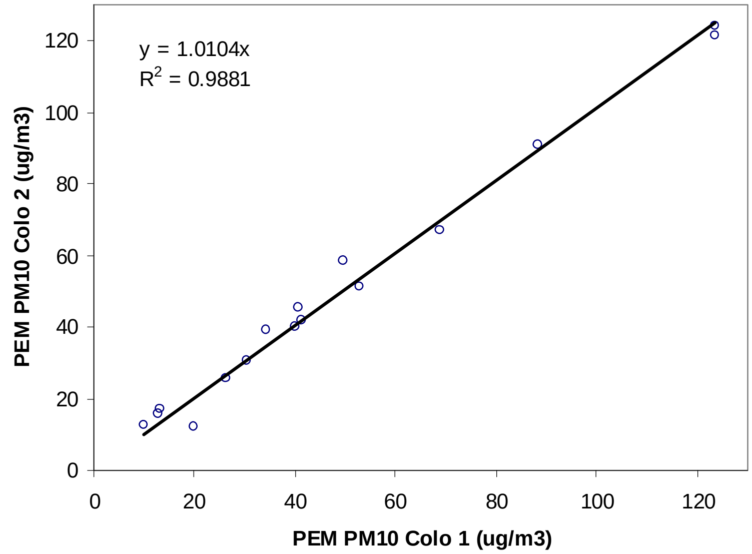
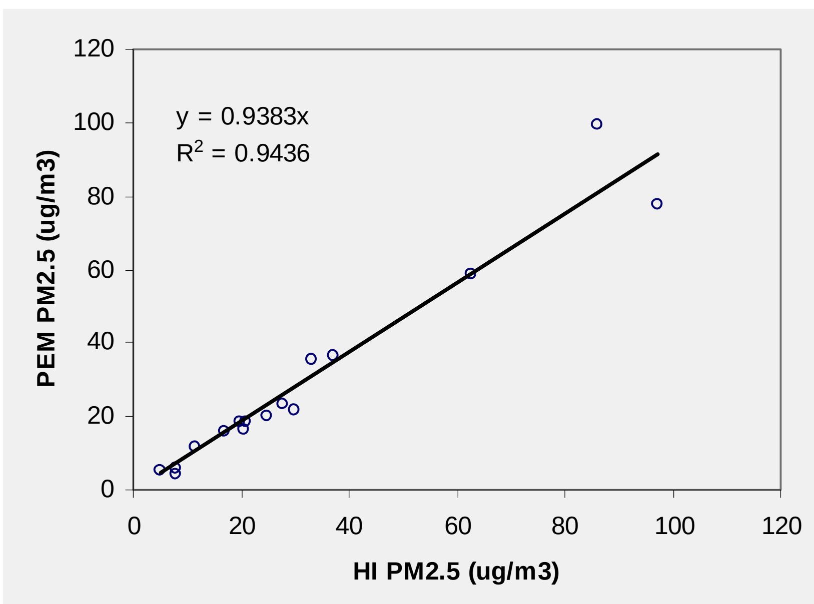


Figure 13. PEM vs. HI $PM_{2.5}$ Co-Location (n=16); accuracy: 0.92



3.2.3.4.2 *Black Carbon.* The precision of outdoor black carbon measurements (as determined by reflectance) was excellent, equaling 7.1%, and with slope and R^2 values close to one (Figure 14). Although lower, the precision of personal black carbon measurements was reasonable, with a value of 32%. Similarly, the slope (0.73) and R^2 (0.72) values for the regression of co-located personal measurements were lower than for the outdoor measurements but still showed good method performance (Figure 15).

Figure 14. Outdoor HI Black Carbon Co-Location (n=28); precision: 7.1%

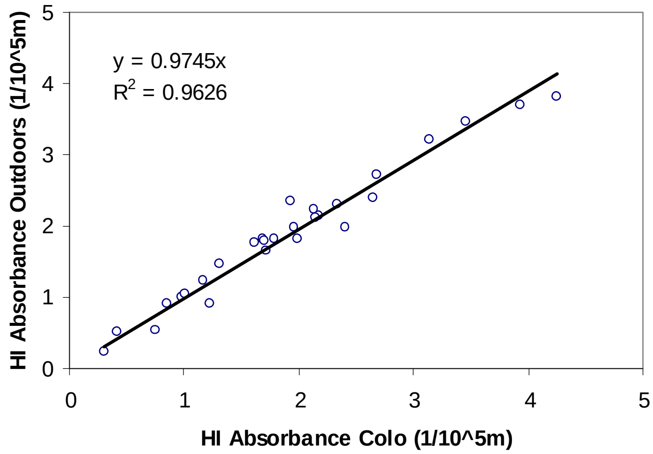


Figure 15. Personal PEM Black Carbon Co-Location (n=16); precision: 32%

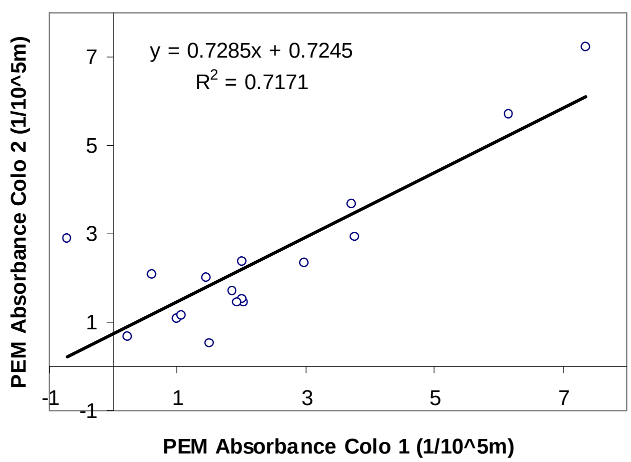
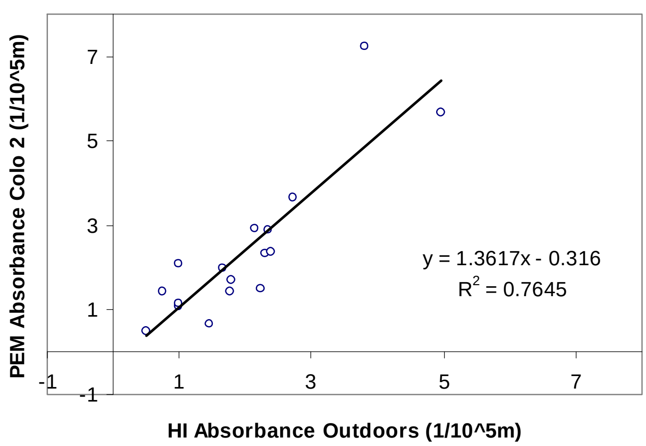


Figure 16. Personal PEM vs. HI Black Carbon Co-Location (n=17); accuracy: 0.20



3.2.3.4.3 ***Nitrate.*** For NO_3^-, a total of 31 valid indoor and outdoor blanks and 15 personal blanks were collected in the study (Table 5). LODs for the NO_3^- measurements were 1.0 µg and 0.5 µg for indoor/outdoor and personal sampling respectively, which correspond to concentration LODs of 0.2 µg/m^3 and 0.4 µg/m^3 for 24-hour sampling. All indoor and outdoor field samples were above the LOD; five personal NO_3^- samples fell below the LOD (Table 4). The accuracy and precision of the NO_3^- HI and mini-PEM were determined using co-located samplers as configured during the actual field sampling (i.e. in the multi-pollutant sampler for the PEMs). The relative precision was found to equal 5.6% for the HI and 7.2% for the mini-PEM, each meeting our data quality objectives of 10% precision. The associations between each of the co-located samplers were also excellent, with R^2 values of 0.99 and slopes ranging from 0.95 to 1.0, as indicated in Figure 17 and Figure 18. Using HI as the reference method, the accuracy of the NO_3^- mini-PEM was high, with a ratio of the mean mini-PEM to the reference HI concentrations equaling 0.98. The association between the mini-PEM and HI measurements was also excellent, with an R^2 value of 0.99 and a slope of 0.99 (Figure 19). These results are again similar to those of our previous field studies conducted in Boston, MA and Los Angeles, CA, where regression of the nitrate mini-PEM measurements on those obtained using the HI also resulted in a slope and R^2 value approximately equal to one.

Figure 17. Outdoor HI Nitrate Co-Location (n=29); precision: 5.6%

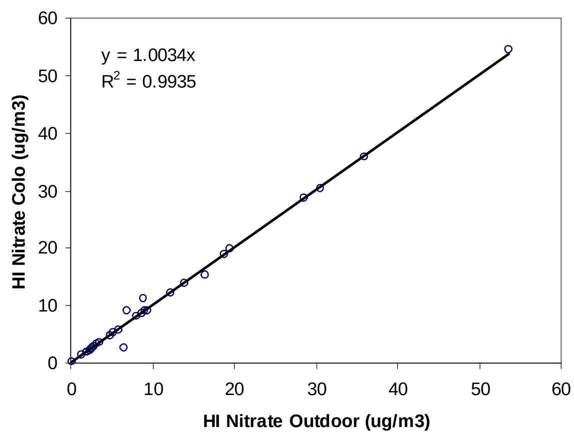


Figure 18. Mini-PEM Nitrate Co-Location (n=17); precision: 7.2%

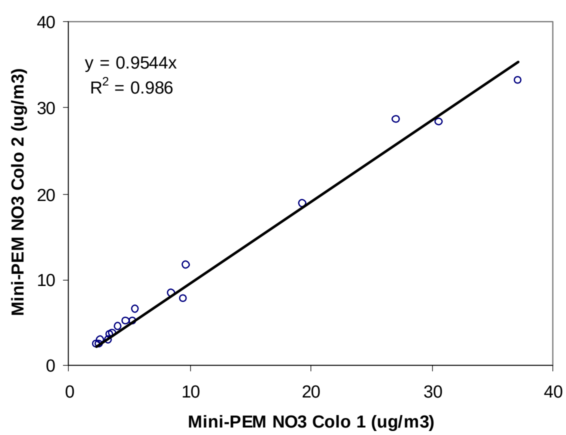
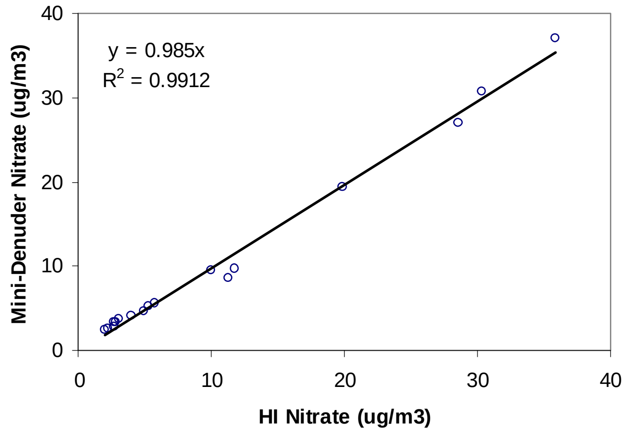


Figure 19. Nitrate Mini-PEM vs. HI Co-Location (n=17); accuracy: 0.98



3.2.4 Time-Activity Diaries (TADs)

TADs were modified versions of diaries from our previous studies of individuals with COPD, with modifications intended to facilitate its use in California (Appendix A). Each monitoring day, the individual wearing the personal monitor completed a TAD, in which they recorded in 30-minute intervals information about each new activity, including a short description of the activity, its location, and whether it occurred near any potential particle generating sources, such as tobacco smoking or cooking. To facilitate the completion of these diaries, information about activity location was recorded by checking the corresponding box for one of five microenvironments: indoors at home, indoors at work, indoors other, outdoors near home, outdoors away from home or in a motor vehicle.

105 subject-days of time-activity data were collected. Data were entered and processed as 30-minute, hourly and 24-hour intervals to correspond with the corresponding air pollutant samples. The six original location variables were reduced to five variables as follows: indoors at home, indoors at work, indoors other, outdoors, and in transit. Activity descriptions were coded by predetermined activity codes adapted from the US National Human Activity Pattern Survey (NHAPS) codes. Codes were then reduced into the following activity variables: food preparation, cleaning, household, personal, other (includes obtaining goods & services, organizational, social, recreation, communication). Participants indicated specific activities only 14% of the time and otherwise indicated their location instead, in which case location codes were assigned as above: indoors at home, indoors at work, indoors other, outdoors, and in transit.

3.2.5 Data Analyses

Personal particulate exposures and corresponding indoor and outdoor particulate concentrations were characterized using 24-h integrated $PM_{2.5}$, BC, and NO_3^- measurements and time/activity diary data. No continuous data were included in these analyses. For data analyses, indoor, outdoor and personal reflectance measurements were converted to equivalent black carbon concentrations based on the relationship between the reflectance measurements and indoor and outdoor co-located aethalometer measurements. Indoor and outdoor black carbon concentrations measured using an aethalometer were averaged into 24-h periods to correspond to the HI data and were subsequently regressed on their corresponding absorbance measurements using generalized mixed models, with house modeled as a random effect. The resulting location-specific slopes and intercepts were used to convert absorbance to black carbon levels, with corrections to personal samples performed using the slope and intercept for the indoor measurements (Table 6). $PM_{2.5}$, NO_3^- and estimated BC concentrations are reported in mass concentrations (μg/m^3).

Table 6. Regression of Black Carbon on Absorbance Measurements

Location	Crude R^2	Slope (SE)	Intercept (SE)
Indoor	0.82	**1.13 (0.06)**	0.17 (0.11)
Outdoor	0.81	**1.06 (0.07)**	0.01 (0.14)

Slopes and intercepts calculated using generalized mixed models; crude R^2 calculated using linear regression models. Bold indicates significance at 0.05 level.

Air pollution and time/activity data were characterized using descriptive statistics, graphical displays, Spearman correlation coefficients, general linear regressions and general mixed models. Individual-specific Spearman correlation coefficients (r_s) were calculated only for those individuals with four or more repeated measurements. Boxplots were used to present the distribution of values, with the dotted line representing the mean value, the solid line representing the median value, the circles representing the 5th and 95th percentiles, and the ends of the boxes representing the 25th and 75th percentiles. The composition of indoor and outdoor $PM_{2.5}$ was examined by 6-hr period for all homes and for each home individually, with all NO_3^- concentrations assumed to be in the form of ammonium nitrate (NH_4NO_3). Percent contributions were determined using the mean ratio of either NO_3^- or BC and $PM_{2.5}$ multiplied by the mean $PM_{2.5}$ level. All data were included in this analysis, even when few 6-h samples were available from a given home.

The relationships between personal, indoor, and outdoor concentrations were examined using general mixed models, in which subjects were modeled as random variables to account for between subject variability (Diggle *et al.* 1994). Autocorrelation between pollutant concentrations over time was modeled using compound symmetry covariance structure. Other covariance structures accounting for correlation over time provided similar AIC values. Since mixed models do not have a single measure of goodness-of-fit, crude R^2 values between the measured and estimated exposures (which was generated based on the results of mixed models) were calculated. Simple linear regression techniques were applied to obtain crude R^2 values to give a rough indication of the data scatter around the estimated regression lines.

Statistical modeling techniques were used to investigate the effects of location (inland or coastal), particle-generating activities, including cooking and cleaning, and time-activity patterns on the exposure levels. For indoor and personal pollutant levels, pollutant-specific models were also constructed to identify factors. These models followed the general format:

$$(C_i)_{ij} = (C_o)_{ij} + \text{Ventilation}_{ij} + (C_o)_{ij}\text{Ventilation}_{ij} + X_i \qquad \text{(Equation 6)}$$

where C_i is the indoor pollutant concentration, C_o the outdoor concentration, *Ventilation* the home ventilation condition, and X a covariate that may influence indoor pollutant concentrations. Home ventilation conditions were determined using 24-h air exchange rates (hr^{-1}) as either a continuous or categorical variable. As categorical variables, air exchange rates were classified as either "high" or "low" based on the median 24-h value of 0.69 exchanges/hr. The covariates tobacco smoke, cooking, and cleaning were included as continuous or categorical variables. As categorical variables, smoking, cooking, and cleaning were assigned a value of 1 if it was present or performed anytime during the 24-hour monitoring period. As continuous variables, smoking, cooking, and cleaning were expressed as number of minutes per hour.

Factors influencing personal exposures were identified based on time-weighted micro-environmental exposure models (Duan 1982). Personal exposures were estimated using time-weighted micro-environmental exposures from two microenvironments, indoor and outdoor:

$$C_p = F_i C_i + F_o C_o \qquad \text{(Equation 7)}$$

where C_p, C_i, and C_o are the measured personal exposures, indoor, and outdoor concentrations, respectively. F_i is the fraction of time spent indoors; F_o is the fraction of time spent outdoors. F_i was calculated as the fraction of time spent indoors in home and non-home, non-work environments. F_o was estimated as the fraction of time spent outdoors near or away from home. F_i was also calculated by including the fraction of time spent indoors at work, while F_o was also calculated to include the fraction of time spent in transit. Information about F_i and F_o were obtained from time-activity diaries. Concentrations for all indoor and outdoor environments were assumed to equal those measured inside and outside the subject's home, respectively. Particle-generating activities, such as ETS, cooking, and cleaning, were not included in the models, since the time participants spent performing these activities were minimal. The contribution of indoor and outdoor exposures to personal $PM_{2.5}$, NO_3^- and BC exposures was determined by dividing the time-weighted micro-environmental concentration by the corresponding personal exposure.

3.3 Part 3: Surface Dust

Phthalates have been identified as potential endocrine disrupting compounds. Because of the wide spread consumer use of these chemicals, concern has arisen about the extent of exposure to these compounds inside the home. We collected phthalate dust samples in our subject homes to assess the levels of phthalates present in the dust in our subset of homes.

Seventeen samples of house dust from seventeen different homes were collected using an HVS3 vacuum sampler. The surface dust entered the HVS3 through a nozzle that was designed to move across a floor with little resistance while still maintaining a sufficient seal to collect a sample. The dust then traveled up to the cyclone, which collected the majority of particles greater than 5 um in diameter in a catch bottle. The catch bottle containing the collected particles was removed and capped for storage. The sample was sieved to remove the larger particles. Surface dust samples were generally collected at the beginning of the seven-day monitoring period. Surface dust samples were taken from the main activity room of the home. The sampling area was at least one meter from any outside door to increase the representative nature of the sample. All samples were collected following SOPs detailed in the HVC operation manual (CS_3, Inc., 1998). Three samples were selected at random and sent for phthalate analysis. Chemical analysis of dust samples was conducted at the Southwest Research Institute (SWRI). Analysis was by Gas Chromatography/Mass Spectrophotometry (GC/MS) in Selective Ion Monitoring (SIM) mode. Results were reported in ug/gram of sieved dust.

3.4 Quality Assurance and Quality Control (QA/QC) Procedures

QA/QC procedures were followed throughout the study as detailed in the QA plan. Briefly, continuous monitors were calibrated prior to the start of the study and to the start of monitoring in each home. Continuous monitors were co-located with integrated monitors to verify their proper operation. Throughout the study, 15% of integrated samples were collected specifically for QA purposes. These samples included blanks, duplicates, and replicates. Sampling, data handling, data processing, data completeness, LOD, accuracy and precision procedures for each particle component are discussed above. Other QA/QC procedures are discussed below.

3.3.1 Record-keeping

A paper-based chain-of-custody and sample-tracking procedure was maintained for all phases of data generation and handling. Duplicate computerized versions were made each week. Comprehensive recording procedures were created or modified for origination, handling, storage, transport, and analysis of samples and data to ensure that they were not contaminated, lost, tampered with, or otherwise compromised. A detailed chronological paper trail was created for each sample or set of samples. A sample list was made and copied prior to sample shipments. The original copies of the sample list, along with the relevant field logs, were included with each shipment. All entries were dated and initialed by anyone coming into contact with the sample or the packaged sample, including the sampling analyst, lab analyst, or data processor. Corrections were dated and initialed, taking care to preserve the original entry information. Prior to shipping, all completed paperwork was photocopied and stored on-site for reference; these copies also served as backup copies of the original logs. Copies of magnetic media were made each week and were stored on-site. Original raw data from all analytical instrumentation was collected on paper and/or chart paper to supplement any automated collection methods and served as a permanent "hard copy" record for backup, troubleshooting, and validation purposes. These analytical records and all chain-of-custody records will be archived after the conclusion of the study, in the event that questions arise about the data or the handling of data. Questionnaire and time-activity data were handled in ways to protect the confidentiality of the information and the identity of the participant. Each participant was assigned an ID number, and all collected data were associated with that participant only through this ID number.

3.3.2 Documentation

All aspects of data generation were documented in detail. The criteria for documentation are such that it can be demonstrated to third parties that raw data can be traced from sample initiation and collection, through each stage of the analytical chain, and ultimately connected to data in the final data sets. Issues related to sample integrity were documented.

3.3.3 Measurement and Test Equipment Controls

All analytical measurements (both in the field and in the laboratory) were run under strict operational control to maintain adequate reproducibility, precision, and accuracy. Instrumentation was calibrated regularly using National Institute of Standards and Technology (NIST) traceable standards, when available. Control charts with Upper and Lower Warning and Control Limits (UWL, LWL, UCL, and LCL) were maintained as an accessible record of proper operation over time and to highlight potential analytical problems. All standard operating procedures (SOPs) included criteria that would trigger corrective action for "out-of-control" situations to resolve analytical problems quickly before data can be affected. Every chemical and reagent was of known quality and appropriate for its designated use. Each chemical was characterized either by assay or measurement of interferences. Chemical purity was documented on the reagent label analysis, the manufacturer's certified analysis, or documentation relating the purity to a NIST standard or equivalent. For synthesized or re-purified chemicals, the HSPH Laboratory assured that purity was adequate to meet the analytical method needs. All commercially obtained chemicals included a material safety data sheet (MSDS) that was filed in a three-ring binder and was available for use by all staff.

4.0 RESULTS AND DISCUSSION

4.1 Part 1: Continuous Data

As described above, continuous particle, housing activity, and air exchange rate data were analyzed in three parts. First, 20-minute data were characterized, with variability in their values by home and by hour examined. [As described in Section 3.1.7, 20-minute data were used to correspond with the 20-minute cycle time of the manifold and the 20-minute reporting period of the housing activity diaries.] Second, data were averaged into 6-hr daytime and nighttime periods to allow indoor and outdoor concentrations to be compared while minimizing the effect of time lags between indoor and outdoor concentrations. Six-hour averaged data were used to estimate values for F_{INF}, P and k using methods based on steady state models. Finally, values for P and k were also estimated using dynamic indoor concentration models based on 5-minute particulate and air exchange rate data. Findings from each part of the analyses were compared. Results from these analyses are discussed below.

4.1.2 Data Characterization

4.1.2.1 Housing Activities. Cooking and cleaning were on average performed over 14% of the monitoring period (Table 7), with cooking and cleaning never occurring in some homes during the monitoring period. The fraction of time spent performing other potential particle generating activities, such as household work or personal care activities, was even less, as the activities were not performed in most homes. When cooking, cleaning and other particle generating activities did occur, they generally were performed during the waking hours, between 6am-10pm (Table 8). Study subjects spent virtually no time near smoking, with only one subject spending 30-minutes near cigarette smoke.

4.1.2.2 Home Ventilation. Air exchange rates (AER) varied between homes. This inter-variation may be due in part to the geographic location of the home, as air exchange rates were significantly higher in coastal (mean=1.76 exchanges/hr) as compared to inland (mean=1.10 exchanges/hr) locations (Figure 20). This difference in air exchange rates was not due to differences in other ventilation measures, such as heater, open window, or fan use ($p>0.10$). Although the use of air conditioners was statistically greater in inland areas (p-value=0.03), this difference has little practical significance, as the frequency of air conditioner use was extremely low in inland (mean=0.02) and coastal (mean=0.00) homes.

Mean 20-minute home-specific AERs (measured in the primary location in the main activity room) ranged from 0.22 to 6.1 exchanges/hour (Table 9). AERs measured at the primary and secondary locations within each home generally agreed well, as reflected by the measured SF_6 concentrations at the two locations (Figure 21). [Measured SF_6 concentrations are the inverse of the air exchange rate.] For Homes 2 and 16, however, the SF_6 concentrations measured at the two locations differed substantially, suggesting that the air and thus particle concentrations within these homes were not well mixed, perhaps as the result of doors that were closed within the homes. For Home 2, the air exchange rates in the primary location were higher than those in the secondary location, while in Home 16, air exchange rates were lower in the primary as compared to secondary location. These intra-home differences in air exchange rates suggest that particle infiltration and deposition will vary within the home, possibly affecting our ability to estimate infiltration factors, penetration efficiencies and deposition rates. Results demonstrate the need for air exchange rates measurements in multiple (e.g., three or more) locations within the home. It is possible that air exchange rates would be more accurate with more precise estimation of the "relevant" house volume (e.g., the volume of the home in which air was well-mixed with regard to the main SF_6 monitor); however, it is not possible to determine the "relevant" house volume given the data collected in our study. Air exchange rates measured at the primary location were thought to be most relevant to the measured air pollutant concentrations, since air pollutant monitors were located in this room as well. AERs were shown to vary diurnally across homes, with median AERs generally exhibiting a single-peak or double-peak pattern corresponding to morning and evening time spent at home (Figure 22). AERs for Houses 4 and 5, for example, peaked during morning and evening hours, whereas AERs for other houses had broader peaks that generally began in the early to late morning hours.

Table 7. Time Spent Performing Particle Generating Activities: Average by House[1]

House	# Days	Cooking	Cleaning	Household Work[2]	Personal Care[3]	Other[4]
2	5	0.01	0.01	0.03	0.27	0.11
3	7	0.05	0.02	0.00	0.01	0.02
4	7	0.00	0.00	0.00	0.09	0.01
5	6	0.08	0.00	0.00	0.04	0.03
6	7	0.03	0.00	0.00	0.00	0.02
7	7	0.02	0.00	0.00	0.00	0.03
8	7	0.00	0.02	0.00	0.00	0.05
9	7	0.04	0.06	0.00	0.10	0.13
10	6	0.06	0.01	0.00	0.00	0.07
11	7	0.00	0.00	0.00	0.00	0.01
12	6	0.04	0.00	0.00	0.00	0.04
13	7	0.03	0.01	0.00	0.05	0.07
14	5	0.05	0.05	0.00	0.10	0.03
15	7	0.07	0.01	0.04	0.00	0.02
16	7	0.00	0.00	0.00	0.00	0.02
17	7	0.01	0.00	0.00	0.22	0.01
Mean	105	0.03	0.01	0.01	0.06	0.04
SD		0.05	0.04	0.03	0.13	0.07
Median		0.00	0.00	0.00	0.00	0.00
Max		0.21	0.26	0.21	0.55	0.30

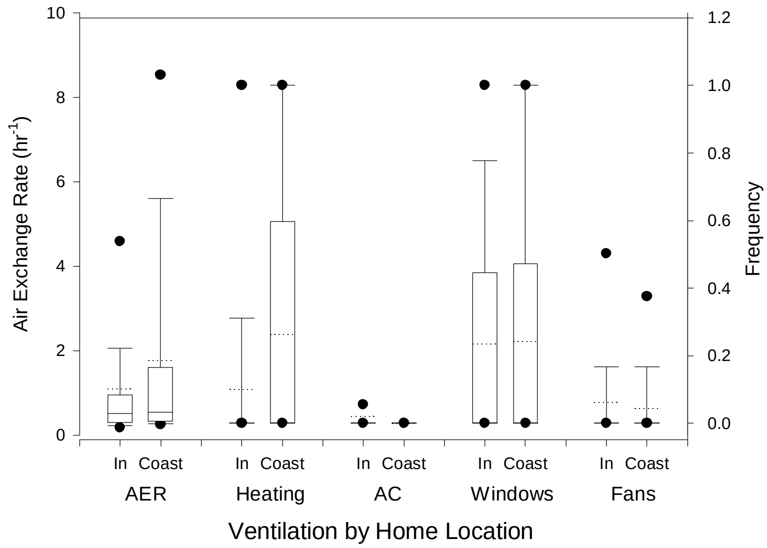
[1] Data obtained from participant completed daily housing activity diaries. Values expressed as fraction of time over 24-hrs for all data. [2] Household work included food clean-up, laundry, car maintenance, repairs, and plant and animal care. [3]Personal care included showering and bathing, medical care, eating, personal hygiene, sleep, and dressing. [4]Other activities included obtaining goods and services, organizational work (e.g. volunteer work), social events, recreational activities, communications (e.g. T.V., reading, conversations).

Table 8. Time Spent Performing Particle Generating Activities: Average by Hour [1]

Hour	N	Cooking	Cleaning	Household Work[2]	Personal Care[3]	Other[4]
0	105	0.00	0.00	0.01	0.16	0.00
1	105	0.00	0.00	0.00	0.17	0.00
2	105	0.00	0.00	0.00	0.17	0.00
3	105	0.00	0.00	0.00	0.17	0.00
4	105	0.00	0.00	0.00	0.17	0.00
5	210	0.00	0.00	0.00	0.16	0.00
6	210	0.00	0.00	0.00	0.14	0.00
7	210	0.02	0.01	0.01	0.07	0.03
8	177	0.02	0.03	0.01	0.01	0.06
9	178	0.02	0.03	0.01	0.00	0.04
10	184	0.01	0.01	0.01	0.00	0.06
11	186	0.03	0.01	0.01	0.00	0.07
12	186	0.02	0.02	0.00	0.01	0.03
13	195	0.02	0.01	0.00	0.02	0.03
14	198	0.02	0.02	0.00	0.01	0.06
15	203	0.05	0.02	0.01	0.00	0.08
16	207	0.07	0.03	0.01	0.00	0.07
17	208	0.17	0.04	0.01	0.00	0.07
18	209	0.12	0.02	0.00	0.01	0.05
19	210	0.06	0.01	0.00	0.02	0.06
20	210	0.01	0.00	0.00	0.01	0.08
21	210	0.00	0.00	0.00	0.00	0.05
22	210	0.00	0.00	0.01	0.08	0.05
23	210	0.00	0.00	0.00	0.15	0.01
Mean		0.03	0.01	0.00	0.07	0.04
SD		0.15	0.10	0.06	0.24	0.17
Median		0.00	0.00	0.00	0.00	0.00

1. Data obtained from participant completed daily housing activity diaries. Values are expressed as fraction of time over a 24-hr period. Summary statistics were calculated using all data rather than mean values for the 16 participants. Sample size differed by hour as the result of different reporting periods (one-hour for midnight to 4am, 30-minute for 5-7am, and 20-minute for 8am-11pm) and different sampling start and stop times.
2. Household work activities included food clean-up, laundry, car maintenance, other repairs, plant care, animal care and other household duties.
3. Personal care activities included showering and bathing, medical care, eating, personal hygiene, night and day sleep, dressing and other personal care activities.
4. Other activities included obtaining goods and services, organizational work (e.g. volunteer work), social events, recreational activities, communications (e.g. T.V., reading, conversations).

Figure 20. Effect of Inland or Coastal Location on Home Ventilation



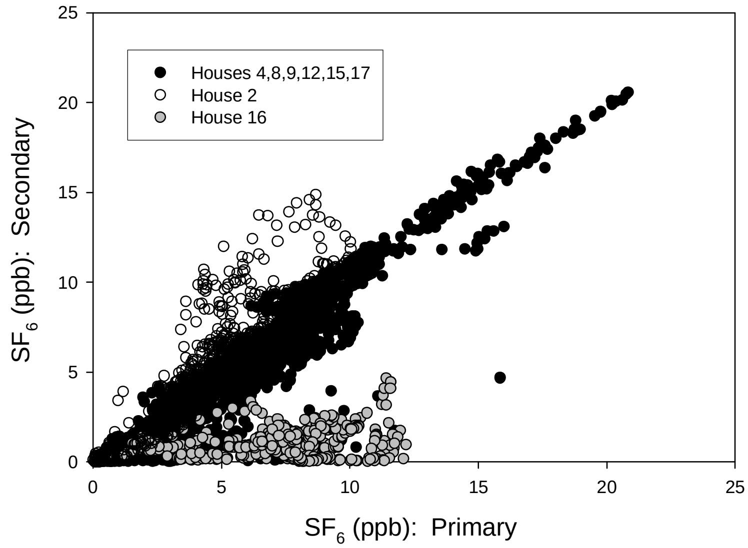
Coastal homes included those homes within 20 miles of the Pacific Ocean and Simi Valley (based on its climate and air quality). Frequency of heater use, air conditioner use, open windows and fan use calculated based on 24-h periods.

Table 9. 20-Minute AER Data: Averaged by House (units: hr^{-1})

House	N	Mean	SD	Min	P5	P25	P50	P75	P95	Max
2	552	1.42	4.57	0.24	0.27	0.37	0.55	0.83	5.77	81.10
3	484	6.11	5.81	0.38	0.45	2.00	3.79	8.85	19.20	27.56
4	422	2.41	4.68	0.21	0.23	0.48	0.61	2.03	10.58	49.35
5	487	1.40	1.98	0.17	0.22	0.43	0.72	1.62	4.43	17.31
6	214	0.96	0.82	0.26	0.30	0.36	0.45	1.51	2.59	3.12
7	489	1.75	2.54	0.44	0.56	0.69	0.81	1.27	7.30	17.45
8	493	0.33	0.19	0.13	0.19	0.23	0.26	0.36	0.73	1.25
9	485	0.76	1.08	0.25	0.29	0.35	0.41	0.78	2.17	13.78
10	413	0.46	0.68	0.17	0.18	0.23	0.26	0.36	1.42	5.91
11	474	0.63	0.34	0.23	0.27	0.36	0.54	0.86	1.12	2.85
12	124	0.34	0.15	0.13	0.18	0.25	0.29	0.41	0.65	1.01
13	482	0.42	0.38	0.20	0.23	0.27	0.33	0.42	0.73	4.01
14	150	0.78	0.20	0.45	0.50	0.62	0.76	0.89	1.14	1.34
15	495	0.22	0.07	0.13	0.14	0.16	0.20	0.25	0.34	0.53
16	424	0.39	0.31	0.19	0.20	0.25	0.29	0.38	1.03	4.08
17	339	2.04	6.45	0.29	0.33	0.43	0.54	0.65	9.01	57.23
Overall	6527	1.36	3.32	0.13	0.19	0.29	0.46	0.85	5.91	81.10

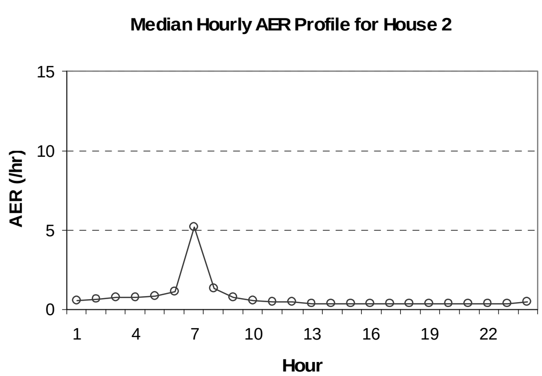
Note that air exchange rate results are reported only for monitors located in the main activity room or primary location. These monitors were located in the same room as the air pollution monitors.

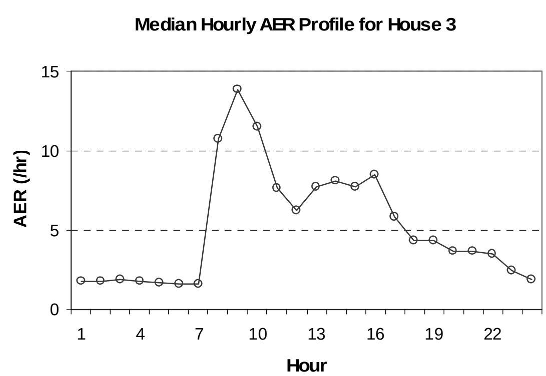
Figure 21. SF_6 Measurements: Primary and Secondary Locations

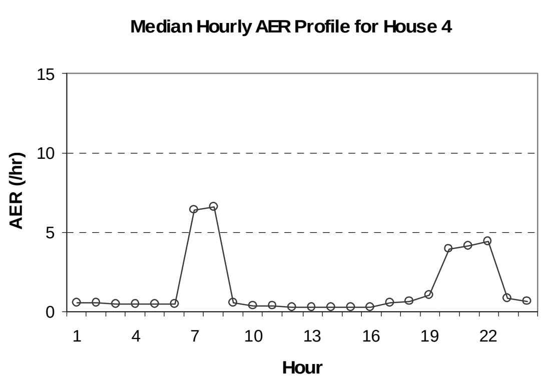


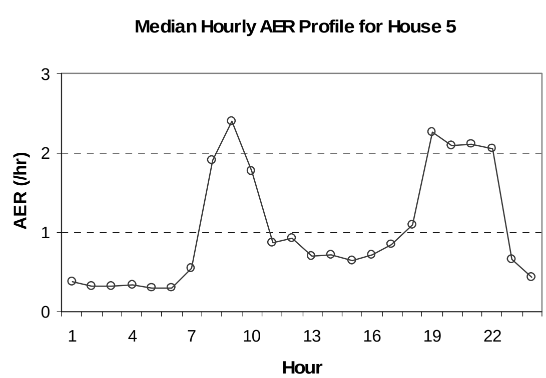
Primary monitors were located in the main activity room. Secondary monitors were located on the same floor but away from air pollution monitors.

Figure 22. Diurnal Profiles for AER by House

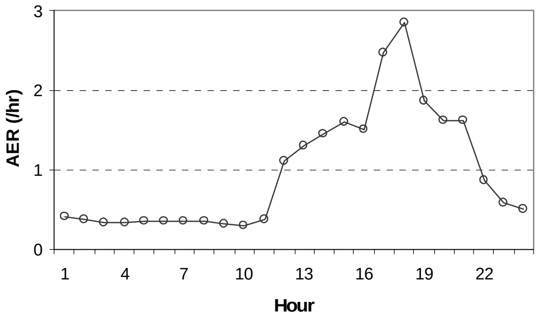




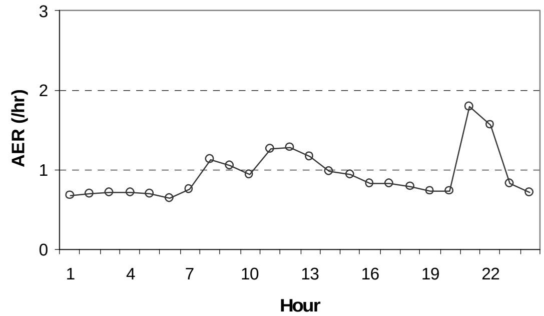




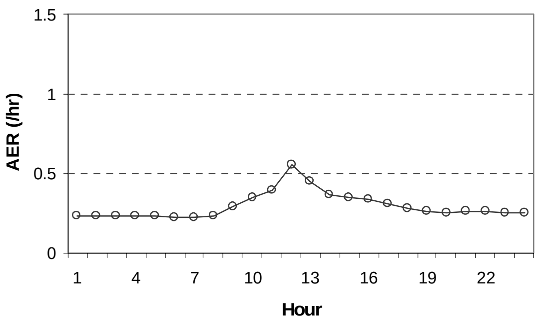
Median Hourly AER Profile for House 6



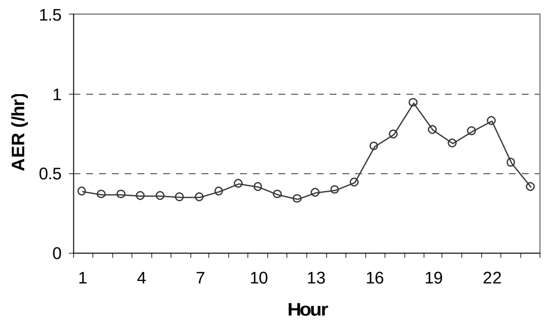
Median Hourly AER Profile for House 7



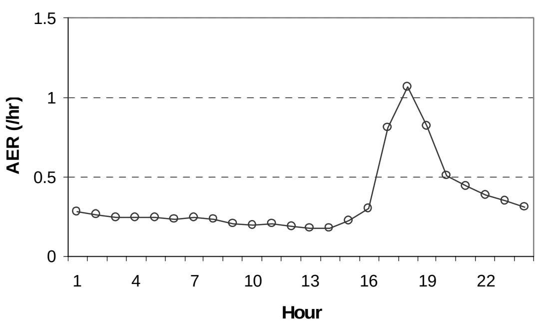
Median Hourly AER Profile for House 8



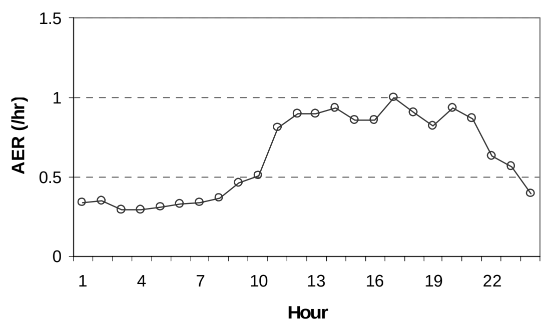
Median Hourly AER Profile for House 9



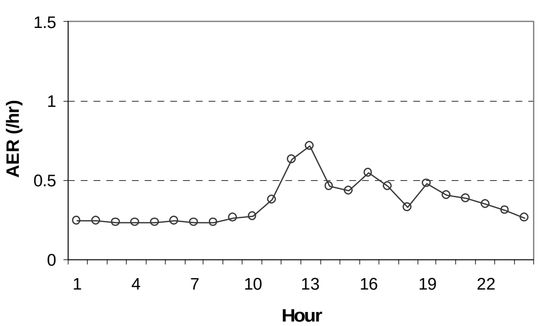
Median Hourly AER Profile for House 10



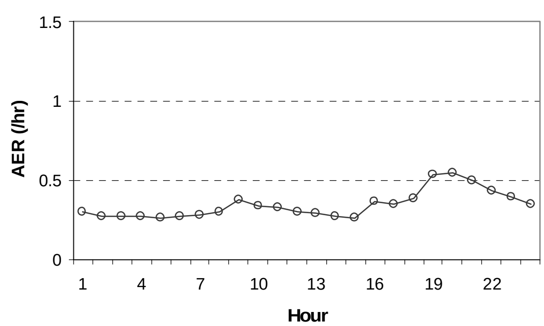
Median Hourly AER Profile for House 11

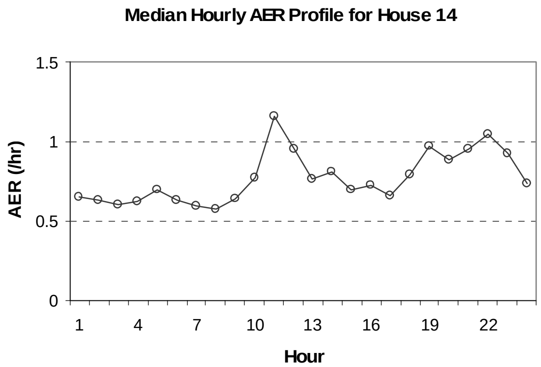


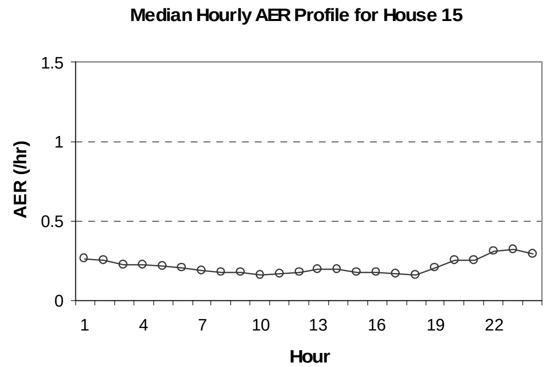
Median Hourly AER Profile for House 12

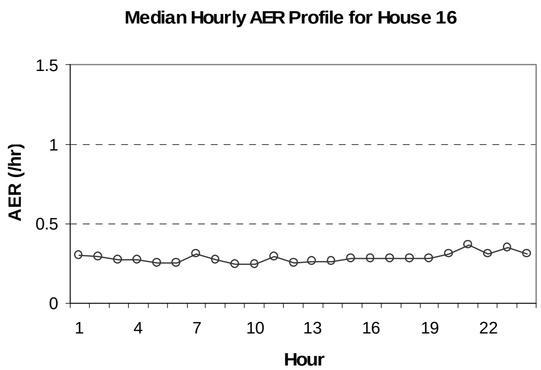


Median Hourly AER Profile for House 13









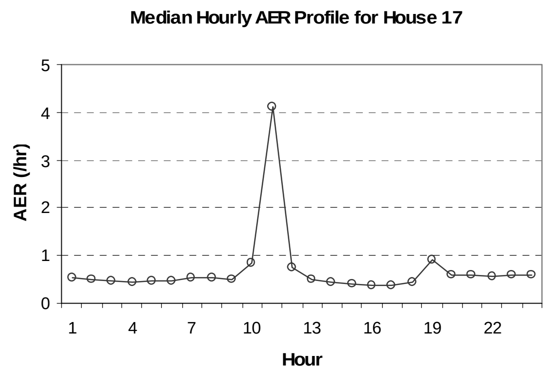


Table 10. Home Ventilation and Activity Patterns: Average by House[1]

House	# Days	Open Windows	AC Use	Fan Use	Heating	Cooking	Cleaning	Other
2	8	0.08	0.01	0.22	0.00	0.02	0.02	0.01
3	7	0.71	0.00	0.17	0.00	0.04	0.01	0.01
4	7	0.43	0.00	0.00	0.00	0.03	0.02	0.01
5	7	0.33	0.00	0.06	0.00	0.34	0.05	0.07
6	7	0.38	0.02	0.25	0.00	0.03	0.02	0.00
7	7	0.56	0.23	0.00	0.00	0.02	0.00	0.00
8	7	0.20	0.00	0.00	0.00	0.07	0.00	0.00
9	7	0.38	0.00	0.00	0.00	0.10	0.02	0.00
10	6	0.19	0.00	0.00	0.12	0.07	0.01	0.00
11	7	0.05	0.00	0.00	0.91	0.01	0.00	0.00
12	6	0.10	0.00	0.01	0.17	0.07	0.03	0.02
13	7	0.04	0.00	0.01	0.31	0.05	0.01	0.00
14	6	0.15	0.00	0.02	0.08	0.04	0.04	0.00
15	7	0.00	0.00	0.00	0.70	0.08	0.05	0.00
16	7	0.17	0.00	0.00	0.01	0.02	0.00	0.00
17	7	0.32	0.00	0.08	0.01	0.02	0.01	0.01
Mean (SD)	110	0.26 (0.26)	0.02 (0.06)	0.05 (0.12)	0.14 (0.31)	0.06 (0.09)	0.02 (0.04)	0.01 (0.02)

Data obtained from HADs. Values are expressed as fraction of time over a 24-hr period. Summary statistics were calculated using all data rather than mean values for the 16 participants.

Consistent with air exchange rate results, home ventilation, as measured by open windows and doors, cooling, and fan and heating use, also varied by home (Table 10) and hour (Table 10). In general, open windows, doors and fan use were most prevalent in the fall, between early-September through mid-November (Houses 3 to 10) and in the day (5am-10pm). Air conditioning use was most common between mid-August through mid-October (Houses 2 to 7) and during the day between 12pm-7pm. In contrast, heating was predominantly used between mid-November (House 10) and late February (House 17). Heating was used more consistently during the night, when individuals spent most of their time at home (Table 10).

Table 11. Home Ventilation and Activity Patterns: Average by Hour[1]

Hour	n	Open Window	AC Use	Fan Use	Heating	Cooking	Cleaning	Other
0	110	0.08	0.00	0.08	0.17	0.00	0.00	0.00
1	110	0.08	0.00	0.06	0.17	0.00	0.00	0.00
2	110	0.08	0.00	0.06	0.17	0.00	0.00	0.00
3	110	0.08	0.00	0.06	0.17	0.00	0.00	0.00
4	110	0.08	0.01	0.06	0.17	0.00	0.00	0.00
5	110	0.15	0.00	0.06	0.19	0.00	0.00	0.01
6	330	0.20	0.00	0.06	0.21	0.03	0.03	0.01
7	330	0.21	0.00	0.02	0.19	0.07	0.04	0.01
8	330	0.23	0.01	0.00	0.12	0.08	0.02	0.02
9	330	0.28	0.00	0.01	0.11	0.08	0.04	0.01
10	330	0.26	0.00	0.03	0.11	0.05	0.03	0.01
11	330	0.27	0.00	0.01	0.11	0.08	0.04	0.02
12	330	0.24	0.02	0.03	0.11	0.06	0.04	0.03
13	330	0.27	0.02	0.05	0.11	0.05	0.02	0.01
14	330	0.29	0.05	0.04	0.11	0.04	0.02	0.00
15	330	0.35	0.05	0.06	0.12	0.06	0.01	0.00
16	330	0.39	0.06	0.08	0.12	0.10	0.03	0.00
17	330	0.40	0.06	0.07	0.13	0.22	0.02	0.01
18	330	0.38	0.04	0.09	0.13	0.18	0.02	0.00
19	330	0.35	0.02	0.10	0.16	0.09	0.01	0.01
20	330	0.34	0.00	0.11	0.17	0.05	0.01	0.01
21	330	0.30	0.00	0.05	0.18	0.02	0.01	0.01
22	330	0.14	0.00	0.05	0.16	0.01	0.01	0.00
23	330	0.10	0.00	0.08	0.16	0.00	0.00	0.00
Mean (SD)	110	0.23 (0.41)	0.01 (0.11)	0.06 (0.22)	0.15 (0.35)	0.05 (0.19)	0.02 (0.10)	0.01 (0.07)
Median		0.00	0.00	0.00	0.00	0.00	0.00	0.00

Data obtained from HADs. Values are expressed as fraction of time over a 24-hr period. Summary statistics were calculated using all data rather than mean values for the 16 participants. Sample size differed by hour as the result of different reporting periods (one-hour for midnight to 4am, 30-minute for 5-7am, and 20-minute for 8am-11pm).

4.1.2.3 Hourly and Sub-Hourly Indoor and Outdoor Concentration Profiles. Summary statistics for indoor and outdoor hourly $PM_{2.5}$ and 20-min BC, NO_3^-, $PV_{0.02-0.1}$, $PV_{0.1-0.5}$, $PV_{0.7-2.5}$ and $PV_{2.5-10}$ are presented in Tables 12 through 18. Time-series plots for all indoor and outdoor measurements are provided in the Appendices (Figure 110 to Figure 123) for reference.

Overall, mean hourly $PM_{2.5}$ concentrations were higher outdoors (32.1$\pm$33.1 ug/m^3) as compared to indoors (17.9$\pm$18.7 ug/m^3). Similarly, mean outdoor 20-minute NO_3^- concentrations (9.4+10.1 ug/m^3) were higher than corresponding indoor levels (2.1$\pm$4.4 ug/m^3). Higher outdoor as compared to indoor $PM_{2.5}$ and NO_3^- levels is likely due to the fact that NO_3^-, which comprises a substantial fraction of $PM_{2.5}$ in Los Angeles, is volatile and as a result, is lost when it penetrates indoor environments. In contrast, BC, a stable particulate species, showed similar mean indoor and outdoor levels, with values equal to 1.6 ($\pm$1.4) and 1.9 ($\pm$1.9) ug/m^3, respectively. All indoor and outdoor concentration distributions were right-skewed and non-normally distributed based on Kolmogorov-Smirnov tests. (Log-transformed distributions were also significantly different from normal.) Mean and median indoor and outdoor $PM_{2.5}$ concentrations (Table 12) and to a lesser extent indoor and outdoor BC and NO_3^- levels (Table 13, 14) ranged broadly by home, with home-specific mean levels differing by as much as a factor of 10. This inter-home variability may be related to seasonal variability in outdoor concentrations, where homes measured in the summer and winter generally had lower particulate concentrations than homes measured in the fall. This observation is consistent with previous findings in Southern California of high $PM_{2.5}$ and PM_{10} masses measured in the fall, when NH_4^+, NO_3^- and BC concentrations are highest (Kim *et al.* 2000). Inter-home variability may also be due to spatial variability in outdoor levels, as $PM_{2.5}$, PM_{10} and NO_3^- (but not EC) concentrations have been shown to increase from coastal to inland areas in Southern California (Kim *et al.* 2000).

Indoor concentrations were more variable than outdoor concentrations for all species except $PM_{2.5}$ and BC, as evidenced by the CV. The CV for indoor $PV_{0.02-0.1}$ of 1.61, for example, was approximately twice that for outdoor $PV_{0.02-0.1}$ (0.80). The greater variability in indoor concentrations as compared to outdoor concentrations may be due to the contribution of indoor particle sources, which may vary substantially over time and by home, and to greater reactivity of particles indoors, particularly for NO_3^-. Despite this, mean outdoor concentrations were generally comparable to or greater than mean indoor concentrations for all of the measured particle species. For $PM_{2.5}$, NO_3^- and $PV_{2.5-10}$, outdoor concentrations were generally higher than indoor levels, with mean relative differences ranging between 0.57 and 0.67. Mean relative differences between indoor and outdoor concentrations were substantially smaller for BC and $PV_{0.02-0.1}$, equaling 0.15 and 0.09, respectively. Higher outdoor concentrations as compared to indoor concentrations, in particular for larger sized particles, are consistent with incomplete penetration of larger sized particles from outdoors (Long *et al.* 2001).

When analyzed cross-sectionally, associations between 20-minute averaged indoor and outdoor concentrations varied by particle species (Figure 23 through Figure 29), with associations strongest for BC (r_s=0.88) and weakest for coarse particles (r_s=0.47) (Figure 29). The majority of the indoor $PM_{2.5}$ (Figure 23), BC (Figure 24) and size-specific particle volume (Figure 26 through Figure 29) concentrations were less than outdoor concentrations. A smaller fraction of the indoor $PM_{2.5}$, BC and particle volume measurements were higher than corresponding outdoor levels, suggesting that indoor sources were important for a relatively small fraction of the 20-minute intervals. As shown on Figure 25, the relationship between indoor and outdoor NO_3^- concentrations varied widely by home and period, with indoor concentrations either comparable to outdoor values or essentially zero, which is consistent with loss of NO_3^- from volatilization and few indoor NO_3^- sources. Since cross-sectional analyses are unable to account for time lags between indoor and outdoor concentrations, correlations may be higher than observed and as shown on the scatter plots.

Table 12. Hourly $PM_{2.5}$ Concentrations: By House (units: mg/m^3)

House	Location	n	Mean	SD	Min	P5	P25	P50	P75	P95	Max
1	Indoor	161	8.6	6.7	-5.7	-1.5	3.9	7.7	12.8	20.0	30.6
	Outdoor	138	2.3	8.0	-14.6	-9.1	-2.9	1.4	5.4	20.6	27.0
2	Indoor	165	13.6	10.6	-4.2	2.3	7.3	12.0	17.3	29.8	96.7
	Outdoor	191	27.0	19.2	-6.6	2.3	13.1	23.8	38.5	65.4	77.6
3	Indoor	167	9.0	6.9	-14.8	-1.8	4.9	8.6	13.9	20.0	28.0
	Outdoor	162	15.2	12.2	-13.8	-3.3	6.7	12.4	23.2	35.8	56.5
4	Indoor	168	10.6	7.9	-3.6	0.4	6.1	9.6	14.1	24.0	59.6
	Outdoor	162	18.5	10.7	-7.2	2.4	11.2	16.3	25.6	36.0	59.9
5	Indoor	168	25.7	20.4	-13.0	2.4	10.1	21.5	36.9	61.9	125.4
	Outdoor	143	27.2	25.9	-10.9	0.9	8.1	17.8	43.7	83.9	100.7
6	Indoor	131	16.7	6.4	-0.9	6.8	12.4	17.0	20.7	27.4	43.1
	Outdoor	117	20.2	15.1	-10.4	-0.5	8.9	18.6	29.2	49.3	61.5
7	Indoor	165	28.7	20.4	2.8	8.1	15.0	23.4	33.6	79.5	101.0
	Outdoor	144	41.6	27.4	2.5	8.0	20.5	35.2	55.0	92.9	141.2
8	Indoor	160	28.6	27.9	0.2	7.0	11.8	20.0	29.8	101.3	134.4
	Outdoor	158	45.2	23.6	-10.4	15.1	27.7	42.5	59.6	86.6	130.7
9	Indoor	143	42.3	25.3	-4.1	1.9	23.0	45.2	57.9	82.9	117.2
	Outdoor	181	82.1	49.3	-11.3	-5.8	46.4	94.3	123.9	145.2	167.7
10	Indoor	131	15.4	16.3	-0.2	2.0	6.1	13.4	20.2	35.7	152.0
	Outdoor	109	22.5	27.4	-14.0	-7.4	1.9	15.1	37.9	78.7	112.7
11	Indoor	179	25.0	14.0	-3.5	3.6	14.6	24.2	33.7	49.3	75.0
	Outdoor	145	40.5	25.3	-7.9	3.9	19.3	39.0	59.6	82.4	99.0
12	Indoor	73	10.9	7.3	-3.6	3.6	7.4	9.9	12.9	23.5	51.5
	Outdoor	0	---	---	---	---	---	---	---	---	---
13	Indoor	138	23.3	16.4	2.1	7.5	13.3	19.9	27.4	48.3	125.7
	Outdoor	114	60.0	36.8	13.3	18.5	29.7	54.2	78.3	132.8	182.1
14	Indoor	167	16.8	18.0	-3.7	1.1	6.9	12.6	20.8	41.6	162.9
	Outdoor	55	28.2	19.4	-2.2	5.0	10.7	26.4	42.4	73.6	74.8
15	Indoor	187	4.6	20.9	-6.6	-3.8	-1.1	1.2	4.8	11.4	229.9
	Outdoor	167	10.9	18.0	-13.3	-7.3	-0.6	7.1	17.3	41.1	152.4
16	Indoor	184	14.1	13.7	-4.1	0.4	5.6	11.4	17.7	47.6	74.1
	Outdoor	0	---	---	---	---	---	---	---	---	---
17	Indoor	160	11.0	9.1	-4.5	-0.3	4.2	10.3	14.6	27.5	48.2
	Outdoor	0	---	---	---	---	---	---	---	---	---
Overall	Indoor	2647	17.9	18.7	-14.8	-0.4	6.5	13.1	22.8	53.0	229.9
	Outdoor	1986	32.1	33.1	-14.6	-3.4	8.8	22.7	45.4	104.5	182.1

Table 13. 20-minute BC Concentrations: By House (units: mg/m^3)

House	Location	n	Mean	SD	Min	P5	P25	P50	P75	P95	Max
1	Indoor	499	0.42	0.33	0.094	0.13	0.23	0.31	0.48	1.1	2.6
	Outdoor	501	0.43	0.30	0.14	0.19	0.24	0.34	0.49	0.99	2.7
2	Indoor	624	1.1	0.87	0.10	0.28	0.62	0.85	1.3	3.3	5.2
	Outdoor	563	1.5	1.0	0.12	0.46	0.85	1.4	1.8	3.4	6.7
3	Indoor	567	0.64	0.39	0.17	0.27	0.39	0.53	0.73	1.5	2.8
	Outdoor	503	0.66	0.39	-0.20	0.28	0.39	0.56	0.74	1.5	2.8
4	Indoor	561	1.3	0.54	0.40	0.55	0.86	1.2	1.6	2.3	3.6
	Outdoor	503	1.7	0.88	0.28	0.80	1.0	1.5	2.1	3.4	5.4
5	Indoor	499	2.0	1.8	0.35	0.46	0.76	1.4	2.5	6.4	10.5
	Outdoor	503	1.9	1.8	0.35	0.55	0.87	1.3	2.4	6.0	11.8
6	Indoor	558	1.2	0.79	0.21	0.41	0.64	1.1	1.6	2.9	4.5
	Outdoor	430	1.3	0.91	0.30	0.39	0.64	1.0	1.6	3.0	6.2
7	Indoor	493	3.5	2.7	0.56	0.89	1.9	2.8	4.3	7.7	22.1
	Outdoor	497	4.4	3.0	0.77	1.4	2.3	3.3	5.7	10.2	23.4
8	Indoor	563	1.8	0.91	0.41	0.51	1.2	1.7	2.3	3.5	4.7
	Outdoor	504	2.4	1.3	0.47	0.63	1.4	2.4	3.3	4.7	7.2
9	Indoor	557	2.6	1.3	0.16	0.29	1.8	2.6	3.4	4.8	6.3
	Outdoor	503	3.4	1.8	0.14	0.24	2.3	3.3	4.6	6.3	10.6
10	Indoor	425	1.4	0.82	0.25	0.40	0.75	1.3	1.9	2.9	4.8
	Outdoor	409	1.7	1.3	0.02	0.19	0.78	1.4	2.1	4.1	11.7
11	Indoor	547	2.4	1.5	0.21	0.41	1.0	2.2	3.5	4.8	8.1
	Outdoor	502	2.8	2.1	0.10	0.38	0.94	2.3	4.4	6.2	18.8
12	Indoor	218	1.2	0.58	0.30	0.38	0.78	1.2	1.6	2.2	3.5
	Outdoor	128	2.4	1.1	0.48	1.0	1.6	2.2	3.2	4.3	5.8
13	Indoor	484	2.7	1.8	0.49	0.59	1.3	2.1	3.9	6.8	8.8
	Outdoor	489	3.5	2.9	0.43	0.69	1.4	2.5	5.2	9.6	16.1
14	Indoor	495	1.6	1.1	0.21	0.45	0.84	1.3	2.3	3.7	5.8
	Outdoor	451	1.6	1.3	-0.12	0.34	0.67	1.2	2.4	4.5	6.7
15	Indoor	507	0.51	0.26	0.16	0.21	0.33	0.44	0.61	1.0	1.9
	Outdoor	511	0.69	0.48	-0.06	0.19	0.33	0.54	0.95	1.6	2.8
16	Indoor	559	1.2	0.73	0.18	0.34	0.69	1.0	1.6	2.7	4.4
	Outdoor	563	1.2	1.0	-0.01	0.24	0.53	0.95	1.6	3.1	8.0
17	Indoor	489	1.0	0.74	0.08	0.16	0.47	0.75	1.2	2.5	5.3
	Outdoor	491	1.4	1.2	-0.03	0.12	0.49	1.0	2.1	3.5	7.8
Overall	Indoor	8645	1.6	1.4	0.08	0.27	0.61	1.1	2.1	4.3	22.1
	Outdoor	8051	1.9	1.9	-0.20	0.25	0.64	1.3	2.6	5.7	23.4

* Outdoor concentrations were corrected by 1.16 based on results from instrument collocation tests.

Table 14. 20-Minute Nitrate Concentrations: By House (units: mg/m^3)

House	Location	n	Mean	SD	Min	P5	P25	P50	P75	P95	Max
1	Indoor	411	-0.05	0.69	-0.67	-0.56	-0.41	-0.26	0.00	1.32	4.26
	Outdoor	409	0.58	1.16	-0.48	-0.31	-0.11	0.13	0.56	3.35	5.17
2	Indoor	551	1.60	2.37	-0.74	-0.37	0.61	1.20	1.78	5.11	18.34
	Outdoor	552	15.09	10.94	-0.39	0.65	7.39	12.79	21.37	38.11	60.26
3	Indoor	405	2.02	2.40	-0.48	-0.30	0.24	1.46	2.98	6.95	13.14
	Outdoor	407	4.77	3.78	-0.33	0.24	1.87	3.91	7.75	11.40	20.40
4	Indoor	481	1.74	1.85	-0.20	0.28	0.70	1.11	1.87	5.19	11.14
	Outdoor	481	5.60	4.75	0.31	1.17	2.32	3.43	7.97	16.92	21.36
5	Indoor	373	3.96	3.30	0.80	1.06	1.78	2.96	4.65	12.19	17.34
	Outdoor	372	8.97	8.15	1.69	2.20	2.98	4.89	13.79	23.53	38.63
6	Indoor	480	2.21	1.36	0.33	0.82	1.24	1.81	2.83	4.76	8.97
	Outdoor	479	9.35	7.28	1.85	2.46	4.54	7.54	11.47	25.96	44.71
7	Indoor	357	8.50	11.03	-0.11	0.41	1.61	3.61	11.64	36.39	50.53
	Outdoor	357	18.51	15.44	0.83	1.87	5.61	10.19	32.44	45.17	64.74
8	Indoor	359	3.28	5.14	0.33	0.57	0.94	1.33	2.67	15.60	31.41
	Outdoor	358	21.72	10.67	3.43	7.54	14.92	19.95	26.00	44.60	59.46
9	Indoor	0	---	---	---	---	---	---	---	---	---
	Outdoor	0	---	---	---	---	---	---	---	---	---
10	Indoor	130	4.04	5.85	-0.28	-0.09	0.48	1.79	3.80	17.77	29.03
	Outdoor	130	16.73	10.56	-0.07	0.76	9.15	15.52	24.96	36.85	39.69
11	Indoor	0	---	---	---	---	---	---	---	---	---
	Outdoor	0	---	---	---	---	---	---	---	---	---
12	Indoor	267	-0.03	0.63	-1.02	-0.50	-0.37	-0.24	0.06	1.43	2.95
	Outdoor	266	4.24	2.61	-0.82	0.65	2.26	3.64	6.41	8.76	10.47
13	Indoor	0	---	---	---	---	---	---	---	---	---
	Outdoor	0	---	---	---	---	---	---	---	---	---
14	Indoor	292	1.75	2.29	-0.30	0.02	0.48	0.99	2.38	4.98	15.66
	Outdoor	292	5.28	4.94	-0.50	0.24	1.80	4.10	7.63	13.86	32.39
15	Indoor	452	0.05	0.76	-0.78	-0.63	-0.44	-0.20	0.22	1.98	2.76
	Outdoor	449	5.13	5.21	-0.74	-0.37	1.15	3.37	7.28	16.71	20.66
16	Indoor	347	-0.08	0.67	-0.93	-0.78	-0.57	-0.31	0.31	1.19	3.34
	Outdoor	218	9.75	7.42	-0.91	-0.72	2.46	10.59	14.92	22.12	34.02
17	Indoor	0	---	---	---	---	---	---	---	---	---
	Outdoor	0	---	---	---	---	---	---	---	---	---
Overall	Indoor	4905	2.10	4.41	-1.02	-0.52	0.06	1.04	2.22	8.56	50.53
	Outdoor	4770	9.36	10.06	-0.91	-0.04	2.37	6.05	13.14	31.80	64.74

Table 15. 20-Minute $PV_{0.02\text{-}0.1}$ Concentrations: By House (units: mm^3/cm^3)

House	Location	n	Mean	SD	Min	P5	P25	P50	P75	P95	Max
1	Indoor	494	0.18	0.17	0.04	0.06	0.09	0.14	0.22	0.38	2.14
	Outdoor	492	0.18	0.37	0.04	0.05	0.10	0.13	0.20	0.39	8.09
2	Indoor	493	0.37	0.17	0.08	0.16	0.26	0.33	0.44	0.68	1.23
	Outdoor	492	0.61	0.26	0.18	0.26	0.41	0.55	0.77	1.05	1.99
3	Indoor	498	0.36	0.19	0.10	0.13	0.25	0.35	0.43	0.59	1.91
	Outdoor	492	0.35	0.14	0.13	0.17	0.25	0.34	0.43	0.57	1.08
4	Indoor	498	0.70	0.83	0.27	0.34	0.43	0.54	0.77	1.36	13.86
	Outdoor	491	0.82	0.41	0.27	0.44	0.59	0.71	0.99	1.44	5.91
5	Indoor	498	1.55	2.69	0.16	0.28	0.45	0.74	1.54	6.62	24.72
	Outdoor	494	0.91	0.52	0.25	0.38	0.59	0.74	1.09	2.00	5.13
6	Indoor	0	---	---	---	---	---	---	---	---	---
	Outdoor	0	---	---	---	---	---	---	---	---	---
7	Indoor	444	0.63	0.30	0.17	0.25	0.47	0.56	0.73	1.15	2.62
	Outdoor	443	0.98	0.39	0.35	0.48	0.72	0.90	1.17	1.73	2.92
8	Indoor	347	0.42	0.37	0.13	0.18	0.25	0.32	0.43	0.89	3.24
	Outdoor	344	0.52	0.19	0.19	0.27	0.38	0.49	0.63	0.87	1.48
9	Indoor	428	0.41	0.56	0.03	0.05	0.22	0.35	0.47	0.77	7.35
	Outdoor	0	---	---	---	---	---	---	---	---	---
10	Indoor	356	0.57	0.74	0.08	0.11	0.20	0.36	0.53	2.17	5.30
	Outdoor	354	0.48	0.32	0.09	0.11	0.27	0.43	0.59	1.10	2.31
11	Indoor	546	0.83	0.53	0.08	0.22	0.49	0.78	1.06	1.57	6.36
	Outdoor	0	---	---	---	---	---	---	---	---	---
12	Indoor	256	0.71	1.29	0.11	0.25	0.33	0.45	0.60	1.52	12.44
	Outdoor	253	0.90	0.43	0.01	0.30	0.59	0.91	1.17	1.50	2.97
13	Indoor	484	0.93	0.80	0.15	0.21	0.46	0.76	1.19	1.97	9.72
	Outdoor	475	1.25	0.98	0.15	0.22	0.52	1.02	1.70	3.13	7.91
14	Indoor	333	1.00	1.85	0.06	0.13	0.30	0.46	1.01	3.15	20.74
	Outdoor	330	0.73	0.66	0.05	0.17	0.31	0.45	0.90	2.38	3.13
15	Indoor	468	0.34	0.48	0.00	0.12	0.18	0.23	0.32	0.83	6.36
	Outdoor	450	0.53	0.27	0.00	0.22	0.36	0.48	0.64	1.00	2.62
16	Indoor	482	0.62	0.30	0.12	0.24	0.39	0.58	0.80	1.18	1.79
	Outdoor	483	0.98	0.68	0.14	0.21	0.49	0.80	1.33	2.33	4.70
17	Indoor	411	0.61	0.58	0.13	0.27	0.37	0.46	0.61	1.15	5.42
	Outdoor	407	0.61	0.35	0.10	0.15	0.29	0.60	0.82	1.18	2.07
Overall	Indoor	7036	0.64	1.03	0.00	0.12	0.28	0.43	0.69	1.59	24.72
	Outdoor	6000	0.70	0.56	0.00	0.13	0.35	0.57	0.88	1.74	8.09

Table 16. 20-Minute $PV_{0.1-0.5}$ Concentrations: By House (units: mm^3/cm^3)

House	Location	n	Mean	SD	Min	P5	P25	P50	P75	P95	Max
1	Indoor	494	5.8	1.9	2.3	3.1	4.5	5.6	6.7	9.3	12.6
	Outdoor	490	6.7	2.8	3.3	4.5	5.3	6.3	7.8	9.7	48.5
2	Indoor	493	9.7	3.7	1.8	3.4	7.5	9.0	11.7	17.1	20.6
	Outdoor	491	17.0	7.2	3.4	5.8	11.7	15.5	21.7	30.0	45.0
3	Indoor	498	8.5	2.2	4.0	5.3	6.9	8.4	10.0	12.1	14.9
	Outdoor	490	9.2	2.3	3.4	5.5	7.8	9.0	10.5	13.3	15.6
4	Indoor	498	10.4	5.8	4.8	5.6	7.4	9.6	11.7	15.6	87.1
	Outdoor	486	12.8	4.3	5.1	6.7	9.6	12.7	15.5	20.0	38.5
5	Indoor	498	14.1	17.8	1.9	2.7	6.6	10.2	17.0	28.1	239.1
	Outdoor	489	13.1	7.4	2.1	3.3	7.8	11.6	17.0	28.1	37.8
6	Indoor	0	---	---	---	---	---	---	---	---	---
	Outdoor	0	---	---	---	---	---	---	---	---	---
7	Indoor	444	14.7	9.9	3.4	5.6	8.2	12.3	17.4	31.3	70.3
	Outdoor	439	22.3	13.5	4.8	6.9	12.7	18.6	28.8	48.0	76.6
8	Indoor	347	9.5	3.7	4.3	4.8	7.2	9.0	10.7	17.0	25.7
	Outdoor	344	16.6	7.0	6.9	9.1	11.8	14.5	19.1	33.2	43.2
9	Indoor	428	10.9	6.7	0.67	0.90	7.4	10.9	14.7	22.1	53.9
	Outdoor	0	---	---	---	---	---	---	---	---	---
10	Indoor	356	6.2	3.8	1.0	1.8	3.2	5.5	8.1	13.5	20.3
	Outdoor	353	10.3	6.5	0.77	1.6	5.0	9.9	14.9	22.1	36.0
11	Indoor	546	10.7	6.8	0.82	1.8	5.8	9.8	14.7	20.0	70.8
	Outdoor	0	---	---	---	---	---	---	---	---	---
12	Indoor	256	10.3	30.2	0.05	1.4	2.8	4.6	6.2	24.6	255.5
	Outdoor	253	9.7	5.1	0.71	1.3	5.4	9.7	14.0	17.5	19.8
13	Indoor	484	16.2	23.8	3.5	5.9	8.5	11.1	17.4	34.4	387.5
	Outdoor	473	20.1	14.3	3.1	6.3	10.5	15.2	25.1	51.9	81.7
14	Indoor	333	8.9	17.4	0.56	1.6	3.5	5.5	9.0	21.2	230.0
	Outdoor	328	9.5	7.2	0.50	1.6	4.9	7.5	12.3	25.3	45.8
15	Indoor	467	2.7	2.9	0.28	0.76	1.3	1.8	2.9	6.0	26.4
	Outdoor	440	6.3	4.8	0.64	1.1	2.7	5.1	8.2	16.5	27.8
16	Indoor	482	7.8	4.8	1.1	1.5	3.5	8.1	10.5	14.2	31.2
	Outdoor	483	12.9	9.1	0.59	1.2	4.6	12.4	20.6	27.5	55.4
17	Indoor	411	7.0	4.2	0.76	1.3	4.0	7.1	9.3	14.4	27.2
	Outdoor	403	12.2	8.7	0.39	0.66	2.2	12.7	20.0	25.8	35.8
Overall	Indoor	7035	9.7	11.9	0.05	1.5	5.1	8.1	11.5	21.1	387.5
	Outdoor	5962	12.9	9.2	0.39	2.1	6.8	10.9	16.7	29.5	81.7

Table 17. 20-Minute $PV_{0.7-2.5}$ Concentrations: By House (units: $\mu m^3/cm^3$)

House	Location	n	Mean	SD	Min	P5	P25	P50	P75	P95	Max
1	Indoor	493	5.7	2.9	1.4	2.0	3.8	5.0	7.1	11.6	20.1
	Outdoor	491	7.8	2.8	3.7	4.2	6.0	7.4	9.1	13.5	24.9
2	Indoor	493	4.5	3.5	0.39	1.0	2.1	3.9	5.2	12.9	23.3
	Outdoor	492	19.3	9.6	0.09	7.4	13.7	16.2	23.1	41.2	49.1
3	Indoor	499	9.7	6.6	1.6	2.1	4.6	7.0	14.6	23.7	31.1
	Outdoor	495	14.2	8.5	1.5	4.3	7.0	12.8	19.6	30.5	49.1
4	Indoor	498	6.4	3.5	2.1	2.6	3.6	5.2	8.2	13.3	19.3
	Outdoor	492	10.8	5.2	2.3	3.9	6.6	10.1	14.0	20.7	24.8
5	Indoor	498	10.9	9.7	1.4	3.0	4.5	8.5	13.2	32.2	55.3
	Outdoor	494	18.4	15.4	2.9	5.3	9.3	12.7	19.9	53.5	84.4
6	Indoor	0	---	---	---	---	---	---	---	---	---
	Outdoor	0	---	---	---	---	---	---	---	---	---
7	Indoor	0	---	---	---	---	---	---	---	---	---
	Outdoor	0	---	---	---	---	---	---	---	---	---
8	Indoor	0	---	---	---	---	---	---	---	---	---
	Outdoor	0	---	---	---	---	---	---	---	---	---
9	Indoor	500	37.0	23.7	0.60	1.0	23.3	37.1	49.3	80.8	136.2
	Outdoor	0	---	---	---	---	---	---	---	---	---
10	Indoor	356	3.8	4.4	0.35	0.65	1.4	2.4	4.2	11.7	33.7
	Outdoor	355	12.4	11.6	0.34	1.0	3.2	7.2	20.0	37.4	45.4
11	Indoor	0	---	---	---	---	---	---	---	---	---
	Outdoor	0	---	---	---	---	---	---	---	---	---
12	Indoor	0	---	---	---	---	---	---	---	---	---
	Outdoor	0	---	---	---	---	---	---	---	---	---
13	Indoor	483	6.9	7.7	0.92	2.5	3.8	5.0	7.7	17.3	108.8
	Outdoor	477	12.8	7.1	2.3	4.6	8.4	11.4	15.8	24.2	55.0
14	Indoor	333	4.1	7.8	1.0	1.4	2.1	2.8	3.8	7.8	106.7
	Outdoor	330	4.2	1.9	0.65	1.3	2.6	4.4	5.5	7.1	10.5
15	Indoor	469	1.3	2.2	0.21	0.34	0.55	0.80	1.3	2.8	23.7
	Outdoor	466	1.5	1.0	0.29	0.62	0.90	1.3	1.7	4.2	5.3
16	Indoor	485	2.7	1.5	0.57	0.86	1.6	2.4	3.4	5.3	9.1
	Outdoor	485	7.5	5.4	0.9	1.4	3.2	6.0	10.1	17.0	28.9
17	Indoor	0	---	---	---	---	---	---	---	---	---
	Outdoor	0	---	---	---	---	---	---	---	---	---
Overall	Indoor	5107	8.8	13.3	0.21	0.70	2.4	4.3	8.6	38.7	136.2
	Outdoor	4577	11.1	9.8	0.1	1.1	4.7	8.6	14.7	29.4	84.4

Table 18. 20-Minute $PV_{2.5-10}$ Concentrations: By House (units: mm^3/cm^3)

House	Location	n	Mean	SD	Min	P5	P25	P50	P75	P95	Max
1	Indoor	493	7.2	6.3	0.73	1.2	2.4	5.7	9.7	20.5	35.5
	Outdoor	491	11.6	4.6	5.3	7.2	8.9	10.7	13.1	17.5	46.5
2	Indoor	493	3.7	4.0	0.26	0.93	1.5	2.1	3.7	13.5	22.1
	Outdoor	492	27.7	10.0	0.02	14.2	20.1	26.2	33.1	46.7	61.4
3	Indoor	499	13.9	9.6	1.2	2.0	7.3	12.4	18.6	31.1	68.6
	Outdoor	495	21.9	11.9	4.1	7.8	12.9	18.7	27.5	47.2	64.2
4	Indoor	498	11.1	10.4	1.3	2.0	3.3	7.6	16.0	31.6	74.3
	Outdoor	492	26.3	17.7	6.0	8.1	14.9	23.1	31.6	57.9	138.4
5	Indoor	498	12.7	9.6	0.73	1.4	4.7	11.3	18.5	30.3	54.1
	Outdoor	494	21.1	9.9	2.2	9.4	14.7	18.3	25.2	42.1	63.4
6	Indoor	0	---	---	---	---	---	---	---	---	---
	Outdoor	0	---	---	---	---	---	---	---	---	---
7	Indoor	0	---	---	---	---	---	---	---	---	---
	Outdoor	0	---	---	---	---	---	---	---	---	---
8	Indoor	0	---	---	---	---	---	---	---	---	---
	Outdoor	0	---	---	---	---	---	---	---	---	---
9	Indoor	500	22.8	15.5	0.66	1.4	13.9	20.8	28.9	52.0	104.4
	Outdoor	0	---	---	---	---	---	---	---	---	---
10	Indoor	356	4.6	6.0	0.35	0.54	1.3	2.2	4.6	20.5	35.5
	Outdoor	355	11.9	7.5	0.77	2.4	6.6	10.4	15.5	28.0	36.7
11	Indoor	0	---	---	---	---	---	---	---	---	---
	Outdoor	0	---	---	---	---	---	---	---	---	---
12	Indoor	0	---	---	---	---	---	---	---	---	---
	Outdoor	0	---	---	---	---	---	---	---	---	---
13	Indoor	483	6.8	9.9	0.52	1.1	2.2	4.4	8.0	17.8	135.9
	Outdoor	477	17.5	6.7	6.5	9.4	12.6	16.0	21.5	29.4	48.2
14	Indoor	333	6.0	7.3	0.65	0.93	1.8	3.7	7.3	16.9	75.3
	Outdoor	330	8.5	4.8	2.0	3.5	5.4	7.3	10.0	19.4	32.7
15	Indoor	469	1.7	3.1	0.10	0.27	0.52	0.80	1.5	5.6	41.0
	Outdoor	466	4.6	2.1	0.58	1.8	3.0	4.4	5.9	9.0	11.2
16	Indoor	485	3.8	4.2	0.39	0.64	1.2	2.2	4.7	13.1	25.7
	Outdoor	485	19.8	15.7	3.2	5.4	10.9	16.5	23.0	40.8	180.0
17	Indoor	0	---	---	---	---	---	---	---	---	---
	Outdoor	0	---	---	---	---	---	---	---	---	---
Overall	Indoor	5107	8.8	10.5	0.10	0.65	1.8	4.5	12.8	28.2	135.9
	Outdoor	4577	17.6	12.7	0.0	3.6	9.0	14.7	23.0	41.0	180.0

Figure 23. Scatter Plot of Indoor vs. Outdoor Hourly $PM_{2.5}$ (r_s=0.65 at p<0.0001)

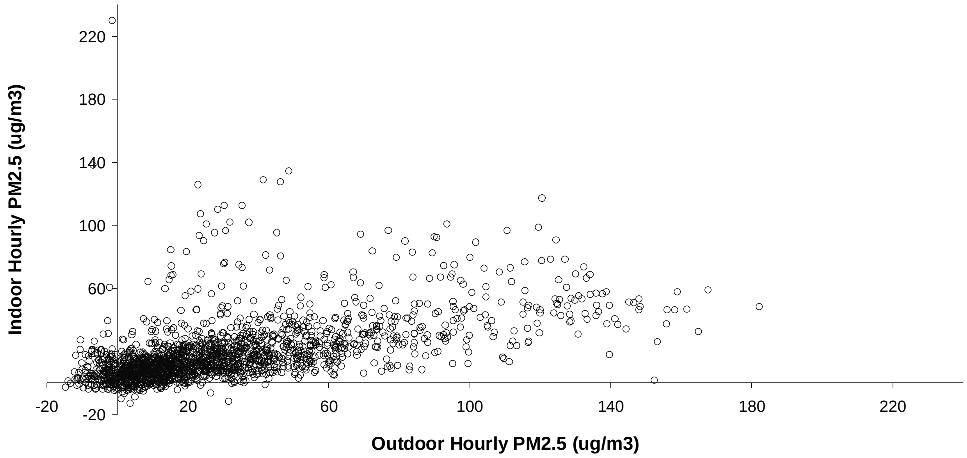


Figure 24. Scatter Plot of Indoor vs. Outdoor 20-Minute BC (r_s=0.88 at p<0.0001)

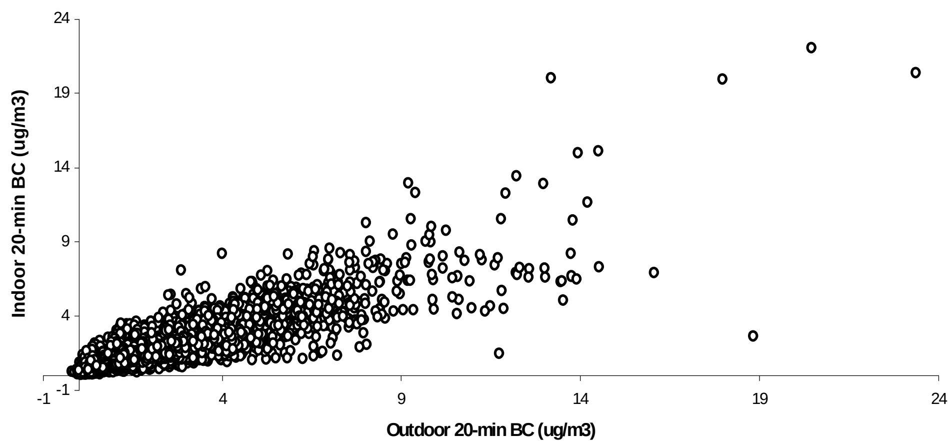


Figure 25. Scatter Plot of Indoor vs. Outdoor 20-Minute NO_3^- (r_s=0.62 at p<0.0001)

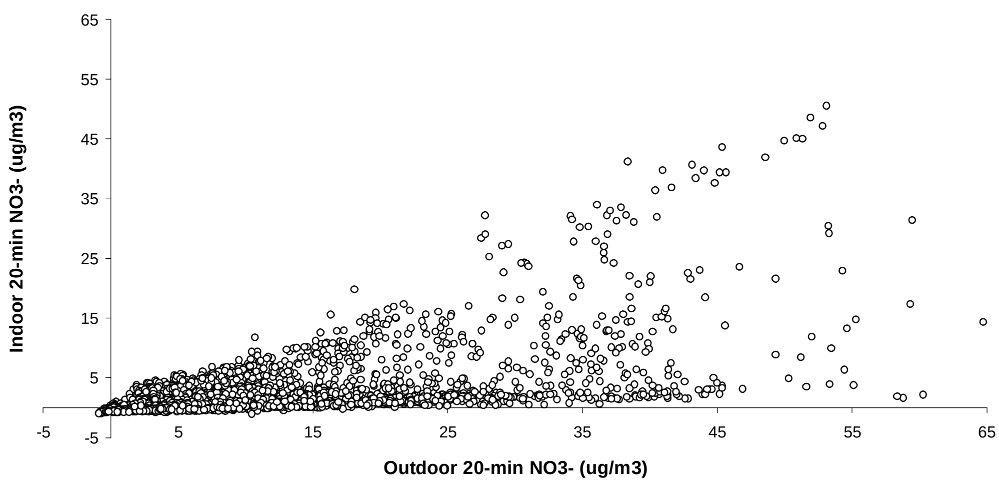


Figure 26. Scatter Plot of Indoor vs. Outdoor 20-Minute $PV_{0.02-0.1}$ (r_s=0.73 at p<0.0001)

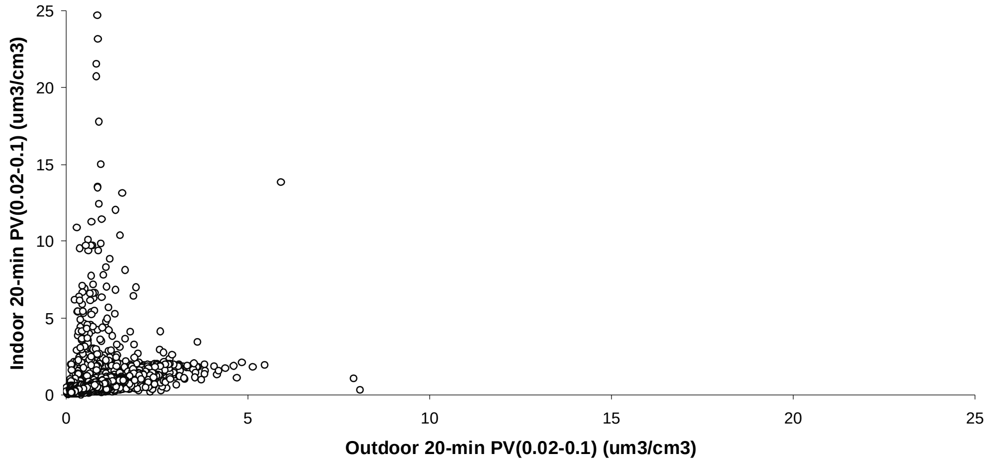


Figure 27. Scatter Plot of Indoor vs. Outdoor 20-Minute $PV_{0.1-0.5}$ (r_s=0.79 at p<0.0001)

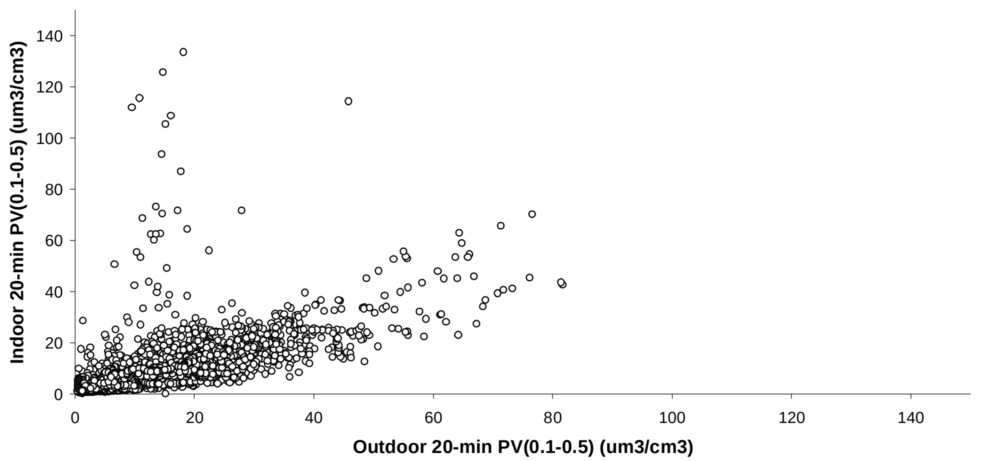


Figure 28. Scatter Plot of Indoor vs. Outdoor 20-Minute $PV_{0.7-2.5}$ (r_s=0.63 at p<0.0001)

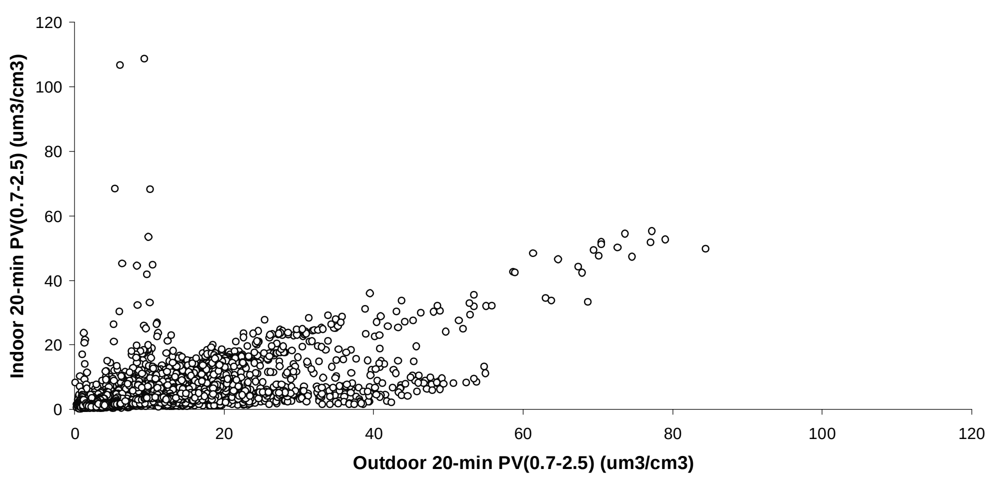
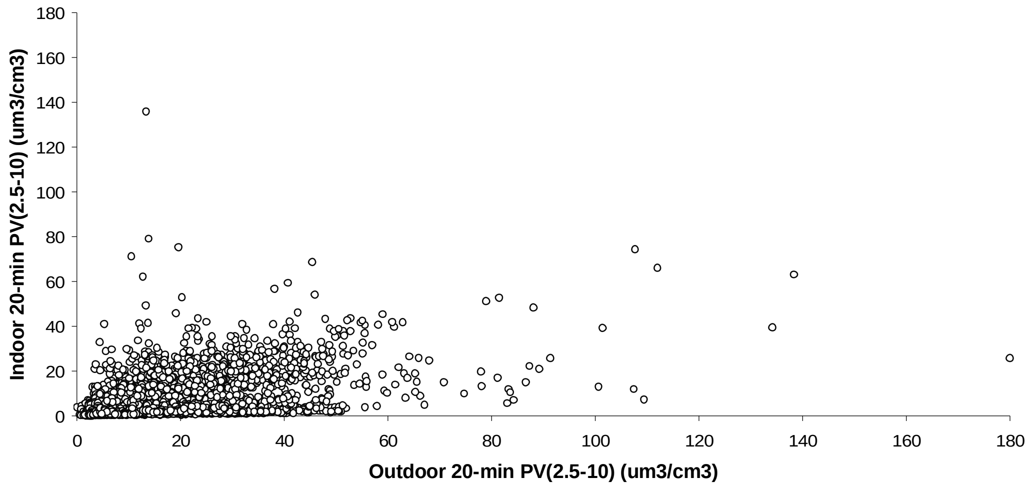
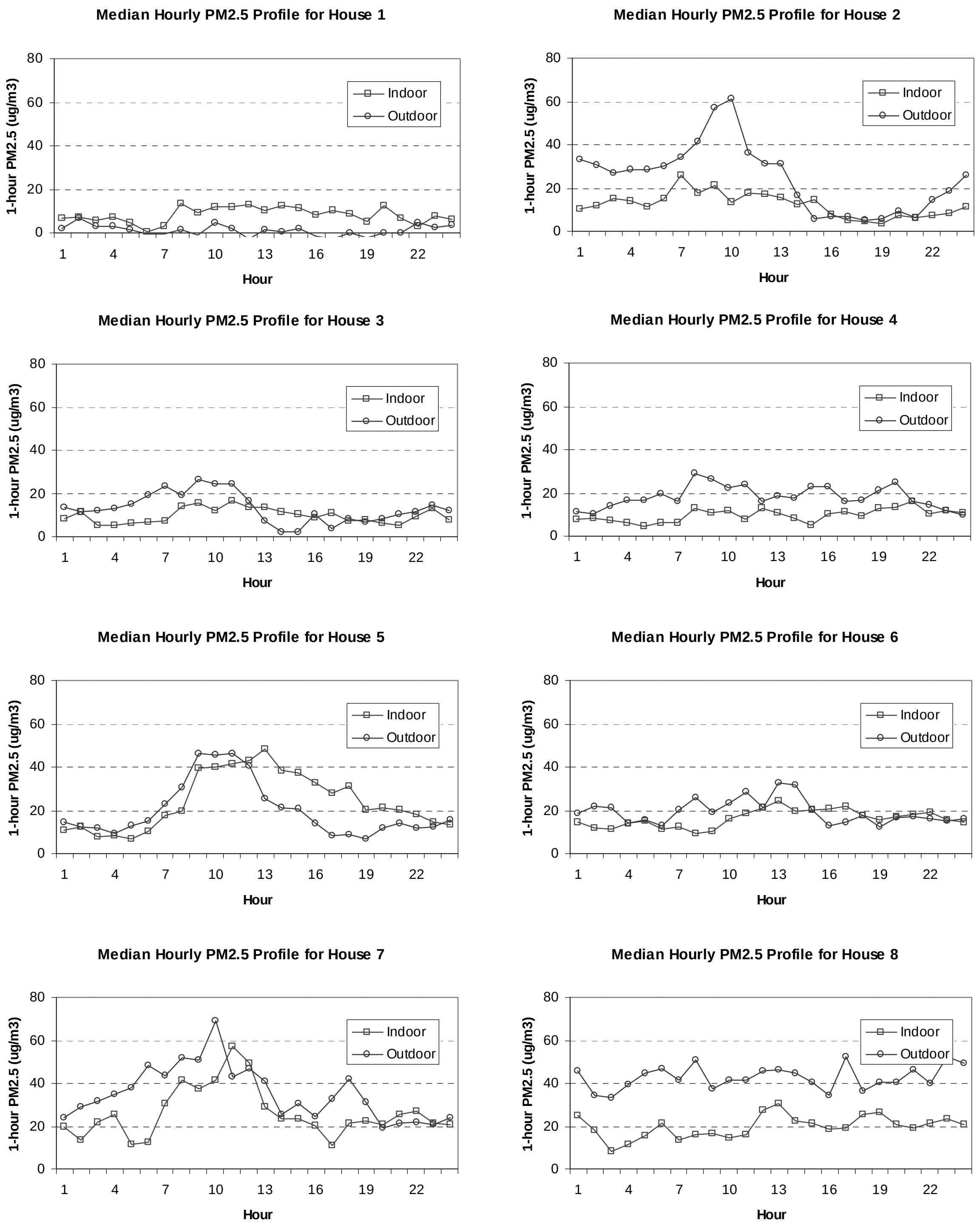


Figure 29. Scatter Plot of Indoor vs. Outdoor 20-Minute $PV_{2.5-10}$ (r_s=0.47 at p<0.0001)

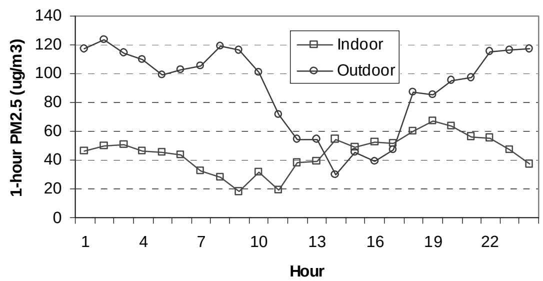


The diurnal profile in indoor and outdoor concentrations varied by home (Figure 30-Figure 32). Diurnal variability was generally less pronounced in homes sampled at the beginning and end of the study as compared to homes sampled in the middle, which is likely related to the lower and less variable pollutant levels at these homes, as illustrated by Homes 3 and 15 (Figure 30-Figure 32). Indoor and outdoor particle concentrations were generally higher during the morning, afternoon or early evening hours, with the exception of three homes (Houses 11, 13, 14) for which $PM_{2.5}$ and BC concentrations peaked during the night. For BC and to a lesser extent $PM_{2.5}$, outdoor and indoor concentrations generally peaked in the morning and evening, consistent with diurnal patterns of motor vehicle traffic, the major source of EC in the South Coast Air Basin (Gray and Cass 1986; Kim et al. 2000). Rush-hour associated peaks in outdoor $PM_{2.5}$ and BC concentrations, however, were pronounced for only three of the five homes located near major roadways (Houses 5, 7, 10), with the concentrations at the three homes similar to those of homes located farther from major roads. These findings qualitatively suggest that distance from major roadways was not a major determinant of the outdoor diurnal profiles for $PM_{2.5}$ and BC. For BC and $PM_{2.5}$, indoor and outdoor concentrations were strongly correlated for all homes, except House 9 for $PM_{2.5}$, although changes in indoor BC often lagged behind those outdoors. Hourly indoor and outdoor NO_3^- concentrations were poorly correlated in most homes, as indoor NO_3^- concentrations were generally substantially lower and less variable than outdoor levels (Figure 32). Home-specific differences in indoor and outdoor diurnal profiles may be attributed to differences in meteorological conditions, home location and for indoor profiles to differences in activity patterns as well.

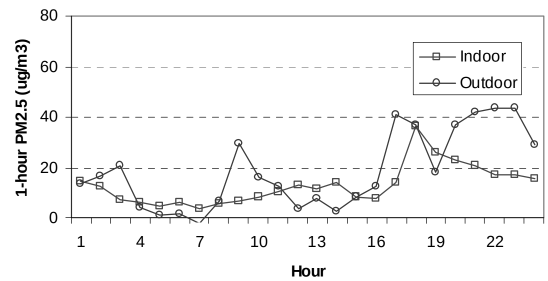
Figure 30. Diurnal Profiles for Indoor and Outdoor $PM_{2.5}$ Concentrations By House



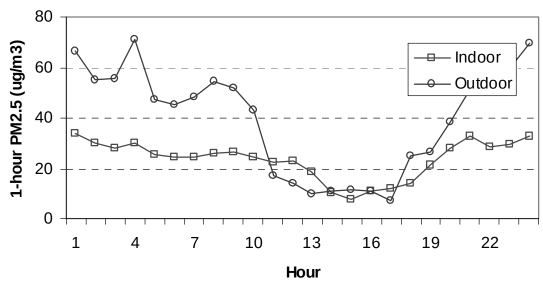
Median Hourly PM2.5 Profile for House 9



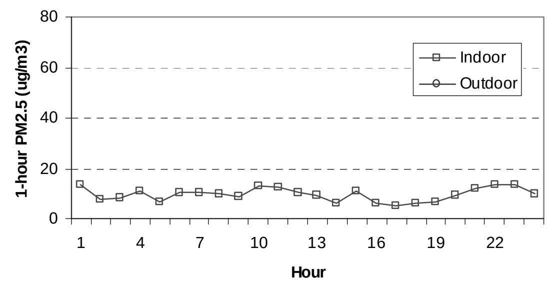
Median Hourly PM2.5 Profile for House 10



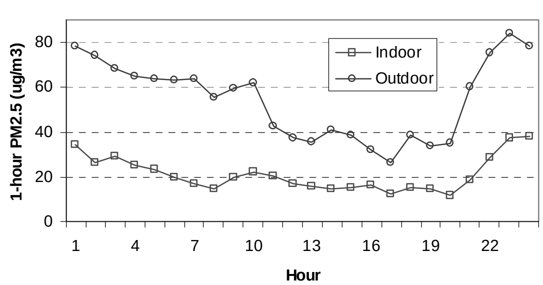
Median Hourly PM2.5 Profile for House 11



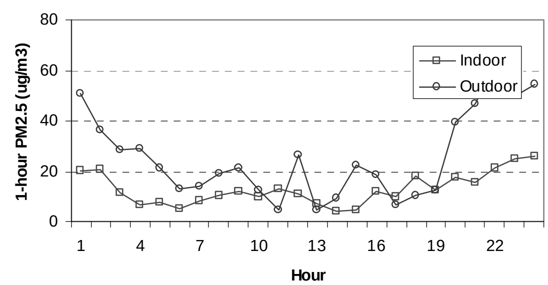
Median Hourly PM2.5 Profile for House 12



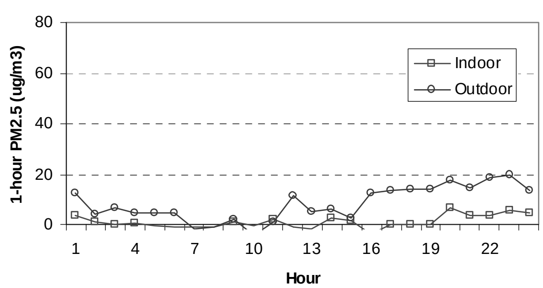
Median Hourly PM2.5 Profile for House 13



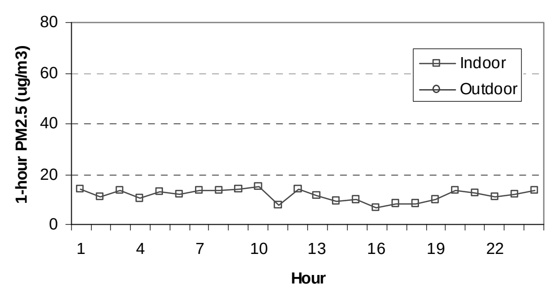
Median Hourly PM2.5 Profile for House 14



Median Hourly PM2.5 Profile for House 15



Median Hourly PM2.5 Profile for House 16



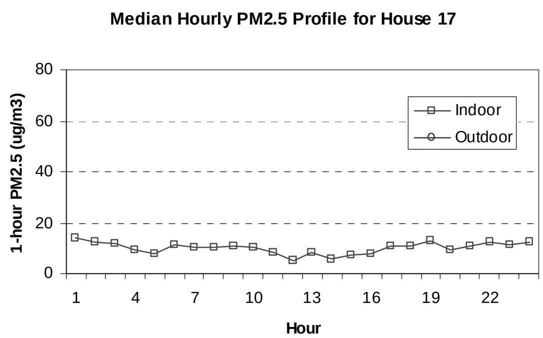
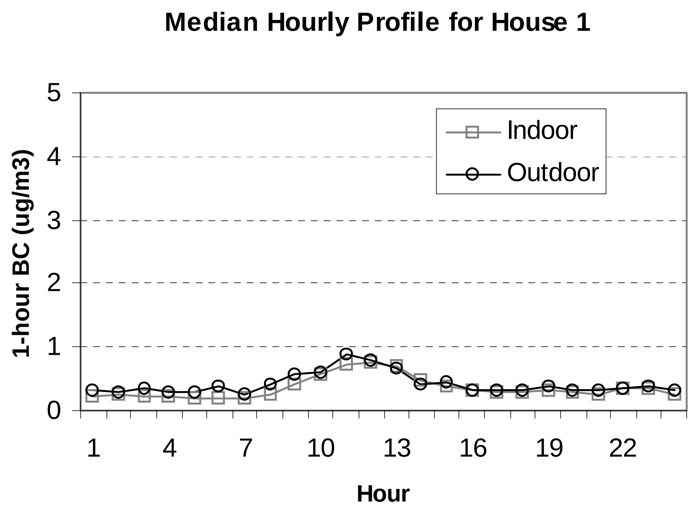
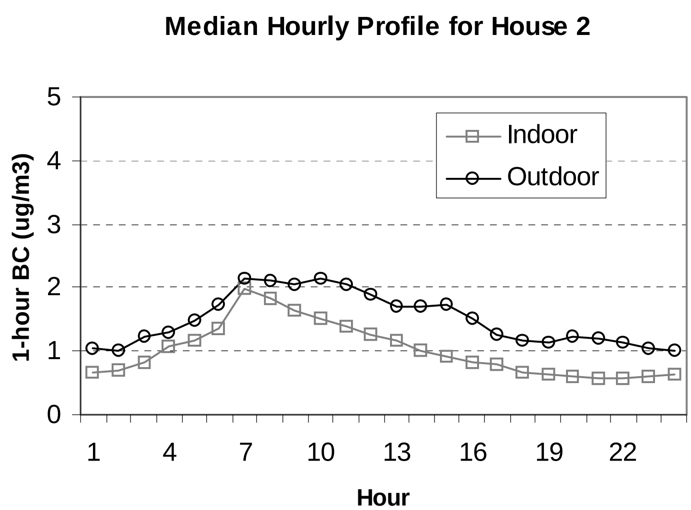
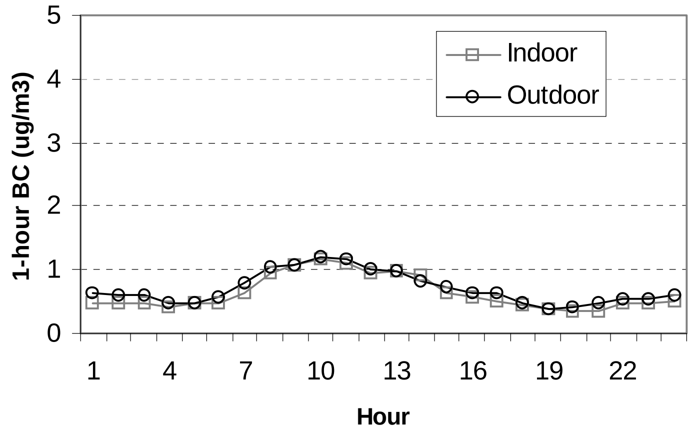


Figure 31. Diurnal Profiles for Indoor and Outdoor BC Concentrations By House*

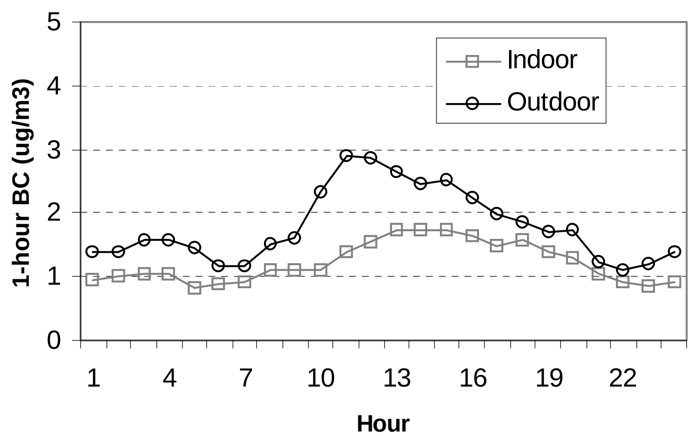




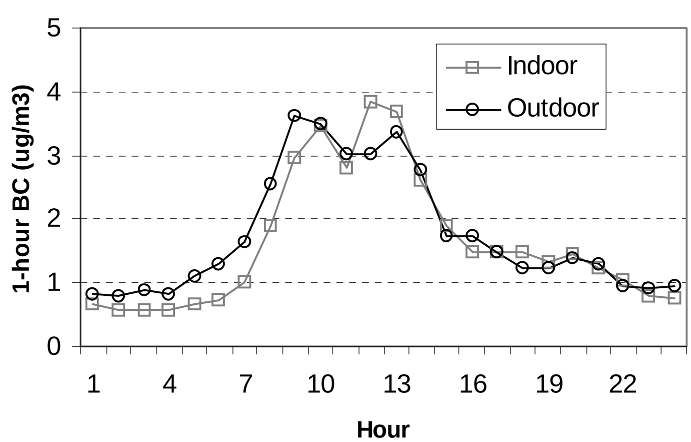
Median Hourly Profile for House 3

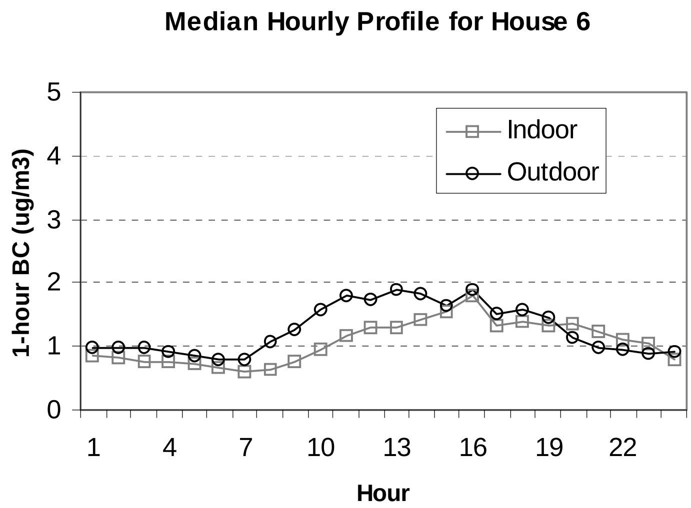


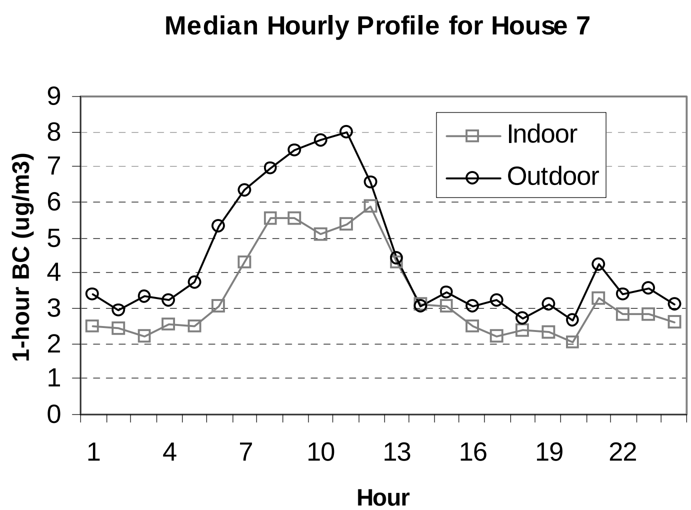
Median Hourly Profile for House 4

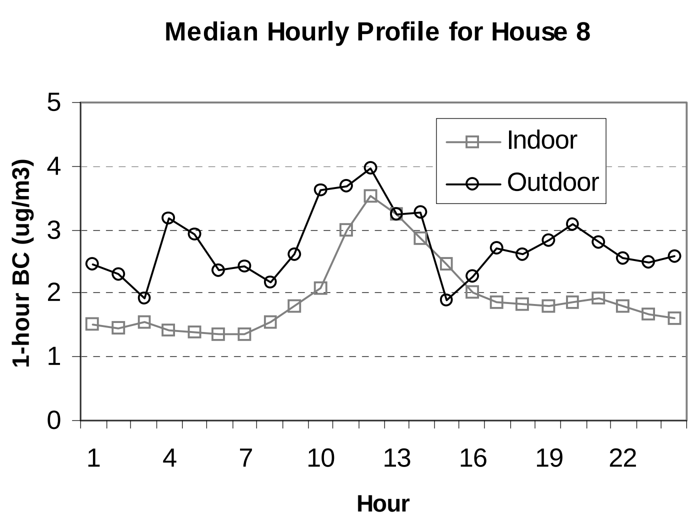


Median Hourly Profile for House 5

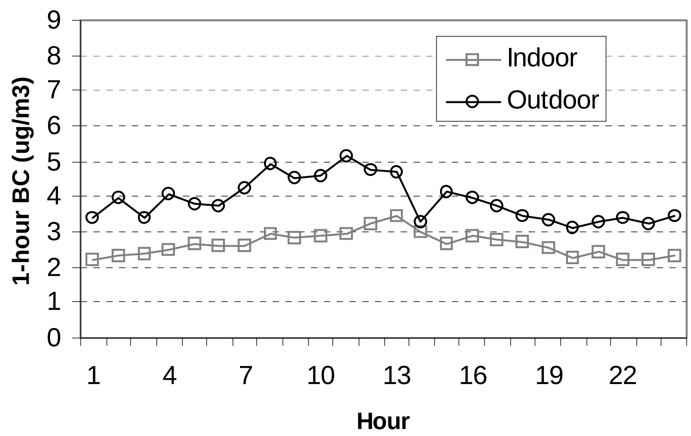



Median Hourly Profile for House 6
Indoor
Outdoor
1-hour BC (ug/m3)
Hour

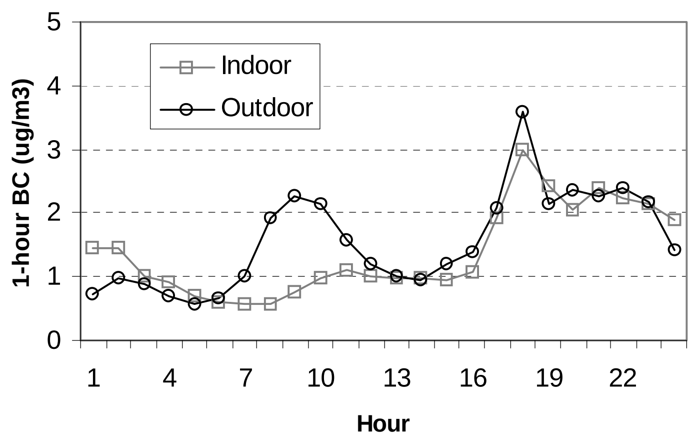

Median Hourly Profile for House 7
Indoor
Outdoor
1-hour BC (ug/m3)
Hour


Median Hourly Profile for House 8
Indoor
Outdoor
1-hour BC (ug/m3)
Hour

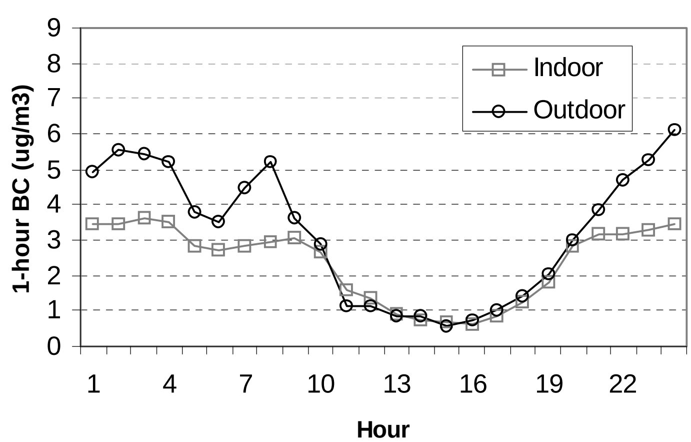
Median Hourly Profile for House 9



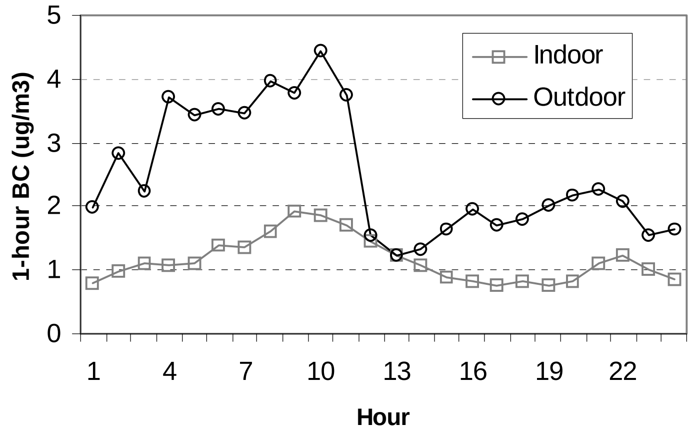
Median Hourly Profile for House 10



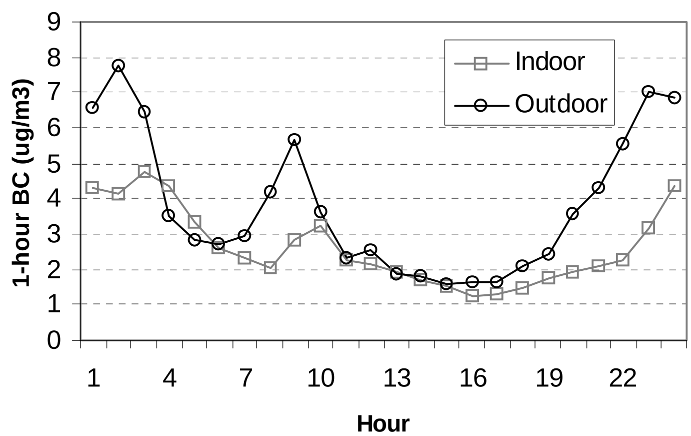
Median Hourly Profile for House 11



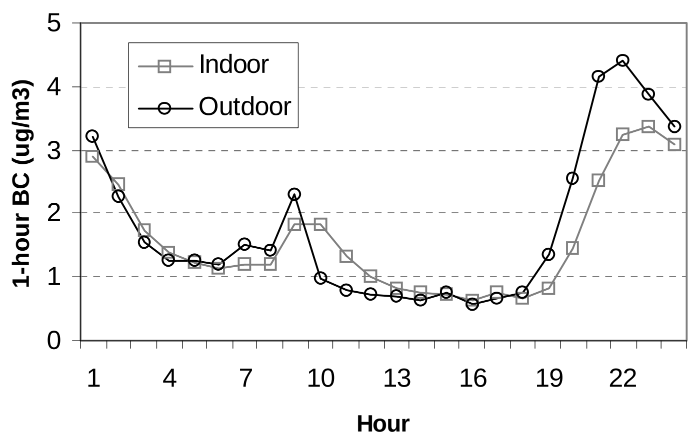
Median Hourly Profile for House 12



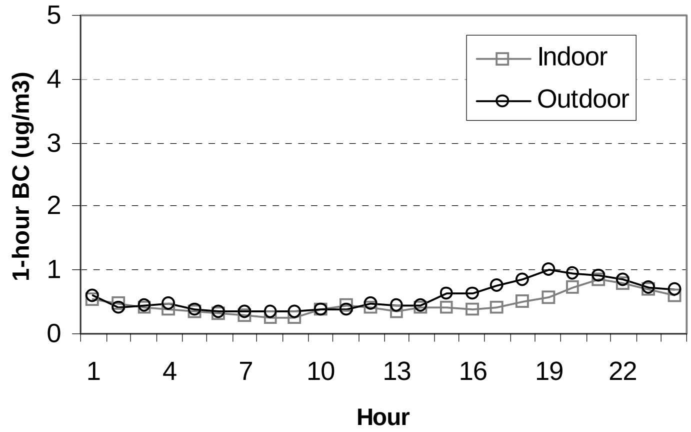
Median Hourly Profile for House 13



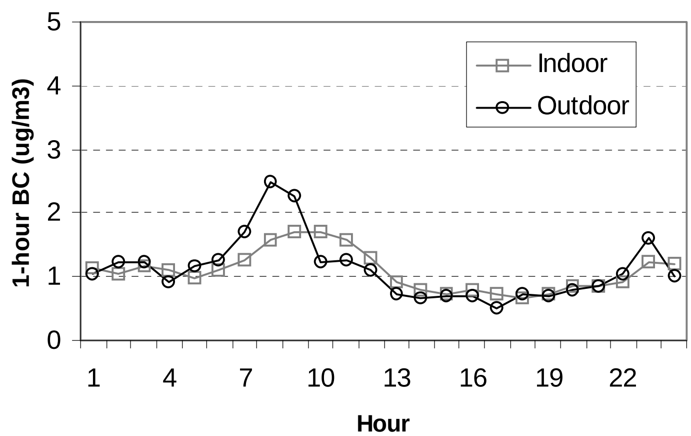
Median Hourly Profile for House 14



Median Hourly Profile for House 15



Median Hourly Profile for House 16



Median Hourly Profile for House 17

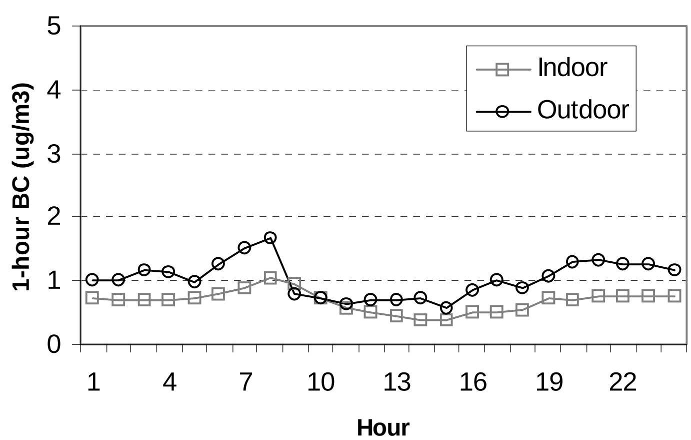
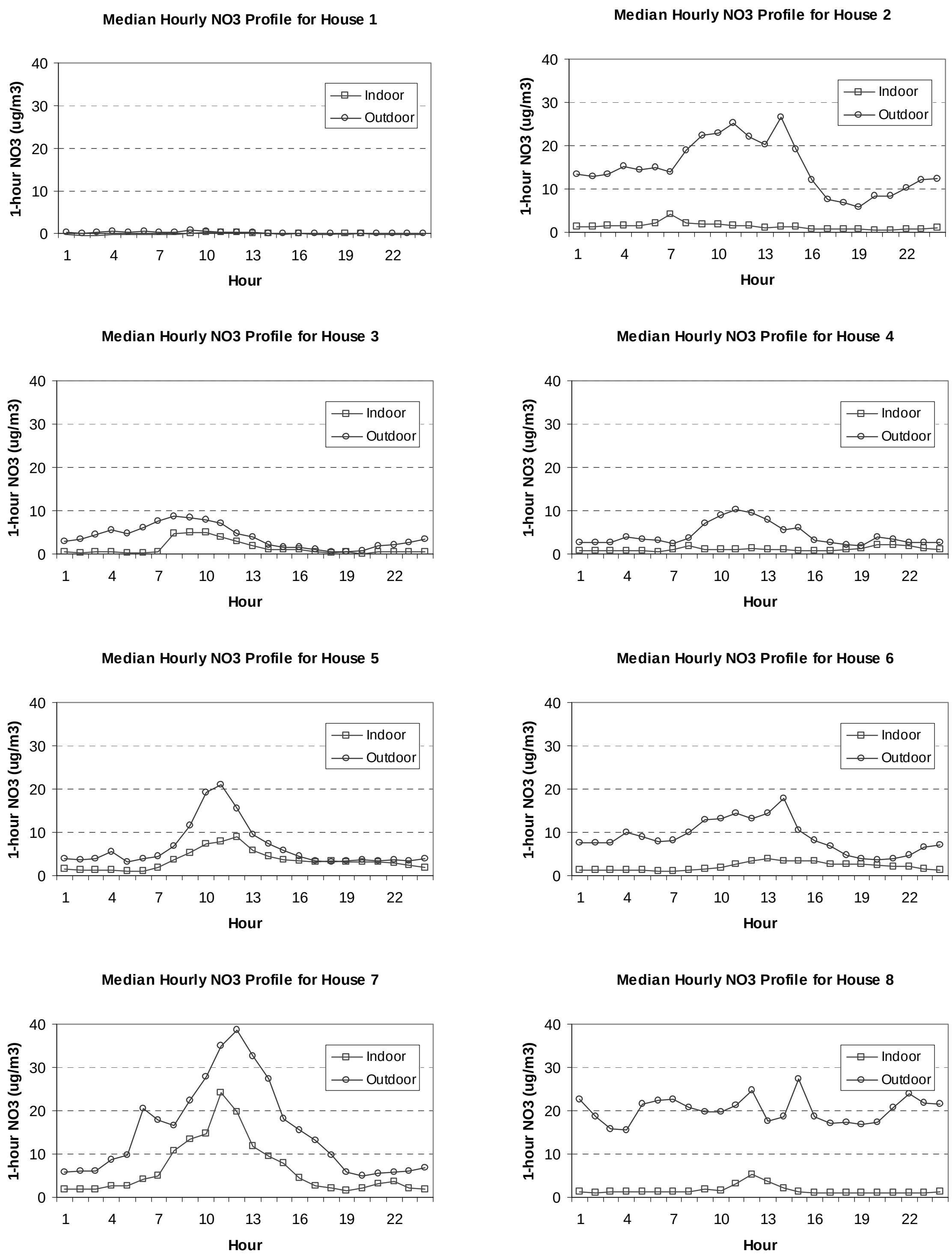
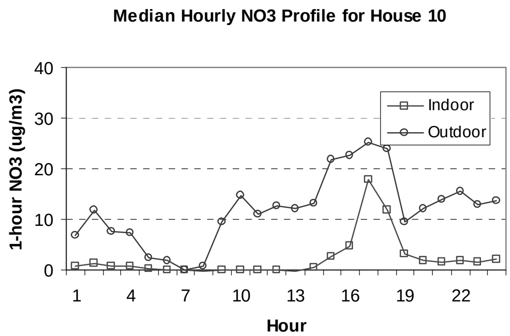
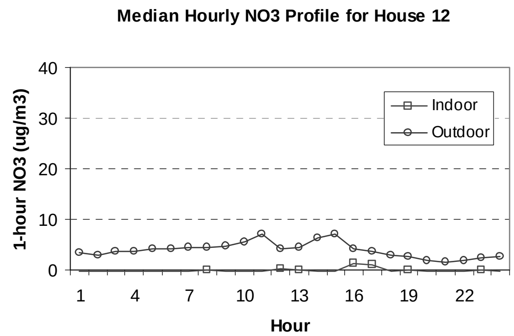
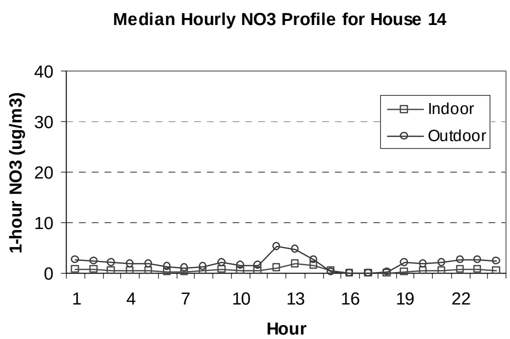


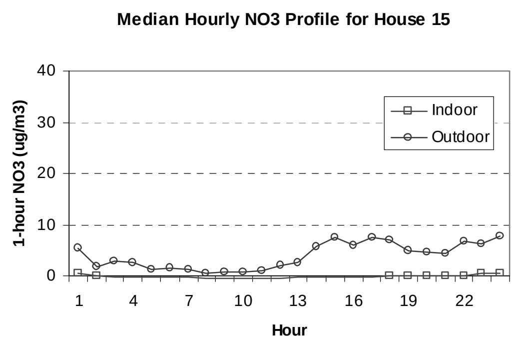
Figure 32. Diurnal Profiles for Indoor and Outdoor NO_3^- Concentrations By House

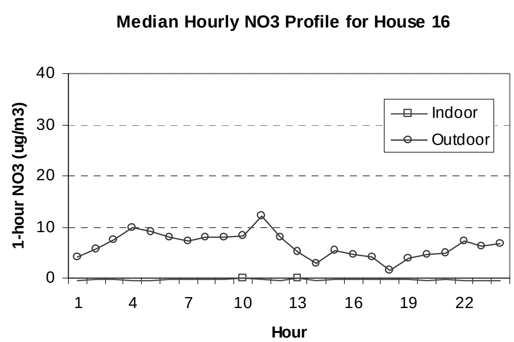










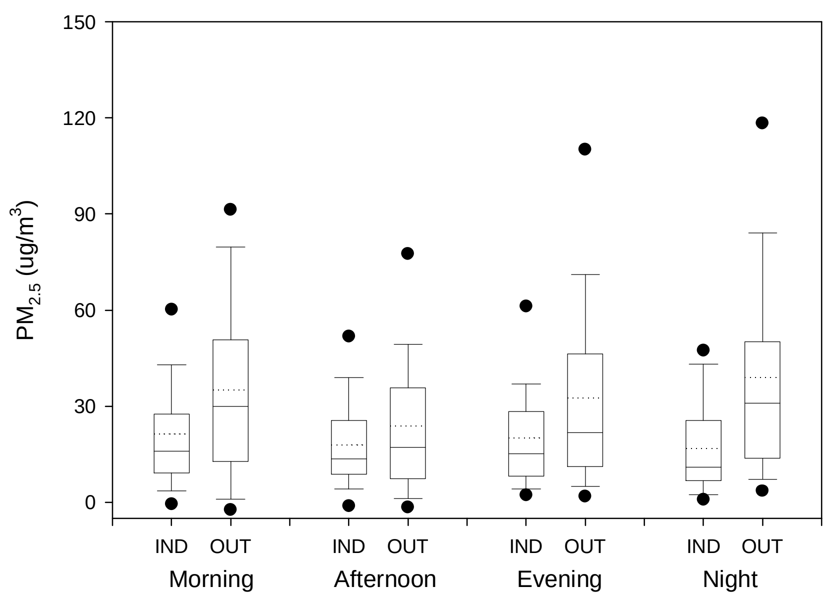


4.1.3 Steady State Models

As described above (*Section 3.1.7*), the association between indoor and outdoor particulate concentrations was examined for each home individually and for all homes using 6-hr averaged data. Six-hour averaged nighttime data were used to minimize the effect of time lags between indoor and outdoor concentrations and the influence of indoor particulate sources, and thus allow the use of steady state modeling techniques. Prior to this effort, 6-hr data were characterized to allow interpretation of the steady state modeling results. In addition, results from the characterization of 6-hr data were compared qualitatively to that for the 20-minute data to assess generalizability. Techniques used in the analyses included indoor/outdoor concentration ratios, linear regression models, and mass balance models. The nighttime indoor/outdoor concentration ratios and slopes from the regression lines were used to provide estimates of F_{INF}, while mass balance models were used to estimate values for $\boldsymbol{P}$ and k. In addition, the association between 6-hr daytime indoor and outdoor particulate concentrations was also characterized and compared to results from the analyses of 6-hr nighttime levels in order to provide a qualitative assessment of the impact of activities on estimates of F_{INF}.

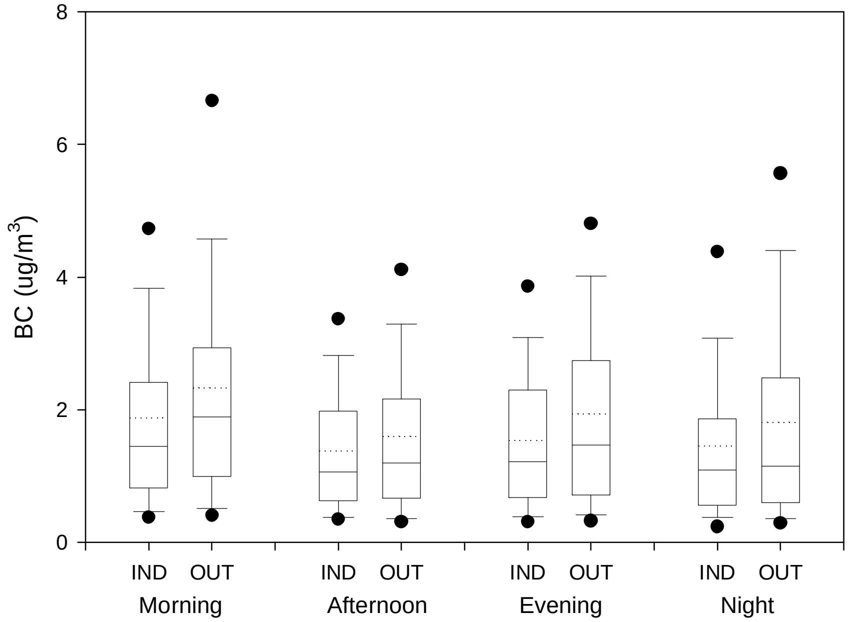
4.1.3.1 6-hr Particulate Concentrations. In general, the distribution of 6-h indoor and outdoor concentrations were similar across periods for all particulate measures, with indoor concentrations lower than corresponding outdoor concentrations for all 6-h periods (Figure 33 through Figure 39). Lower indoor as compared to outdoor levels were especially pronounced for NO_3^-, for which indoor levels were consistently low, especially at night. This difference indicates that NO_3^- behaves differently than other PM components, likely as the result of its volatility. By period, the most pronounced difference in the concentration distributions was that for indoor $PV_{2.5-10}$, for which nighttime indoor concentrations were more narrowly distributed and lower than indoor daytime concentrations (Figure 39). Lower nighttime indoor $PV_{2.5-10}$ concentrations were likely due to the fact that indoor sources of coarse particles, such as particle resuspension and cleaning, generally did not occur during the night. For $PM_{2.5}$, mean 6-h outdoor levels were highest at night, with a mean value of 38.2 ($\pm$34.3) ug/m^3 as compared to values of 35.7 ($\pm$30.7), 24.8 ($\pm$25.0), and 32.5 ($\pm$30.6) ug/m^3 in the morning, afternoon, and evening, respectively. Indoors, however, mean $PM_{2.5}$ values were highest in the morning (19.3$\pm$18.1 ug/m^3), followed by evening (18.8$\pm$15.6 ug/m^3), afternoon (17.8$\pm$15.9 ug/m^3), and finally by night (15.1$\pm$13.2 ug/m^3), likely due to the fact that indoor particle generating activities generally occur during waking hours. Outdoor concentrations generally were more variable than indoor levels for all 6-h periods and particle measures, with the exception of $PV_{0.02-0.1}$.

Figure 33. 6-hr Indoor and Outdoor $PM_{2.5}$ Concentrations by Period*



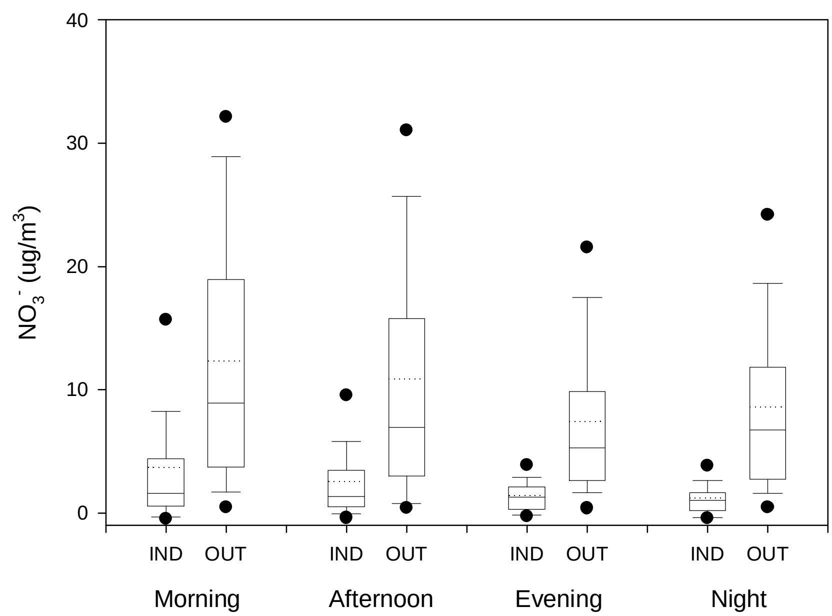
* Dotted line represents mean concentration, solid line median concentration. "Morning" defined as 6am-12pm; "afternoon" as 12-6pm; "evening" as 6pm-12am; and "night" as 12-6am.

Figure 34. 6-hr Indoor and Outdoor BC Concentrations by Period



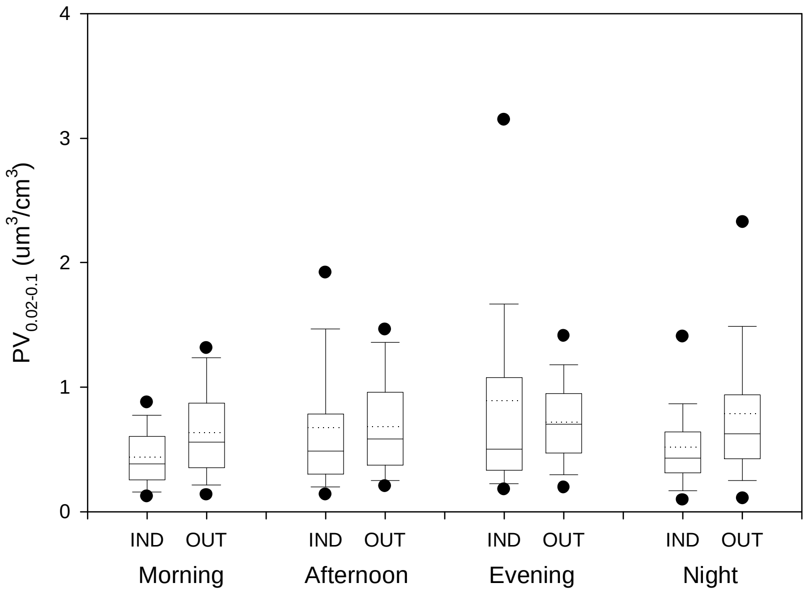
* Dotted line represents mean concentration, solid line median concentration. Outdoor concentrations corrected by 1.16. "Morning" defined as 6am-12pm; "afternoon" as 12-6pm; "evening" as 6pm-12am; and "night" as 12-6am.

Figure 35. 6-hr Indoor and Outdoor NO_3^- Concentrations by Period



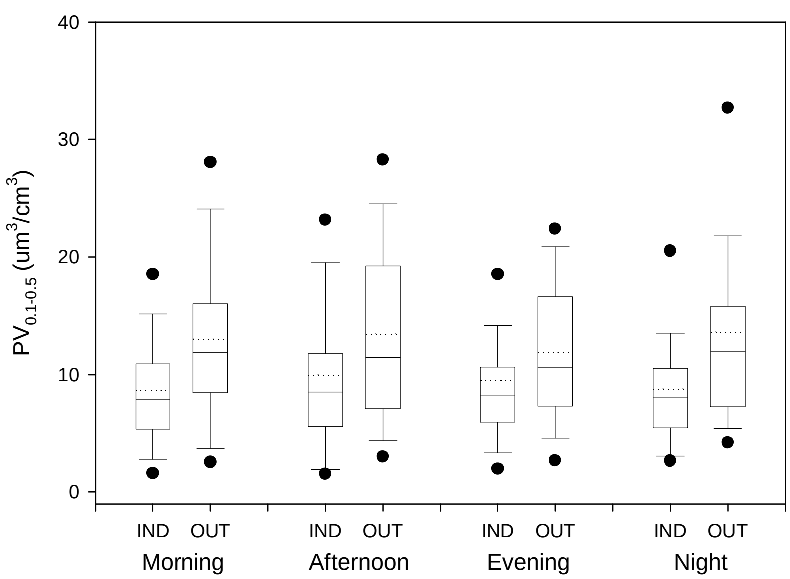
* Dotted line represents mean concentration, solid line median concentration. "Morning" defined as 6am-12pm; "afternoon" as 12-6pm; "evening" as 6pm-12am; and "night" as 12-6am.

Figure 36. 6-hr Indoor and Outdoor $PV_{0.02-0.1}$ Concentrations by Period



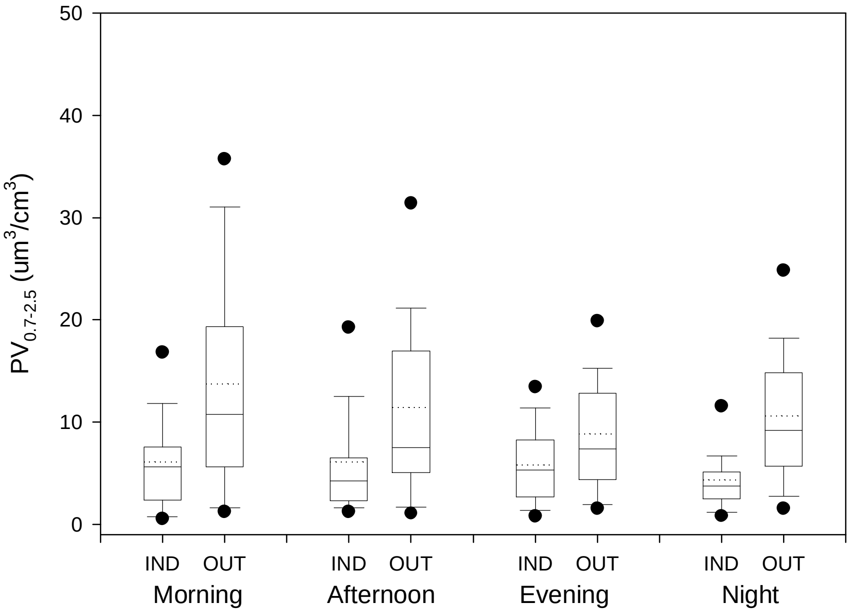
* Dotted line represents mean concentration, solid line median concentration. "Morning" defined as 6am-12pm; "afternoon" as 12-6pm; "evening" as 6pm-12am; and "night" as 12-6am.

Figure 37. 6-hr Indoor and Outdoor $PV_{0.1-0.5}$ Concentrations by Period



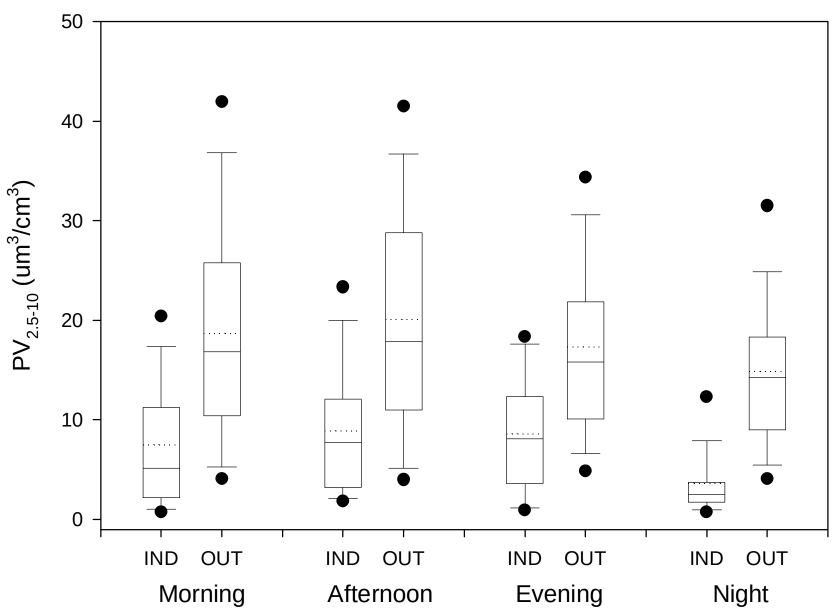
* Dotted line represents mean concentration, solid line median concentration. "Morning" defined as 6am-12pm; "afternoon" as 12-6pm; "evening" as 6pm-12am; and "night" as 12-6am.

Figure 38. 6-hr Indoor and Outdoor $PV_{0.7-2.5}$ Concentrations by Period



* Dotted line represents mean concentration, solid line median concentration. "Morning" defined as 6am-12pm; "afternoon" as 12-6pm; "evening" as 6pm-12am; and "night" as 12-6am.

Figure 39. 6-hr Indoor and Outdoor $PV_{2.5-10}$ Concentrations by Period



* Dotted line represents mean concentration, solid line median concentration. "Morning" defined as 6am-12pm; "afternoon" as 12-6pm; "evening" as 6pm-12am; and "night" as 12-6am.

Table 19. 6-Hr Indoor and Outdoor $PM_{2.5}$ Concentrations: By Period and House

House / Location	Morning			Afternoon			Evening			Night		
	N	Mean (SD)	Max	N	Mean (SD)	Max	N	Mean	Max	N	Mean	Max
1: Indoor	6	10.60 (5.55)	19.65	6	9.85 (4.17)	4.17	7	9.02 (5.59)	5.59	4	3.69 (4.69)	4.69
Outdoor	5	0.62 (4.15)	4.46	6	-0.15 (4.30)	4.30	6	2.09 (3.03)	3.03	3	11.29 (8.31)	8.31
2: Indoor	7	22.64 (9.07)	34.04	7	11.91 (7.27)	7.27	7	7.31 (4.10)	4.10	7	13.04 (3.03)	3.03
Outdoor	8	43.56 (17.75)	64.74	6	15.80 (7.90)	7.90	9	18.29 (8.53)	8.53	8	32.29 (14.68)	14.68
3: Indoor	6	12.88 (6.54)	20.54	7	8.99 (5.47)	5.47	7	7.89 (3.45)	3.45	7	6.99 (4.89)	4.89
Outdoor	6	24.37 (7.77)	32.97	6	7.89 (5.34)	5.34	7	10.72 (5.95)	5.95	7	19.57 (11.76)	11.76
4: Indoor	7	11.88 (6.12)	24.10	7	12.18 (8.07)	8.07	7	11.27 (4.71)	4.71	7	7.25 (2.89)	2.89
Outdoor	6	22.00 (9.44)	34.12	6	18.68 (9.01)	9.01	8	17.02 (8.03)	8.03	6	16.32 (9.95)	9.95
5: Indoor	7	33.62 (15.39)	60.11	7	37.77 (17.48)	17.48	7	20.95 (13.41)	13.41	7	10.19 (8.08)	8.08
Outdoor	6	45.45 (25.42)	90.00	6	22.42 (18.75)	18.75	6	15.60 (14.45)	14.45	6	25.49 (27.15)	27.15
6: Indoor	5	13.98 (4.17)	18.62	6	21.53 (4.33)	4.33	6	17.14 (4.07)	4.07	3	14.58 (4.42)	4.42
Outdoor	4	26.32 (17.61)	44.41	5	24.47 (15.63)	15.63	5	16.57 (6.13)	6.13	3	23.39 (7.20)	7.20
7: Indoor	6	48.22 (27.11)	90.04	7	25.64 (13.40)	13.40	7	23.14 (7.68)	7.68	7	21.35 (13.26)	13.26
Outdoor	5	58.95 (16.30)	83.82	6	41.42 (26.48)	26.48	6	33.33 (29.03)	29.03	6	37.80 (22.79)	22.79
8 Indoor	6	34.04 (42.29)	119.65	6	22.12 (6.00)	6.00	7	27.11 (21.26)	21.26	6	16.63 (7.85)	7.85
Outdoor	6	44.67 (20.73)	82.06	6	50.39 (21.54)	21.54	7	39.90 (17.75)	17.75	6	48.13 (15.12)	15.12
9: Indoor	5	31.46 (14.54)	48.39	6	45.15 (25.17)	25.17	6	52.52 (32.15)	32.15	6	41.62 (19.59)	19.59
Outdoor	6	88.25 (48.92)	137.13	6	57.19 (45.69)	45.69	8	88.57 (41.07)	41.07	8	96.03 (49.15)	49.15
10: Indoor	4		17.29	5	18.00 (12.14)	12.14	6	20.75 (6.07)	6.07	5	10.22 (4.16)	4.16
Outdoor	3	14.78 (16.45)	30.55	4	27.44 (34.00)	34.00	5	32.49 (22.51)	22.51	4	13.07 (3.71)	3.71
11: Indoor	7	25.94 (11.88)	39.51	6	12.32 (6.62)	6.62	8	30.18 (5.88)	5.88	7	28.01 (11.23)	11.23
Outdoor	5	36.54 (19.37)	63.27	5	13.88 (9.88)	9.88	7	49.74 (11.19)	11.19	5	58.90 (17.09)	17.09
12: Indoor	3	11.61 (3.35)	15.42	3	8.23 (3.92)	3.92	3	13.44 (8.48)	8.48	3	10.36 (2.84)	2.84
Outdoor	0	--	--	0	--	--	0	--	--	0	--	
13: Indoor	6	17.24 (4.70)	21.82	5	14.65 (3.93)	3.93	6	31.02 (15.82)	15.82	6	29.02 (11.57)	11.57
Outdoor	5	54.62 (25.90)	84.31	4	37.38 (12.66)	12.66	5	70.57 (38.19)	38.19	5	72.04 (37.62)	37.62
14: Indoor	7	14.42 (8.84)	26.74	6	17.61 (20.09)	20.09	7	21.74 (8.24)	8.24	7	14.30 (6.96)	6.96
Outdoor	2	16.29 (4.84)	19.72	2	16.43 (12.54)	12.54	3	46.67 (10.69)	10.69	2	29.90 (0.07)	0.07
15: Indoor	8	1.05 (3.28)	8.11	7	9.20 (23.91)	23.91	8	5.67 (5.50)	5.50	7	1.33 (3.02)	3.02
Outdoor	7	1.25 (5.08)	9.66	7	13.10 (15.49)	15.49	7	19.24 (11.09)	11.09	6	10.60 (14.55)	14.55
16: Indoor	7	15.99 (15.58)	49.62	6	12.12 (13.32)	13.32	8	11.76 (7.97)	7.97	8	15.87 (15.01)	15.01
Outdoor	0	--	--	0	--	--	0	--	--	0	--	
17: Indoor	6	11.20 (8.88)	25.91	6	10.63 (9.69)	9.69	7	12.96 (6.60)	6.60	7	9.11 (5.78)	5.78
Outdoor	0	--	--	0	--	--	0	--	--	0	--	
All: Indoor	103	19.28 (18.13)	119.65	103	17.82 (15.92)	15.92	114	18.77 (15.59)	15.59	104	15.12 (13.18)	13.18
Outdoor	74	35.69 (30.67)	137.13	75	24.77 (25.02)	25.02	89	32.48 (30.57)	30.57	75	38.19 (34.32)	34.32

* Units in ug/m^3. "Morning" defined as 6am-12pm; "afternoon" as 12-6pm; "evening" as 6pm-12am; and "night" as 12-6am.

Table 20. 6-Hr Indoor and Outdoor BC Concentrations: By Period and House

House / Location	Morning			Afternoon			Evening			Night		
	N	Mean (SD)	Max	N	Mean (SD)	Max	N	Mean	Max	N	Mean	Max
1: Indoor		0.63 (0.37)		7	0.49 (0.22)	0.74	7	0.32 (0.08)	0.42	7	0.22 (0.09)	0.38
Outdoor	7	0.63 (0.32)	1.15	7	0.45 (0.19)	0.68	7	0.33 (0.06)	0.40	7	0.30 (0.10)	0.46
2: Indoor	9	1.97 (1.19)	3.97	8	1.02 (0.49)	2.03	9	0.60 (0.29)	1.08	9	1.08 (0.54)	2.03
Outdoor	8	2.30 (1.28)	4.36	7	1.44 (0.45)	2.04	8	1.07 (0.48)	1.73	8	1.49 (0.89)	2.96
3: Indoor	8	1.03 (0.40)	1.54	8	0.64 (0.23)	0.93	8	0.44 (0.11)	0.57	8	0.47 (0.13)	0.65
Outdoor	7	1.02 (0.41)	1.58	7	0.64 (0.26)	0.91	7	0.47 (0.14)	0.68	7	0.51 (0.12)	0.70
4: Indoor	8	1.28 (0.33)	1.99	7	1.63 (0.57)	2.45	8	1.18 (0.42)	1.70	8	1.08 (0.48)	1.97
Outdoor	7	2.00 (0.56)	2.89	7	2.11 (0.86)	3.07	7	1.31 (0.38)	1.82	7	1.39 (0.43)	2.02
5: Indoor	7	3.59 (2.15)	6.95	7	2.36 (0.76)	3.31	7	1.17 (0.44)	1.65	6	0.74 (0.26)	1.21
Outdoor	7	3.62 (2.16)	7.06	7	2.03 (0.77)	3.30	7	1.06 (0.42)	1.65	6	1.07 (0.44)	2.02
6: Indoor	8	1.13 (0.69)	2.44	7	1.73 (0.97)	3.24	8	1.29 (0.70)	2.63	8	0.94 (0.53)	1.75
Outdoor	6	1.46 (0.94)	2.94	6	1.64 (0.88)	2.93	6	1.16 (0.74)	2.57	6	0.93 (0.55)	1.90
7: Indoor	6	5.99 (4.10)	13.52	7	2.74 (1.52)	4.82	7	2.75 (1.04)	4.10	7	2.84 (1.03)	4.97
Outdoor	7	6.80 (3.57)	12.82	7	3.70 (2.20)	7.67	7	3.42 (1.63)	6.80	7	3.58 (1.18)	5.79
8 Indoor	8	2.02 (1.03)	3.62	7	2.00 (0.88)	2.81	8	1.64 (0.61)	2.42	8	1.45 (0.65)	2.56
Outdoor	7	2.65 (1.33)	4.42	7	2.55 (1.21)	4.07	7	2.24 (1.12)	3.72	7	2.33 (1.24)	4.39
9: Indoor	8	2.61 (1.43)	4.34	7	2.60 (1.25)	3.77	8	2.58 (1.39)	5.34	8	2.51 (1.25)	4.54
Outdoor	7	3.48 (2.25)	6.68	7	3.18 (1.58)	4.88	7	3.22 (1.76)	6.25	7	3.43 (1.78)	6.05
10: Indoor	5	0.92 (0.43)	1.50	6	1.50 (0.44)	1.99	6	2.12 (0.67)	2.93	6	1.03 (0.45)	1.65
Outdoor	5	1.95 (0.86)	2.76	5	1.76 (0.69)	2.78	6	2.24 (0.84)	3.35	6	0.80 (0.56)	1.77
11: Indoor	6	2.24 (0.79)	2.99	7	0.82 (0.28)	1.12	8	2.95 (1.16)	4.76	8	3.06 (1.28)	4.42
Outdoor	6	2.60 (0.89)	3.25	7	0.82 (0.26)	1.08	7	3.49 (1.22)	4.91	7	3.94 (1.78)	5.66
12: Indoor	3	1.66 (0.22)	1.89	3	0.90 (0.51)	1.40	3	1.23 (0.58)	1.84	3	1.10 (0.42)	1.54
Outdoor	2	3.10 (0.70)	3.60	1	1.39 (--)	1.39	2	2.01 (0.30)	2.22	2	2.59 (0.32)	2.81
13: Indoor	7	2.62 (1.12)	3.99	6	1.50 (0.60)	2.10	7	2.80 (1.38)	4.35	7	3.62 (2.48)	6.77
Outdoor	7	3.43 (1.44)	5.50	6	1.61 (0.73)	2.54	7	4.56 (2.92)	8.25	7	4.31 (2.96)	7.95
14: Indoor	7	1.58 (0.61)	2.35	6	0.80 (0.28)	1.15	7	2.36 (0.78)	3.43	7	1.84 (0.38)	2.35
Outdoor	6	1.37 (0.45)	1.89	6	0.70 (0.38)	1.19	6	2.93 (1.00)	4.24	6	1.67 (0.35)	2.09
15: Indoor	7	0.41 (0.18)	0.69	6	0.43 (0.09)	0.53	7	0.68 (0.24)	0.91	7	0.48 (0.20)	0.89
Outdoor	7	0.51 (0.28)	1.06	6	0.79 (0.34)	1.21	7	0.91 (0.33)	1.45	7	0.59 (0.47)	1.63
16: Indoor	8	1.61 (0.69)	2.44	7	0.98 (0.53)	1.98	8	1.14 (0.74)	2.64	8	1.13 (0.38)	1.65
Outdoor	8	1.71 (0.96)	3.71	7	0.73 (0.39)	1.47	8	1.24 (0.82)	2.76	8	1.11 (0.48)	1.79
17: Indoor	7	1.06 (0.60)	2.03	6	0.87 (0.75)	2.19	7	1.04 (0.77)	2.64	7	0.89 (0.64)	1.95
Outdoor	7	1.41 (0.80)	2.51	6	1.31 (1.14)	2.98	7	1.49 (1.16)	3.59	7	1.23 (0.92)	2.64
All: Indoor	119	1.88 (1.72)	13.52	112	1.37 (0.99)	4.82	123	1.54 (1.13)	5.34	122	1.46 (1.27)	6.77
Outdoor	111	2.33 (2.01)	12.82	106	1.60 (1.28)	7.67	113	1.93 (1.62)	8.25	112	1.82 (1.66)	7.95

* Units in ug/m^3. Outdoor concentrations corrected by 1.16 based on collocated instrument tests. "Morning" defined as 6am-12pm; "afternoon" as 12-6pm; "evening" as 6pm-12am; and "night" as 12-6am.

Table 21. 6-Hr Indoor and Outdoor NO_3^- Concentrations: By Period and House

House / Location	Morning			Afternoon			Evening			Night		
	N	Mean (SD)	Max	N	Mean (SD)	Max	N	Mean (SD)	Max	N	Mean (SD)	Max
1: Indoor		0.45 (0.75)		5	-0.02 (0.37)	0.37	6	-0.21 (0.19)	0.19	6	-0.41 (0.11)	0.11
Outdoor	6	1.51 (1.65)	3.54	5	0.17 (0.36)	0.36	6	0.01 (0.21)	0.21	6	0.69 (0.69)	0.69
2: Indoor	8	3.25 (2.58)	7.91	6	1.00 (0.50)	0.50	8	0.77 (0.94)	0.94	8	1.58 (0.79)	0.79
Outdoor	8	21.86 (10.42)	32.46	6	17.69 (7.46)	7.46	8	9.12 (5.91)	5.91	8	14.29 (7.79)	7.79
3: Indoor	5	4.54 (2.12)	7.47	5	1.14 (1.07)	1.07	6	0.92 (0.74)	0.74	6	1.49 (1.73)	1.73
Outdoor	5	8.68 (2.56)	11.86	5	1.71 (1.35)	1.35	6	2.44 (0.57)	0.57	6	6.18 (2.68)	2.68
4: Indoor	7	2.54 (2.52)	7.86	6	1.35 (0.93)	0.93	7	1.97 (1.03)	1.03	7	0.83 (0.34)	0.34
Outdoor	7	8.54 (5.17)	14.91	6	5.69 (4.26)	4.26	7	3.88 (2.13)	2.13	7	4.03 (3.06)	3.06
5: Indoor	5	7.23 (3.60)	12.64	6	4.20 (0.93)	0.93	5	2.85 (0.69)	0.69	5	1.44 (0.40)	0.40
Outdoor	5	15.79 (8.19)	25.71	6	6.04 (2.47)	2.47	5	6.31 (4.57)	4.57	5	9.23 (8.73)	8.73
6: Indoor	6	2.17 (0.81)	3.37	6	3.44 (0.35)	0.35	7	2.06 (0.82)	0.82	7	1.31 (0.39)	0.39
Outdoor	6	13.27 (7.59)	24.09	6	11.62 (4.33)	4.33	7	5.28 (2.17)	2.17	7	7.84 (3.47)	3.47
7: Indoor	4	17.67 (15.55)	37.41	5	8.52 (8.54)	8.54	5	3.38 (2.26)	2.26	4	5.58 (6.40)	6.40
Outdoor	4	26.15 (15.83)	41.79	5	23.57 (15.69)	15.69	5	11.92 (13.36)	13.36	4	15.85 (14.34)	14.34
8 Indoor	5	6.29 (7.64)	19.38	5	3.36 (2.47)	2.47	5	1.36 (0.48)	0.48	5	2.05 (1.46)	1.46
Outdoor	5	23.59 (11.24)	42.86	5	22.80 (6.22)	6.22	5	18.63 (8.28)	8.28	5	22.55 (12.23)	12.23
10: Indoor	1		0.55	1		11.26	2	4.52 (3.19)	3.19	2	1.34 (0.03)	0.03
Outdoor	2	12.95 (7.90)	18.53	1	31.56 (--)	31.56	2	19.06 (2.53)	2.53	2	8.74 (0.34)	0.34
12: Indoor	3	-0.26 (0.08)	-0.17	1	0.94 (--)	0.94	5	-0.11 (0.19)	0.19	5	0.02 (0.63)	0.63
Outdoor	3	5.07 (2.13)	7.07	1		6.54	5	2.91 (2.11)	2.11	5	4.63 (2.57)	2.57
14: Indoor	4	2.00 (2.30)	5.38	4	2.14 (2.66)	2.66	4	1.22 (0.61)	0.61	4	1.50 (1.10)	1.10
Outdoor	4	5.77 (5.65)	13.89	4	5.53 (5.99)	5.99	4	4.33 (2.55)	2.55	4	5.18 (3.97)	3.97
15: Indoor	6	-0.41 (0.19)	-0.06	6	-0.08 (0.41)	0.41	7	0.52 (0.89)	0.89	6	0.17 (0.77)	0.77
Outdoor	6	1.31 (0.98)	2.51	6	7.26 (4.15)	4.15	7	7.63 (5.34)	5.34	6	4.13 (4.47	4.47
16: Indoor	4	-0.21 (0.51)	0.46	4	-0.02 (0.63)	0.63	5	-0.06 (0.78)	0.78	5	-0.17 (0.48)	0.48
Outdoor	3	10.28 (3.45)	14.22	3	9.69 (8.78)	8.78	3	10.33 (9.75)	9.75	3	9.91 (7.04)	7.04
All: Indoor	64	3.52 (6.09)	37.41	60	2.42 (3.61)	3.61	72	1.30 (1.52)	1.52	70	1.18 (2.03)	2.03
Outdoor	64	12.02 (10.59)	42.86	59	10.51 (9.93)	9.93	70	7.01 (7.18)	7.18	68	8.48 (8.32)	8.32

* Units in ug/m^3. No data available for Houses 9, 11, 13, and 17. "Morning" defined as 6am-12pm; "afternoon" as 12-6pm; "evening" as 6pm-12am; and "night" as 12-6am.

Table 22. 6-Hr Indoor and Outdoor $PV_{0.02-0.1}$ Concentrations: By Period and House

House / Location	Morning			Afternoon			Evening			Night		
	N	Mean (SD)	Max	N	Mean (SD)	Max	N	Mean	Max	N	Mean	Max
1: Indoor		0.16 (0.09)		7	0.18 (0.07)	0.07	7	0.27 (0.11)	0.11	7	0.11 (0.05)	0.05
Outdoor	6	0.15 (0.10)	0.36	7	0.19 (0.08)	0.08	7	0.25 (0.19)	0.19	7	0.13 (0.09)	0.09
2: Indoor	7	0.45 (0.21)	0.89	6	0.33 (0.05)	0.05	7	0.30 (0.14)	0.14	7	0.38 (0.13)	0.13
Outdoor	7	0.59 (0.23)	0.98	6	0.68 (0.06)	0.06	7	0.60 (0.25)	0.25	7	0.57 (0.23)	0.23
3: Indoor	7	0.33 (0.10)	0.44	7	0.45 (0.09)	0.09	7	0.39 (0.12)	0.12	7	0.28 (0.12)	0.12
Outdoor	7	0.35 (0.11)	0.48	7	0.37 (0.08)	0.08	7	0.37 (0.11)	0.11	7	0.32 (0.10)	0.10
4: Indoor	7	0.60 (0.16)	0.90	6	1.04 (0.84)	0.84	7	0.72 (0.19)	0.19	7	0.45 (0.07)	0.07
Outdoor	7	0.76 (0.08)	0.84	6	1.17 (0.18)	0.18	7	0.76 (0.17)	0.17	7	0.61 (0.08)	0.08
5: Indoor	7	0.68 (0.35)	1.34	6	1.45 (0.24)	0.24	7	3.55 (2.08)	2.08	7	0.51 (0.16)	0.16
Outdoor	7	0.85 (0.37)	1.29	6	1.41 (0.22)	0.22	7	0.79 (0.16)	0.16	7	0.67 (0.22)	0.22
7: Indoor	6	0.70 (0.19)	1.05	6	0.67 (0.20)	0.20	6	0.58 (0.14)	0.14	6	0.60 (0.09)	0.09
Outdoor	6	1.09 (0.13)	1.27	6	0.92 (0.28)	0.28	6	1.00 (0.19)	0.19	6	0.93 (0.16)	0.16
8 Indoor	5	0.26 (0.06)	0.31	3	0.49 (0.10)	0.10	5	0.53 (0.43)	0.43	4	0.30 (0.06)	0.06
Outdoor	5	0.43 (0.15)	0.64	3	0.59 (0.19)	0.19	5	0.59 (0.11)	0.11	4	0.56 (0.18)	0.18
9: Indoor	6	0.29 (0.15)	0.43	5	0.45 (0.46)	0.46	6	0.42 (0.19)	0.19	6	0.37 (0.18)	0.18
Outdoor	0	--	--	0	--	--	0	--	--	0	--	--
10: Indoor	5	0.20 (0.09)	0.33	4	0.92 (1.03)	1.03	4	0.90 (0.52)	0.52	3	0.34 (0.03)	0.03
Outdoor	5	0.30 (0.14)	0.49	4	0.47 (0.08)	0.08	4	0.69 (0.22)	0.22	3	0.45 (0.05)	0.05
11: Indoor	8	0.72 (0.24)	0.95	6	0.50 (0.12)	0.12	7	0.85 (0.23)	0.23	8	1.17 (0.32)	0.32
Outdoor	0	--	--	0	--	--	0	--	--	0	--	--
12: Indoor	4	0.47 (0.19)	0.67	2	0.53 (0.15)	0.15	2	0.46 (0.14)	0.14	3	0.48 (0.14)	0.14
Outdoor	4	0.94 (0.45)	1.39	2	0.70 (0.14)	0.14	2	0.81 (0.19)	0.19	3	0.98 (0.06)	0.06
13: Indoor	7	0.58 (0.21)	0.85	6	0.78 (0.30)	0.30	6	1.14 (0.18)	0.18	6	1.25 (0.40)	0.40
Outdoor	7	0.88 (0.39)	1.37	6	0.94 (0.54)	0.54	6	1.18 (0.50)	0.50	6	2.25 (0.79)	0.79
14: Indoor	4	0.34 (0.13)	0.46	5	1.33 (1.59)	1.59	4	1.43 (0.60)	0.60	4	1.10 (0.41)	0.41
Outdoor	4	0.46 (0.18)	0.67	5	0.39 (0.10)	0.10	4	0.77 (0.30)	0.30	4	1.47 (0.55)	0.55
15: Indoor	6	0.20 (0.05)	0.29	6	0.20 (0.05)	0.05	7	0.58 (0.47)	0.47	5	0.29 (0.04)	0.04
Outdoor	6	0.43 (0.13)	0.63	5	0.41 (0.15)	0.15	6	0.70 (0.07)	0.07	5	0.61 (0.15)	0.15
16: Indoor	6	0.66 (0.15)	0.82	6	0.60 (0.24)	0.24	7	0.48 (0.29)	0.29	7	0.74 (0.19)	0.19
Outdoor	6	1.14 (0.36)	1.53	6	0.82 (0.37)	0.37	7	0.90 (0.50)	0.50	7	1.12 (0.49)	0.49
17: Indoor	6	0.37 (0.07)	0.50	5	0.52 (0.12)	0.12	5	0.92 (0.60)	0.60	4	0.52 (0.10)	0.10
Outdoor	6	0.46 (0.21)	0.65	5	0.44 (0.22)	0.22	5	0.91 (0.33)	0.33	4	0.83 (0.01)	0.01
All: Indoor	97	0.45 (0.25)	1.34	86	0.65 (0.60)	0.60	94	0.85 (1.02)	1.02	91	0.57 (0.39)	0.39
Outdoor	83	0.64 (0.37)	1.53	74	0.69 (0.41)	0.41	80	0.72 (0.35)	0.35	77	0.80 (0.61)	0.61

* Units in um^3/cm^3. No data available for House 6. "Morning" defined as 6am-12pm; "afternoon" as 12-6pm; "evening" as 6pm-12am; and "night" as 12-6am.

Table 23. 6-Hr Indoor and Outdoor $PV_{0.1\text{-}0.5}$ Concentrations: By Period and House

House / Location	Morning			Afternoon			Evening			Night		
	N	Mean (SD)	Max	N	Mean (SD)	Max	N	Mean (SD)	Max	N	Mean (SD)	Max
1: Indoor		6.46 (1.73)		7	6.58 (1.53)	1.53	7	5.61 (1.14)	1.14	7	4.44 (1.26)	1.26
Outdoor	6	7.54 (2.34)	11.74	7	6.91 (1.54)	1.54	7	6.30 (1.79)	1.79	7	6.24 (1.22)	1.22
2: Indoor	7	12.58 (3.85)	18.39	6	9.50 (2.00)	2.00	7	7.03 (2.72)	2.72	7	10.09 (2.96)	2.96
Outdoor	7	20.60 (7.73)	29.54	6	17.29 (5.18)	5.18	7	13.74 (6.51)	6.51	7	16.44 (5.50)	5.50
3: Indoor	7	9.68 (1.46)	11.75	7	9.18 (1.53)	1.53	7	7.88 (1.75)	1.75	7	7.38 (2.01)	2.01
Outdoor	7	10.59 (1.51)	12.83	7	9.04 (1.52)	1.52	7	8.32 (1.91)	1.91	7	8.83 (2.27)	2.27
4: Indoor	7	10.03 (2.93)	13.73	6	11.78 (5.21)	5.21	7	10.39 (2.41)	2.41	7	8.54 (2.17)	2.17
Outdoor	7	14.13 (1.97)	16.04	6	14.12 (3.46)	3.46	7	11.40 (2.79)	2.79	7	10.93 (2.97)	2.97
5: Indoor	7	9.50 (2.99)	14.73	6	18.46 (4.34)	4.34	7	20.95 (20.89)	20.89	6	6.86 (3.36)	3.36
Outdoor	7	12.22 (3.08)	17.01	6	19.51 (5.30)	5.30	7	10.96 (5.19)	5.19	6	9.18 (4.65)	4.65
7: Indoor	6	17.04 (10.74)	37.11	6	19.00 (10.94)	10.94	6	11.28 (3.24)	3.24	6	12.45 (5.84)	5.84
Outdoor	6	25.01 (12.83)	46.69	6	26.78 (14.86)	14.86	6	19.37 (9.07)	9.07	6	18.86 (12.23)	12.23
8 Indoor	5	7.20 (1.80)	9.32	3	13.95 (2.12)	2.12	5	9.76 (1.26)	1.26	5	7.80 (1.41)	1.41
Outdoor	5	13.02 (2.33)	16.22	3	25.82 (3.87)	3.87	5	16.53 (4.07)	4.07	5	13.25 (2.27)	2.27
9: Indoor	6	9.48 (5.76)	16.06	5	10.10 (5.58)	5.58	6	11.88 (6.62)	6.62	6	11.38 (6.65)	6.65
Outdoor	0	--	--	0	--	--	0	--	--	0	--	--
10: Indoor	5	3.53 (1.90)	6.63	4	4.70 (2.13)	2.13	4	9.37 (4.01)	4.01	5	6.73 (2.67)	2.67
Outdoor	5	6.79 (4.14)	12.64	4	11.62 (7.61)	7.61	4	13.72 (6.04)	6.04	5	8.92 (4.07)	4.07
11: Indoor	8	12.27 (5.45)	19.10	6	7.80 (4.83)	4.83	7	8.91 (2.38)	2.38	8	13.27 (4.74)	4.74
Outdoor	0	--	--	0	--	--	0	--	--	0	--	--
12: Indoor	4	4.85 (2.15)	7.08	2	4.32 (1.00)	1.00	2	3.41 (2.76)	2.76	2	3.18 (0.72)	0.72
Outdoor	4	11.20 (5.55)	15.76	2	8.06 (1.91)	1.91	2	5.99 (5.32)	5.32	2	9.48 (3.32)	3.32
13: Indoor	7	13.35 (5.96)	21.24	6	10.62 (1.89)	1.89	6	14.71 (12.21)	12.21	6	21.44 (11.38)	11.38
Outdoor	7	17.75 (7.39)	27.50	6	15.62 (3.66)	3.66	6	15.04 (7.06)	7.06	6	34.98 (20.23)	20.23
14: Indoor	4	4.90 (1.79)	6.15	5	11.57 (17.09)	17.09	4	7.66 (2.15)	2.15	4	12.23 (5.15)	5.15
Outdoor	4	7.19 (2.84)	9.05	5	6.59 (3.20)	3.20	4	8.50 (4.16)	4.16	4	16.69 (6.56)	6.56
15: Indoor	6	1.91 (1.26)	4.35	6	1.34 (0.32)	0.32	7	4.00 (2.55)	2.55	6	3.01 (1.26)	1.26
Outdoor	5	4.54 (2.98)	9.46	5	4.30 (1.99)	1.99	6	9.42 (4.85)	4.85	6	7.83 (4.19)	4.19
16: Indoor	6	6.87 (3.96)	11.47	6	6.96 (2.72)	2.72	7	8.20 (6.40)	6.40	7	8.51 (2.97)	2.97
Outdoor	6	12.64 (8.65)	21.82	6	11.25 (6.49)	6.49	7	12.38 (8.34)	8.34	7	14.05 (8.22)	8.22
17: Indoor	6	6.58 (2.28)	9.38	5	7.19 (6.12)	6.12	5	7.58 (4.42)	4.42	4	8.24 (3.06)	3.06
Outdoor	6	12.27 (7.52)	20.22	5	12.66 (11.71)	11.71	5	13.01 (9.10)	9.10	4	16.21 (4.06)	4.06
All: Indoor	97	8.94 (5.56)	37.11	86	9.73 (7.15)	7.15	94	9.57 (7.93)	7.93	93	9.36 (5.99)	5.99
Outdoor	82	13.01 (7.77)	46.69	74	13.47 (8.77)	8.77	80	11.91 (6.47)	6.47	79	13.70 (10.15)	10.15

* Units in um^3/cm^3. No data available for House 6. "Morning" defined as 6am-12pm; "afternoon" as 12-6pm; "evening" as 6pm-12am; and "night" as 12-6am.

Table 24. 6-Hr Indoor and Outdoor $PV_{0.7\text{-}2.5}$ Concentrations: By Period and House

House / Location	Morning			Afternoon			Evening			Night		
	N	Mean (SD)	Max	N	Mean (SD)	Max	N	Mean	Max	N	Mean	Max
1: Indoor		6.78 (1.72)		7	6.32 (1.99)	1.99	7	6.23 (2.34)	2.34	7	3.46 (1.05)	1.05
Outdoor	5	8.48 (3.13)	13.76	7	7.25 (1.77)	1.77	7	7.50 (2.59)	2.59	7	7.52 (1.51)	1.51
2: Indoor	7	7.26 (3.09)	11.54	6	3.01 (0.89)	0.89	7	3.14 (2.83)	2.83	7	4.67 (1.18)	1.18
Outdoor	7	28.58 (9.58)	38.53	6	18.72 (3.68)	3.68	7	13.45 (4.49)	4.49	7	16.94 (4.23)	4.23
3: Indoor	7	14.02 (7.60)	26.13	7	7.12 (3.90)	3.90	7	8.37 (4.55)	4.55	7	9.56 (7.40)	7.40
Outdoor	7	19.90 (8.31)	33.20	7	8.31 (4.52)	4.52	7	11.00 (5.21)	5.21	7	17.43 (6.45)	6.45
4: Indoor	7	8.48 (2.36)	13.05	6	4.69 (1.09)	1.09	7	7.57 (2.69)	2.69	7	4.01 (1.15)	1.15
Outdoor	7	13.49 (4.51)	19.28	6	10.50 (5.50)	5.50	7	9.85 (3.94)	3.94	7	8.39 (3.17)	3.17
5: Indoor	7	9.09 (5.31)	21.10	6	19.44 (13.24)	13.34	7	9.45 (3.12)	3.12	7	5.95 (1.86)	1.86
Outdoor	7	20.79 (15.41)	52.01	6	28.27 (21.50)	21.50	7	10.26 (4.08)	4.08	7	13.82 (6.67)	6.67
9: Indoor	7	32.94 (18.55)	51.96	6	26.43 (16.07)	16.07	7	44.35 (20.05)	20.05	7	39.16 (20.86)	20.86
Outdoor	0	--	--	0	--	--	0	--	--	0	--	--
10: Indoor	5	1.65 (0.72)	2.82	6	2.13 (1.42)	1.42	4	8.56 (5.52)	5.52	5	2.84 (0.97)	0.97
Outdoor	5	8.74 (7.24)	20.88	4	16.17 (16.93)	16.93	4	15.79 (14.21)	14.21	5	11.31 (7.43)	7.43
13: Indoor	7	5.21 (2.50)	9.38	6	5.14 (1.55)	1.55	6	6.99 (3.43)	3.43	7	9.72 (6.24)	6.24
Outdoor	7	13.93 (7.53)	26.09	6	13.84 (6.60)	6.60	6	10.34 (4.51)	4.51	7	13.11 (4.93)	4.93
14: Indoor	4	2.05 (0.40)	2.41	5	7.18 (8.53)	8.53	4	4.17 (2.02)	2.02	4	2.70 (0.70)	0.70
Outdoor	4	4.26 (1.09)	5.05	5	4.13 (2.33)	2.33	4	3.52 (1.36)	1.36	4	4.94 (1.37)	1.37
15: Indoor	6	0.59 (0.15)	0.78	6	1.65 (0.72)	0.72	7	2.01 (2.59)	2.59	7	0.97 (0.62)	0.62
Outdoor	6	1.39 (0.56)	2.43	5	1.07 (0.32)	0.32	7	1.82 (1.15)	1.15	7	1.69 (1.07)	1.07
16: Indoor	6	2.53 (1.60)	5.12	6	2.97 (1.48)	1.48	7	2.37 (0.79)	0.79	7	2.74 (1.36)	1.36
Outdoor	6	8.22 (7.12)	20.53	6	6.45 (3.39)	3.39	7	6.16 (3.57)	3.57	7	8.19 (5.35)	5.35
All: Indoor	69	8.91 (10.99)	51.96	65	7.98 (9.89)	9.89	70	9.68 (13.58)	13.58	72	8.15 (12.57)	12.57
Outdoor	61	13.73 (10.98)	52.01	58	11.49 (11.18)	11.18	63	8.88 (6.02)	6.02	65	10.55 (6.62)	6.62

* Units in um^3/cm^3. No data available for House 6, 7, 8, 11, 12, 17. “Morning” defined as 6am-12pm; “afternoon” as 12-6pm; “evening” as 6pm-12am; and “night” as 12-6am.

Table 25. 6-Hr Indoor and Outdoor $PV_{2.5-10}$ Concentrations: By Period and House

House / Location	Morning			Afternoon			Evening			Night		
	N	Mean (SD)	Max	N	Mean (SD)	Max	N	Mean	Max	N	Mean	Max
1: Indoor		11.09 (2.47)		7	8.44 (2.98)	2.98	7	7.57 (2.68)	2.68	7	2.19 (0.59)	0.59
Outdoor	5	12.82 (1.68)	14.15	7	11.63 92.00)	2.00	7	11.06 (3.23)	3.23	7	10.03 (1.21)	1.21
2: Indoor	7	5.52 (3.19)	12.05	6	3.47 (1.49)	1.49	7	3.31 (3.72)	3.72	7	2.52 (0.85)	0.85
Outdoor	7	32.86 (9.38)	45.07	6	33.00 (4.62)	4.62	7	26.36 (6.86)	6.86	7	19.92 (3.51)	3.51
3: Indoor	7	18.71 (12.18)	39.39	7	16.16 (5.56)	5.56	7	11.80 (4.86)	4.86	7	9.76 (6.30)	6.30
Outdoor	7	24.50 (14.00)	48.68	7	19.29 (6.07)	6.07	7	20.50 (9.87)	9.87	7	23.67 (12.80)	12.80
4: Indoor	7	13.09 (5.84)	20.93	6	9.68 (2.20)	2.20	7	16.76 (7.26)	7.26	7	3.02 (0.71)	0.71
Outdoor	7	29.23 (7.00)	42.38	6	29.34 (11.99)	11.99	7	31.91 (16.96)	16.96	7	13.70 (3.54)	3.54
5: Indoor	7	11.52 (3.68)	19.13	6	19.98 (5.24)	5.24	7	13.60 (3.99)	3.99	6	5.69 (1.80)	1.80
Outdoor	7	19.27 (8.73)	36.45	6	31.43 (7.58)	7.58	7	17.56 (3.87)	3.87	6	17.38 (3.13)	3.13
9: Indoor	7	22.47 (16.60)	56.35	6	15.22 (8.32)	8.32	7	29.01 (10.24)	10.24	7	21.25 (10.59	10.59
Outdoor	0	-	-	0	-	-	0	-	-	0	-	-
10: Indoor	5	1.90 (0.60)	2.73	4	2.36 (1.88)	1.88	4	10.13 (2.63)	2.63	5	2.42 (0.66)	0.66
Outdoor	5	10.57 (5.21)	18.63	4	14.29 (10.25)	10.25	4	12.59 (5.50)	5.50	5	10.00 (4.83)	4.83
13: Indoor	7	3.10 (1.19)	5.58	6	6.34 (2.52)	2.52	6	10.13 (4.80)	4.80	3	4.38 (2.03)	2.03
Outdoor	7	16.79 (5.05)	27.67	6	18.74 (6.53)	6.53	6	15.94 (4.70)	4.70	3	18.80 (7.72)	7.72
14: Indoor	4	2.26 (0.42)	2.86	5	9.82 (8.47)	8.47	4	8.23 (1.71)	1.71	4	2.60 (0.94)	0.94
Outdoor	4	6.66 (1.08)	7.74	5	9.80 (5.91)	5.91	4	9.49 (4.72)	4.72	4	7.78 (2.23)	2.23
15: Indoor	6	0.79 (0.31)	1.26	6	2.68 (0.51)	0.51	7	2.38 (2.74)	2.74	6	0.77 (0.16)	0.16
Outdoor	6	4.36 (1.24)	5.85	5	4.10 (1.08)	1.08	7	5.50 (2.19)	2.19	6	4.77 (2.13)	2.13
16: Indoor	6	3.05 (2.20)	6.75	6	6.49 (4.85)	4.85	7	3.07 (1.74)	1.74	7	2.98 (3.18)	3.18
Outdoor	6	18.92 (10.85)	36.44	6	24.55 (22.80)	22.80	7	16.73 (5.02)	5.02	7	19.46 (9.05)	9.05
All: Indoor	69	9.11 (9.74)	56.35	65	9.44 (7.70)	7.70	70	10.67 (8.98)	8.98	66	5.55 (7.33)	7.33
Outdoor	61	18.72 (11.61)	48.68	58	20.09 (13.02)	13.02	63	17.32 (10.57)	10.57	59	14.88 (8.29)	8.29

* Units in um^3/cm^3. No data available for House 6, 7, 8, 11, 12, 17. “Morning” defined as 6am-12pm; “afternoon” as 12-6pm; “evening” as 6pm-12am; and “night” as 12-6am.

When 6-hr concentrations were stratified by home, home-specific differences in outdoor and indoor concentrations were apparent, although general patterns, such as higher outdoor as compared to indoor concentrations, remained (Table 19 through Table 25). Overall mean 6-hr outdoor $PM_{2.5}$ concentrations were highest during the night as compared to day, although maximum 6-hr outdoor $PM_{2.5}$ concentrations were highest during the morning (Table 19). Indoor overall mean $PM_{2.5}$ concentrations were relatively similar across 6-hr periods, with maximum 6-hr indoor levels again highest in the morning. For BC, mean 6-hr indoor and outdoor concentrations did not vary by period, while maximum 6-hr concentrations were highest during the morning period. Maximum $PM_{2.5}$ and BC concentrations during the morning likely show the influence of morning rush hour.

Table 26. Air Exchange Rates: By 6-hr Period*

House	Morning			Afternoon			Evening			Night		
	N	Mean (SD)	Max	N	Mean	Max	N	Mean (SD)	Max	N	Mean (SD)	Max
2	8	1.55 (0.89)	3.43	7	0.39 (0.10)	0.10	8	2.67 (4.52)	4.52	8	0.96 (0.28)	0.28
3	6	8.34 (2.93)	12.94	6	8.57 (3.55)	3.55	7	4.50 (1.94)	1.94	7	2.87 (3.92)	3.92
4	6	4.08 (2.98)	8.70	5	0.77 (0.75)	0.75	6	4.22 (3.15)	3.15	6	0.54 (0.03	0.03
5	7	1.64 (0.58)	2.25	6	0.95 (0.26)	0.26	7	2.63 (1.86)	1.86	7	0.34 (0.10)	0.10
6	3	0.42 (0.17)	0.61	3	1.79 (0.59)	0.59	3	1.19 (0.13)	0.13	3	0.36 (0.02)	0.02
7	7	2.42 (2.21)	6.24	6	1.15 (0.43)	0.43	7	2.65 (2.43)	2.43	7	0.73 (0.12)	0.12
8	7	0.41 (0.19)	0.73	6	0.40 (0.13)	0.13	7	0.30 (0.09)	0.09	7	0.24 (0.02)	0.02
9	6	0.40 (0.09)	0.56	6	0.82 (0.22)	0.22	7	1.29 (1.37)	1.37	7	0.51 (0.41)	0.41
10	6	0.22 (0.02)	0.24	5	0.87 (0.48)	0.48	6	0.54 (0.24)	0.24	6	0.26 (0.03)	0.03
11	7	0.57 (0.13)	0.82	5	0.90 (0.10)	0.10	7	0.74 (0.18)	0.18	7	0.35 (0.08)	0.08
12	1	0.32 (--)	0.32	1	0.54 (--)		2	0.38 (0.10)	0.10	2	0.24 (0.06)	0.06
13	7	0.33 (0.05)	0.40	6	0.44 (0.30)	0.30	7	0.55 (0.19)	0.19	7	0.29 (0.06)	0.06
14	2	0.79 (0.09)	0.85	1	0.73 (--)		2	0.93 (0.09)	0.09	2	0.64 (0.17)	0.17
15	7	0.19 (0.04)	0.27	6	0.18 (0.03)	0.03	7	0.26 (0.10)	0.10	7	0.23 (0.06)	0.06
16	6	0.31 (0.09)	0.42	5	0.49 (0.50)	0.50	6	0.39 (0.11)	0.11	6	0.38 (0.28)	0.28
17	4	4.62 (5.44)	12.02	4	0.57 (0.34)	0.34	5	2.57 (3.71)	3.71	5	0.50 (0.07)	0.07
Overall	90	1.70 (2.69)	12.94	78	1.31 (2.34)	2.34	94	1.72 (2.37)	2.37	94	0.63 (1.21)	1.21

* No data for House 1. Units are exchanges/hour. "Morning" defined as 6am-12pm; "afternoon" as 12-6pm; "evening" as 6pm-12am; and "night" as 12-6am.

4.1.3.2 6-Hr Air Exchange Rates. In general, 6-h air exchange rates were lower during the night as compared to the day, as illustrated by both the mean and maximum air exchange rates (Table 25). At night, mean home-specific air exchange rates were lower than one exchange/hour, with the exception of House 3, which had a mean air exchange rate of 2.87 (±3.92) (Table 25). During the day, air exchange rates showed no pattern by 6-h period, as morning, afternoon, and evening air exchange rates varied randomly by home. For all periods, House 3 had mean 6-h air exchange rates above 2 exchanges/hour, while Houses 8, 10, 11, 12, 13, 14, 15, and 16 had mean 6-h air exchange rates lower than one exchange/hour.

4.1.3.3 Activities and Home Ventilation. Potential particle generative activities, such as cooking and cleaning, were not performed during the 6-hr nighttime periods by definition. Cooking was performed in approximately half of the 6-h daytime periods, although with a slightly lower frequency in the morning (Table 27). Cleaning was performed in approximately 18% of 6-hr daytime periods, with cleaning occurring most often in the morning and afternoon (Table 27). Home ventilation varied by ventilation measure and sometimes by period as well. During the night, windows were opened approximately 15% of the 6-h periods, while during the day windows were opened more than 50% of the 6-hr periods. In contrast, the frequency of heater use during the day and night was comparable. [Air conditioners were rarely used in both day and nighttime periods.] Perhaps as a result of the difference in open window use, the frequency of homes with "high" air exchange rates was greater during the daytime as compared to nighttime 6-hr periods.

Table 27. Activity and Home Ventilation: Frequency by 6-Hr Period[1]

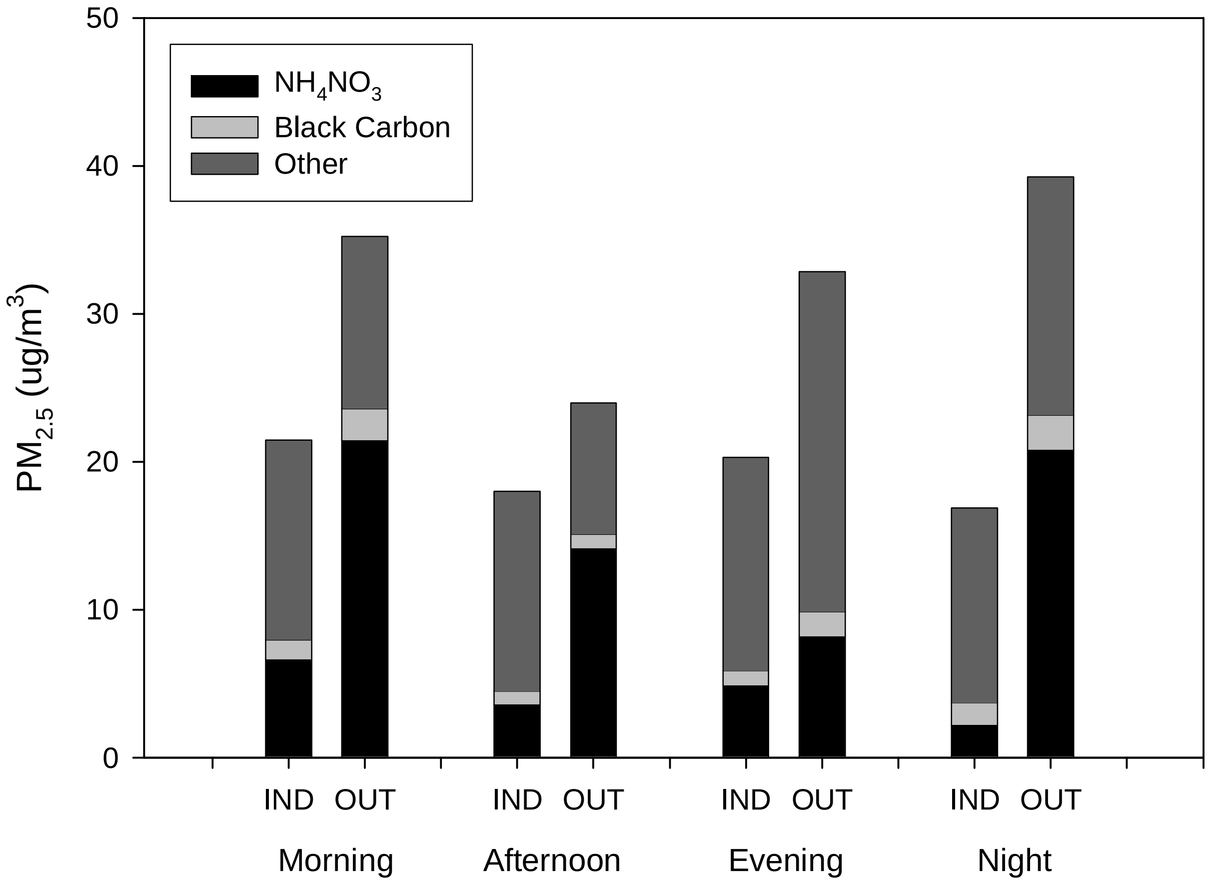
Period	Cooking		Cleaning		Open Windows		Heater Use		AER Group		
	Yes	No	Yes	No	Yes	No	Yes	No	Low	Med	High
Night	--	--	--	--	16	94	21	89	30	32	32
Day	150	164	56	258	178	136	71	243	40	73	149
Morning	43	51	22	72	53	41	27	67	18	24	48
Afternoon	54	56	21	89	67	43	18	92	13	22	43
Evening	53	57	13	97	58	52	26	84	9	27	58

[1] Values represent number of 6-h periods in which activity occurred or open window or heaters were used. "Low AER" represents data for which AER$\leq$ 0.28 exchanges/hr; "medium AER" for which 0.28<AER$\leq$0.51 exchanges/hr; and "high AER" for which AERs> 0.51 exchanges/hr.

Cooking was not significantly associated with air exchange rate group or heater use, when analyzed using all daytime data or by the individual daytime periods (p>0.10). Similar results were found for cleaning, although cleaning was weakly associated with air exchange rate group in the morning (p-value=0.06). In contrast, cooking (chi-square=4.18, p=0.04) and cleaning (chi-square=4.66, p=0.03) were significantly associated with open window use, with windows opened more frequently during "cooking" and "cleaning" as compared to "non-cooking" or "non-cleaning" periods. During the day, open window use, heater use, and air exchange rate group were strongly associated, with the air exchange rate being higher more frequently when windows were open and heaters were off. When analyzed by daytime period, heater use was not associated with air exchange rate group in the evening. Similar relationships among the home ventilation measures were found for the night period, although the frequencies of open window and heater use were not significantly associated (chi-square=2.00, p-value=0.16).

4.1.3.4 Composition of 6-Hr Indoor and Outdoor $PM_{2.5}$. The composition of $PM_{2.5}$ concentrations varied by location, house and by 6-hour period. In general, NO_3^- (as NH_4NO_3) comprised a large fraction of outdoor $PM_{2.5}$, contributing 61%, 59%, 25% and 53% to morning, afternoon, evening, and nighttime outdoor $PM_{2.5}$ concentrations, respectively (Figure 40). The fraction of $PM_{2.5}$ that was NO_3^- (as NH_4NO_3) was smaller indoors, comprising 31% in the morning, 20%, in the afternoon, 24% in the evening, and 13% in the night (Figure 40). Black carbon, on the other hand, comprised similarly low fractions of $PM_{2.5}$ across locations and periods, as illustrated by the relatively narrow range in its percent contribution across locations and periods (4% to 9%) (Figure 40). For all locations and periods, however, the contribution of non-identified $PM_{2.5}$ species was substantial (Figure 40), indicating the need for additional measurements of $PM_{2.5}$ species.

Figure 40. Composition of Indoor and Outdoor $PM_{2.5}$: By 6-Hour Period*

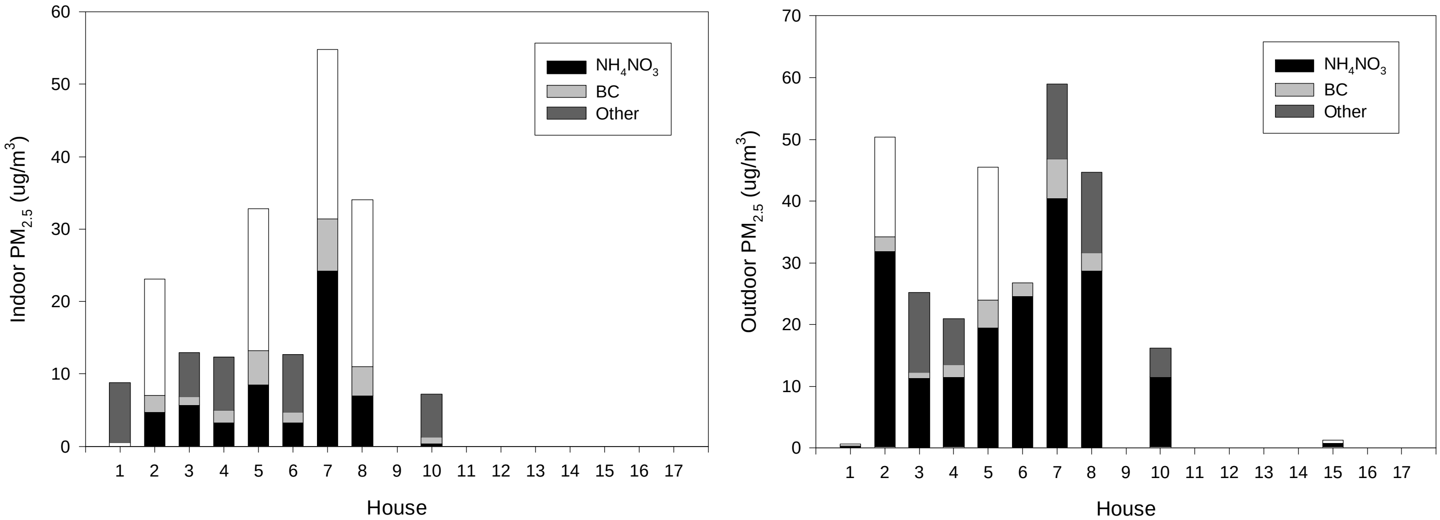


* NO_3^- assumed to be in the form of NH_4NO_3. Contributions of NO_3^- and black carbon determined based on its average ratio with $PM_{2.5}$ multiplied by the mean $PM_{2.5}$ concentration.

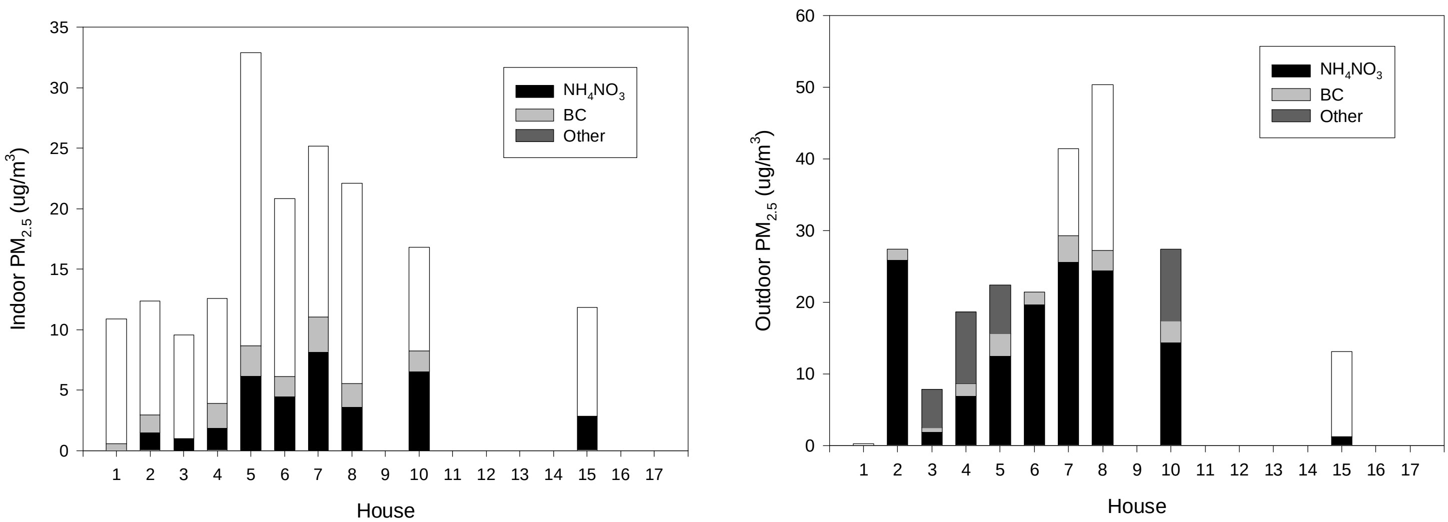
When the composition of 6-hour $PM_{2.5}$ concentrations was analyzed by home, similar results were found, as the contribution of NO_3^- to $PM_{2.5}$ was greater outdoors as compared to indoors in each home and unidentified $PM_{2.5}$ components remained a substantial contributor to both indoor and outdoor $PM_{2.5}$ in most of the homes. The major home-to-home differences were found in the daytime fractions of $PM_{2.5}$ that was fine particle NO_3^-;, as the home-specific daytime percent contributions of NO_3^- to $PM_{2.5}$ varied between zero and 73% indoors and zero to nearly 100% outdoors. BC, in contrast, exhibited relatively little home-to-home variability in its contribution to either indoor or outdoor $PM_{2.5}$, generally comprising less than 10% of indoor or outdoor $PM_{2.5}$. For each home and time period, unidentified fine particle components comprised a larger fraction of $PM_{2.5}$ indoors as compared to outdoors.

Figure 41. Composition of Indoor and Outdoor $PM_{2.5}$ by House and Period

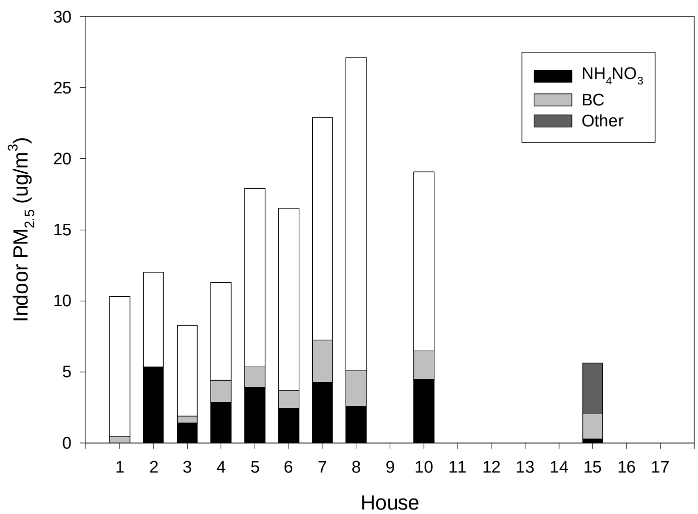
a) Morning

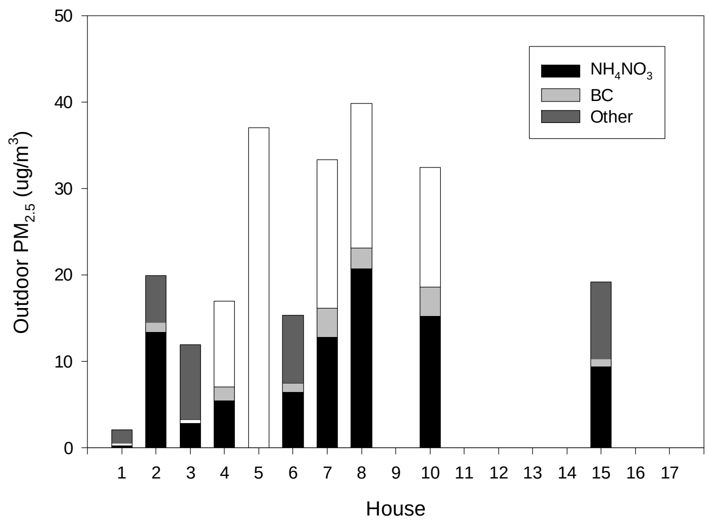


b) Afternoon

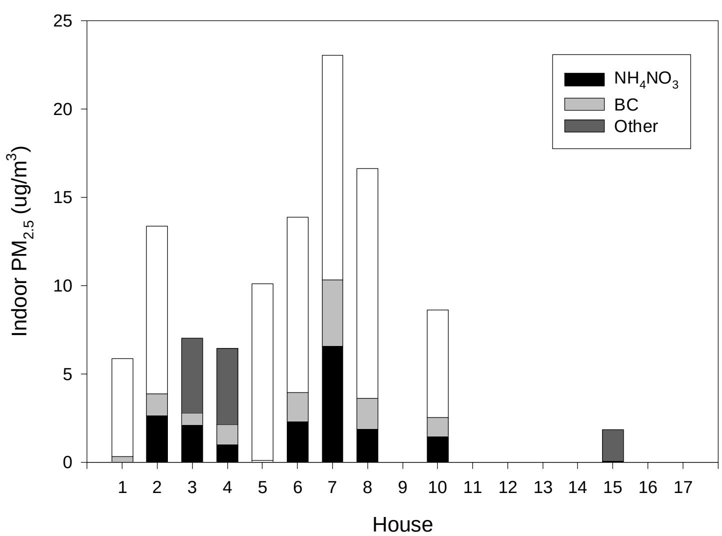


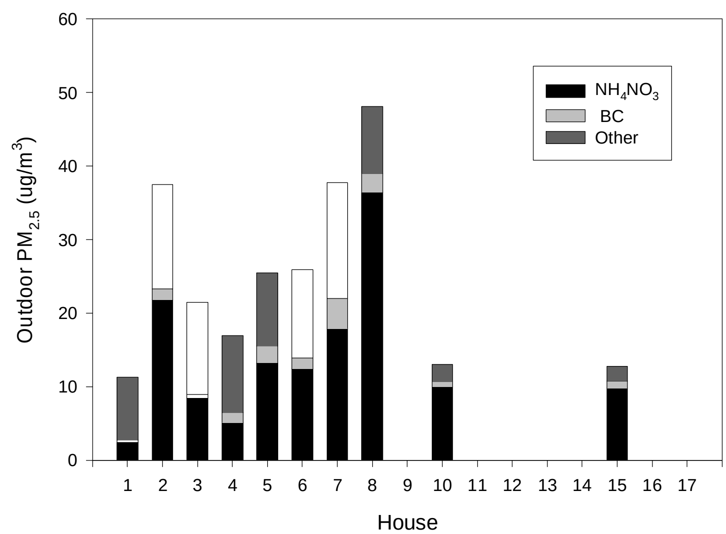
c) Evening





d) Night





4.1.3.5 Relationship between Indoor and Outdoor $PM_{2.5}$. Ratios of indoor to outdoor $PM_{2.5}$ concentrations varied by 6-hour period and by house. During the night, mean ratios for each home were relatively uniform, with all ratios lower than one (Table 27). The mean ratio for all homes equaled 0.4, suggesting a night F_{INF} of 40%. During the afternoon, evening, and to a lesser extent morning, mean home-specific ratios varied substantially, with mean ratios for the morning and evening higher than those observed in the nighttime and with maximum values for all daytime periods often greater than one. Higher daytime ratios are consistent with a larger indoor particle source contribution during the daytime hours, which was expected since individuals performed particle-generating activities primarily during these periods. Cooking and cleaning, however, did not have a significant effect on daytime indoor/outdoor ratios, as indoor/outdoor ratios for periods with “cooking” or “cleaning” did not differ significantly from the ratios for periods when these activities did not occur ($p=0.72$ and 0.92, respectively).

Although mean nighttime ratios were relatively uniform across the homes, individual nighttime ratios were broadly distributed, with ratios varying between approximately zero and 0.90 (Figure 42). As shown on Figure 43, this variation in nighttime ratios did not appear to be related to corresponding variability in the 6-hr outdoor $PM_{2.5}$ concentration or in the 6-hr air exchange rates. Correspondingly, other measures of home ventilation, including open window (p=0.11) and heater (p=0.13) use, were not significant modifiers of nighttime indoor/outdoor ratios as determined using generalized linear models.

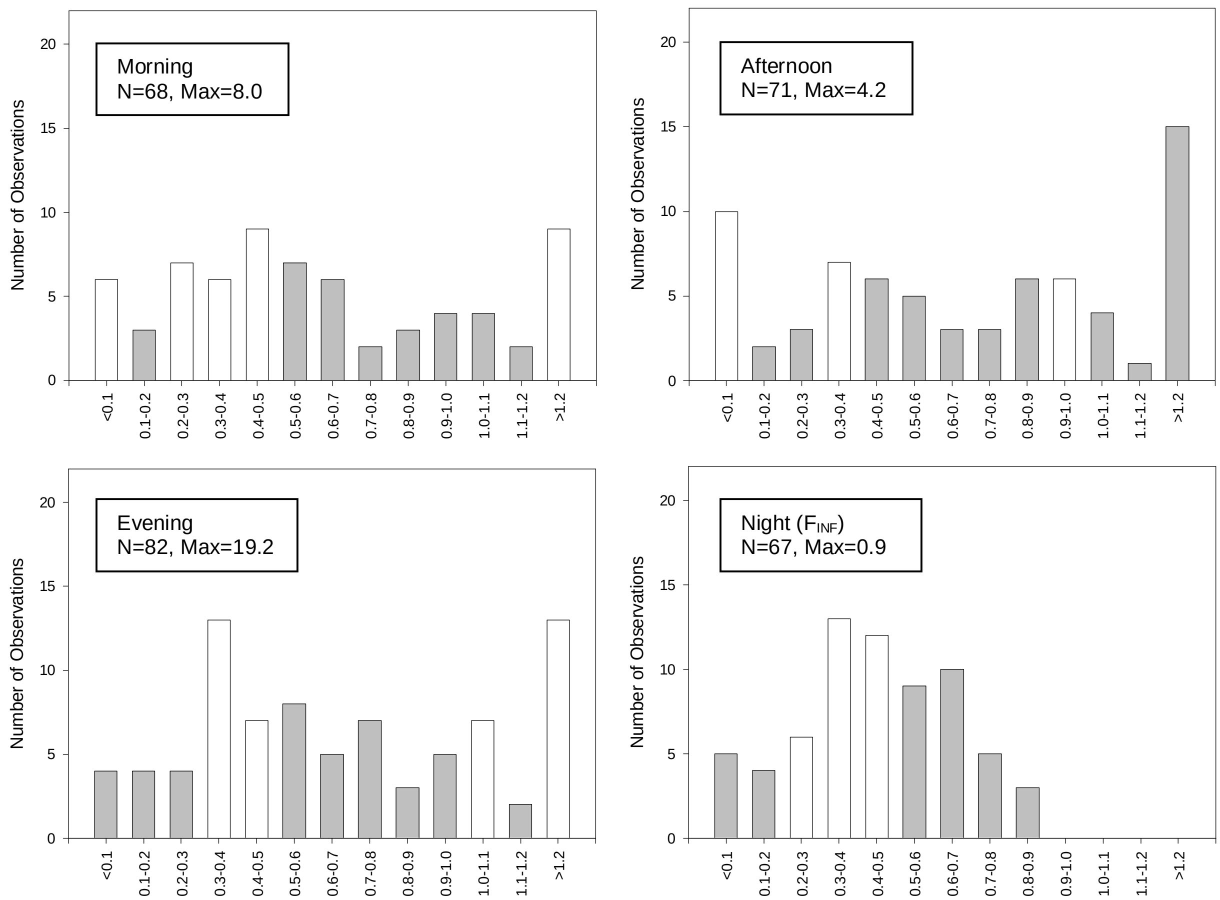
Table 28. Summary of 6-Hr Indoor-Outdoor Ratios by Time Period for $PM_{2.5}$

House	Morning			Afternoon			Evening			Night		
	N	Mean	SD	N	Mean	SD	N	Mean	SD	N	Mean	SD
1	5	0.2	3.0	5	-6.5	13.2	6	4.7	8.2	3	0.5	0.3
2	6	0.5	0.1	6	1.1	1.4	7	0.4	0.3	6	0.4	0.1
3	5	0.5	0.2	6	1.2	0.9	6	0.8	0.4	6	0.4	0.2
4	5	0.6	0.3	6	0.7	0.2	7	0.7	0.1	5	0.5	0.2
5	6	0.8	0.2	6	2.3	1.4	6	-2.3	8.3	6	0.4	0.4
6	3	1.7	2.1	4	1.4	1.0	4	1.1	0.2	2	0.5	0.1
7	5	0.9	0.4	6	0.7	0.3	6	0.9	0.3	6	0.6	0.2
8	6	0.9	1.1	6	0.5	0.3	7	1.1	1.4	6	0.4	0.2
9	5	1.9	3.4	5	0.0	2.2	6	0.6	0.2	6	0.3	0.4
10	3	-0.5	1.4	4	1.1	0.8	5	1.4	1.8	4	0.7	0.1
11	5	0.8	0.3	4	-1.8	5.4	7	0.7	0.2	5	0.6	0.1
13	5	0.4	0.1	4	0.4	0.0	5	0.7	0.8	5	0.4	0.1
14	2	1.1	0.1	2	0.7	0.4	3	0.6	0.3	2	0.6	0.3
15	7	1.0	1.7	7	-1.6	4.5	7	0.4	0.7	5	0.2	0.3
All homes	68	0.8	1.4	71	0.01	4.3	82	0.8	3.3	67	0.4	0.3

Note that there was no valid data for Houses 12, 16, 17. "Morning" defined as 6am-12pm; "afternoon" as 12-6pm; "evening" as 6pm-12am; and "night" as 12-6am.

The distribution of nighttime F_{INF} values in Los Angeles is lower than the summer distribution and consistent with the fall/winter distribution of nighttime F_{INF} values reported in an earlier study conducted in Boston, MA (Long *et al.*, 2001). Lower F_{INF} values in Los Angeles were expected due to the higher concentrations of the highly volatile NO_3^- in California as compared to Massachusetts (Lunden et al., 2004). As a result of these high NO_3^- concentrations, a large fraction of $PM_{2.5}$ is lost as it enters indoor environments. Support for this theory is provided by the observed low indoor NO_3^- concentrations.

Figure 42. Frequency distributions of I/O ratios by time period for $PM_{2.5}$.



Note that there was no valid data for Houses 12, 16, 17. “Morning” defined as 6am-12pm; “afternoon” as 12-6pm; “evening” as 6pm-12am; and “night” as 12-6am.

Figure 43. 6-hr Nighttime (12-6am) Indoor/Outdoor $PM_{2.5}$ vs. Outdoor Concentrations and Air Exchange Rates

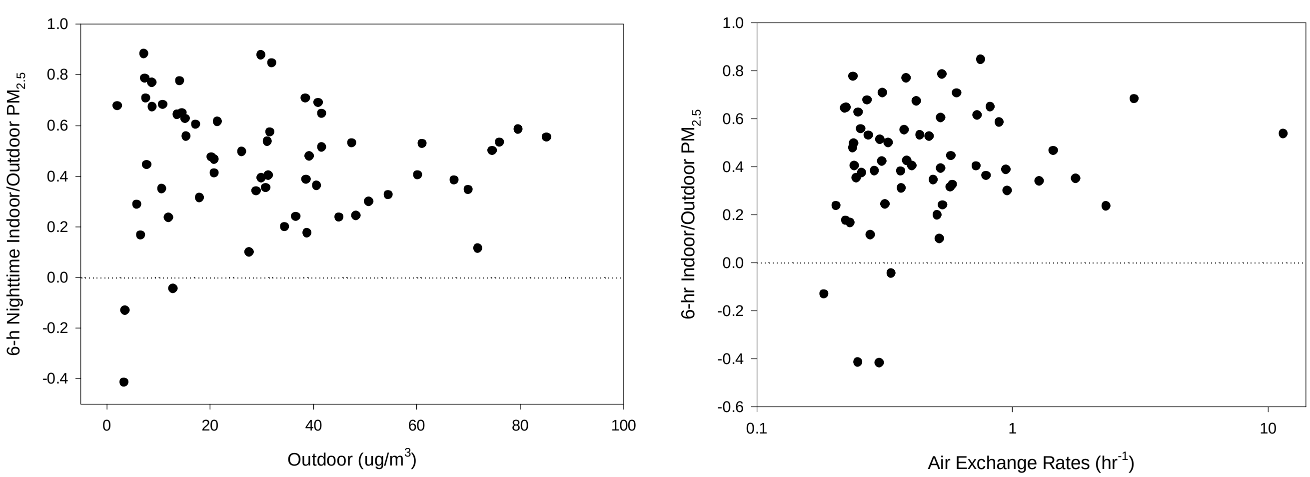
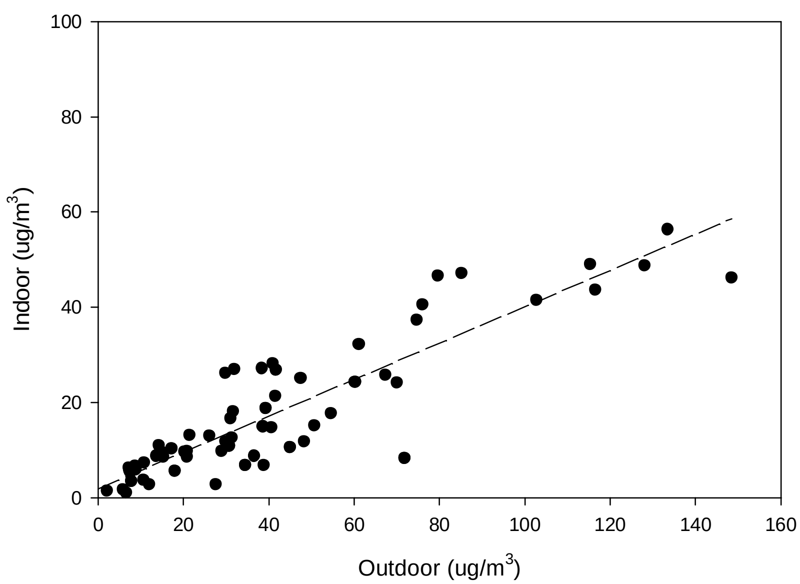


Table 29. Association between Indoor and Outdoor $PM_{2.5}$: 6-hr Nighttime Data

House	N	R^2	Slope	SE	Int.	SE
2	6	**0.88**	**0.23**	**0.04**	**4.75**	**1.69**
3	5	0.28	0.24	0.20	1.82	4.67
4	6	0.13	0.08	0.12	5.01	2.43
5	6	**0.85**	**0.29**	**0.06**	2.00	2.18
7	6	**0.82**	**0.54**	**0.13**	2.45	5.45
8	6	0.02	-0.06	0.26	19.71	12.90
9	4	**0.85**	**0.32**	**0.07**	9.21	7.55
10	4	0.71	0.54	0.25	1.50	3.31
11	5	**0.98**	**0.52**	**0.05**	-0.05	3.02
13	5	**0.96**	**0.33**	**0.04**	5.85	2.99
15	5	**0.77**	**0.17**	**0.06**	-0.58	1.04
Full (simple)	59	**0.83**	**0.38**	**0.02**	1.45	1.28
Full (mixed)	59	**---**	**0.35**	**0.03**	2.99	1.72

*Note that slopes, R^2 values and intercepts calculated for each home using simple linear regression of indoor on outdoor concentrations. The "full model (mixed)" slope and intercepts were calculated using mixed models of indoor on outdoor concentrations with home as a random subject. Nighttime defined as 12-6am. Values in bold indicate significance at p<=0.05.

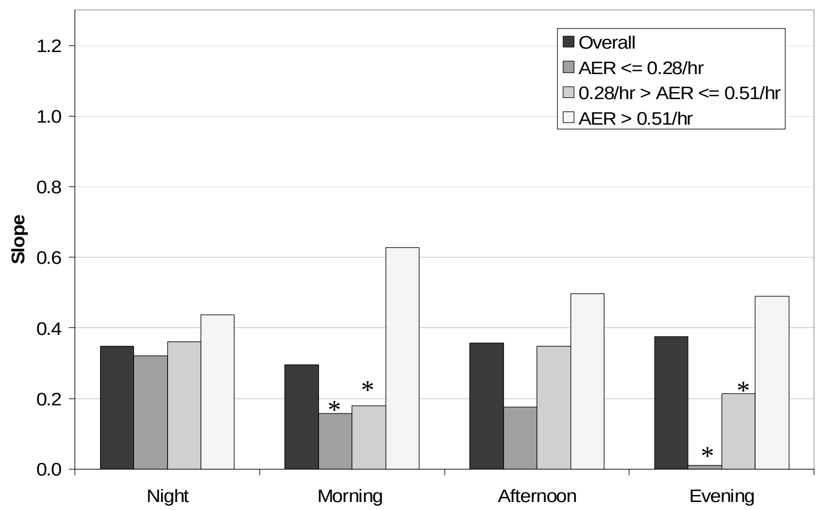
Figure 44. Indoor vs. Outdoor $PM_{2.5}$: 6-hr Integrated Nighttime Data



* Dotted line represents regression line. Nighttime defined as 12-6am.

An overall slope of 0.38 (±0.02) was found when indoor were regressed on outdoor concentrations (Table 29), suggesting an average F_{INF} of approximately 40%, which is comparable to the estimate of F_{INF} obtained using indoor/outdoor ratios. The home-specific slopes varied in magnitude and significance (Table 29). Four homes had insignificant slopes, while the remaining homes had slopes ranging between 0.17 and 0.54. Insignificant slopes were likely due to the relatively narrow range in outdoor $PM_{2.5}$ concentrations for these four homes. Even with this inter-home variability, the relationship between indoor and outdoor $PM_{2.5}$ was strong when data were analyzed together (Figure 44).

Figure 45. Indoor-Outdoor $PM_{2.5}$ Associations by Air Exchange Rate Category



[*] Slope is insignificant (p>0.05)

Table 30. Indoor vs. Outdoor Associations for $PM_{2.5}$ by Air Exchange Rate[1] and Period

Period	Low AER			Medium AER			High AER		
	N	Slope (SE)	Intercept (SE)	N	Slope (SE)	Intercept (SE)	N	Slope (SE)	Intercept (SE)
Night	18	**0.32** (0.06)	2.11 (2.45)	19	**0.36** (0.03)	2.67 (2.88)	22	**0.44** (0.07)	0.47 (2.96)
Day[2]		0.17 (0.11)[3]	3.86 (3.45)		**0.25** (0.04)[3]	**6.62** (2.54)		**0.48** (0.04)[3]	**7.70** (1.86)
Morning	12	0.16 (0.08)	3.61 (2.72)	12	**0.18** (0.07)	10.52 (5.77)	32	**0.63** (0.11)	2.54 (5.60)
Afternoon	9	**0.18** (0.04)	3.87 (3.30)	14	**0.35** (0.07)	5.38 (3.75)	31	**0.50** (0.09)	**9.22** (3.66)
Evening	9	0.01 (0.17)	12.03 (7.70)	17	**0.21** (0.09)	8.17 (5.07)	40	**0.49** (0.05)	5.20 (2.34)

Note that "morning" was defined as 6am-12pm; "afternoon" as 12-6pm; "evening" as 6pm-12am; and "night" as 12-6am.[1] "Low AER" defined as ≤ 0.28 exchanges/hr; "medium AER" 0.28<AER≤0.51 exchanges/hr; and "high AER" > 0.51 exchanges/hr. [2] Analyses of all daytime data were performed using mixed models that included AER groups as an interaction term and main effect; period-specific analyses used mixed models stratified by AER. [3] The low and medium AER groups differed significantly from the high AER group at 0.05 level.

Inter-home variation in the slopes of nighttime indoor on outdoor $PM_{2.5}$ was associated with home-specific differences in ventilation (Figure 45). When air exchange rates were included as a categorical variable in the regression model, nighttime slopes were found to increase with air exchange rate tertile, resulting in a slope of 0.44 (±0.07) when air exchange rates were highest as compared to a slope of 0.32 (±0.0.03) when air exchange rates were lowest (Table 30). These findings suggest that the F_{INF} for $PM_{2.5}$ is approximately 10% higher in well-ventilated homes as compared to poorly ventilated homes. Higher F_{INF} for high air exchange rates homes is likely due to the fact that (1) high air exchange rates are associated with more open windows and doors, allowing particles to more easily penetrate indoors, and (2) the indoor air residence time is shorter in homes with high air exchange rates, thus giving particles less time to deposit indoors. The observed effect of air exchange rates is consistent, although lower in magnitude, with findings from a previous study of personal exposures conducted in Baltimore, MD, which showed personal on ambient $PM_{2.5}$ slopes to be higher for individuals spending time in well-ventilated (slope=0.83) as compared to poorly ventilated (slopes=0.46) environments (Sarnat et al., 2000). The observed effect in Los Angeles may be lower in magnitude due to the lower overall slopes found in our Los Angeles study, which may, in turn, result from the fact that the Los Angeles study was conducted during multiple seasons, while the Baltimore study reports results for summer only. Lower slopes in our Los Angeles study may also be attributed to differences in particle composition, with the reactive NO_3^- comprising a greater fraction of $PM_{2.5}$ in Los Angeles, thus potentially leading to greater loss of $PM_{2.5}$ indoors.

Table 31. Effect Modifiers of Daytime Indoor-Outdoor $PM_{2.5}$ Associations

Activity/Ventilation	N[1]	Slope (SE)[2]	Intercept (SE)[2]
Cooking:			
Yes	164	**0.40** (0.04) [4]	5.69 (2.10)[3]
No	150	**0.29** (0.05) [4]	10.25 (2.24)
Cleaning:			
Yes	56	**0.52** (0.08) [3]	**8.64** (3.08)
No	258	**0.33** (0.03) [3]	6.86 (1.68)
Open Windows:			
Yes	178	**0.44** (0.04) [3]	7.41 (1.92)
No	136	**0.25** (0.05) [3]	**8.03** (2.19)
Heater Use:			
Yes	71	**0.22** (0.08) [4]	10.11 (3.21)
No	243	0.38 (0.03) [4]	7.29 (1.73)

Note that slopes and intercepts were calculated using mixed models with the activity included as a main effect and interaction term and home included as a random variable. Activities were included in the model one at a time and were classified as"yes" if the activity was performed any time during the sampling period. [1] Sample size reflects total number of data points in which activity did or did not occur. [2] Bold values indicate significance at the 0.05 level. [3] Interaction terms or main effects significant at the 0.05 level. [4] Interaction terms or main effects significant at the 0.10 level.

The effect of ventilation on the association between indoor and outdoor $PM_{2.5}$ concentrations was also evident for 6-hour daytime periods, where again the slope for the high AER group was significantly higher than that for the low and medium AER groups (Figure 45). The increase in the daytime slopes with air exchange rates was more pronounced than that for nighttime values, primarily due to the much lower slopes for the low and medium air exchange rate groups (Table 30). This effect was consistent when daytime data were stratified by morning, afternoon, and evening periods. Correspondingly, indoor-outdoor slopes were also significantly modified by the use of open windows or heaters, as slopes were significantly higher when windows were opened and heaters were off, both of which are conditions consistent with increased ventilation (Table 31). Cooking and cleaning were also found to modify the association between indoor and outdoor $PM_{2.5}$ concentrations, with slopes significantly higher when cooking or cleaning was performed (Table 31). This impact may result from the fact that windows were open more often when cooking or cleaning was performed. When the impacts of activity and ventilation were analyzed simultaneously using a multiple regression model, results were consistent, as the slope of the indoor-outdoor relationship was significantly higher when windows were open (Table 32). In addition, cooking and cleaning were found to result in a higher, albeit statistically insignificant intercept, suggesting that both cooking and cleaning contributed to indoor particle concentrations (Table 32). Time of day, in contrast, did not significantly impact the relationship between indoor and outdoor concentrations. Likely as a result of varying influences of activities and ventilation, daytime slopes ranged broadly by home and were generally insignificant (Table 33).

Table 32. Impact of Period, Activities and Ventilation on Indoor-Outdoor $PM_{2.5}$ Relationship: Results from Multivariate Mixed Model

Parameter	Intercept		Slope	
	Estimate (SE)	t-value	Estimate (SE)	t-value
Period				
Morning	9.20 (2.52) [1]	3.66	0.32 (0.05) [1]	6.90
Afternoon	8.86 (2.33) [1]	3.81	0.38 (0.06) [1]	6.30
Evening	12.17 (3.50) [1]	3.48	0.40 (0.05) [1]	7.89
Window Use				
Open	12.17 (3.50) [1]	3.48	0.40 (0.05) [2]	7.89
Closed	10.07 (2.45) [1]	4.12	0.26 (0.04) [2]	6.00
Cooking				
Yes	12.17 (3.50) [1]	3.48	0.40 (0.05) [3]	7.89
No	10.08 (2.11) [1]	4.78		
Cleaning				
Yes	12.17 (3.50) [1]	3.48	0.40 (0.05) [3]	7.89
No	6.65 (1.69) [1]	3.94		

Values estimated using a mixed model that included cooking and cleaning as main effects and daytime period and window use as both main effects and interaction terms. Only daytime data were included in the analysis, as no activities were performed at night. [1] Intercepts or slopes did not differ significantly by open window, cooking, or cleaning status. [2] Interaction term differed significantly by open window status ($p=0.007$). [3] Interaction terms for cooking and cleaning status were not included in the model.

Table 33. Indoor vs. Outdoor Associations: 6-hr Daytime and Nighttime $PM_{2.5}$

House	N	Morning			Afternoon			Evening		
		R^2	Slope	Int.	R^2	Slope	Int.	R^2	Slope	Int.
2	5	0.69	0.48 (0.19)	-2.88 (9.60)	0.23	-0.46 (0.49)	21.61 (9.03)	0.56	0.27 (0.14)	1.70 (3.34)
3	4	0.20	0.39 (0.55)	3.02 (14.75)	0.74	0.57 (0.24)	5.01 (2.57)	0.59	0.64 (0.38)	-0.98 (5.56)
4	4	0.10	0.12 (0.26)	7.10 (5.36)	0.53	0.92 (0.62)	-3.50 (9.45)	0.69	0.37 (0.17)	3.75 (3.05)
5	5	**0.86**	**0.63** (0.15)	6.03 (7.23)	**0.76**	**0.53** (0.17)	**19.62** (4.27)	0.74	0.72 (0.25)	6.19 (3.09)
7	5	0.37	0.91 (0.69)	1.35 (41.69)	0.33	0.33 (0.28)	12.28 (14.39)	0.49	0.19 (0.11)	14.94 (5.23)
8	5	0.08	-0.59 (1.14)	65.36 (58.22)	0.01	0.01 (0.08)	**23.58** (4.27)	0.11	0.13 (0.21)	15.32 (9.11)
9	4	0.66	0.17 (0.09)	13.68 (8.28)	0.86	0.43 (0.12)	12.02 (8.44)	0.77	0.46 (0.18)	-0.90 (17.71)
11	4	0.63	0.26 (0.14)	15.24 (5.28)	**0.95**	**0.54** (0.09)	5.68 (1.39)	0.20	0.16 (0.24)	21.49 (12.44)
13	4	0.10	-0.05 (0.11)	22.56 (7.00)	**0.91**	**0.24** (0.05)	4.54 (1.99)	0.08	-0.12 (0.29)	43.36 (23.53)
15	6	0.02	0.07 (0.24)	0.20 (0.84)	**0.84**	**0.18** (0.04)	**-2.64** (0.81)	0.00	0.00 (0.26)	6.11 (5.99)
All	*	--	**0.30** (0.06)	**9.71** (4.13)	**--**	**0.36** (0.06)	**8.43** (3.20)	--	**0.37** (0.05)	**6.66** (2.54)

"Morning" was defined as 6am-12pm; "afternoon" as 12-6pm; "evening" as 6pm-12am; and "night" as 12-6am [*] Sample size for overall data is 56 for morning, 54 for afternoon, and 66 for evening. For comparison, results are reported only for homes for which regressions were run using 6-hr nighttime data. Mixed model results of indoor on outdoor concentrations and home as a random subject are presented for "all" data.

Estimates of *P* obtained using nighttime $PM_{2.5}$ data corresponded well with estimated F_{INF} values. Using the mass balance model, *P* was estimated to equal 0.42 (±0.11) for $PM_{2.5}$ (Table 34), which is comparable to the F_{INF} of 0.40 estimated using nighttime indoor/outdoor concentration ratios and regressions of nighttime indoor on outdoor values. The similarity in estimates for *P* and F_{INF} suggest that decay in nighttime $PM_{2.5}$ concentrations inside the homes was small relative to *P*. Consistent with this, values for *k* estimated using the mass balance model were statistically insignificant. Estimated values for both *P* and *k* were lower than that found in the earlier Boston indoor monitoring study, which found values of 1.11 (±0.10) and 0.15 (±0.04) hr^{-1}, respectively (Long et al., 2000).

Table 34. Estimates of P and k for $PM_{2.5}$, BC, and NO_3^- using the Mass Balance Model

Particulate Measure	Mixed Model			*P* (SE)	*k* (hr^{-1}) (SE)
	N^b	Intercept	Slope		
$PM_{2.5}$ [c]	55	**2.37** (0.61)	0.14 (0.21)	**0.42** (0.11)	0.06 (0.10)
BC	92	**1.13** (0.09)	0.03 (0.03)	**0.89** (0.06)	0.03 (0.03)

Estimates of *P* and *k* determined using mixed regression models based on the mass balance model and 6-hr nighttime data to correspond to non-source periods. Estimates for BC obtained using corrected outdoor concentrations. [a] Bold values indicate significance at 0.05 level of intercept and/or slope from mixed model. [b] $PM_{2.5}$ models exclude outdoor/indoor ratios below zero.

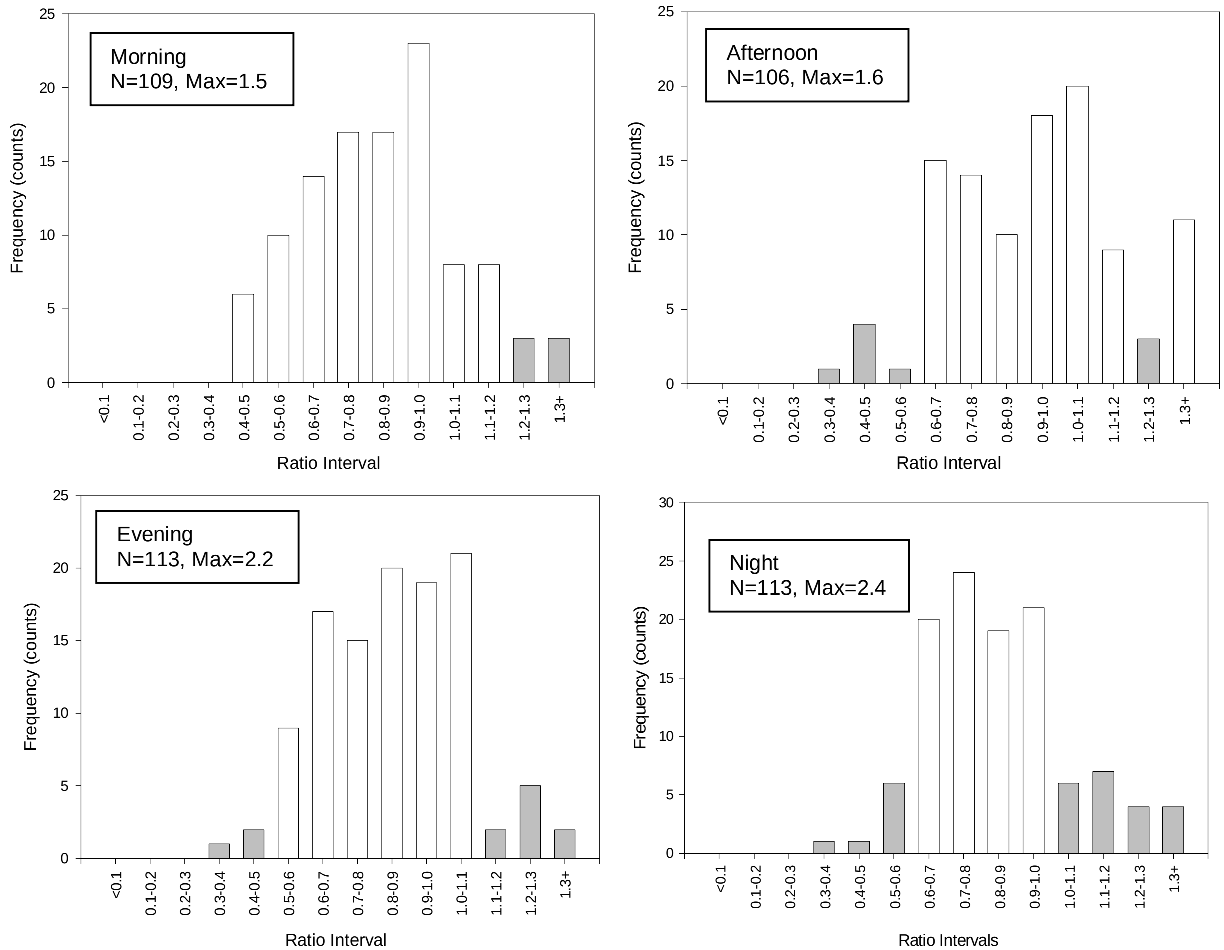
Table 35. Summary of Indoor-outdoor Ratios by Time Period for BC

House	Morning		Afternoon		Evening		Night	
	N	Mean (SD)	N	Mean (SD)	N	Mean (SD)	N	Mean (SD)
1	7	1.0 (0.1)	7	1.1 (0.1)	7	1.0 (0.1)	7	0.7 (0.1)
2	8	0.9 (0.1)	7	0.7 (0.1)	8	0.6 (0.2)	8	0.8 (0.1)
3	7	0.9 (0.1)	7	1.0 (0.0)	7	1.0 (0.1)	7	0.9 (021)
4	7	0.7 (0.3)	7	0.8 (0.2)	7	0.9 (0.1)	7	0.8 (0.1)
5	7	1.0 (0.1)	7	1.2 (0.1)	7	1.1 (0.1)	7	0.7 (0.2)
6	6	0.7 (0.2)	6	0.9 (0.1)	6	1.0 (0.0)	6	0.9 (0.1)
7	6	0.9 (0.1)	7	0.7 (0.2)	7	0.8 (0.2)	7	0.8 (0.1)
8	7	0.7 (0.1)	7	0.8 (0.3)	7	0.8 (0.2)	7	0.7 (0.0)
9	7	0.8 (0.2)	7	0.9 (0.1)	7	0.8 (0.1)	7	0.7 (0.1)
10	5	0.5 (0.1)	5	0.8 (0.1)	6	1.0 (0.2)	6	1.5 (0.6)
11	5	0.9 (0.1)	7	1.0 (0.0)	7	0.8 (0.1)	7	0.8 (0.1)
12	2	0.6 (0.2)	1	1.0 (--)	2	0.7 (0.1)	2	0.5 (0.2)
13	7	0.8 (0.1)	6	1.0 (0.2)	7	0.7 (0.2)	7	0.8 (0.1)
14	6	1.1 (0.2)	6	1.3 (0.3)	6	0.8 (0.0)	6	1.1 (0.1)
15	7	0.9 (0.3)	6	0.6 (0.2)	7	0.8 (0.2)	7	0.9 (0.4)
16	8	1.0 (0.2)	7	1.4 (0.1)	8	1.0 (0.4)	8	1.1 (0.2)
17	7	0.8 (0.2)	6	0.7 (0.1)	7	0.9 (0.6)	7	0.8 (0.2)
Full	109	0.8 (0.2)	106	0.9 (0.3)	113	0.9 (03)	113	0.9 (0.3)

"Morning" was defined as 6am-12pm; "afternoon" as 12-6pm; "evening" as 6pm-12am; and "night" as 12-6am. Outdoor BC concentrations multiplied by 1.16 to correct data based on results from collocated instrument tests.

4.1.3.6 Relationship between Indoor and Outdoor BC. During the night, mean indoor/outdoor concentration ratios for BC equaled 0.9 suggesting a nighttime F_{INF} of 90% (Table 35). Nighttime ratios varied somewhat by home, with mean home-specific ratios ranging between 0.7 and 1.5. During the morning, afternoon and evening, mean indoor/outdoor mean ratios also equaled 0.9, with ratios again varying by home (Table 35). Similar daytime and nighttime mean ratios are consistent with the fact that indoor sources of BC are few and that cooking, one of the few indoor BC sources, occurred infrequently during the study. Even though the day and nighttime mean ratios were similar, mean daytime ratios were found to differ significantly by cooking status (p=0.05), with mean ratios of 0.90 (±0.26) when cooking occurred and of 0.85 (±0.24) when cooking did not. Differences in the mean ratios for the cooking and non-cooking groups were due primarily to the morning period. Correspondingly, the distributions of indoor/outdoor ratios for day and nighttime periods were comparable, with most ratios between 0.5 and 1.0, suggesting that F_{INF} values were relatively narrowly distributed across homes and 6-hour periods (Figure 46).

Figure 46. Frequency distributions of I/O ratios by time period for BC*



"Morning" was defined as 6am-12pm; "afternoon" as 12-6pm; "evening" as 6pm-12am; and "night" as 12-6am. Outdoor BC concentrations multiplied by 1.16 to correct data based on results from collocated instrument tests.

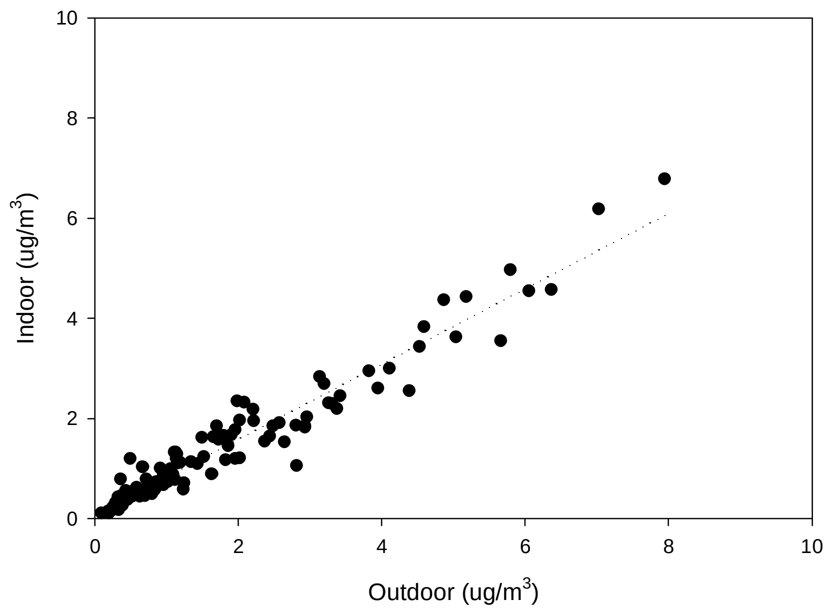
The association between nighttime indoor and outdoor BC concentrations was strong (Figure 47), resulting in a crude R^2 of 0.94 and a slope of 0.75 (±0.02) (Table 36), suggesting an average F_{INF} of approximately 75%. This value is lower than the F_{INF} of 90% estimated using indoor/outdoor ratios, with the lower value likely due to the contribution of the intercept to indoor BC levels. When data were analyzed by home, slopes were significant for all homes (Houses 3 and 5 at the 0.10 level), slopes ranging between 0.39 and 1.1. The inter-home variation in slopes may be attributed to the narrow range in outdoor BC concentrations that was found for some homes, as homes measured when outdoor BC concentrations were low throughout the seven-day monitoring period tended to have lower or insignificant slopes. Unlike $PM_{2.5}$, variability in the home-specific slopes for nighttime periods was not due to variability in air exchange rates. Slopes of nighttime indoor on outdoor levels were comparable across air exchange rates (Figure 48), with slopes approximately equal to 0.70 irrespective of air exchange rate category (Table 37). These results suggest that infiltration of BC at night is relatively constant and unaffected by home ventilation.

Table 36. 6-hr Nighttime Indoor vs. Outdoor BC: By House

House	N	R^2	Slope (SE)	Intercept (SE)
1	7	**0.79**	**0.81** (0.19)	-0.02 (0.06)
2	8	**0.97**	**0.64** (0.05)	0.13 (0.08)
3	7	0.48*	0.70 (0.32)*	0.09 (0.17)
4	7	**0.93**	**0.97** (0.12)	-0.18 (0.17)
5	7	0.55*	0.44 (0.18)*	0.27 (0.20)
6	6	**0.98**	**0.88** (0.06)	-0.01 (0.06)
7	7	**0.89**	**0.82** (0.13)	-0.11 (0.48)
8	7	**0.99**	**0.56** (0.02)	**0.17** (0.06)
9	7	**0.96**	**0.75** (0.07)	-0.03 (0.26)
10	6	**0.74**	**0.68** (0.20)	0.49 (0.19)*
11	7	**0.91**	**0.72** (0.10)	0.12 (0.43)
12	--	--	--	--
13	7	**0.98**	**0.83** (0.06)	0.04 (0.29)
14	6	**0.91**	**1.1** (0.18)	-0.02 (0.30)
15	7	**0.87**	**0.40** (0.07)	**0.24** (0.05)
16	8	**0.90**	**0.76** (0.10)	0.30 (0.13)*
17	7	**0.88**	**0.65** (0.11)	0.09 (0.16)
Full	113	**0.94**[1]	**0.75** (0.02)	0.07 (0.07)

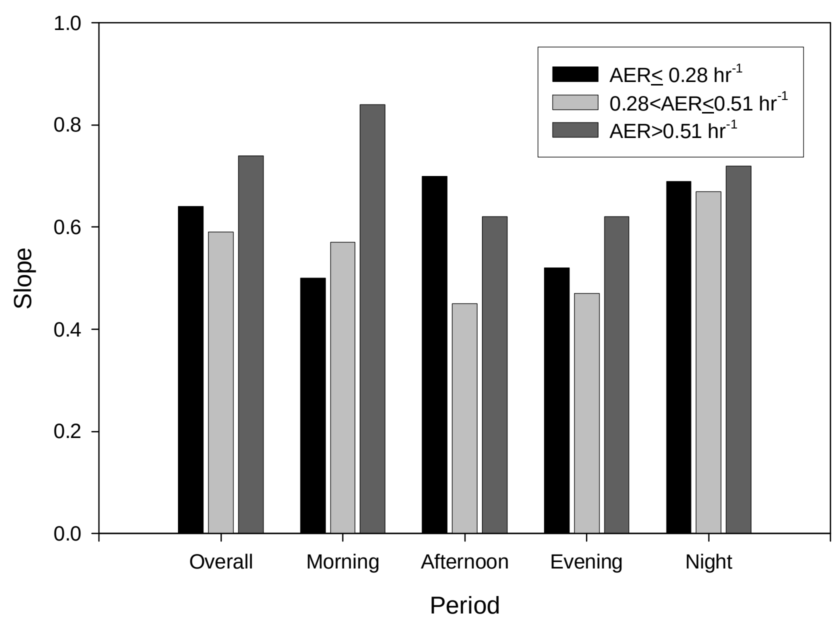
Outdoor BC concentrations multiplied by 1.16 to correct data based on results from collocated instrument tests. Nightime defined as 12-6am. *Bold values indicate significance at the 0.05 level. * indicates significance at 0.10 level. [1] R^2 from simple regression model.

Figure 47. 6-hr Nighttime Indoor vs. Outdoor BC



Outdoor BC levels were multiplied by 1.16 to correct data based on results from collocated instrument tests. Nightime defined as 12-6am. Dotted line represents regression line; solid line 1:1 line.

Figure 48. Slopes of Indoor on Outdoor BC: By AER Category



"Morning" was defined as 6am-12pm; "afternoon" as 12-6pm; "evening" as 6pm-12am; and "night" as 12-6am. Outdoor BC concentrations multiplied by 1.16 to correct data based on results from collocated instrument tests.

Table 37. Indoor vs. Outdoor Associations for BC by Air Exchange Rate[1] and Period

Period	N	Low AER		Medium AER		High AER	
		Slope	Intercept	Slope	Intercept	Slope	Intercept
Night	92	**0.78** (0.04)	0.06 (0.10)	**0.75** (0.03)	0.03 (0.09)	**0.79** (0.05)	0.14 (0.12)
Day[2]	253	**0.59**[3] (0.08)	0.24 (0.17)	**0.55**[3] (0.03)	**0.37** (0.10)	**0.84**[3] (0.02)	0.22 (0.19)
Morning	85	**0.56**[3] (0.12)	0.28 (0.24)	**0.64**[3] (0.06)	0.20 (0.19)	**0.94**[3] (0.03)	-0.17 (0.12)
Afternoon	76	**0.79** (0.15)	0.09 (0.25)	**0.50** (0.10)	0.49 (0.21)	**0.69** (0.04)	**0.32** (0.11)
Evening	92	**0.59** (0.10)	0.29 (0.04)	**0.53**[3] (0.04)	**0.39** (0.12)	**0.70**[3] (0.03)	**0.28** (0.10)

"Morning" was defined as 6am-12pm; "afternoon" as 12-6pm; "evening" as 6pm-12am; and "night" as 12-6am. Outdoor BC concentrations multiplied by 1.16 to correct data based on results from collocated instrument tests. [1]"Low AER" represents data for which AER$\leq$ 0.28 exchanges/hr; "medium AER" for which 0.28<AER$\leq$0.51 exchanges/hr; and "high AER" for which AERs> 0.51 exchanges/hr. [2] Analyses of daytime data were performed using mixed models that included air exchange rate categories as an interaction term and main effect. [3] Air exchange rate groups differed significantly at 0.05 level. Bold values indicate significance at 0.05 level.

When the role of ventilation on the indoor-outdoor association was examined, home ventilation was found to influence daytime indoor-outdoor slopes. Slopes, for example, were significantly higher when conditions associated with increased home ventilation, such as when windows were open as compared to closed and when air conditioners and heaters were off as compared to on (Table 39). Consistent with these findings, indoor-outdoor slopes were significantly higher for homes with the highest air exchange rates (Table 37). When analyzed by daytime period, the effect of air exchange rates only persisted for the morning period (Figure 48). Like nighttime slopes, afternoon and evening slopes were not modified by air exchange rates (Figure 48). Reasons for the morning-only effect of air exchange rates on indoor-outdoor slopes are not known; however, it is possible that their effect may be explained by the fact that outdoor concentrations tended to be highest in the morning, likely due to the morning rush hour. These high outdoor concentrations may allow the effect of air exchange rates on indoor BC concentrations to be observed more clearly, since outdoor air is the primary source of indoor BC and as a result, the absolute change in indoor BC concentrations may be greater when outdoor concentrations are highest.

Correspondingly, the slopes of the regression of indoor on outdoor BC concentrations were highest in the morning as compared to other daytime periods, when the impact of ventilation and activities on the indoor-outdoor relationship was examined using a multivariate mixed model (Table 38). As with models examining air exchange rates or window usage alone, open window use was found to be an important predictor of the indoor-outdoor slope for all daytime periods, with again slopes highest when windows were open, especially in the morning as compared to afternoon and evening periods. In contrast, intercepts did not vary with daytime period, open window use, cooking or cleaning, suggesting that the contribution of indoor sources to indoor BC concentrations was not affected by any of these parameters.

Table 38. Impact of Period, Activities and Ventilation on Indoor-Outdoor BC Relationship: Results from Multivariate Mixed Model

Parameter	Intercept		Slope	
	Estimate (SE)	t-value	Estimate (SE)	t-value
Period				
Morning	0.00 (0.08) [1]	-0.08	0.94 (0.03) [1]	33.81
Afternoon	0.22 (0.08) [1]	2.93	0.82 (0.04) [1]	21.17
Evening	0.27 (0.10) [1]	2.64	0.85 (0.04) [1]	23.40
Window Use				
Open	0.27 (0.10) [2]	2.64	0.85 (0.04) [3]	23.40
Closed	0.27 (0.07) [2]	3.74	0.74 (0.03) [3]	24.79
Cooking				
Yes	0.27 (0.10) [2]	2.64	0.85 (0.04) [4]	23.40
No	0.13 (0.06) [2]	2.35		
Cleaning				
Yes	0.27 (0.10) [2]	2.64	0.85 (0.04) [4]	23.40
No	0.15 (0.05) [2]	3.22		

Outdoor BC concentrations corrected by a factor of 1.16 based on results from collocated instrument tests. Intercepts and slopes estimated using mixed model with cooking and cleaning as main effects and daytime period and open window status as both main effects and interaction terms. Only daytime data were included in analyses, as no activities were performed at night. [1]Morning intercept and slope was significantly lower than afternoon and evening values. [2]Values did not differ significantly by open window, cooking, or cleaning status. [3]Interaction term differed significantly by open window status (p=0.007). [4] Interaction terms for cooking and cleaning status were not included in the model.

Table 39. Effect Modification of Daytime Indoor-Outdoor Association for BC

Activity/Ventilation	N[1]	Slope (SE)[2]	Intercept (SE)[2]
Cooking:			
Yes	293	**0.81** (0.02) [3]	0.04 (0.07)
No		**0.67** (0.02) [3]	0.22 (0.06)
Cleaning:			
Yes	293	**0.89** (0.05) [3]	-0.06 (0.11)
No		**0.73** (0.02) [3]	0.16 (0.05)
Open Windows:			
Yes	293	**0.82** (0.02) [3]	0.03 (0.06)[2]
No		**0.62** (0.03) [3]	**0.30** (0.07)[2]
Heater Use:			
Yes	293	**0.60** (0.05) [3]	**0.25** (0.12)
No		**0.77** (0.02) [3]	0.13 (0.05)

Note that slopes and intercepts were calculated using mixed models with the activity included as a main effect and interaction term and home included as a random variable. Activities were classified as"yes" if the activity was performed any time during the sampling period. [11] [2] Bold values indicate significance at the 0.05 level. [3] Interaction terms or main effects significant at the 0.05 level.

Estimates of P obtained using nighttime BC data corresponded well with estimated F_{INF} values. Using the mass balance model, P was estimated to equal 0.89 (±0.06) (Table 34), which was comparable to the estimated F_{INF} value using nighttime indoor/outdoor ratios and was 0.15 higher than the estimated F_{INF} value obtained using the slope of the nighttime indoor on outdoor regression line. The similarity in estimates for P and F_{INF} suggest that decay in nighttime $PM_{2.5}$ concentrations inside the homes was small relative to P. Consistent with this, the value for k estimated using the mass balance model was low, equaling 0.03 (±0.03), which was statistically insignificant at the 0.05 level.

4.1.3.7 Relationship between Indoor and Outdoor NO_3^-. During the night, mean indoor/outdoor concentration ratios for NO_3^- were extremely low across homes and periods, with mean ratios for each home near zero (Table 40) and approximately 85% of all samples having values below 0.30 (Figure 49). Correspondingly, the overall mean nighttime ratio equaled 0.01 (±0.7), suggesting a nighttime F_{INF} of 0%. The nighttime F_{INF} value did not vary significantly by home ventilation, although mean indoor/outdoor ratios were higher for conditions consistent with increased ventilation, such as when windows were open (mean I/O_{open}=0.27±0.26 vs. mean I/O_{closed}=0.09±0.37) and heaters were off (mean I/O_{off}=0.14±0.37 and mean I/O_{on}=0.00±0.12).

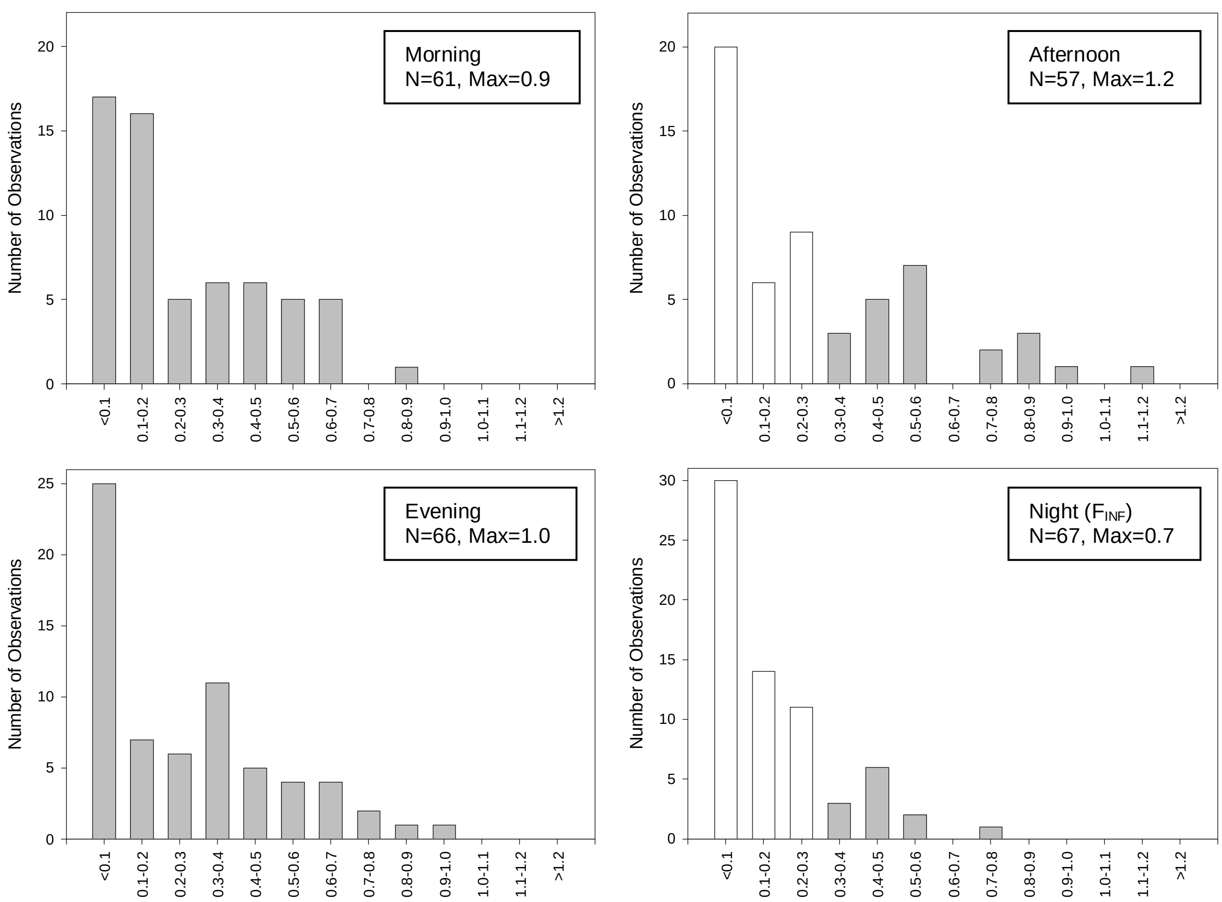
Table 40. Indoor-Outdoor NO_3^- Ratios By House and Time Period

House	Morning		Afternoon		Evening		Night	
	N	Mean (SD)	N	Mean (SD)	N	Mean (SD)	N	Mean (SD)
1	5	-0.2 (1.0)	3	0.4 (0.5)	3	-0.7 (1.0)	5	-1.5 (1.4)
2	8	0.1 (0.1)	6	0.1 (0.0)	8	-0.1 (0.5)	8	0.1 (0.1)
3	5	0.5 (0.2)	5	0.5 (0.5)	6	0.4 (0.3)	6	0.3 (0.3)
4	7	0.3 (0.2)	6	0.3 (0.1)	7	0.5 (0.1)	7	0.3 (0.1)
5	5	0.5 (0.1)	6	0.8 (0.3)	5	0.6 (0.3)	5	0.3 (0.2)
6	6	0.2 (0.1)	6	0.3 (0.1)	7	0.4 (0.1)	7	0.2 (0.1)
7	4	0.6 (0.3)	5	0.3 (0.2)	5	0.4 (0.1)	4	0.3 (0.1)
8	5	0.2 (0.2)	5	0.2 (0.1)	5	0.1 (0.1)	5	0.1 (0.1)
10	1	0.03 (--)	1	0.4 (--)	2	0.2 (0.1)	2	0.2 (0.0)
12	3	-0.1 (0.3)	1	0.1 (--)	5	-0.1 (0.2)	5	-0.04 (0.1)
14	4	0.3 (0.1)	4	0.3 (0.3)	4	0.3 (0.0)	4	0.3 (0.0)
15	6	-0.7 (0.6)	6	-0.04 (0.1)	7	0.03 (0.1)	6	-0.4 (0.9)
16	2	0.01 (0.0)	3	-0.1 (0.1)	2	0.04 (0.0)	3	-0.1 (0.2)
Overall	61	0.2 (0.5)	57	0.3 (0.3)	66	0.2 (0.4)	67	0.01 (0.6)

Note: "Morning" was defined as 6am-12pm; "afternoon" as 12-6pm; "evening" as 6pm-12am; and "night" as 12-6am. No data are available for Houses 9, 11, 13, 17.

During the afternoon, evening, and morning hours, indoor/outdoor mean ratios for each home were also low, with overall mean ratios equaling 0.2 (±0.5), 0.3 (±0.3) and 0.2 (±0.04), respectively (Table 40). While mean ratios for daytime periods were low, their distribution was more broadly distributed than that for nighttime periods, with a larger fraction of ratios having values higher than 0.1 (Figure 49). The observed variability in daytime indoor/outdoor ratios were not due to variability in particle generating activities, such as cooking and cleaning, as mean daytime indoor/outdoor ratios did not differ by whether cooking ($p=0.58$) or cleaning ($p=0.70$) occurred. Daytime mean ratios, however, did vary by home ventilation. Mean ratios were significantly higher when windows were opened ($p<0.0001$), with mean ratios of 0.35 (±0.24) when windows were opened as compared to 0.05 (±0.41) when windows were closed. Similarly, mean indoor/outdoor ratios were higher when heaters were off ($p<0.0001$). The mean ratio when heaters were off and on equaled 0.30 (±0.30) and –0.12 (±0.41), respectively. Since both open windows and no heater use are conditions consistent with better ventilation, results suggest that penetration of NO_3^- from outdoor to indoor environments is greatest when homes are well ventilated, although indoor/outdoor ratios were generally low even for well-ventilated homes. Low ratios may be attributed to the high reactivity of NO_3^-, which results in the loss of NO_3^- indoors.

Figure 49. Frequency Distributions of Indoor/Outdoor NO_3^- Ratios: By Time Period



"Morning" was defined as 6am-12pm; "afternoon" as 12-6pm; "evening" as 6pm-12am; and "night" as 12-6am.

A slope of 0.16 (±0.03) was found when all nighttime indoor were regressed on outdoor concentrations (Table 41), suggesting an average F_{INF} of 16%. This value is higher than the F_{INF} estimated using indoor/outdoor ratios, with the higher value possibly due to the fact that losses of NO_3^- indoors, which are reflected in the indoor/outdoor ratio, may be included in the intercept and not the slope of the regression line. When data were analyzed by home, the home-specific nighttime slopes varied in magnitude and strength (Table 41). Four homes had an insignificant slope, while three homes had significant slopes ranging between 0.08 and 0.44. This variation in home-specific slopes may be of little practical significance as indoor NO_3^- levels were extremely low in all homes (Figure 50). Slopes of nighttime indoor on outdoor levels, however, were higher for homes with the highest air exchange rates (0.27±0.05) as compared to other homes (0.08±0.03 and 0.07±0.03 for low and medium AER groups, respectively) (Table 42). Results suggest that the nighttime F_{INF} for NO_3^- will be greater than zero only when AERs are high.

Figure 50. Indoor vs. Outdoor NO_3^-: Night

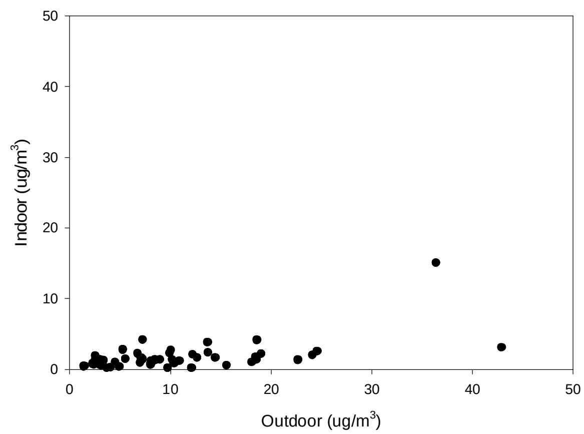
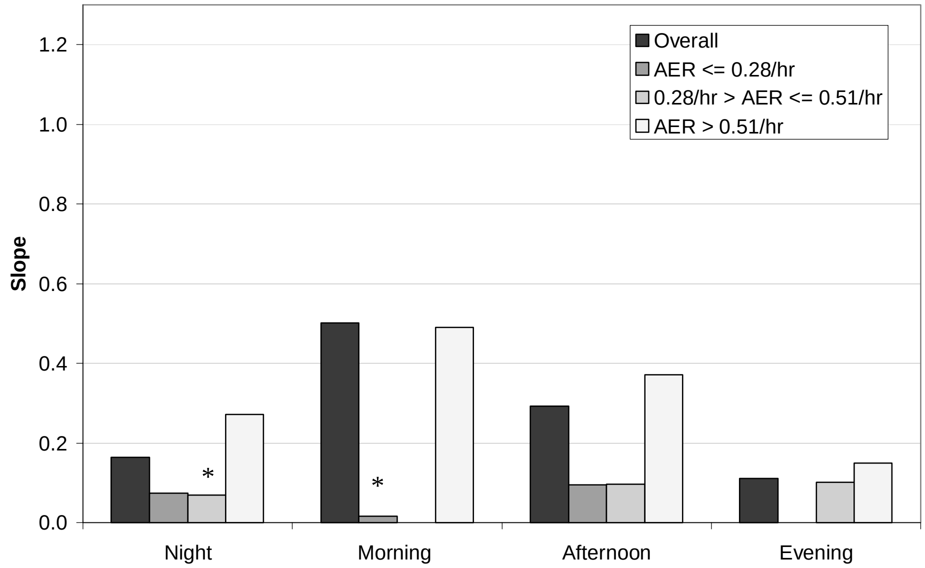


Table 41. Association between Indoor and Outdoor NO_3^-: 6-hr Nighttime Data

House	N	R^2	Slope (SE)	Intercept (SE)
2	8	**0.61**	**0.08** (0.03)	0.44 (0.42)
3	6	0.05	-0.14 (0.32)	2.36 (2.10)
4	6	0.31	0.04 (0.03)	**0.57** (0.15)
5	5	0.51	0.03 (0.02)	**1.14** (0.22)
7	4	**0.98**	**0.44** (0.05)	-1.42 (0.93)
8	5	0.21	0.05 (0.06)	0.82 (1.54)
15	6	**0.99**	**0.17** (0.01)	**-0.54** (0.04)
Full (simple)	40	**0.37**	**0.15** (0.03)	0.06 (0.46)
Full (mixed)	40	--	**0.16** (0.03)	0.03 (0.63)

Slopes, R^2 values and intercepts calculated by home using simple linear regression of indoor on outdoor concentrations. The "full model" values were calculated using mixed models of indoor on outdoor concentrations with home as a random subject. Nighttime defined as 12-6am. Values in bold indicate significance at p<=0.05.

Figure 51. Slopes of Indoor on Outdoor NO_3^-: By AER Category



Note that slopes, R^2 values and intercepts calculated for each home using simple linear regression of indoor on outdoor concentrations. The "full model (mixed)" slope and intercepts were calculated using mixed models of indoor on outdoor concentrations with home as a random subject. Nighttime defined as 12-6am. * Non-significant at 0.05 level.

For the 6-h daytime periods, the slopes of the indoor on outdoor regression line varied by period, as the slope was highest for the 6-h morning period, followed by that for the 6-h afternoon period, followed by that for the 6-h evening period, which was similar to the median home-specific slope for the nighttime period (Table 44, Figure 52). By home, slopes were generally insignificant and low (Table 44). Insignificant home-specific slopes are likely due to the generally low indoor NO_3^- concentrations and the relatively small sample size. As was the case for nighttime periods, variability in the home-specific slopes of indoor on outdoor concentrations can be attributed to differences in home ventilation, where again slopes were highest and significant when air exchange rates were highest (Figure 51). Similarly, indoor-outdoor daytime slopes were also significantly higher when windows were open and heaters were off (Table 45). Results provide further evidence that infiltration of NO_3^- will only occur when air exchange rates are greater than 0.5 exchanges/hr. Neither cooking nor cleaning, in contrast, significantly modified daytime slopes of indoor on outdoor NO_3^- concentrations (Table 45).

When the impact of activities and ventilation were examined using a multivariate model, results were consistent with other results. For example, open window use, but not cooking and cleaning status, was an important predictor of the association between indoor and outdoor NO_3^- concentrations (Table 43), with a higher slope when windows were opened. In addition, the indoor-outdoor slope was significantly lower in the evening as compared to morning and afternoon periods, suggesting that the effective penetration efficiency of NO_3^- is lower in the evening hours.

Table 42. Indoor vs. Outdoor Associations for NO_3^- by Air Exchange Rate and Period[1]

Period	Low AER			Medium AER			High AER		
	N	Slope (SE)	Intercept (SE)	N	Slope (SE)	Intercept (SE)	N	Slope (SE)	Intercept (SE)
Night	12	**0.08** (0.03)	0.29 (0.46)	6	0.07 (0.03)	0.35 (0.36)	22	**0.27** (0.05)	-0.36 (0.94)
Day[2]		0.12 (0.07)[3]	-0.67 (1.67)		0.11 (0.07)[3]	-0.36 (1.01)		**0.39** (0.03)[3]	-0.15 (0.53)
Morning	8	0.02 (0.03)	0.36 (0.88)	1	--	--	30	**0.49** (0.08)	-1.09 (2.25)
Afternoon	9	**0.10** (0.01)	-0.68 (0.29)	9	**0.10** (0.03)	0.13 (0.65)	20	**0.37** (0.06)	0.41 (0.89)
Evening	9	--[4]	--[4]	8	**0.10** (0.02)	-0.14 (0.37)	25	**0.15** (0.02)	**1.12** (0.34)

"Morning" was defined as 6am-12pm; "afternoon" as 12-6pm; "evening" as 6pm-12am; and "night" as 12-6am. [1]"Low AER" represents data for which AER≤ 0.28 hr^{-1}; "medium AER" for which 0.28<AER≤0.51 hr^{-1}; and "high AER" for which AERs> 0.51 hr^{-1}. Bold and grey values indicate significance at 0.05 and 0.10 level, respectively. [2]Regression model for all daytime data included AER as interaction term and main effect; regression model for separate 6-hr periods is stratified by AER. [3]Interaction term significant at 0.05 level. [4] The model did not converge.

Table 43. Impact of Period, Activities and Ventilation on Indoor-Outdoor NO_3^- Relationship: Results from Multivariate Mixed Model

Parameter	Intercept		Slope	
	Estimate (SE)	t-value	Estimate (SE)	t-value
Period				
Morning	-1.64 (0.59) [1]	-2.79	0.35 (0.04) [1]	10.03
Afternoon	-1.53 (0.64) [1]	-2.38	0.34 (0.03) [1]	10.89
Evening	0.29 (0.78) [1]	0.38	0.27 (0.04) [1]	6.41
Window Use				
Open	0.29 (0.78) [2]	2.64	0.27 (0.04) [3]	6.41
Closed	-0.56 (0.66) [2]	-0.84	0.13 (0.04) [3]	3.64
Cooking				
Yes	0.29 (0.78) [2]	2.64	0.27 (0.04) [4]	6.41
No	-0.89 (0.48) [2]	-1.84		
Cleaning				
Yes	0.29 (0.78) [2]	2.64	0.27 (0.04) [4]	6.41
No	-0.91 (0.43) [2]	-2.14		

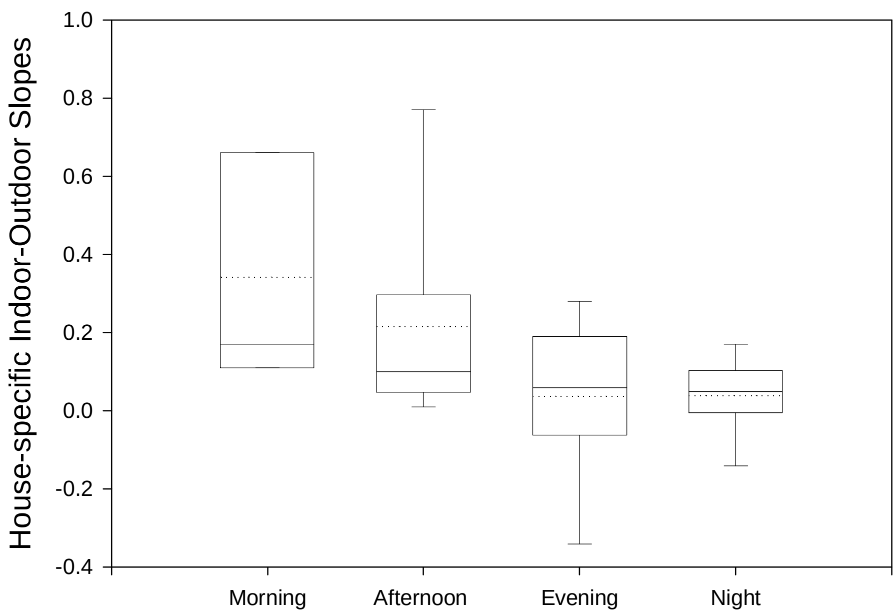
Outdoor BC concentrations corrected by a factor of 1.16 based on results from collocated instrument tests. Intercepts and slopes estimated using mixed model with cooking and cleaning as main effects and daytime period and open window status as both main effects and interaction terms. Only daytime data were included in analyses, as no activities were performed at night. [1]Evening intercept and slope values were significantly higher and lower, respectively, than morning and afternoon values. [2]Values did not differ significantly by open window, cooking or cleaning status. [3]Interaction term differed significantly by open window status (p<0.001). [4] Interaction terms for cooking and cleaning status were not included in the model.

Table 44. Associations between 6-Hr Daytime Indoor and Outdoor NO_3^-: By House

House	N	Morning			Afternoon			Evening		
		R^2	Slope	Intercept	R^2	Slope	Intercept	R^2	Slope	Intercept
2	6	0.33	0.11 (0.07)	0.36 (1.78)	**0.88**	**0.06** (0.01)	-0.12 (0.22)	0.23	0.06 (0.05)	0.08 (0.65)
3	5	0.63	0.66 (0.29)	-1.15 (2.62)	**0.93**	**0.77** (0.12)	-0.17 (0.25)	0.03	-0.34 (1.04)	1.62 (2.40)
4	6	0.25	0.11 (0.09)	0.85 (0.80)	0.41	0.14 (0.08)	0.55 (0.58)	0.56	0.28 (0.12)	0.73 (0.45)
8	4	0.82	0.66 (0.22)	-9.65 (6.06)	0.00	0.01 (0.27)	3.53 (6.43)	0.31	0.03 (0.04)	0.79 (0.69)
15	6	**0.70**	**0.17** (0.05)	**-0.63** (0.09)	**0.97**	**0.10** (0.01)	**-0.80** (0.07)	**0.96**	**0.16** (0.02)	**-0.73** (0.17)
Total	*	--	**0.50** (0.71)	-1.74 (1.85)	--	**0.29** (0.05)	-0.72 (1.17)	--	**0.11** (0.02)	0.69 (0.47)

"Morning" was defined as 6am-12pm; "afternoon" as 12-6pm; "evening" as 6pm-12am; and "night" as 12-6am. For comparison, results are reported only for homes for which regressions were run using 6-hr nighttime data. Mixed model results of indoor on outdoor concentrations with home as a random subject are presented for "all" data. Sample size is 39 for morning, 38 for afternoon, and 42 for evening.

Figure 52. House-specific indoor-outdoor slopes by time period for NO_3^-.



"Morning" was defined as 6am-12pm; "afternoon" as 12-6pm; "evening" as 6pm-12am; and "night" as 12-6am. Dotted line represents mean concentration, solid line median concentration

Table 45. Effect Modification of Daytime Indoor-Outdoor Association for NO_3^-

Activity/Ventilation	N[1]	Slope (SE)[1]	Intercept (SE)[1]
Cooking:			
Yes	168	**0.33** (0.04)	-0.74 (0.63)
No		**0.33** (0.04)	-1.16 (0.59)
Cleaning:			
Yes	168	**0.24** (0.06)	-0.23 (0.86)
No		**0.35** (0.03)	-1.11 (0.48)
Open Windows:			
Yes	168	**0.44** (0.03)[2]	-1.11 (0.47)
No		**0.14** (0.04)[2]	-0.47 (0.66)
Heater Use:			
Yes	168	**0.18** (0.08)[3]	-0.89 (1.22)
No		0.34 **(0.03)**[3]	-1.00 **(0.50)**

Note that slopes and intercepts were calculated using mixed models with the activity included as a main effect and interaction term and home included as a random variable. Activities were classified as"yes" if the activity was performed any time during the sampling period [1]Bold values indicate significance at the 0.05 level; grey values at 0.10 level. [2]Interaction terms or main effects significant at the 0.05 level. [3]Interaction term significant at 0.10 level.

4.1.3.8 Relationship between Indoor and Outdoor $PV_{0.02\text{-}0.1}$. The mean overall ratio of nighttime indoor to outdoor $PV_{0.02\text{-}0.1}$ concentrations equaled 0.7 ($\pm$0.2), suggesting a F_{INF} for $PV_{0.02\text{-}0.1}$ of 70% (Table 46). This value was extremely stable across homes, as the range in mean home-specific ratios ranged narrowly, with mean ratios for all homes between 0.5 and 0.9. Furthermore, over 90% of all ratios fell between 0.5 and 1.0 (Figure 53), providing further support for a night-time F_{INF} for $PV_{0.02\text{-}0.1}$ of approximately 70%.

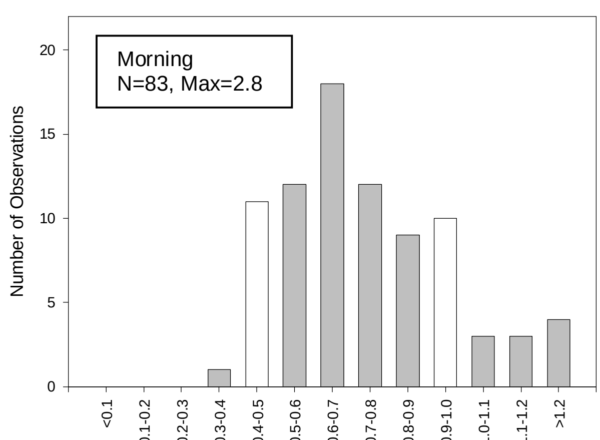
During the day, indoor/outdoor $PV_{0.02\text{-}0.1}$ ratios tended to be higher and more broadly distributed, especially in the afternoon and evening periods. Although the overall mean ratios were comparable, the home-specific mean ratios for the daytime periods tended to be higher (Table 46), with a greater fraction of individual ratios higher than 0.80 (Figure 53). During the afternoon and evening, ratios were even higher and ranged more broadly (Table 46, Figure 53), as reflected by the mean overall ratios and standard deviations which equaled 1.1 (±1.1) and 1.4 (±1.6), respectively. Higher ratios during the evening hours were likely due to cooking, as mean ratios in the evening were significantly higher when cooking occurred (mean=1.87) as compared to when it did not (mean=0.95) (p=0.01). Mean ratios, in contrast, did not differ significantly by cooking during the morning or afternoon periods.

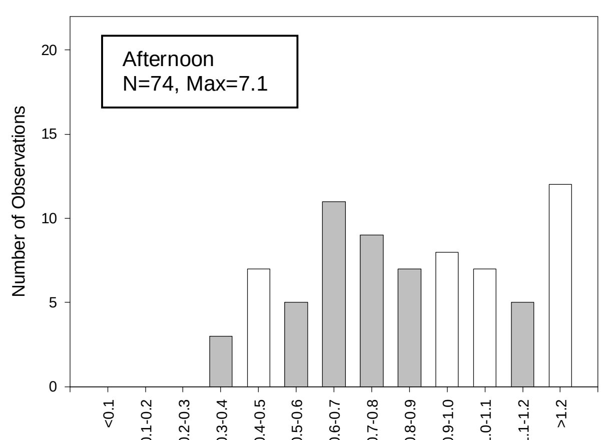
Table 46. Indoor-Outdoor Ratios by Time Period for $PV_{0.02-0.1}$

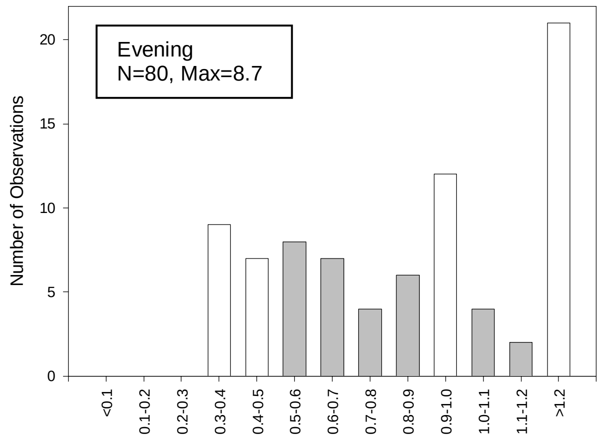
House	Morning		Afternoon		Evening		Night	
	N	Mean (SD)	N	Mean (SD)	N	Mean	N	Mean
1	6	1.1 (0.2)	7	0.9 (0.2)	7	1.4 (0.8)	7	0.9 (0.3)
2	7	0.8 (0.1)	6	0.5 (0.1)	7	0.5 (0.2)	7	0.7 (0.1)
3	7	1.0 (0.0)	7	1.2 (0.2)	7	1.1 (0.2)	7	0.8 (0.1)
4	7	0.8 (0.2)	6	0.8 (0.5)	7	0.9 (0.1)	7	0.7 (0.0)
5	7	0.8 (0.2)	6	1.0 (0.1)	7	4.6 (2.6)	7	0.8 (0.1)
7	6	0.6 (0.1)	6	0.7 (0.1)	6	0.6 (0.2)	6	0.7 (0.1)
8	5	0.6 (0.1)	3	0.9 (0.2)	5	1.0 (1.0)	4	0.6 (0.1)
10	5	0.7 (0.2)	4	2.2 (2.7)	4	1.5 (1.2)	3	0.8 (0.1)
12	4	0.5 (0.1)	2	0.7 (0.1)	2	0.6 (0.0)	3	0.5 (0.2)
13	7	0.7 (0.1)	6	1.0 (0.5)	6	1.3 (1.1)	6	0.6 (0.0)
14	4	0.7 (0.1)	5	2.8 (2.9)	4	2.5 (2.4)	4	0.7 (0.0)
15	6	0.5 (0.1)	5	0.5 (0.1)	6	0.9 (0.6)	5	0.5 (0.1)
16	6	0.6 (0.1)	6	0.8 (0.2)	7	0.6 (0.2)	7	0.7 (0.1)
17	6	1.1 (0.9)	5	1.5 (0.9)	5	1.5 (2.0)	4	0.6 (0.1)
Overall	83	0.8 (0.3)	74	1.1 (1.1)	80	1.4 (1.6)	77	0.7 (0.2)

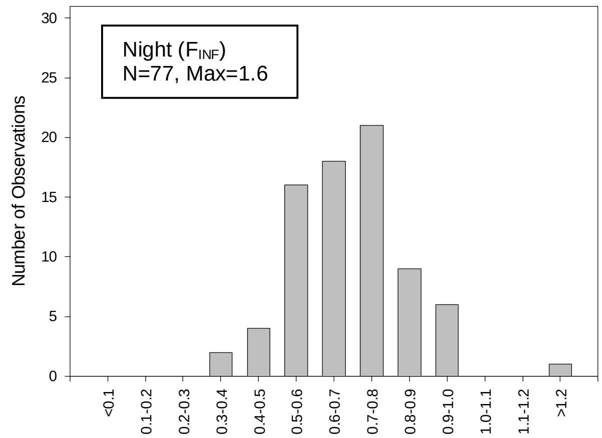
"Morning" was defined as 6am-12pm; "afternoon" as 12-6pm; "evening" as 6pm-12am; and "night" as 12-6am. No data available for Houses 6, 9, 11.

Figure 53. Frequency Distributions of Indoor/Outdoor $PV_{0.02-0.1}$ Ratios: by Time Period









"Morning" was defined as 6am-12pm; "afternoon" as 12-6pm; "evening" as 6pm-12am; and "night" as 12-6am.

A slope of 0.51 (±0.11) was found when nighttime indoor were regressed on outdoor $PV_{0.02-0.1}$ concentrations for all homes, suggesting an average F_{INF} of approximately 50%. This value is lower than the F_{INF} estimated using indoor/outdoor ratios, with the lower slope from the regression line possibly due to the contribution of the intercept to indoor $PV_{0.02-0.1}$ concentrations. When data were analyzed by home, the home-specific nighttime slopes varied widely in magnitude, with significant slopes ranging between 0.33 and 1.23. This variation in home-specific slopes may be due to variations in the range in outdoor $PV_{0.02-0.1}$ concentrations and in the mean outdoor $PV_{0.02-0.1}$ levels, where for many homes outdoor $PV_{0.02-0.1}$ levels were relatively low and narrowly distributed (Figure 54).

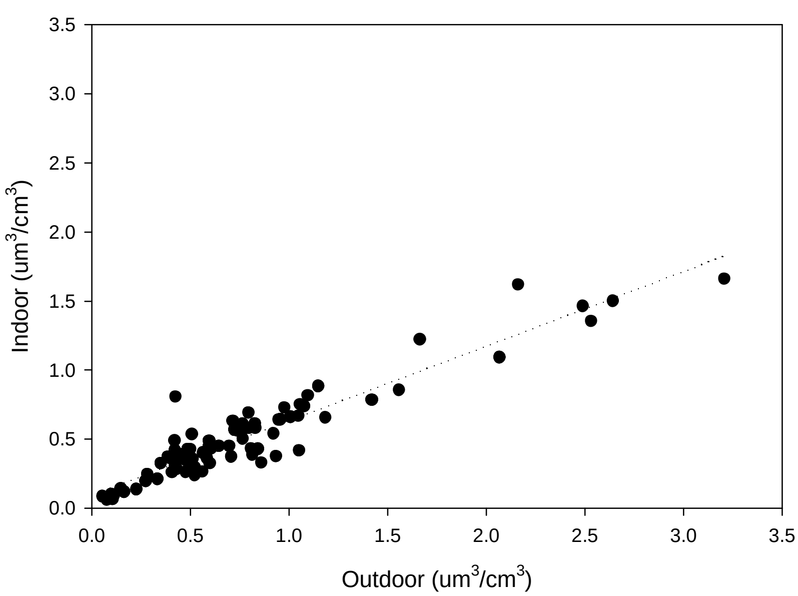
Daytime slopes for $PV_{0.02-0.1}$ varied by period, with overall slopes highest in the afternoon (0.88±0.12), followed by the morning (0.60±0.06), and were statistically insignificant in the evening. The distributions of home-specific slopes in afternoon and evening were skewed to the right, with one to two of the homes having slopes greater than one (Table 45). Distributions of the home-specific slopes for all periods were otherwise narrowly distributed (Figure 55). Median home-specific slopes were comparable across all periods (Figure 55). In general, home-specific slopes for the afternoon and evening periods were statistically insignificant, with only three and two of the eight homes having significant slopes, respectively. In contrast, five of the eight homes had significant slopes in the morning. The right skewed distributions for the afternoon and evening may reflect indoor source contributions of $PV_{0.02-0.1}$, for example cooking, which occurred infrequently but most often during late afternoon and evening hours.

Table 47. Association between Indoor and Outdoor $PV_{0.02\text{-}0.1}$: 6-hr Nighttime Data

House	N	R^2	Slope (SE)	Intercept (SE)
2	7	**0.84**	**0.54** (0.11)	0.07 (0.07)
3	7	**0.97**	**1.23** (0.10)	**-0.12** (0.03)
4	6	**0.87**	**0.85** (0.16)	-0.07 (0.10)
5	7	**0.84**	**0.67** (0.13)	0.07 (0.09)
7	6	0.56	0.40 (0.18)	0.23 (0.17)
8	4	**0.98**	**0.33** (0.04)	**0.12** (0.02)
13	6	**0.97**	**0.49** (0.04)	0.14 (0.10)
15	5	0.52	0.19 (0.11)	0.17 (0.07)
16	6	**0.65**	**0.36** (0.13)	0.34 (0.13)
Full (simple)	54	**0.93**	**0.52** (0.02)	0.11 (0.02)
Full (mixed)	54	--	**0.51** (0.02)	0.11 (0.03)

Slopes, R^2 values and intercepts calculated for each home using simple linear regression of indoor on outdoor concentrations. The "full model (mixed)" slope and intercepts were calculated using mixed models of indoor on outdoor concentrations with home as a random subject. Nighttime defined as 12-6am.

Figure 54. Indoor vs. Outdoor $PV_{0.02\text{-}0.1}$: 6-hr Nighttime Data



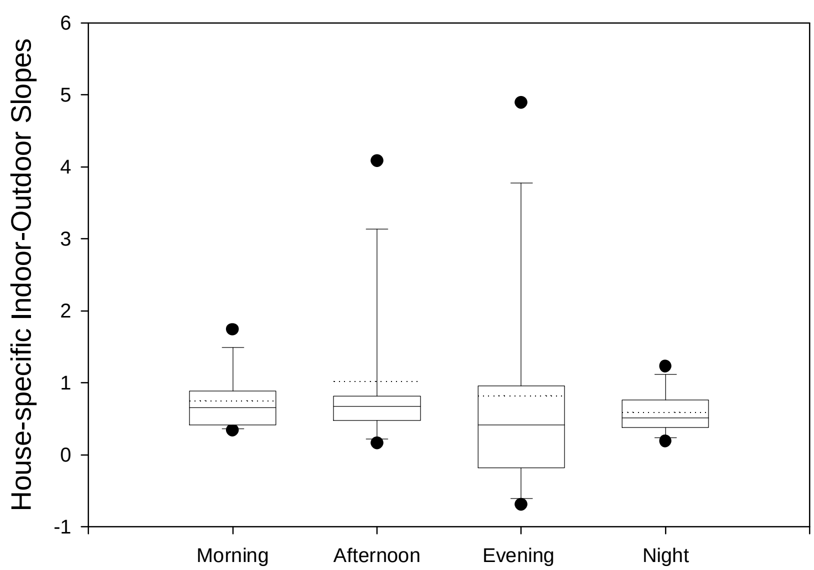
Nightime defined as 12-6am. Dotted line represents regression line.

Table 48. Indoor on Outdoor $PV_{0.02-0.1}$ Associations for Daytime Periods: By House

House	N	Morning			Afternoon			Evening		
		R^2	Slope (SE)	Intercept (SE)	R^2	Slope (SE)	Intercept (SE)	R^2	Slope (SE)	Intercept (SE)
2	6	**0.87**	**0.85** (0.16)	-0.04 (0.10)	0.58	0.72 (0.31)	-0.16 (0.21)	0.35	0.31 (0.21)	0.13 (0.14)
3	6	**0.99**	**0.91** (0.04)	0.02 (0.02)	0.37	0.68 (0.44)	0.18 (0.16)	0.57	0.74 (0.33)	0.12 (0.13)
4	6	0.01	0.42 (1.92)	0.28 (1.51)	**0.75**	**4.08** (1.19)	-3.74 (1.40)	**0.97**	**1.17** (0.10)	-0.17 (0.07)
5	6	**0.71**	**0.87** (0.28)	-0.07 (0.27)	**0.75**	**0.92** (0.27)	0.16 (0.38)	0.01	-0.69 (3.88)	3.46 (3.08)
7	4	0.63	1.74 (0.94)	-1.25 (1.09)	0.73	0.67 (0.28)	0.05 (0.31)	0.46	-0.41 (0.31)	0.98 (0.30)
13	6	**0.76**	**0.46** (0.13)	0.18 (0.13)	0.44	0.37 (0.21)	0.43 (0.22)	0.01	0.04 (0.18)	**1.09** (0.22)
15	5	**0.87**	**0.42** (0.09)	0.03 (0.04)	0.44	0.16 (0.10)	0.11 (0.05)	0.57	4.89 (2.45)	-2.75 (1.74)
16	6	0.63	0.34 (0.13)	0.27 (0.15)	**0.83**	**0.59** (0.13)	0.12 (0.12)	**0.87**	**0.53** (0.10)	0.04 (0.10)
Overall	*	--	**0.60** (0.06)	0.06 (0.05)	**--**	**0.88** (0.12)	-0.04 (0.11)	**--**	0.41 (0.39)	0.61 (0.45)

"Morning" was defined as 6am-12pm; "afternoon" as 12-6pm; "evening" as 6pm-12am; and "night" as 12-6am. For comparison, results are reported only for homes for which regressions were run using 6-hr nighttime data. Mixed model results of indoor on outdoor concentrations with home as a random subject are presented for "all" data.

Figure 55. House-Specific Indoor-Outdoor Slopes for $PV_{0.02-0.1}$: By Time Period



"Morning" was defined as 6am-12pm; "afternoon" as 12-6pm; "evening" as 6pm-12am; and "night" as 12-6am. Dotted line represents mean concentration, solid line median concentration.

During the night, air exchange rates did not modify the indoor-outdoor slopes, as the slopes were comparable across air exchange rate categories (Table 49). Similar statistically non-significant results were found during the day, although slopes were higher for the high air exchange rate group as compared to the low air exchange rate group. By specific daytime period, slopes of indoor on outdoor $PV_{0.02\text{-}0.1}$ concentrations for the evening and especially afternoon periods varied with air exchange rates (Figure 56, Table 49). When air exchange rates were greater than 0.51 exchanges/hour in the afternoon, for example, the slope equaled 1.25 (±0.20) as compared to a slope of approximately 0.50 when air exchange rates were lower than 0.51 exchanges/hour. Although statistically non-significant, the indoor-outdoor slopes in the evening showed similar trends across air exchange rate groups, with slopes of approximately 0.70 and 0.35 for air exchange rates above and below 0.51 exchanges/hour, respectively. These results suggest that the indoor-outdoor slope of ultra-fine particles can increase with air exchange rate, but that this effect is not consistent across 6-h periods and may be dependent on the ultra-fine particle generating activities that occur within homes.

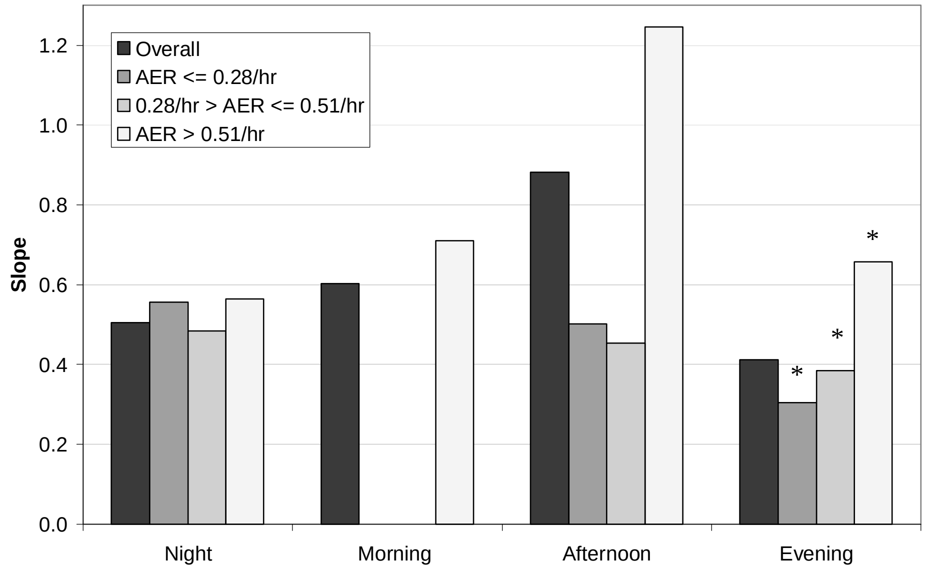
Consistent with these findings, open window and heater use did not modify significantly the slope of indoor on outdoor $PV_{0.02\text{-}0.1}$ concentrations (Table 50), although the indoor-outdoor slope was higher when windows were opened as compared to closed (p=0.13). Cooking was also a weak modifier of the association between indoor and outdoor $PV_{0.02\text{-}0.1}$, with the indoor-outdoor slopes for "cooking" and "non-cooking" periods differing significantly at the 0.10 level (Table 50). Cleaning, on the other hand, had no effect on the indoor-outdoor slopes for $PV_{0.02\text{-}0.1}$. The physical meaning of the observed effect of cooking is not clear, since cooking is not likely to affect directly the ability of particles to infiltrate indoors. As was the case with BC, it is possible that the influence of cooking on the indoor-outdoor association for $PV_{0.02\text{-}0.1}$ is indirect, possibly through increased use of open windows during cooking.

Table 49. Association between Indoor on Outdoor $PV_{0.02\text{-}0.1}$: By AER and Period

Period	Low AER			Medium AER			High AER		
	N	Slope (SE)	Intercept (SE)	N	Slope (SE)	Intercept (SE)	N	Slope (SE)	Intercept (SE)
Night	17	**0.56** (0.04)	0.07 (0.06)	12	**0.48** (0.03)	0.10 (0.05)	25	**0.56** (0.06)	0.10 (0.04)
Day		0.50 (0.30)	0.05 (0.25)		**0.49** (0.23)	0.24 (0.20)		**0.78** (0.19)	0.27 (0.16)
Morning	10	--[2]	--[2]	12	--[2]	--[2]	33	**0.71** (0.08)	0.04 (0.07)
Afternoon	11	**0.50** (0.05)	0.03 (0.07)	13	**0.45** (0.14)	0.24 (0.14)	24	**1.25** (0.20)	-0.23 (0.20)
Evening	8	0.30 (0.61)	0.21 (0.43)	16	0.39 (0.22)	0.37 (0.22)	32	0.66 (0.87)	0.59 (0.82)

"Morning" was defined as 6am-12pm; "afternoon" as 12-6pm; "evening" as 6pm-12am; and "night" as 12-6am. [1]"Low AER" represents data for which AER≤ 0.28 hr^{-1}; "medium AER" for which 0.28<AER≤0.51 hr^{-1}; and "high AER" for which AERs> 0.51 hr^{-1}. Bold indicates significance at 0.05 level; grey significance at 0.10 level. Results for all daytime data were determined using mixed models (N=187) that included AER as an interaction term and main effect. Results reported for specific daytime periods were calculated using mixed models stratified by AER. [2]The model did not converge.

Figure 56. Association between Indoor on Outdoor $PV_{0.02\text{-}0.1}$: By AER and Period



"Morning" was defined as 6am-12pm; "afternoon" as 12-6pm; "evening" as 6pm-12am; and "night" as 12-6am. * Non-significant at 0.05 level.

Table 50. Effect Modification of Daytime Indoor-Outdoor Association[1] for $PV_{0.02\text{-}0.1}$

Activity/Ventilation	N[1]	Slope (SE)[1]	Intercept (SE)[1]
Cooking:			
Yes	207	**0.78** (0.18)[2]	0.24 (0.16)
No		**0.28** (0.20)[2]	0.40 (0.17)
Cleaning:			
Yes	207	**0.55** (0.27)	0.32 (0.22)
No		**0.55** (0.16)	0.29 (0.14)
Open Windows:			
Yes	207	**0.78** (0.20)	0.18 (0.16)
No		**0.35** (0.19)	0.40 (0.18)
Heater Use:			
Yes	207	**0.55** (0.36)	0.15 (0.27)
No		**0.53** (0.15)	0.35 (0.13)

Note that slopes and intercepts were calculated using mixed models with the activity included as a main effect and interaction term and home included as a random variable. Activities were classified as"yes" if the activity was performed any time during the sampling period. Bold values indicate significance at the 0.05 level; grey values at 0.10 level. [2]Interaction term significant at the 0.10 level.

Table 51. Estimates of P and k for $PV_{0.02-0.1}$ using Mass Balance Model[a]

Particulate Measure	Mixed Model			P (SE)	k (hr^{-1}) (SE)
	N[b]	Intercept	Slope		
$PV_{0.02-0.1}$:	54	**1.31** (0.11)	**0.10** (0.04)	**0.77** (0.07)	**0.07** (0.03)
0.02-0.03 um	61	**1.76** (0.19)	**0.14** (0.06)	**0.57** (0.06)	**0.08** (0.04)
0.03-0.04 um	61	**1.53** (0.13)	**0.11** (0.04)	**0.65** (0.06)	**0.07** (0.03)
0.04-0.06 um	61	**1.39** (0.09)	**0.09** (0.03)	**0.72** (0.05)	**0.07** (0.03)
0.06-0.08 um	61	**1.29** (0.08)	**0.08** (0.03)	**0.77** (0.05)	**0.06** (0.03)
0.08-0.1 um	61	**1.21** (0.09)	**0.09** (0.03)	**0.83** (0.06)	**0.07** (0.03)

Note: Estimates of P and k determined using a regression equation based on the mass balance model and 6-hr nighttime data to correspond to non-source periods. [a] Bold values indicate significance at 0.05 level of intercept and/or slope from mixed model; red values indicate significance at 0.10 level. [b] Note that the N between the aggregated size bins and the individual size bins differ because aggregated size bins were run to match nighttime regression analyses and includes data only for homes with $\geq$4 data points.

Penetration efficiencies for nighttime $PV_{0.02-0.1}$ estimated using the mass balance model (0.77±0.07) were significant and were comparable and somewhat higher than estimated nighttime F_{INF} values obtained using indoor/outdoor ratios (0.70±0.20) and the indoor-outdoor slope (0.51±0.11), respectively (Table 51). Estimates of P for ultra-fine particles were found to increase as particle size intervals increased from 0.02 to 0.1 um, with a value of 0.57 (±0.06) for particles between 0.02 and 0.03 um and a value of 0.83 (±0.06) for particles between 0.08 and 0.1 um. These estimates suggest that between approximately 60 and 80% of the ultra-fine particles penetrate from outdoor to indoor environments. Estimated decay rates for nighttime $PV_{0.02-0.1}$ were statistically significant and relatively low, with a value for k equaling 0.07 (±0.03). Unlike P, values for k were stable across the size interval.

4.1.3.9 Relationship between Indoor and Outdoor $PV_{0.1-0.5}$. During the night, the overall mean indoor/outdoor ratio for $PV_{0.1-0.5}$ equaled 0.7 (±0.2), suggesting an F_{INF} of 70%. This value was relatively stable across homes, with eleven of the fourteen homes with valid data had mean ratios between 0.6 and 0.8 (Table 52). Furthermore, approximately 85% of all ratios fell between 0.5 and 0.9 (Figure 57), providing further evidence that 70% is a stable estimate of night-time F_{INF} for $PV_{0.1-0.5}$. In the morning, the distribution of indoor/outdoor $PV_{0.1-0.5}$ ratios mirrored that during the night, as shown by their similar means and standard deviations. Afternoon and particularly evening ratios, in contrast, were distributed more broadly (Table 52), with larger standard deviations and a greater fraction of ratios greater than one (Figure 57). The broader and higher ratio distributions for the afternoon and evening periods were not related to particle generating activities, such as cooking (p=0.51) or cleaning (p=0.72).

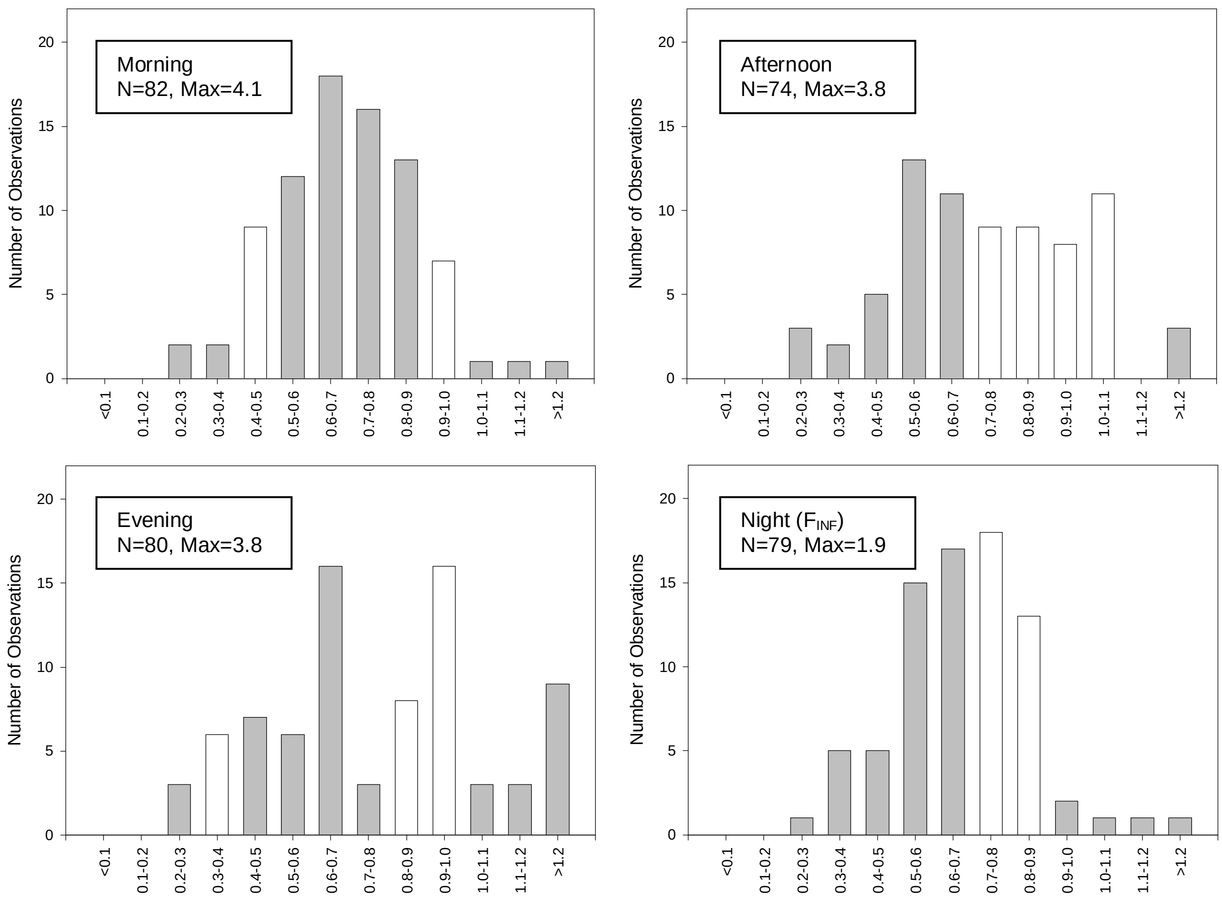
A slope of 0.53 (±0.02) was found when nighttime indoor were regressed on outdoor $PV_{0.1-0.5}$ concentrations for all homes, suggesting an average F_{INF} of approximately 50%. As was the case for $PV_{0.02-0.1}$, this value is lower than the F_{INF} estimated using indoor/outdoor ratios, with the lower slope from the regression line possibly due to the fact that the contribution of $PV_{0.1-0.5}$ from indoor sources is reflected in the intercept of the regression line and not in its slope, whereas the indoor $PV_{0.1-0.5}$ source contribution is reflected in the ratio itself. When data were analyzed by home, the home-specific nighttime slopes were all significant but varied in magnitude, with slopes ranging between 0.27 and 0.86. The highest home-specific slope was found for House 3, which also had the highest nighttime air exchange rate (Table 25). Despite this, the overall association between nighttime indoor and outdoor $PV_{0.1-0.5}$ did not vary with air exchange rates, as the slopes were comparable for the high, medium, and low air exchange rate groups (Table 54). Variation in home-specific slopes may instead be due to variations in the range in outdoor $PV_{0.1-0.5}$ concentrations and in the mean outdoor $PV_{0.1-0.5}$ levels, since the overall association between indoor and outdoor $PV_{0.1-0.5}$ levels was extremely strong across homes, with a crude R^2 value of 0.93 (Figure 58).

Table 52. Indoor-Outdoor Ratios by Time Period for $PV_{0.1-0.5}$***

House	Morning		Afternoon		Evening		Night	
	N	Mean (SD)	N	Mean (SD)	N	Mean (SD)	N	Mean (SD)
1	6	0.9 (0.1)	7	1.0 (0.1)	7	0.9 (0.1)	7	0.7 (0.1)
2	7	0.6 (0.1)	6	0.6 (0.1)	7	0.5 (0.2)	7	0.6 (0.1)
3	7	0.9 (0.0)	7	1.0 (0.0)	7	0.9 (0.1)	7	0.8 (0.1)
4	7	0.7 (0.1)	6	0.9 (0.4)	7	0.9 (0.0)	7	0.8 (0.1)
5	7	0.8 (0.1)	6	1.0 (0.1)	7	1.8 (1.0)	6	0.8 (0.1)
7	6	0.7 (0.1)	6	0.7 (0.1)	6	0.6 (0.2)	6	0.7 (0.1)
8	5	0.5 (0.1)	3	0.5 (0.0)	5	0.6 (0.1)	5	0.6 (0.0)
10	5	0.6 (0.2)	4	0.5 (0.1)	4	0.8 (0.3)	5	0.8 (0.2)
12	4	0.5 (0.2)	2	0.5 (0.0)	2	0.6 (0.1)	2	0.3 (0.0)
13	7	0.8 (0.1)	6	0.7 (0.1)	6	1.1 (1.2)	6	0.6 (0.1)
14	4	0.7 (0.1)	5	1.4 (1.4)	4	1.2 (0.9)	4	0.7 (0.0)
15	5	0.5 (0.1)	5	0.4 (0.2)	6	0.4 (0.3)	6	0.4 (0.1)
16	6	0.6 (0.3)	6	0.7 (0.2)	7	0.7 (0.3)	7	0.8 (0.5)
17	6	1.2 (1.4)	5	0.9 (0.2)	5	1.0 (0.9)	4	0.5 (0.2)
Overall	82	0.7 (0.4)	74	0.8 (0.5)	80	0.9 (0.6)	79	0.7 (0.2)

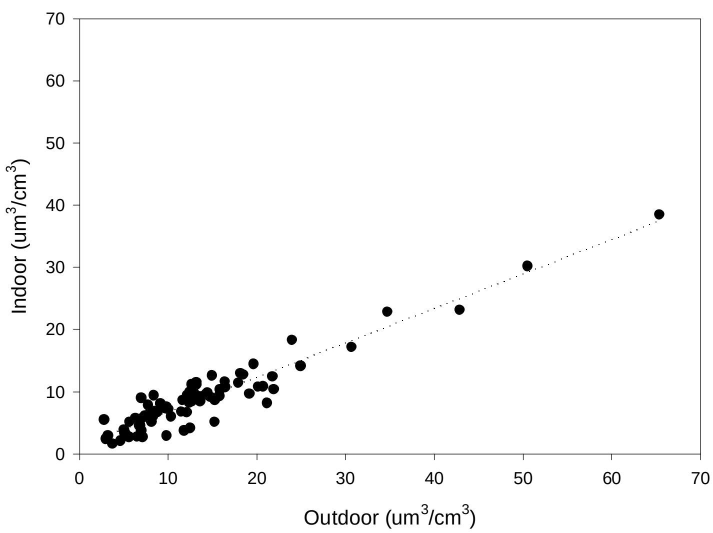
"Morning" was defined as 6am-12pm; "afternoon" as 12-6pm; "evening" as 6pm-12am; and "night" as 12-6am. No data available for Houses 6, 9, 11.

Figure 57. Distribution of I/O Ratios for $PV_{0.1\text{-}0.5}$



"Morning" was defined as 6am-12pm; "afternoon" as 12-6pm; "evening" as 6pm-12am; and "night" as 12-6am.

Figure 58. Indoor vs. Outdoor $PV_{0.1\text{-}0.5}$: 6-hr Nighttime Values



Nightime defined as 12-6am. Dotted line represents regression line.

Table 53. Indoor on Outdoor Associations for $PV_{0.1-0.5}$: 6-hr Nighttime

House	N	R^2	Slope (SE)	Intercept (SE)
2	7	**0.93**	**0.52** (0.06)	1.57 (1.10)
3	7	**0.94**	**0.86** (0.09)	-0.22 (0.86)
4	6	**0.87**	**0.68** (0.13)	1.16 (1.50)
5	6	**0.93**	**0.69** (0.10)	0.48 (1.00)
7	6	**0.95**	**0.47** (0.05)	**3.64** (1.11)
8	5	**0.84**	**0.57** (0.14)	0.29 (1.91)
10	5	**0.82**	**0.59** (0.16)	1.43 (1.55)
13	6	**0.99**	**0.56** (0.03)	1.86 (1.12)
15	6	**0.82**	**0.27** (0.06)	0.87 (0.55)
16	6	**0.70**	**0.30** (0.10)	**4.20** (1.51)
Full (simple)	60	**0.93**	**0.55** (0.02)	**1.43** (0.36)
Full (mixed)	60	--	**0.53** (0.02)	**1.76** (0.49)

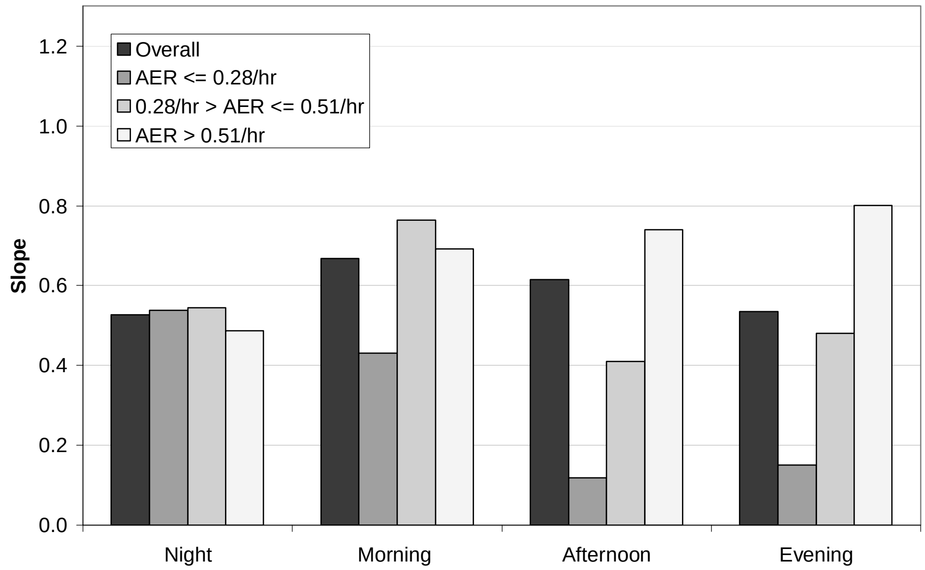
Slopes, R^2 values and intercepts calculated for each home using simple linear regression of indoor on outdoor concentrations. The "full model (mixed)" slope and intercepts were calculated using mixed models of indoor on outdoor concentrations with home as a random subject. Nighttime defined as 12-6am. Values in bold indicate significance at p<=0.05.

Table 54. Association between Indoor and Outdoor $PV_{0.1-0.5}$: By Air Exchange Rate

Period	Low AER			Medium AER			High AER		
	N	Slope (SE)	Intercept (SE)	N	Slope (SE)	Intercept (SE)	N	Slope (SE)	Intercept (SE)
Night	22	**0.54** (0.02)	1.03 (0.77)	13	**0.54** (0.04)	1.61 (0.71)	25	**0.49** (0.03)	**3.16** (0.57)
Day		**0.44** (0.14)	0.87 (1.91)		**0.52** (0.10)	1.86 (1.59)		**0.68** (0.06)	1.84 (1.07)
Morning	14	**0.43** (0.03)	0.39 (0.27)	12	**0.76** (0.07)	-0.80 (1.33)	33	**0.69** (0.05)	0.34 (1.04)
Afternoon	12	**0.12** (0.04)	**6.40** (1.63)	13	**0.41** (0.08)	3.00 (1.57)	27	**0.74** (0.06)	1.18 (1.34)
Evening	8	0.15 (0.18)	5.03 (2.99)	19	0.48 (0.29)	3.03 (3.87)	33	**0.80** (0.29)	1.44 (4.31)

"Morning" was defined as 6am-12pm; "afternoon" as 12-6pm; "evening" as 6pm-12am; and "night" as 12-6am. "Low AER" represents data for which AER≤ 0.28 hr^{-1}; "medium AER" for which 0.28<AER≤0.51 hr^{-1}; and "high AER" for which AERs> 0.51 hr^{-1}. Bold indicates significance at 0.05 level; grey significance at 0.10 level. Results for all daytime data were determined using mixed models (N=186) that included AER as an interaction term and main effect. Results reported for specific daytime periods were calculated using mixed models stratified by AER.

Figure 59. Association between Indoor on Outdoor $PV_{0.1\text{-}0.5}$: By AER and Period



"Morning" was defined as 6am-12pm; "afternoon" as 12-6pm; "evening" as 6pm-12am; and "night" as 12-6am. "Low AER" represents data for which AER≤ 0.28 hr^{-1}; "medium AER" for which 0.28<AER≤0.51 hr^{-1}; and "high AER" for which AERs> 0.51 hr^{-1}. Slopes calculated using mixed model of indoor on outdoor concentrations with air exchange rates as both a main effect and interaction term. * Non-significant at 0.05 level.

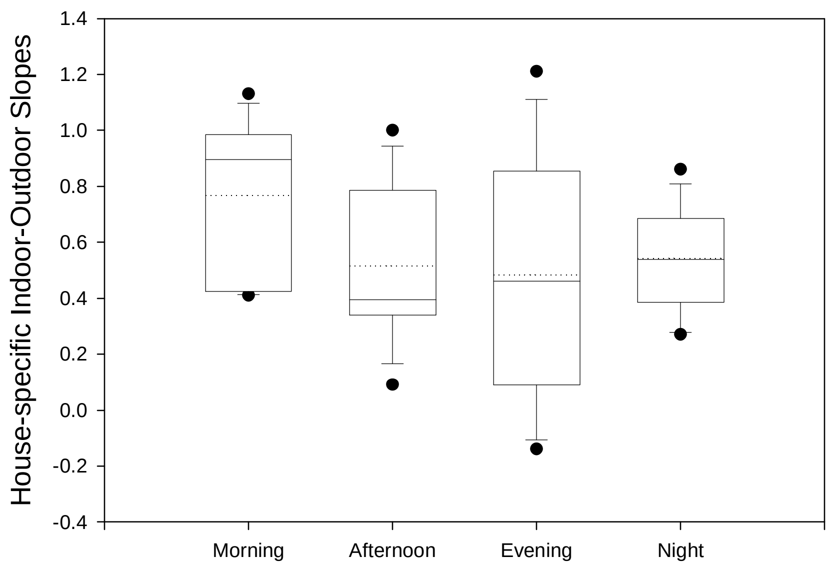
Table 55. Indoor on Outdoor $PV_{0.1\text{-}0.5}$ Associations for Daytime Periods: By House

House	N	Morning			Afternoon			Evening		
		R^2	Slope (SE)	Intercept (SE)	R^2	Slope (SE)	Intercept (SE)	R^2	Slope (SE)	Intercept (SE)
2	6	**0.72**	**0.43** (0.14)	3.59 (2.78)	**0.77**	**0.34** (0.09)	3.62 (1.66)	0.41	0.21 (0.13)	4.56 (2.05)
3	6	**0.99**	**0.95** (0.05)	-0.30 (0.57)	**1.00**	**1.00** (0.03)	0.18 (0.30)	**0.93**	**0.83** (0.12)	1.03 (1.04)
4	6	**0.68**	**1.13** (0.39)	-6.20 (5.41)	0.05	0.34 (0.73)	6.94 (10.61)	**0.99**	**0.88** (0.04)	0.39 (0.41)
5	6	**0.93**	**0.95** (0.13)	-2.24 (1.60)	**0.98**	**0.81** (0.06)	2.64 (1.19)	0.55	1.21 (0.54)	1.53 (5.87)
7	4	**1.00**	**1.02** (0.01)	**-10.45** (0.49)	**0.91**	**0.76** (0.16)	-1.88 (5.83)	0.86	0.31 (0.09)	5.79 (1.92)
13	6	**0.94**	**0.84** (0.11)	-1.87 (2.21)	**0.75**	**0.45** (0.13)	3.65 (2.06)	0.00	-0.03 (0.86)	15.11 (14.14)
15	4	**0.99**	**0.42** (0.03)	0.34 (0.14)	0.24	0.09 (0.11)	1.06 (0.49)	0.06	-0.14 (0.39)	6.26 (4.74)
16	6	**0.82**	**0.41** (0.10)	1.64 (1.46)	**0.66**	**0.34** (0.12)	3.14 (1.56)	0.64	0.61 (0.23)	0.64 (3.40)
Overall	*	**--**	**0.67** (0.04)	0.06 (0.17)	**--**	**0.62** (0.05)	1.08 (1.25)	--	0.53 (0.18)	3.42 (2.77)

"Morning" was defined as 6am-12pm; "afternoon" as 12-6pm; "evening" as 6pm-12am; and "night" as 12-6am. For comparison, results are reported only for homes for which regressions were run using 6-hr nighttime data. Mixed model results of indoor on outdoor concentrations with home as a random subject are presented for "all" data.

Overall indoor-outdoor $PV_{0.1-0.5}$ slopes for the morning and afternoon periods were slightly higher than that found using nighttime data, while the overall slope for the evening was insignificant (Table 55). Variation in home-specific slopes was greater for all daytime periods as compared to night. In addition, the number of homes having significant daytime slopes decreased as the day progressed, possibly due to the greater frequency of particle-generating activities during these times. In the morning, for example, all home-specific slopes were significant, with values ranging between 0.41 (±0.10) and 1.13 (±0.39). In the afternoon, six of the eight homes had significant slopes, ranging between 0.34 (±0.12) and 1.00 (±0.03). In the evening, only two of the eight homes had significant slopes, with slopes of 0.83 (±0.12) and 0.88 (±0.04), respectively. Of the homes, House 3 had significant and relatively high indoor-outdoor slopes during each daytime period, with values of 0.95 (±0.05), 1.00 (±0.03), and 0.83 (±0.12) for the morning, afternoon, and evening periods, respectively. It is possible that the consistently high daytime slopes for House 3 may be related to the fact that this home was extremely well ventilated during the day (as it was at night), as evidenced by its daytime air exchange rates (Table 26).

Figure 60. House-specific Indoor-Outdoor Slopes by Time Period for $PV_{0.1-0.5}$



"Morning" defined as 6am-12pm; "afternoon" as 12-6pm; "evening" as 6pm-12am; and "night" as 12-6am. Slopes calculated using linear regression models of indoor on outdoor levels by home.

In general, however, variation in home-specific indoor-outdoor slopes for $PV_{0.1-0.5}$ could not be attributed to variations in air exchange rates. During the day, indoor-outdoor slopes did increase with air exchange rate category; however, this increase was not statistically significant (Table 54). Consistent with these findings, open window and heater use did not significantly modify indoor-outdoor $PV_{0.1-0.5}$ slopes; however, slopes were higher when windows were open and heaters were off, both of which are conditions consistent with increased ventilation (Table 53). Indoor-outdoor slopes for $PV_{0.1-0.5}$ increased with cooking, but not cleaning, with slopes higher when cooking occurred within the home. As was the case with BC and ultrafine particles, it is possible that the influence of cooking on the indoor-outdoor association for $PV_{0.1\text{-}0.5}$ is indirect, possibly through increased use of open windows during cooking.

Penetration efficiencies for nighttime $PV_{0.1\text{-}0.5}$ estimated using the mass balance model (0.68±0.08) were significant and were comparable to estimated nighttime F_{INF} values obtained using indoor/outdoor ratios (0.70±0.20) and were higher than nighttime F_{INF} values estimated using the indoor-outdoor slope (0.53±0.02), respectively (Table 57). Estimates of ***P*** for this fine particle size range decreased with particle size, with ***P*** equaling 0.85 (±0.07) for particles between 0.1-0.2 um and 0.66 (±0.08) for particles between 0.4 and 0.5 um. These estimates suggest that between 70 and 85% of the fine particles penetrate from outdoor to indoor environments. Estimated decay rates for nighttime $PV_{0.1\text{-}0.5}$ were statistically insignificant and low, with a value for ***k*** equaling 0.02 (±0.04). Unlike ***P***, values for ***k*** showed no discernable trend across the size interval.

Table 56. Effect Modification of Daytime Indoor-Outdoor Association[1] for $PV_{0.1\text{-}0.5}$

Activity/Ventilation	N[1]	Slope (SE)[1]	Intercept (SE)[1]
Cooking:			
Yes	206	**0.69** (0.07)[2]	1.01 (1.17)
No		**0.47** (0.07)[2]	2.76 (1.21)
Cleaning:			
Yes	206	**0.57** (0.15)	2.29 (2.13)
No		**0.59** (0.06)	1.61 (0.94)
Open Windows:			
Yes	206	**0.63** (0.07)	1.85 (1.14)
No		**0.55** (0.08)	1.41 (1.28)
Heater Use:			
Yes	206	0.46 **(0.15)**	**1.62 (1.82)**
No		0.59 **(0.06)**	**2.04 (0.98)**

[1]Note that slopes and intercepts were calculated using mixed models with the activity included as a main effect and interaction term and home included as a random variable. Activities were classified as "yes" if the activity was performed any time during the sampling period. Bold values indicate significance at the 0.05 level; grey values at 0.10 level. [2]Interaction term significant at the 0.05 level.

Table 57. Estimates of *P* and *k* for $PV_{0.1\text{-}0.5}$ using Mass Balance Model[a]

Particulate Measure	Mixed Model			*P* (SE)	*k* (hr^{-1}) (SE)
	N[b]	Intercept	Slope		
$PV_{0.1\text{-}0.5}$:	60	**1.48** (0.18)	0.03 (0.05)	**0.68** (0.08)	0.02 (0.04)
0.1-0.15 um	64	**1.17** (0.10)	**0.08** (0.03)	**0.85** (0.07)	**0.07** (0.03)
0.15-0.2 um	64	**1.22** (0.12)	0.06 (0.04)	**0.82** (0.08)	0.05 (0.04)
0.2-0.3 um	64	**1.20** (0.13)	0.09 (0.04)	**0.84** (0.09)	0.07 (0.04)
0.3-0.4 um	64	**1.26** (0.14)	**0.12** (0.05)	**0.79** (0.09)	**0.09** (0.05)
0.4-0.5 um	64	**1.51** (0.18)	0.09 (0.06)	**0.66** (0.08)	0.06 (0.05)

Note: Estimates of *P* and *k* determined using a regression equation based on the mass balance model and 6-hr nighttime data to correspond to non-source periods. [a] Bold values indicate significance at 0.05 level of intercept and/or slope from mixed model; grey values indicate significance at 0.10 level. [b] Note that the N between the aggregated size bins and the individual size bins differ because aggregated size bins were run to match nighttime regression analyses and includes data only for homes with ≥4 data points.

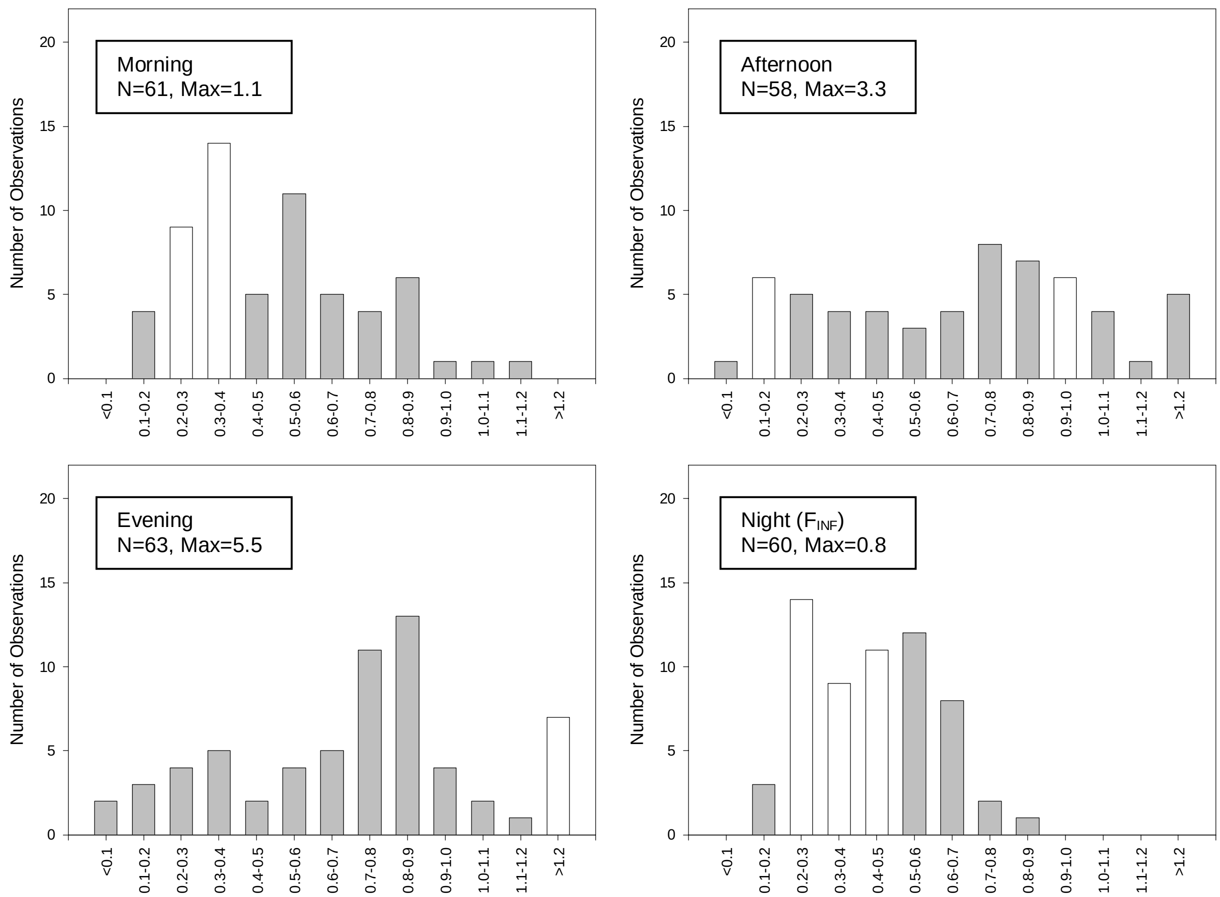
4.1.3.10 Relationship between Indoor and Outdoor $PV_{0.7\text{-}2.5}$. The mean overall indoor/outdoor $PV_{0.7\text{-}2.5}$ ratio during the night equaled 0.4 (±0.2), suggesting an F_{INF} of 40% (Table 58). This value was relatively stable across homes, with mean home-specific ratios ranging narrowly between 0.3 and 0.6. Furthermore, approximately 90% of all ratios fell between 0.2 and 0.7 (Figure 61), further suggesting that 40% is a robust estimate of the night-time F_{INF} for $PV_{0.7\text{-}2.5}$.

Table 58. Indoor-Outdoor $PV_{0.7\text{-}2.5}$ Ratios: By Time Period

House	Morning		Afternoon		Evening		Night	
	N	Mean	N	Mean	N	Mean	N	Mean
1	5	0.8 (0.2)	7	0.9 (0.1)	7	0.8 (0.1)	7	0.5 (0.1)
2	7	0.3 (0.1)	6	0.2 (0.0)	7	0.2 (0.2)	7	0.3 (0.1)
3	7	0.7 (0.2)	7	0.9 (0.1)	7	0.7 (0.1)	7	0.5 (0.3)
4	7	0.7 (0.3)	6	0.5 (0.2)	7	0.8 (0.0)	7	0.5 (0.1)
5	7	0.5 (0.2)	6	0.7 (0.1)	7	1.0 (0.2)	7	0.5 (0.1)
10	5	0.3 (0.2)	4	0.3 (0.3)	4	0.8 (0.5)	5	0.4 (0.2)
13	7	0.4 (0.3)	6	0.4 (0.2)	6	0.8 (0.4)	4	0.5 (0.1)
14	4	0.5 (0.1)	5	1.6 (1.0)	4	1.2 (0.4)	4	0.6 (0.2)
15	6	0.5 (0.1)	5	1.3 (0.4)	7	1.5 (1.9)	5	0.4 (0.1)
16	6	0.4 (0.2)	6	0.5 (0.3)	7	0.5 (0.2)	7	0.4 (0.2)
Overall	61	0.5 (0.2)	58	0.7 (0.5)	63	0.8 (0.7)	60	0.4 (0.2)

"Morning" was defined as 6am-12pm; "afternoon" as 12-6pm; "evening" as 6pm-12am; and "night" as 12-6am. No data available for Houses 6, 7, 8, 9, 11, 12, 17.

Figure 61. Frequency Distributions of I/O ratios by time period for $PV_{0.7\text{-}2.5}$.



"Morning" was defined as 6am-12pm; "afternoon" as 12-6pm; "evening" as 6pm-12am; and "night" as 12-6am.

Table 59. Indoor on Outdoor Associations for $PV_{0.7\text{-}2.5}$: 6-hr Nighttime

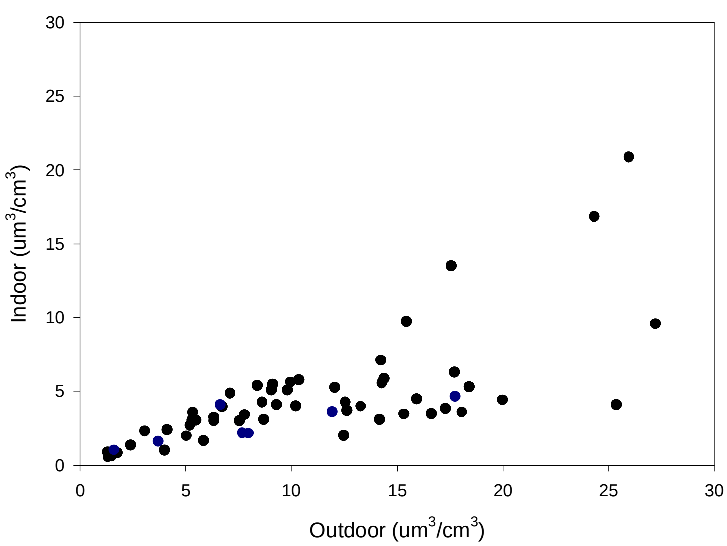
House	N	R^2	Slope (SE)	Intercept (SE)
2	7	0.01	0.03 (0.12)	4.18 (2.16)
3	7	**0.66**	**0.93** (0.30)	-6.64 (5.53)
4	6	0.57	0.28 (0.12)	1.62 (1.01)
5	7	0.50	0.20 (0.09)	3.22 (1.33)
10	5	**0.90**	**0.12** (0.02)	**1.43** (0.31)
13	4	0.77	0.71 (0.27)	-2.88 (3.34)
15	5	0.48	0.11 (0.06)	**0.56** (0.14)
16	6	0.50	0.23 (0.12)	0.90 (0.85)
Full (simple)	47	0.49	**0.40** (0.06)	0.08 (0.81)
Full (mixed)	47	--	**0.39** (0.07)	0.18 (0.93)

Home-specific results calculated using linear regression models. The "full model" values were calculated using mixed models with home as a random subject. Nighttime defined as 12-6am.

Consistent with these findings, the slope of nighttime indoor on outdoor $PV_{0.7\text{-}2.5}$ concentrations equaled 0.39 (±0.07) (Figure 62). When data were analyzed by home, the home-specific nighttime slopes were generally insignificant, with only two homes having significant slopes (Table 59). Low slopes for some homes may be related to the relatively narrow range in outdoor $PV_{0.7\text{-}2.5}$ concentrations at these homes and to differences in ventilation, as the well-ventilated House 3 again had the highest home-specific slope. Home ventilation was generally found to explain variation in the indoor-outdoor association for $PV_{0.7\text{-}2.5}$. Slopes, for example, were significantly higher (at the 0.10 level) when air exchange rates were classified as "high" (0.55±0.15) as compared to when classified as "low" (0.17±0.02) and "medium" (0.31±0.07) (Table 61). Similar results were found when open window and heater use were used as the measures of ventilation (results not shown).

During the day, mean indoor/outdoor $PV_{0.7\text{-}2.5}$ ratios were higher than those at night, with mean values of 0.5 (±0.2), 0.7 (±0.5), and 0.8 (±0.7) for the morning, afternoon, and night, respectively (Table 58). In addition, the distribution of the ratios was broader during the day than at night, especially during the afternoon and evening, as evidenced by the home-specific mean (Table 58) and individual ratios (Figure 61). During the afternoon and evening, indoor/outdoor ratios greater than one were not uncommon, with mean ratios for Houses 14 and 15 greater than one. These results suggest that $PV_{0.7\text{-}2.5}$ was generated indoors. Despite this, the observed variability in daytime indoor/outdoor ratios could not be attributed to particle generating activities, such as cooking and cleaning, as mean daytime indoor/outdoor ratios did not differ by whether cooking (p=0.93) or cleaning (p=0.54) occurred. Daytime mean ratios also did not vary by open windows (p=0.72), but varied by heater use (p=0.01). Mean $PV_{0.7\text{-}2.5}$ ratios were significantly higher when heaters were on (0.91±0.98) as compared to when heaters were off (0.61±0.41).

Figure 62. Indoor vs. Outdoor $PV_{0.7\text{-}2.5}$: 6-hr Nighttime Values



Nighttime defined as 12-6am.

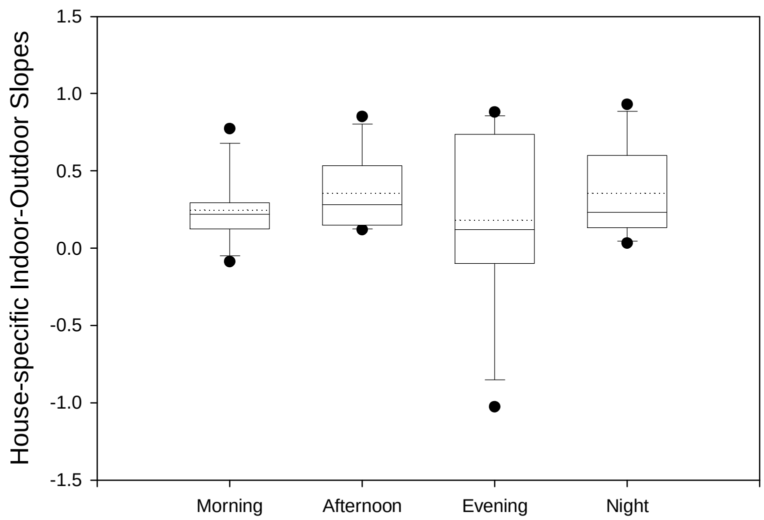
Slopes for $PV_{0.7-2.5}$ for daytime periods were comparable to those at night, with overall daytime slopes ranging between 0.31 (±0.04) and 0.41 (±0.07) (Table 60). The distribution of the morning and afternoon home-specific slopes were similar to that for the night, while the distribution of home-specific evening slopes was broader (Figure 63). Slopes were significant for four, two, and three homes in the morning, afternoon and evening, respectively. House 3 had significant and high slopes for each of the daytime periods. As was the case at night, variations in home-specific daytime slopes may be attributed to variability in air exchange rates, as daytime slopes were significantly higher (at the 0.10 level) when air exchange rates were "high" (1.00±0.00) as compared to "low" (0.21±0.16) and "medium" (0.26±0.13) (Table 61). Similar results were found when data were stratified by daytime period (Figure 64) and when data were evaluated using open window and heater use as the measures of home ventilation (Table 62). The particle generating activities, cooking and cleaning, modified significantly the indoor-outdoor association, although inconsistently. Cooking was found to result in a significantly higher indoor-outdoor slope, while cleaning was found to result in a significantly lower slope (Table 62). The physical meaning of the observed effect of activities is not clear.

Table 60. Indoor on Outdoor $PV_{0.7-2.5}$ Associations for Daytime Periods: By House

House	N	Morning			Afternoon			Evening		
		R^2	Slope (SE)	Intercept (SE)	R^2	Slope (SE)	Intercept (SE)	R^2	Slope (SE)	Intercept (SE)
2	6	**0.65**	**0.25** (0.09)	0.84 (2.66)	0.25	0.12 (0.10)	0.74 (1.98)	0.03	-0.14 (0.39)	5.60 (5.76)
3	6	**0.83**	**0.77** (0.18)	-1.89 (3.61)	**0.95**	**0.85** (0.10)	-0.04(0.98)	**0.97**	**0.88** (0.08)	-1.45 (0.98)
4	6	0.08	-0.09 (0.15)	**8.81** (1.96)	0.50	0.14 (0.07)	**3.22**(0.82)	**0.98**	**0.66** (0.05)	1.06 (0.44)
5	6	**0.83**	**0.31** (0.07)	2.83 (1.81)	**0.97**	**0.61** (0.05)	2.28(1.81)	**0.81**	**0.76** (0.18)	1.78 (1.78)
13	6	0.11	0.11 (0.15)	4.03 (2.42)	0.58	0.18 (0.08)	2.68(1.15)	0.03	0.12 (0.37)	5.73 (4.17)
15	5	0.58	0.17 (0.09)	0.31 (0.13)	0.14	0.28 (0.41)	1.06(0.46)	0.15	-1.03 (1.42)	4.61 (3.44)
16	6	**0.93**	**0.22** (0.03)	0.75 (0.31)	0.50	0.31 (0.15)	0.98(1.10)	0.01	0.03 (0.15)	2.04 (0.80)
Overall	*	**--**[1]	**0.31** (0.04)	1.56 (1.21)	**--**[1]	**0.44** (0.05)	0.10 (1.56)	**--**[1]	**0.41** (0.07)	1.98 (1.07)

"Morning" was defined as 6am-12pm; "afternoon" as 12-6pm; "evening" as 6pm-12am; and "night" as 12-6am.
*Sample size is 49, 43, and 50 for morning, afternoon and evening periods, respectively. Overall results are from mixed models with home as a random variable.

Figure 63. House-Specific Indoor/Outdoor Slopes By Time Period for $PV_{0.7-2.5}$



"Morning" was defined as 6am-12pm; "afternoon" as 12-6pm; "evening" as 6pm-12am; and "night" as 12-6am. Slopes calculated using simple linear regression models of indoor on outdoor concentrations stratified by home.

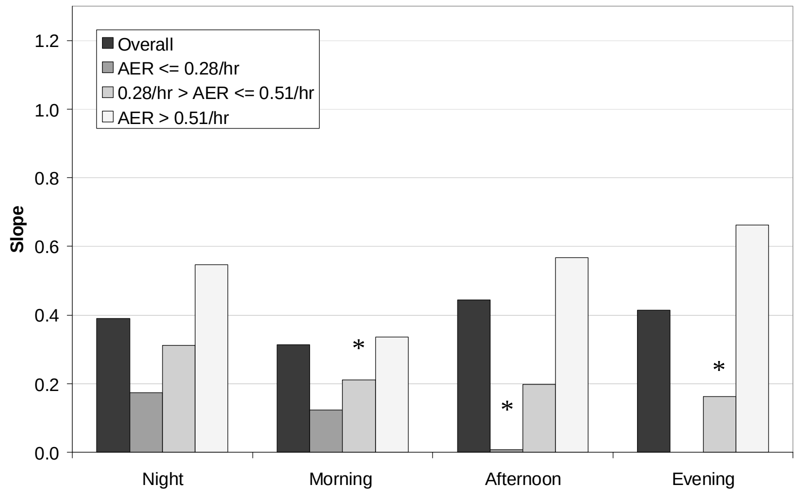
Table 61. Association between Indoor and Outdoor $PV_{0.7-2.5}$: By Air Exchange Rate

Period	Low AER			Medium AER			High AER		
	N	Slope (SE)	Intercept (SE)	N	Slope (SE)	Intercept (SE)	N	Slope (SE)	Intercept (SE)
Night	16	**0.17** (0.02)	1.75 (0.74)	12	**0.31** (0.07)	1.17 (1.01)	19	**0.55** (0.15)	-1.16 (2.52)
Day		0.21 (0.16)[2]	0.73 (1.99)		0.26 (0.13)[2]	0.60 (2.03)		**1.00** (0.00)[2]	**-5.74** (1.35)
Morning	14	**0.12** (0.02)	0.76 (0.32)	9	0.21 (0.10)	2.08 (1.33)	26	**0.34** (0.06)	2.59 (2.28)
Afternoon	12	0.01 (0.04)	**2.51** (0.81)	10	**0.20** (0.04)	1.45 (0.91)	21	**0.57** (0.05)	-0.41 (1.58)
Evening	6	--[3]	--[3]	17	0.16 (0.10)	2.39 (1.44)	27	**0.66** (0.07)	-0.67 (1.38)

Slopes and intercepts calculated using mixed model of indoor on outdoor concentrations, with air exchange rates (as a categorical variable) included as a main effect and interaction term with outdoor pollution. Low AER" represents data for which AER$\leq$ 0.28 hr^{-1}; "medium AER" for which 0.28<AER$\leq$0.51 hr^{-1}; and "high AER" for which AERs> 0.51 hr^{-1}. Bold indicates significance at 0.05 level; grey significance at 0.10 level. [2]The overall daytime slope for the low and medium AER groups differed significantly from that for the high AER group at the 0.05 level. [3]The model did not converge.

Penetration efficiencies for nighttime $PV_{0.7-2.5}$ estimated using the mass balance model (0.49±0.13) were significant and were comparable to estimated nighttime F_{INF} values obtained using indoor/outdoor ratios (0.40±0.20) and the indoor-outdoor slope (0.39±0.07) (Table 63). Estimates of P were similar for all particles within this size interval, with P equaling 0.49 (±0.15) for particles between 0.7-1.0 um and 0.57 (±0.15) for particles between 1.0 and 2.0 um. These estimates suggest that between 50 and 60% of particles between 0.7 and 2.5 um penetrate from outdoor to indoor environments. Estimated k for nighttime $PV_{0.1-0.5}$ were statistically insignificant, but were higher than those for smaller particle size intervals, with a value for k equaling 0.13 (±0.12). Values for k showed no discernable trend across the size interval.

Figure 64. Association between Indoor on Outdoor $PV_{0.7\text{-}2.5}$: By AER and Period



"Morning" was defined as 6am-12pm; "afternoon" as 12-6pm; "evening" as 6pm-12am; and "night" as 12-6am. Slopes calculated using mixed model of indoor on outdoor concentrations, with air exchange rates (as a categorical variable) included as a main effect and interaction term with outdoor pollution.

Table 62. Effect Modification of Daytime Indoor-Outdoor Association[1] for $PV_{0.7\text{-}2.5}$

Activity/Ventilation	N	Slope	Intercept
Cooking			
Yes	157	**0.43** (0.03)[2]	0.90 (0.68)
No		**0.25** (0.05)[2]	2.56 (0.84)
Cleaning			
Yes	157	**0.27** (0.05)[2]	**1.88** (0.94)
No		**0.45** (0.03)[2]	0.70 (0.61)
Open Windows			
Yes	157	**0.33** (0.04)[3]	**2.53** (0.74)
No		**0.43** (0.04)[3]	-0.22 (0.75)
Heater Use			
Yes	157	0.18 (0.10)[2]	**2.46** (1.22)
No		**0.40** (0.03)[2]	1.80 (1.05)

Slopes and intercepts calculated using mixed model of indoor on outdoor concentrations, with activity (as a categorical variable) included as a main effect and interaction term with outdoor pollution. [1] Bold values indicate significance at the 0.05 level; grey values at 0.10 level. [2] Interaction term significant at 0.05 level. [3] Interaction term significant at 0.10 level.

Table 63. Estimates of *P* and *k* for $PV_{0.7\text{-}2.5}$ using Mass Balance Model[a]

Particulate Measure	Mixed Model			*P* (SE)	*k* (hr^{-1}) (SE)
	N[b]	Intercept	Slope		
$PV_{0.7\text{-}2.5}$:	47	**2.05** (0.55)	0.27 (0.17)	**0.49** (0.13)	0.13 (0.12)
0.7-1.0 um	49	**2.03** (0.60)	0.29 (0.21)	**0.49** (0.15)	0.14 (0.14)
1.0-2.0 um	49	**1.75** (0.46)	0.30 (0.16)	**0.57** (0.15)	0.17 (0.13)

Estimates of *P* and *k* determined using a regression equation based on the mass balance model and 6-hr nighttime data to correspond to non-source periods. [a] Bold values indicate significance at 0.05 level; grey values indicate significance at 0.10 level. [b] N of the aggregated and individual size bins differ because aggregated size bins matched to nighttime analyses and includes data only for homes with $\geq$4 data points.

4.1.3.11 Relationship between Indoor and Outdoor $PV_{2.5\text{-}10}$. Mean nighttime indoor/outdoor ratios of $PV_{2.5\text{-}10}$ equaled 0.2 (±0.1), indicating an overall F_{INF} of 20% (Table 64). This value was stable across homes, as mean ratios at the homes ranged narrowly between 0.1 and 0.4. Furthermore, approximately 75% of all ratios fell between 0.1 and 0.3 (Figure 65), further suggesting that 20% is a robust estimate of the night-time F_{INF} for $PV_{2.5\text{-}10}$. Low indoor-outdoor ratios for $PV_{2.5\text{-}10}$ is consistent with loss due to gravitational settling, which based on particle theory should be substantial for coarse particles. As would be expected from the stable nighttime ratios, mean nighttime indoor/outdoor ratios did not vary significantly by open window status (p=0.62) or by heater use (p=0.99).

Slopes of nighttime indoor on outdoor $PV_{2.5\text{-}10}$ concentrations suggested a higher F_{INF} value, equaling 0.43 (±0.05) (Table 65; Figure 66). When data were analyzed by home, the home-specific nighttime slopes varied widely, with the slopes for approximately half of the homes having insignificant values and slopes for the other homes ranging between 0.06 and 0.57 (Table 65). Variation in the home-specific slopes may be due to differences in ventilation at the homes. Slopes were significantly higher when air exchange rates were classified as "high" (0.49±0.07) as compared to when classified as "low" (0.16±0.06) and "medium" (0.18±0.09) (Table 67). Similarly significant results were found when open window and heater use were used as the measure of ventilation (results not shown).

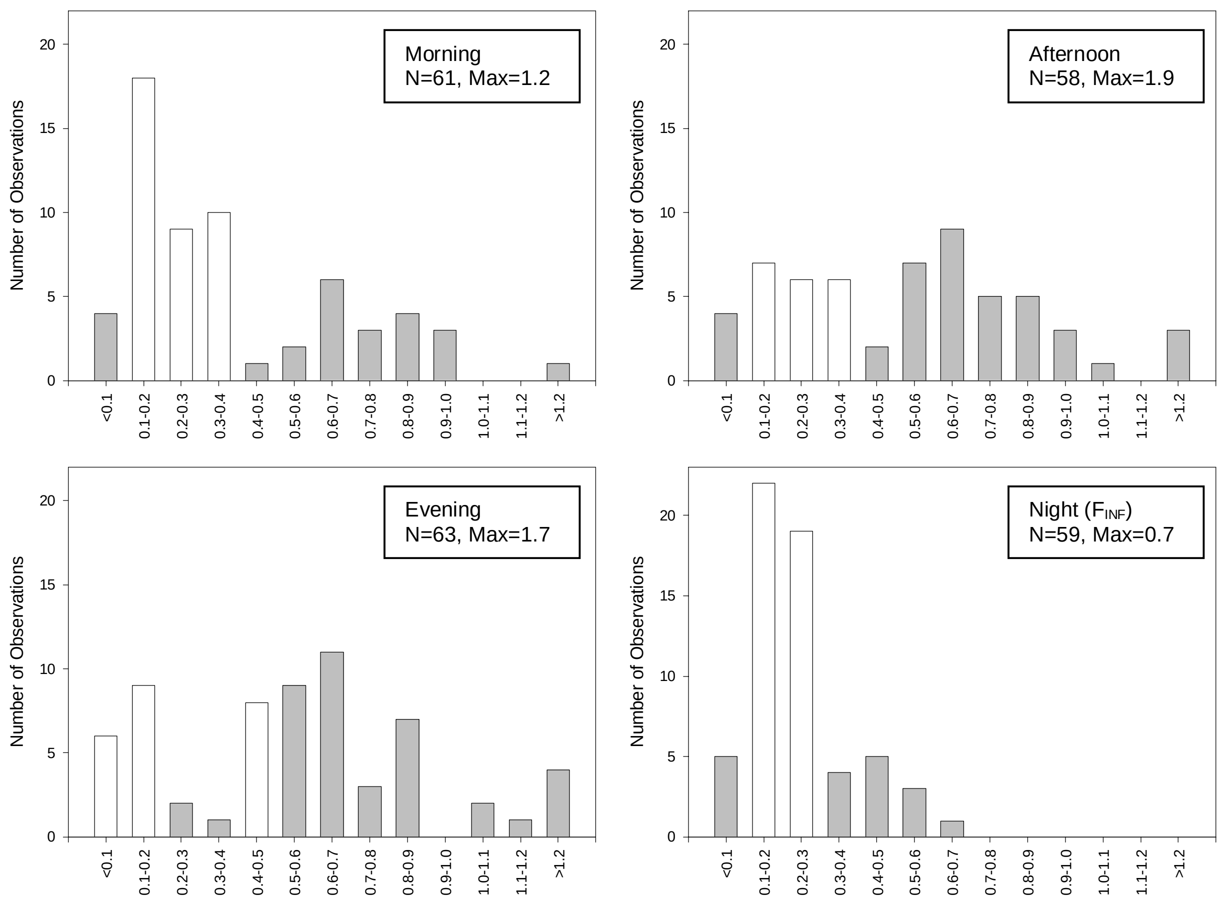
During the day, indoor/outdoor $PV_{2.5\text{-}10}$ ratios tended to be higher and more broadly distributed, with maximum values above one in each of the daytime periods (Figure 65). Correspondingly, the overall mean ratios were higher in the day as compared to night, although home-specific mean ratios were low for some homes and daytime periods (Table 64). Higher ratios during the daytime hours were likely due to the contribution of indoor sources to indoor concentrations. Mean indoor/outdoor ratios were significantly higher, for example, during "cooking" as compared to "non-cooking" periods (p=0.04), with mean ratios equal to 0.53 (±0.34) and 0.41 (±0.36), respectively. Cleaning, however, did not have a significant effect on indoor/outdoor ratios (p=0.99).

Table 64. Summary of Indoor-Outdoor Ratios By Time Period for $PV_{2.5-10}$

House	Morning		Afternoon		Evening		Night	
	N	Mean (SD)	N	Mean (SD)	N	Mean	N	Mean (SD)
1	5	0.8 (0.3)	7	0.7 (0.2)	7	0.7 (0.1)	7	0.2 (0.1)
2	7	0.2 (0.1)	6	0.1 (0.0)	7	0.1 (0.1)	7	0.1 (0.0)
3	7	0.7 (0.1)	7	0.9 (0.2)	7	0.6 (0.1)	7	0.4 (0.2)
4	7	0.5 (0.2)	6	0.4 (0.2)	7	0.5 (0.1)	7	0.2 (0.0)
5	7	0.7 (0.2)	6	0.6 (0.1)	7	0.8 (0.2)	6	0.3 (0.1)
10	5	0.2 (0.1)	4	0.2 (0.1)	4	0.9 (0.2)	5	0.3 (0.1)
13	7	0.2 (0.0)	6	0.4 (0.2)	6	0.7 (0.5)	3	0.3 (0.2)
14	4	0.3 (0.1)	5	1.0 (0.6)	4	1.0 (0.5)	4	0.4 (0.2)
15	6	0.2 (0.1)	5	0.6 (0.1)	7	0.6 (0.6)	6	0.2 (0.1)
16	6	0.2 (0.0)	6	0.3 (0.2)	7	0.2 (0.1)	7	0.1 (0.1)
Full	61	0.4 (0.3)	58	0.5 (0.4)	63	0.6 (0.4)	59	0.2 (0.1)

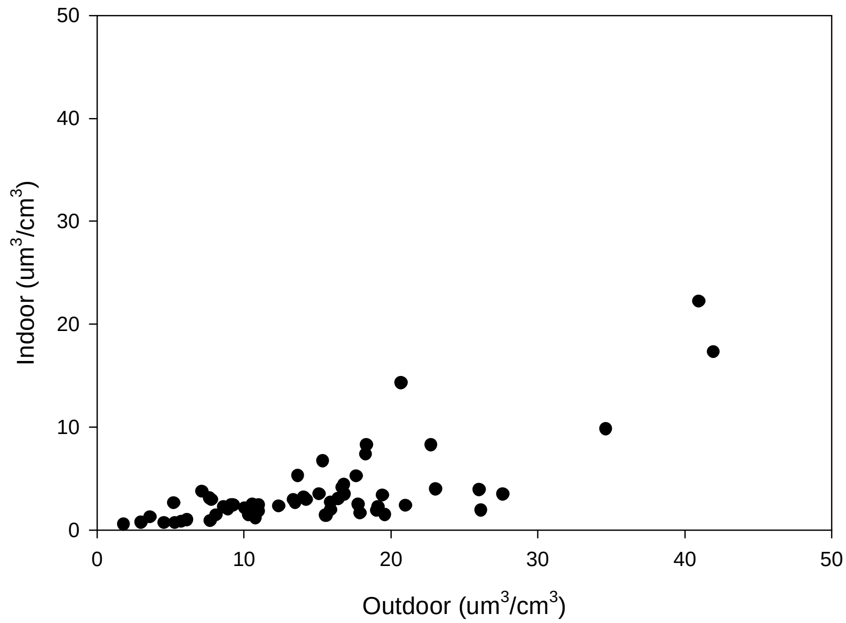
"Morning" 6am-12pm; "afternoon" 12-6pm; "evening" 6pm-12am; "night" 12-6am. No data for Houses 6, 7, 8, 9, 11, 12, 17.

Figure 65. Frequency Distributions of Indoor/Outdoor $PV_{2.5-10}$ Ratios By Time Period



"Morning" was defined as 6am-12pm; "afternoon" as 12-6pm; "evening" as 6pm-12am; and "night" as 12-6am.

Figure 66. Indoor vs. Outdoor $PV_{2.5-10}$ Concentrations: Nightime Values



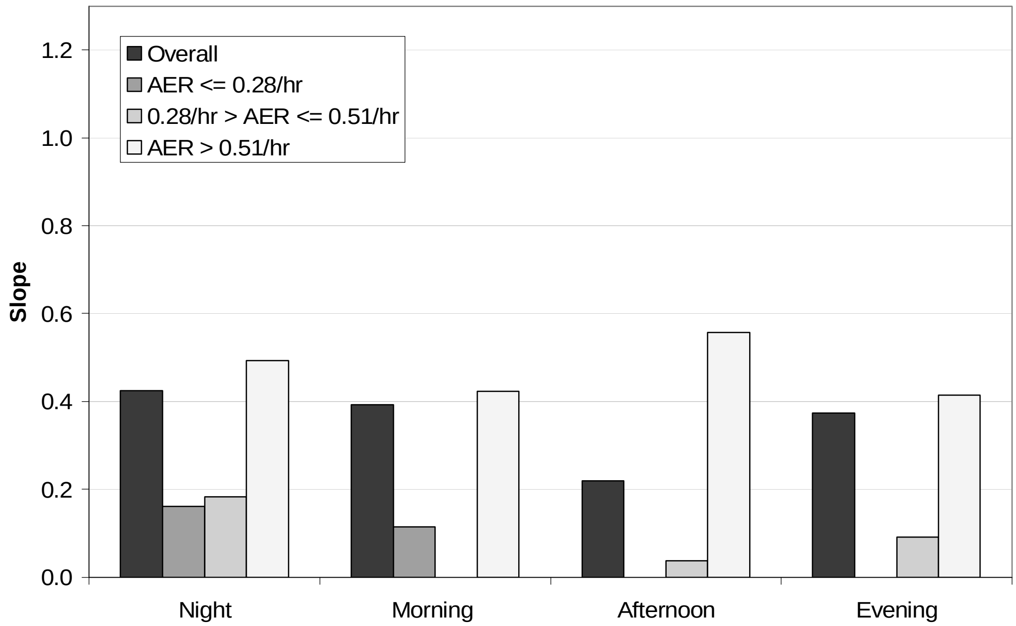
"Night " was defined as 12-6am.

Table 65. Indoor on Outdoor Associations for $PV_{2.5-10}$: 6-hr Nighttime

House	N	R^2	Slope (SE)	Intercept (SE)
2	7	0.07	0.06 (0.10)	1.25 (2.11)
3	7	**0.78**	**0.57** (0.14)	-3.77 (3.62)
4	6	**0.78**	**0.19** (0.05)	0.51 (0.66)
5	6	0.63	0.46 (0.17)	-2.27 (3.08)
10	5	0.47	0.09 (0.06)	1.48 (0.62)
15	6	**0.66**	**0.06** (0.02)	**0.48** (0.11)
16	6	**0.79**	**0.33** (0.08)	-3.19 (1.69)
Full (simple)	43	**0.61**	**0.40** (0.05)	**-2.29** (0.90)
Full (mixed)	43	--	**0.43** (0.05)	**-2.68** (1.10)

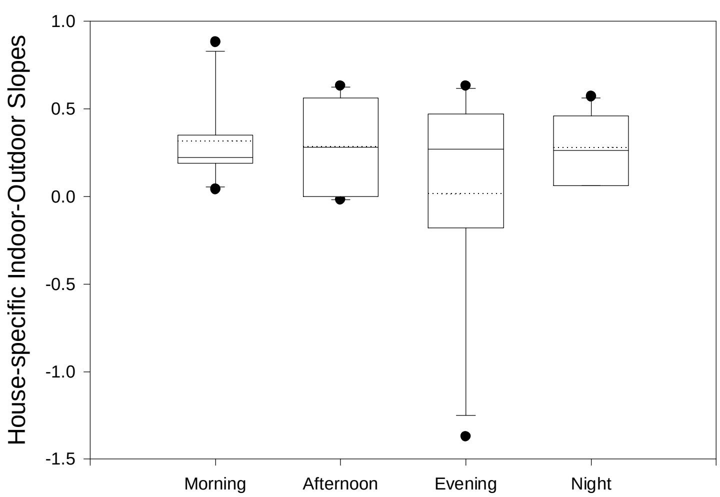
Slopes, R^2 values and intercepts calculated for each home using simple linear regression of indoor on outdoor concentrations. The "full model (mixed)" slope and intercepts were calculated using mixed models of indoor on outdoor concentrations with home as a random subject. Nighttime defined as 12-6am. Values in bold indicate significance at p<=0.05.

Figure 67. Association between Indoor on Outdoor $PV_{2.5-10}$: By AER and Period



Slopes calculated using mixed models of indoor on outdoor concentrations with air exchange rates included as a main effect and interaction term. "Morning" was defined as 6am-12pm; "afternoon" as 12-6pm; "evening" as 6pm-12am; and "night" as 12-6am.

Figure 68. House-Specific Indoor-Outdoor Slopes for $PV_{2.5-10}$: By Time Period



Slopes calculated using linear regression models of indoor on outdoor concentrations stratified by home. "Morning" was defined as 6am-12pm; "afternoon" as 12-6pm; "evening" as 6pm-12am; and "night" as 12-6am.

Table 66. Indoor on Outdoor $PV_{2.5-10}$ Associations for Daytime Periods: By House[1]

House	N	Morning			Afternoon			Evening		
		R^2	Slope (SE)	Intercept (SE)	R^2	Slope (SE)	Intercept (SE)	R^2	Slope (SE)	Intercept (SE)
2	6	0.55	0.25 (0.11)	-1.96 (3.67)	0.00	-0.02 (0.16)	4.08 (5.36)	0.07	-0.18 (0.34)	8.85 (9.62)
3	6	**0.97**	**0.88** (0.07)	-2.71 (1.61)	**0.86**	**0.56** (0.11)	4.79 (2.26)	**0.92**	**0.47** (0.07)	1.99 (1.63)
4	6	0.07	0.19 (0.34)	6.28 (10.37)	0.00	0.00 (0.09)	**9.73** (2.88)	**0.90**	**0.41** (0.07)	3.29 (2.48)
5	6	0.61	0.35 (0.14)	4.53 (3.16)	**0.82**	**0.63** (0.15)	0.26 (4.67)	0.42	0.63 (0.37)	2.19 (6.36)
15	5	0.06	0.04 (0.10)	0.52 (0.44)	0.65	0.39 (0.16)	1.01 (0.68)	0.46	-1.37 (0.86)	11.66 (5.63)
16	6	**0.86**	**0.19** (0.04)	-0.51 (0.81)	0.62	0.17 (0.07)	2.38 (2.11)	0.15	0.13 (0.16)	0.70 (2.65)
Overall[3]	*	--[1]	**0.39** (0.07)	-0.02 (2.31)	--[1]	**0.22** (0.07)	3.74 (2.78)	--[1]	**0.37** (0.05)	1.65 (2.14)

Slopes calculated using mixed models of indoor on outdoor concentrations with air exchange rates included as a main effect and interaction term. "Morning" was defined as 6am-12pm; "afternoon" as 12-6pm; "evening" as 6pm-12am; and "night" as 12-6am. "Low AER" represents data for which AER≤ 0.28 exchanges/hr; "medium AER" for which 0.28<AER≤0.51 exchanges/hr; and "high AER" for which AERs> 0.51 exchanges/hr. [2]Sample size is 42, 37, and 44 for morning, afternoon and evening periods, respectively. [3] Results are from mixed models.

Table 67. Association between Indoor and Outdoor $PV_{2.5-10}$: By Air Exchange Rate[1]

Period	Low AER			Medium AER			High AER		
	N	Slope (SE)	Intercept (SE)	N	Slope (SE)	Intercept (SE)	N	Slope (SE)	Intercept (SE)
Night	15	**0.16** (0.06)	0.89 (1.18)	9	0.18 (0.09)	0.46 (1.36)	19	**0.49** (0.07)	-4.48 (2.19)
Day		0.22 (0.22)[2]	0.69 (3.29)[2]		0.07 (0.17)[2]	2.22 (2.94)[2]		**1.00** (0.00)[2]	**-13.29** (1.56)[2]
Morning	14	**0.11** (0.02)	0.39 (0.28)	2	--[2]	--[2]	26	**0.42** (0.10)	0.88 (4.06)
Afternoon	11	-0.06 (0.06)	4.97 (2.09)	6	0.04 (0.14)	4.24 (4.32)	20	**0.56** (0.07)	-0.96 (2.94)
Evening	6	--[3]	--[3]	13	0.09 (0.09)	2.55 (2.41)	25	**0.41** (0.06)	1.78 (2.33)

Slopes and intercepts calculated using mixed model of indoor on outdoor concentrations, with air exchange rates (as a categorical variable) included as a main effect and interaction term with outdoor pollution. [1]"Low AER" represents data for which AER≤ 0.28 exchanges/hr; "medium AER" for which 0.28<AER 0.51 exchanges/hr; and "high AER" for which AERs≥ 0.51 exchanges/hr. [2]Low and medium AER groups differed significantly from high AER group. [3]The model did not converge.

Daytime slopes of indoor on outdoor $PV_{2.5-10}$ were slightly lower than those found in the night (Table 66). As was the case at night, home-specific slopes varied widely, although slopes were insignificant for most homes for each daytime period. In the morning, afternoon, and evening, two of the six homes had significant indoor-outdoor slopes, with House 3 again having significant and relatively high slopes for all daytime periods. Correspondingly, home ventilation was found to affect indoor-outdoor associations significantly, with slopes highest when air exchange rates were classified as "high" as compared to "low" and "medium" (Table 67).

Similar results were found for open window but not heater use (results not shown). Surprisingly, cooking and cleaning, known sources of $PV_{2.5\text{-}10}$, were not found to be significant modifiers of the indoor-outdoor association for $PV_{2.5\text{-}10}$.

Penetration efficiencies for nighttime $PV_{2.5\text{-}10}$ estimated using the mass balance model (0.54±0.42) were not statistically significant, with a nominal value higher than the nighttime F_{INF} values obtained using indoor/outdoor ratios (0.2±0.1) and the indoor-outdoor slope (0.43±0.05) (Table 68). Estimates of P for particles within this size interval tended to decrease as the particle size increased, as the value for P was significant and equaled 0.65 (±0.23) for particles between 2.0 and 3.0 um and dropped to 0.28 (±0.08) for particles between 6.0 and 10.0 um. These estimates suggest that between 30 and 65% of coarse particles penetrate from outdoor to indoor environments. Estimated decay rates for nighttime $PV_{2.5\text{-}10}$ were generally insignificant, but with nominal values higher than those for smaller particle size intervals, with a value for k equaling 0.74 (±0.12). Values for k generally increased with particle size.

Table 68. Estimates of P and k for $PV_{2.5\text{-}10}$ using Mass Balance Model[a]

Particulate Measure	Mixed Model			P (SE)	k (hr^{-1}) (SE)
	N[b]	Intercept	Slope		
$PV_{2.5\text{-}10}$:	43	1.85 (1.44)	**1.37** (0.32)	0.54 (0.42)	0.74 (0.69)
2.0-3.0 um	48	**1.53** (0.54)	**0.61** (0.16)	**0.65** (0.23)	**0.40** (0.23)
3.0-4.0 um	48	2.04 (1.02)	**0.92** (0.32)	0.49 (0.25)	0.45 (0.35)
4.0-5.0 um	48	2.38 (1.53)	**1.36** (0.47)	0.42 (0.27)	0.57 (0.53)
5.0-6.0 um	48	2.21 (1.80)	**1.85** (0.58)	0.45 (0.37)	0.84 (0.89)
6.0-10 um	48	**3.52** (1.04)	**0.82** (0.36)	**0.28** (0.08)	**0.23** (0.16)

Bold values indicate significance at 0.05 level of intercept and/or slope from mixed model; grey values indicate significance at 0.10 level. [b] Note that the N between the aggregated size bins and the individual size bins differ because aggregated size bins were run to match nighttime regression analyses and includes data only for homes with ≥4 data points.

4.1.3.12 Comparison of Results for Different Particle Species. Nighttime F_{INF} values estimated using indoor/outdoor ratios and regression techniques showed patterns across the measured particle species that were consistent with particle theory. Estimated F_{INF} values were highest for BC, which given its non-reactive nature and its typical size (~0.1-0.5 um) was not surprising (Table 69). Both its stability and size suggest that losses due to reactions, gravitational settling and diffusion will be minimal, thus allowing BC to penetrate the building envelope with great efficiency and to stay suspended indoors for long time periods (Hogan *et al.* 1984; Horvath 1993; Liu and Nazaroff 2001; Long *et al.* 2001). Correspondingly, F_{INF} values were lowest for fine particle NO_3^-, a highly reactive pollutant that in Los Angeles may consist primarily of particles coarse in size (e.g., between 1.0-2.5 um) and thus may have greater losses due to gravitational settling (Table 69) ((Babich *et al.* 2000; Christoforou *et al.* 2000; Kim *et al.* 2000). Nighttime F_{INF} values for $PM_{2.5}$ fell between those for BC and NO_3^-, which can be attributed to the fact that both BC and NO_3^- are major components of $PM_{2.5}$ in Los Angeles (Table 69). Nighttime F_{INF} values for the particle size intervals were consistent with those for

$PM_{2.5}$ and its components, where F_{INF} values were highest for the smallest size fractions $PV_{0.02-0.1}$ and $PV_{0.1-0.5}$ and were lowest for the largest size fractions $PV_{0.7-2.5}$ and $PV_{2.5-10}$ (Table 69).

Table 69. Summary of Nighttime F_{INF} Values by Particulate Measure

Particulate Measure	Nighttime F_{INF}	
	Ratio (SD)	**Slope (SE)**
$PM_{2.5}$	0.4 (0.3)	**0.35** (0.03)
BC	0.8 (0.2)	**0.67** (0.02)
$PV_{0.02-0.1}$	0.7 (0.2)	**0.51** (0.02)
$PV_{0.1-0.5}$	0.7 (0.2)	**0.53** (0.02)
$PV_{0.7-2.5}$	0.4 (0.2)	**0.39** (0.07)
$PV_{2.5-10}$	0.2 (0.1)	**0.43** (0.05)

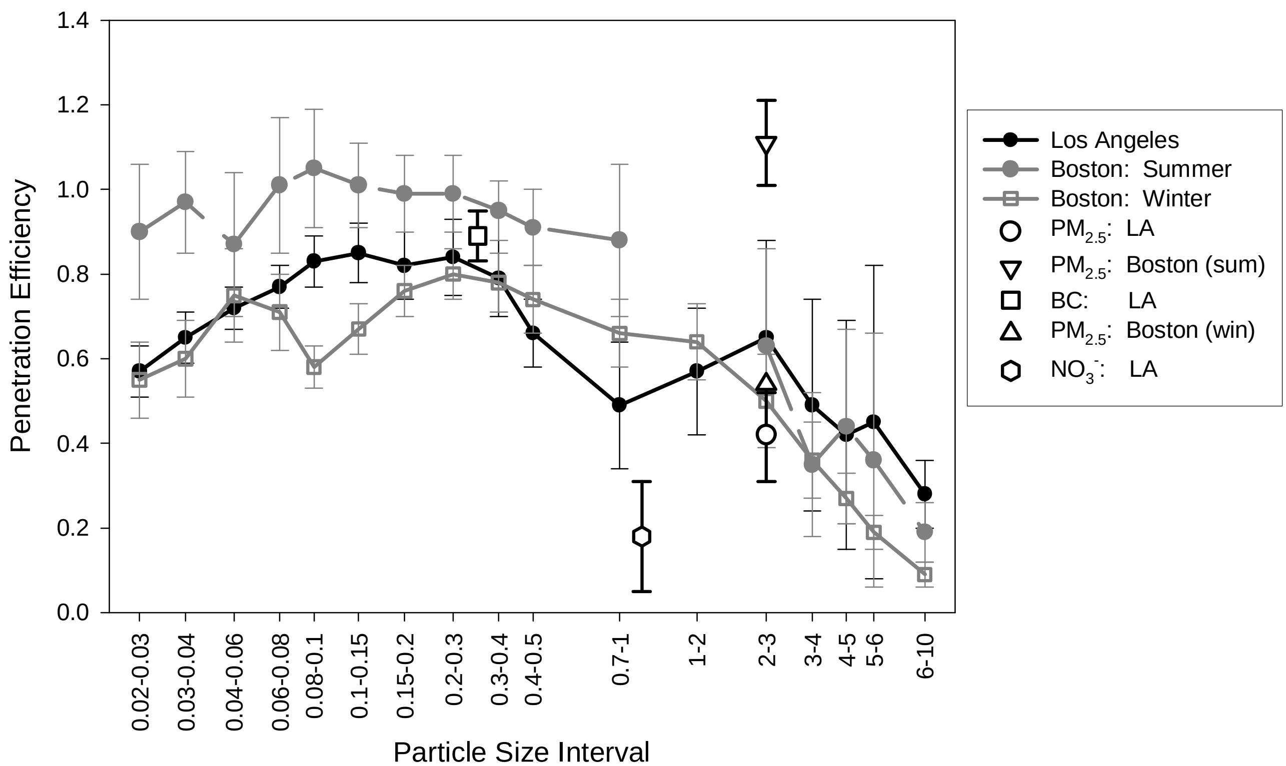
Note: F_{INF} values calculated using 6-h nighttime data. "Ratio" represents mean indoor/outdoor ratio, while "slope" represents the slope of the mixed model of indoor on outdoor concentrations.

Similarly, estimates of ***P*** and ***k*** obtained using steady state models for nighttime periods were also consistent with particle theory and with results from previous studies as well (Figure 69, 70). As was the case with estimated F_{INF} values, the estimated value of ***P*** was highest for BC, which again is consistent with the fact that BC is typically comprised of stable particles whose size falls in the accumulation mode (Hogan *et al.* 1984; Horvath 1993; Long *et al.* 2001). The estimated ***P*** for $PM_{2.5}$ (0.42±0.11) was low given the high air exchange rates measured in the study homes, but was consistent with the large contribution of the volatile NO_3^- to its mass. [Note that the value of F_{INF} and ***P*** for BC should be considered rough estimates, given that outdoor BC concentrations were corrected for the observed bias between the indoor and outdoor instruments but not the tape change artifact. Given the high F_{INF} and ***P*** observed for BC, conclusions about their relative value as compared to $PM_{2.5}$ and NO_3^- are likely valid.]

Estimated penetration efficiencies for $PM_{2.5}$ and the components are consistent with those estimated for the size-resolved particles. Penetration efficiencies for size-resolved PV data were highest for particles between 0.08 and 0.4 um, which was expected since losses due to diffusion and gravitational settling tend to be small for particles in this size range. Correspondingly, ***P*** was lowest for particles between 2.5 and 10 um, for which losses due to gravitational settling is greatest. Estimated values for ***P*** were consistent with wintertime estimates and were lower than summertime estimates, especially within the 0.4 to 2 um size range, from our Boston study (Long et al., 2001). Lower estimates in Los Angeles for the 0.4 to 2 um size range is consistent with the size distribution of nitrate in Los Angeles, suggesting that the difference between the Los Angeles and Boston studies was probably due to nitrate volatilization.

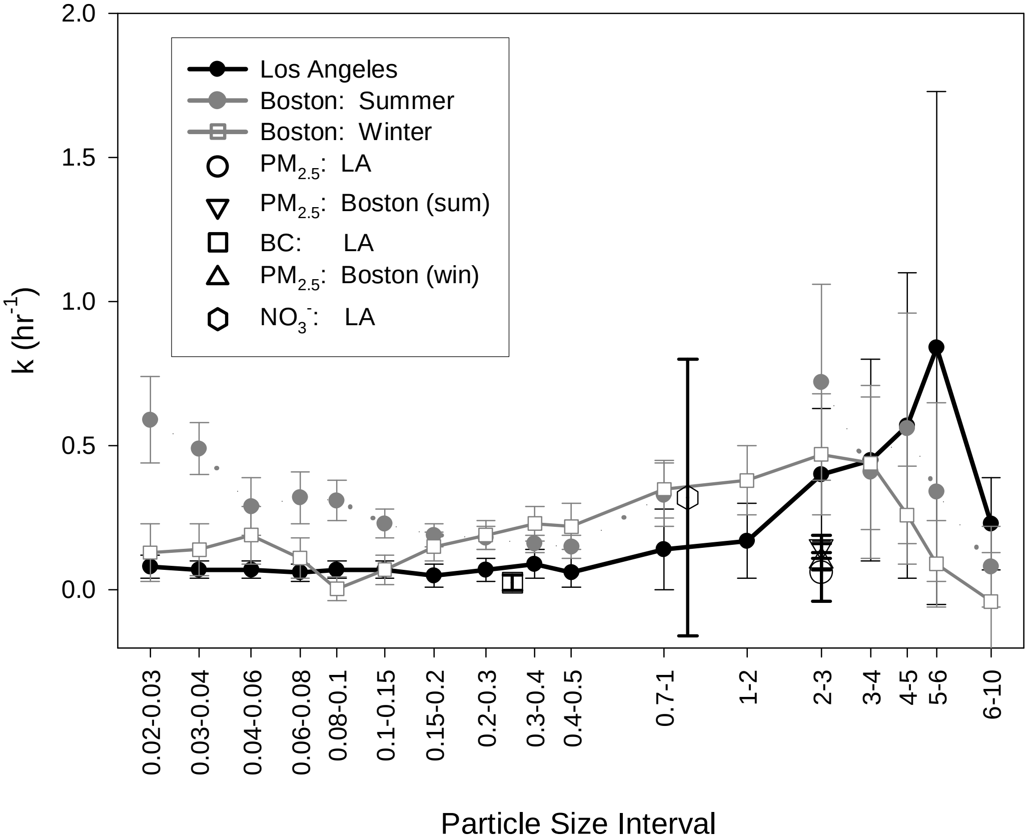
Particle deposition rates were generally insignificant for all of the measured pollutants. Although insignificant, decay rates did follow expected trends, with estimated values greatest for coarse particles and for NO_3^- and smallest for ultra-fine and accumulation mode particles and BC. It is not clear why estimated decay rates were insignificant, but results suggest that decay rates may vary by home or over time, which may contribute to the observed large standard errors relative to the mean values for *k*. As was the case with *P*, decay rates are similar to those estimated using our Boston data, especially in the winter.

Figure 69. Estimates of *P*: Comparison of LA and Boston Results



P was estimated for each particulate measure using 6-h nighttime data and mass balance model. Boston results are from Long et al. (2001).

Figure 70. Estimates of *k*: Comparison of LA and Boston Results



P was estimated for each particulate measure using 6-h nighttime data and mass balance model. Boston results are from Long et al. (2001).

4.1.4 Dynamic Mass Balance Models

Dynamic mass balance models were used to estimate values for *P* and *k*, with results presented for three particle size intervals and for three time periods, including (1) a steady nighttime, non-source period, (2) a post-indoor source event, and (3) a variable, non- source nighttime period. As described in the Methods section, "optimal" *P* and *k* values were identified as the pair of values that minimized the sum of the squared differences between measured and modeled indoor concentrations.

4.1.4.1 Steady nighttime, non-source data. Nighttime, non-source periods were examined in order to compare estimates of *P* and *k* with those estimated using steady state models, with results illustrated using data from House 16 obtained on February 14, 2002 from 12-6am. For this house and time period, outdoor concentrations for each of the three particle size intervals were greater than indoor concentrations, as no indoor source contributed to indoor concentrations during this period (Figure 71-Figure 73; Table 70).

Figure 71. Indoor and Outdoor $PV_{0.03-0.04}$ Concentrations and AER: House 16 on Feb. 14, 2002 from 12-6am

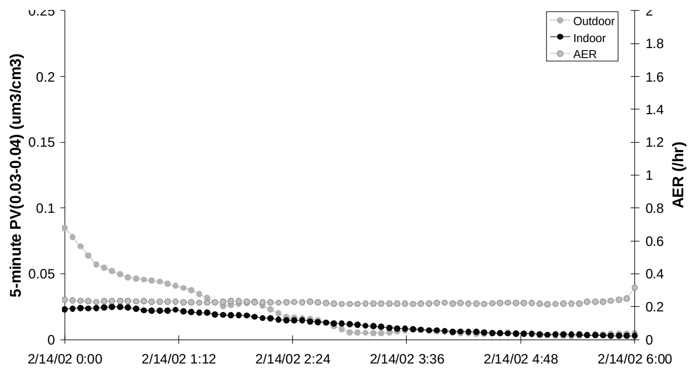


Figure 72. Indoor and Outdoor $PV_{0.3-0.4}$ Concentrations and AER: House 16 on Feb. 14, 2002 from 12-6am

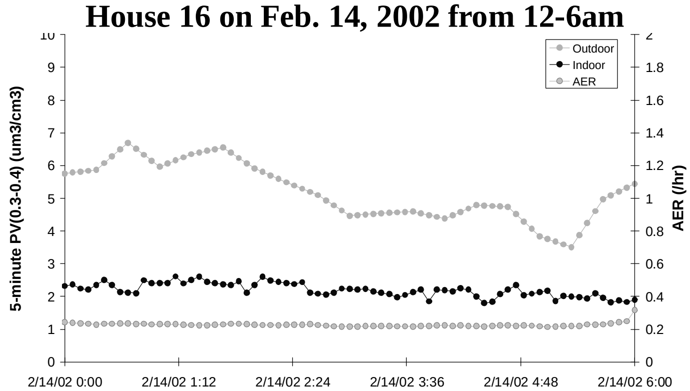


Figure 73. Indoor and Outdoor PV_{3-4} Concentrations and AER: House 16 on Feb. 14, 2002 from 12-6am

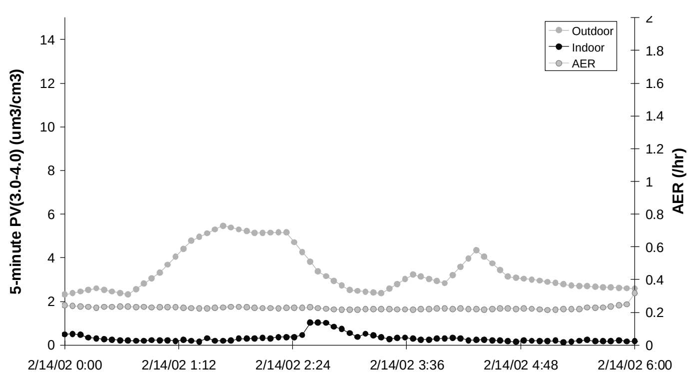


Table 70. Indoor and Outdoor Particle Volume Concentrations ($\mu m^3/cm^3$) and Optimal *P* and *k* values: House 16, February 14, 2002 (12-6am)[1]

Size Bin (µm)	Location	N	Mean (SD)	Min	Max	P (SE)	k (SE), hr^{-1}
0.03-0.04	Indoor	72	0.013 (0.008)	0.0029	0.025	**1.00[2]**	**0.39 (0.00)**
	Outdoor	72	0.021 (0.021)	0.0026	0.085		
0.3-0.4	Indoor	72	2.21 (0.21)	1.80	2.61	**0.63 (0.10)**	**0.14 (0.05)**
	Outdoor	72	5.19 (0.87)	3.50	6.69		
3.0-4.0	Indoor	72	0.32 (0.20)	0.13	1.02	**0.44 (0.16)**	**1.05 (0.41)**
	Outdoor	72	3.41 (0.99)	2.31	5.47		

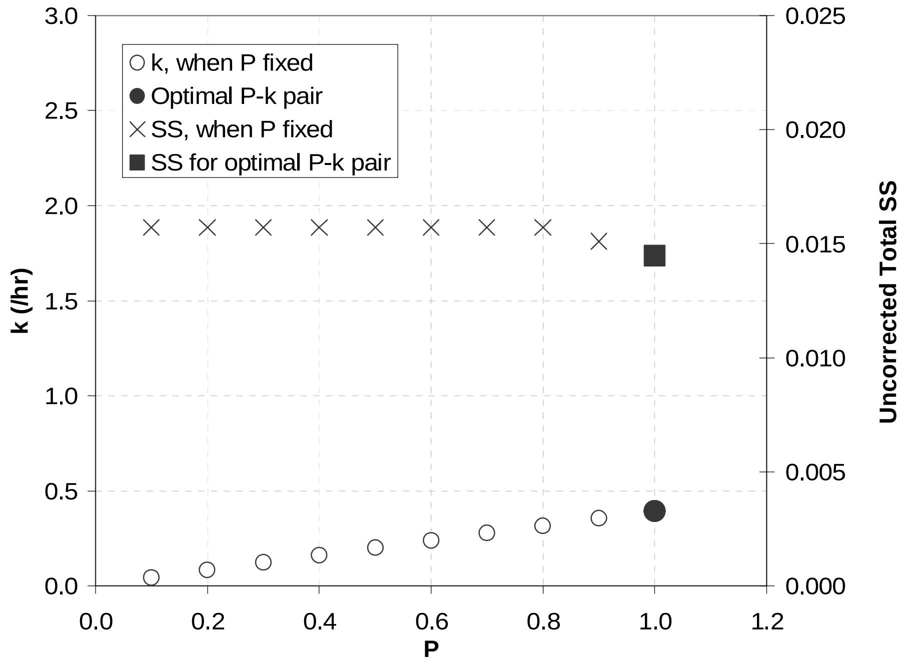
[1]Bold indicates significance at the 0.05 level. [2]Estimate was bounded at one. *P* and *k* were estimated using dynamic mass balance model.

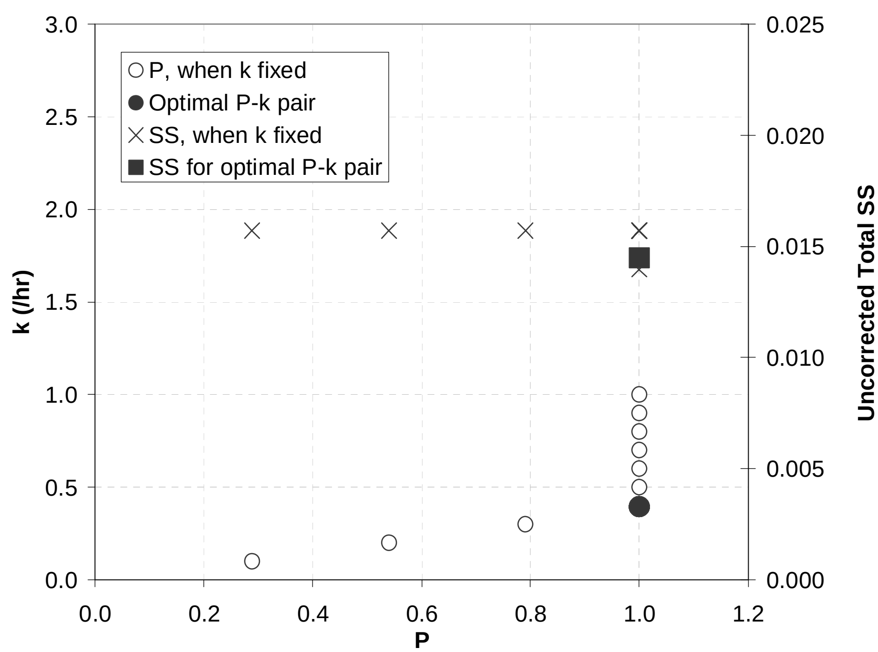
Optimal values for *P* and *k* were found to vary by particle size (Table 70). *P* was highest for $PV_{0.03-0.04}$ and lowest for PV_{3-4}, while *k* was lowest for $PV_{0.3-0.4}$ and highest for PV_{3-4}. Estimates of *k* are consistent with particle theory, where deposition is greatest for ultra-fine and coarse particles, since these particles are most affected by diffusion and gravitational settling, respectively. Estimates, however, were somewhat surprising for *P*, especially for $PV_{0.03-0.04}$, for which a lower value was expected due to its high diffusion coefficient.

When values for *P* and *k* were estimated independently by holding the other value constant, *P* and *k* values for each of the three particle sizes were found to increase together linearly, which is likely due to the fact that *P* and *k* are coupled. Model errors (as determined using the sum of squared differences) for many of these *P* and *k* pairs were similar, suggesting that numerous "optimal" values existed for *P* and *k* (Figure 74). These "optimal" values included a wide range of *P* and *k* values. For $PV_{0.03-0.04}$, for example, "optimal" values for *P* ranged between 0.2 and 1.0 and for *k* between 0 and 0.4 hr^{-1} (Figure 74). For $PV_{3.0-4.0}$, the range of "optimal" values of *P* was slightly narrower, with values 0.05 and 0.45, while for *k* the range was broader, between 0 and 2.5 hr^{-1}. The wide range of "optimal" estimates suggests that for this time period, the dynamic models provided only imprecise estimates of *P* and *k* for the three particle size intervals. Of the three size intervals, the estimates were the most imprecise for $PV_{0.3-0.4}$, as indicated by its model error, which was large even when normalized by the mean indoor or outdoor concentration (Figure 74). Large model errors may be attributed to the broad range in indoor and outdoor concentrations for accumulation mode particles.

Figure 74. *P* and *k* Estimates and Errors: House 16 – Nighttime, Non-Source Period*

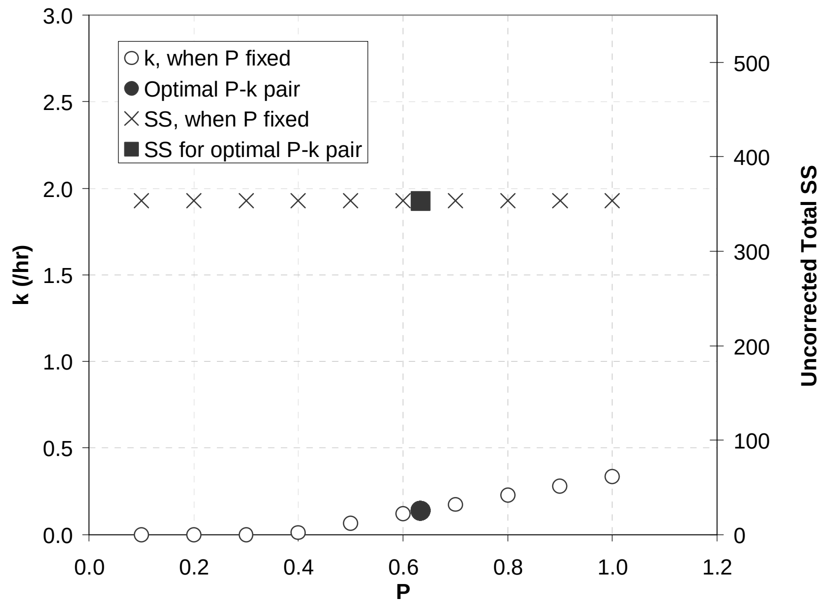
(a) $PV_{0.03\text{-}0.04}$

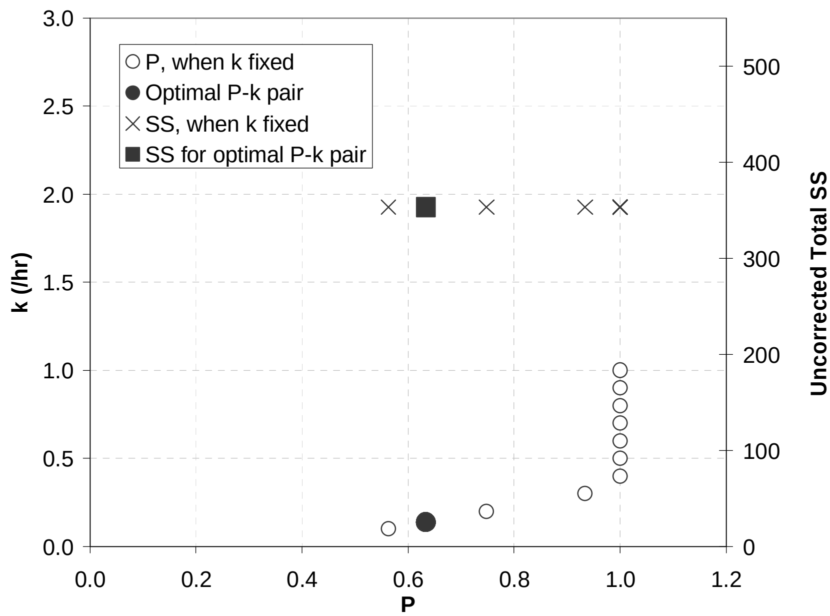




* Plot on top shows the variation in *k* when *P* is fixed; plot on bottom shows variation in *P* when *k* is fixed. Data from February 14, 2002 (12-6am).

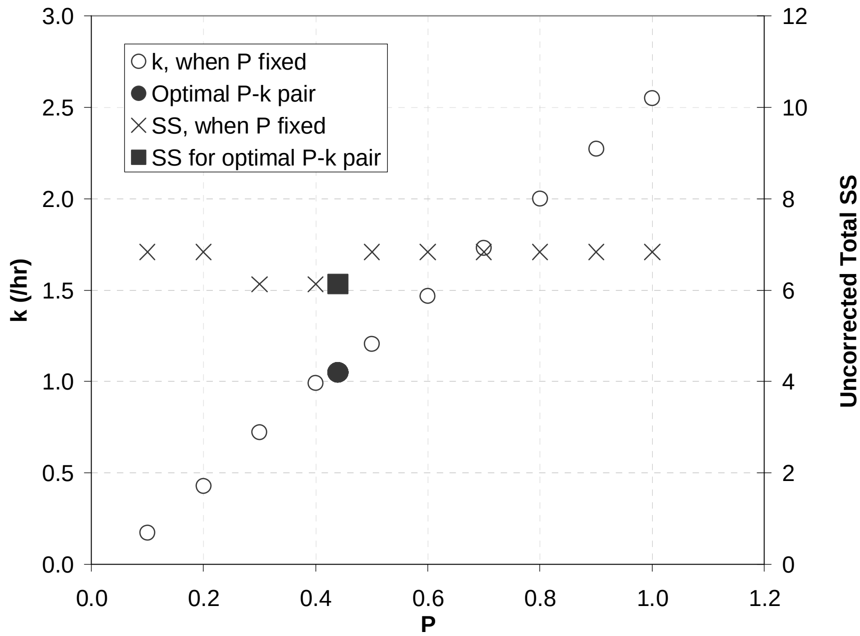
(b) $PV_{0.3\text{-}0.4}$

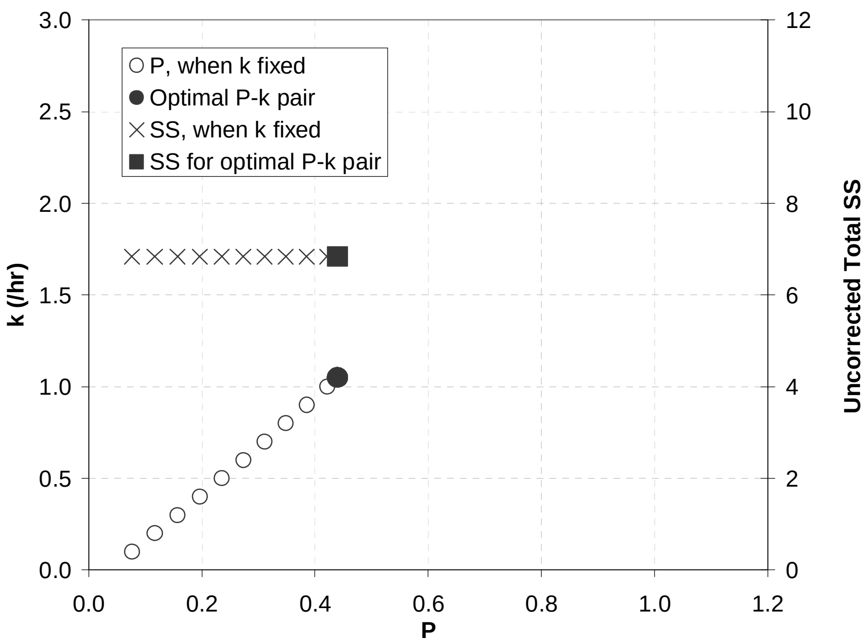




* Plot on top shows the variation in *k* when *P* is fixed; plot on bottom shows variation in *P* when *k* is fixed. Data from February 14, 2002 (12-6am).

(c) $PV_{3.0\text{-}4.0}$





* Plot on top shows the variation in *k* when *P* is fixed; plot on bottom shows variation in *P* when *k* is fixed. Data from February 14, 2002 (12-6am).

4.1.4.2 Particle decay after an indoor source event. Following an approach similar to that used by the controlled test home studies (Thatcher and Layton, 1995; Vette et al., 2001; Chao et al., 2003; Thatcher et al., 2003), periods following indoor source peaks were examined in order to estimate *P* and *k* for times in which indoor concentrations changed significantly over time. Post-indoor source periods were selected manually using housing activity diaries and indoor time-series plots. Since initial declines in indoor concentrations following an indoor source event were likely due to dilution rather than deposition, selected post-source periods generally began well into the post-indoor source period, to allow particles generated by the indoor source to mix throughout the home.

Results from these analyses are illustrated using a post-cleaning event from House 13, for which the peak concentration occurred at 11:45 pm on January 14, 2002 (Figure 75a-c, top plots). During the cleaning event, peak concentrations were extremely high (approximately 145 $\mu m^3/cm^3$ for the 0.3-0.4 µm size range) and were evident for all particle size intervals (Figure 75). ***P*** and were ***k*** were estimated using 2.5 hours of data after this peak concentration, from 12:25am to 2:45am. [Data after 2:45am were not included in the model due to the elevation of indoor coarse particle concentrations at 2:50 am (Figure 75c).] During this time, mean indoor concentrations were much higher than mean outdoor concentrations (Table 71).

Table 71. Indoor and Outdoor Particle Volume Concentrations ($\mu m^3/cm^3$) and Optimal *P* and *k* values: House 13, January 15, 2002 (12:25-2:45am)[1]

Size Bin (µm)	Location	N	Mean	SD	Min	Max	P (SE)	k (SE), hr^{-1}
0.03-0.04	Indoor	28	0.022	0.014	0.009	0.062	1.0*	**0.91 (0.03)**
	Outdoor	28	0.009	0.002	0.006	0.014		
0.3-0.4	Indoor	28	24.85	13.49	9.47	55.48	1.0*	**0.57 (0.01)**
	Outdoor	28	4.02	0.76	3.08	5.25		
3.0-4.0	Indoor	28	2.53	1.42	0.87	5.29	0.03 (0.11)	**0.63 (0.04)**
	Outdoor	28	4.14	0.33	3.62	4.66		

[1]Values in bold indicate model significance at the 0.05 level; [*]Estimate was limited to 1.0 as specified by the model.

Optimal values for ***P*** and ***k*** were found to vary by particle size (Table 71). ***P*** was estimated to equal 1.0 (as bounded by the model) for $PV_{0.03\text{-}0.04}$ and $PV_{0.3\text{-}0.4}$ and approximately zero for $PV_{3\text{-}4}$, while ***k*** was lowest for $PV_{0.3\text{-}0.4}$ (0.57±0.01) and highest for $PV_{0.03\text{-}0.04}$ (0.91±0.03). Estimates of ***k*** are consistent with particle theory, where deposition is greatest for ultra-fine and coarse particles, since these particles are most affected by diffusion and gravitational settling, respectively. As was the case with the estimate for nighttime, non-source periods, estimates were again somewhat surprising for ***P***, especially for $PV_{0.03\text{-}0.04}$, for which a lower value was expected due to its high diffusion coefficient.

Model errors were again largest for particles between 0.3-0.4 µm in size, which is likely due to their high initial indoor levels and their large concentration change over the modeled time period (Figure 75). In addition, when values for ***P*** and ***k*** were estimated independently by holding the other value constant, numerous ***P-k*** pairs were again found to fit the model with similar accuracy, suggesting that the model was still not able to differentiate between ***P*** and ***k*** (Figure 75). [For an unknown reason, when asked to simultaneously solve for both ***P*** and ***k***, the model did not choose the pair with the lowest error for $PV_{3.0\text{-}4.0}$.]

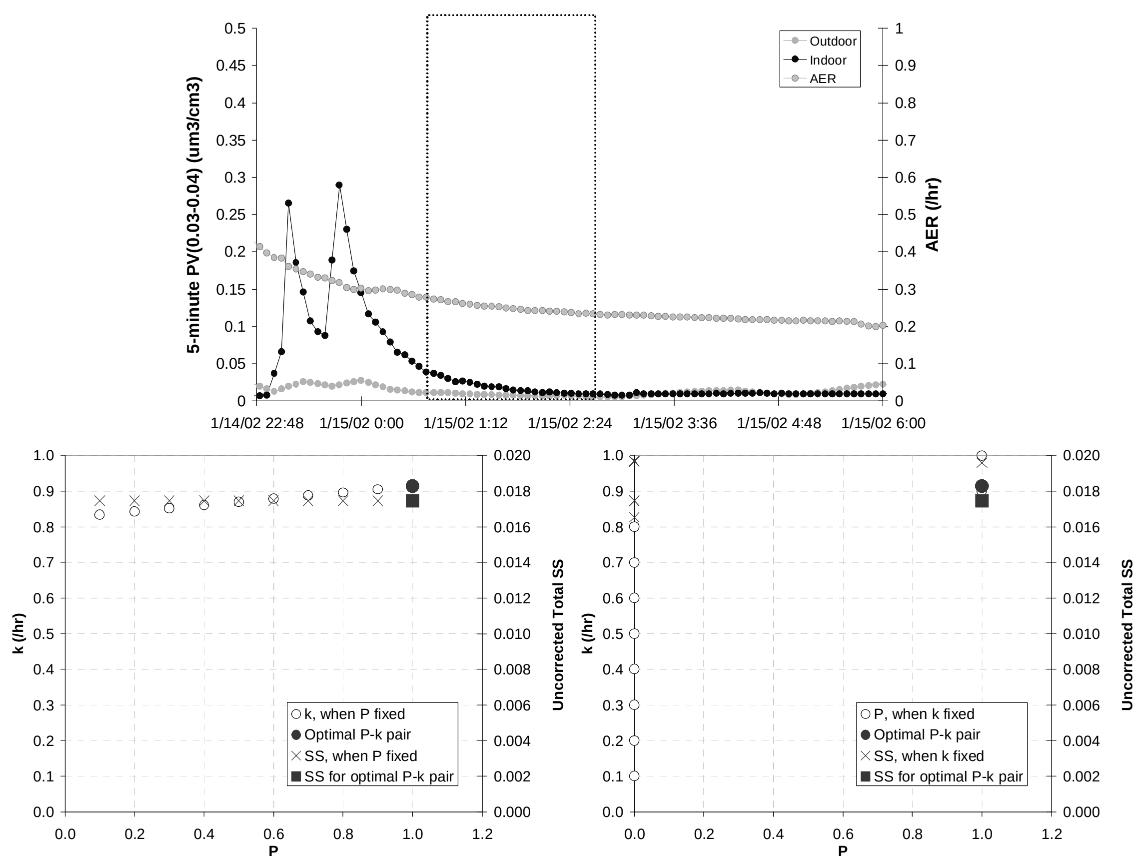
Although truely "optimal" values were not identified using post-indoor source data, possible values for ***k*** were narrowly distributed. For $PV_{0.03\text{-}0.04}$, possible estimates ranged between 0.8 and 0.9 hr^{-1}; for $PV_{0.3\text{-}0.4}$ estimates ranged between 0.5 and 0.6 hr^{-1}; and for $PV_{3\text{-}4,}$

estimates ranged between 0.6 and 1.0 hr^{-1} (Figure 75; lower left). The narrow range in possible *k* values suggests that estimated *k* values were relatively stable across particle sizes for the post-indoor source periods. These stable estimates are likely due to the fact that values for *k* were estimated for periods when particle losses due to deposition were large relative to particle gains from infiltration. It should be noted that deposition estimates for the three particle size intervals were greater than those estimated using mass balance models, which is likely due to the fact that mass balance model estimates were based on all nighttime data with longer averaging times. Large errors, however, were associated with mass balance deposition estimates, as mass balance model estimates were statistically insignificant.

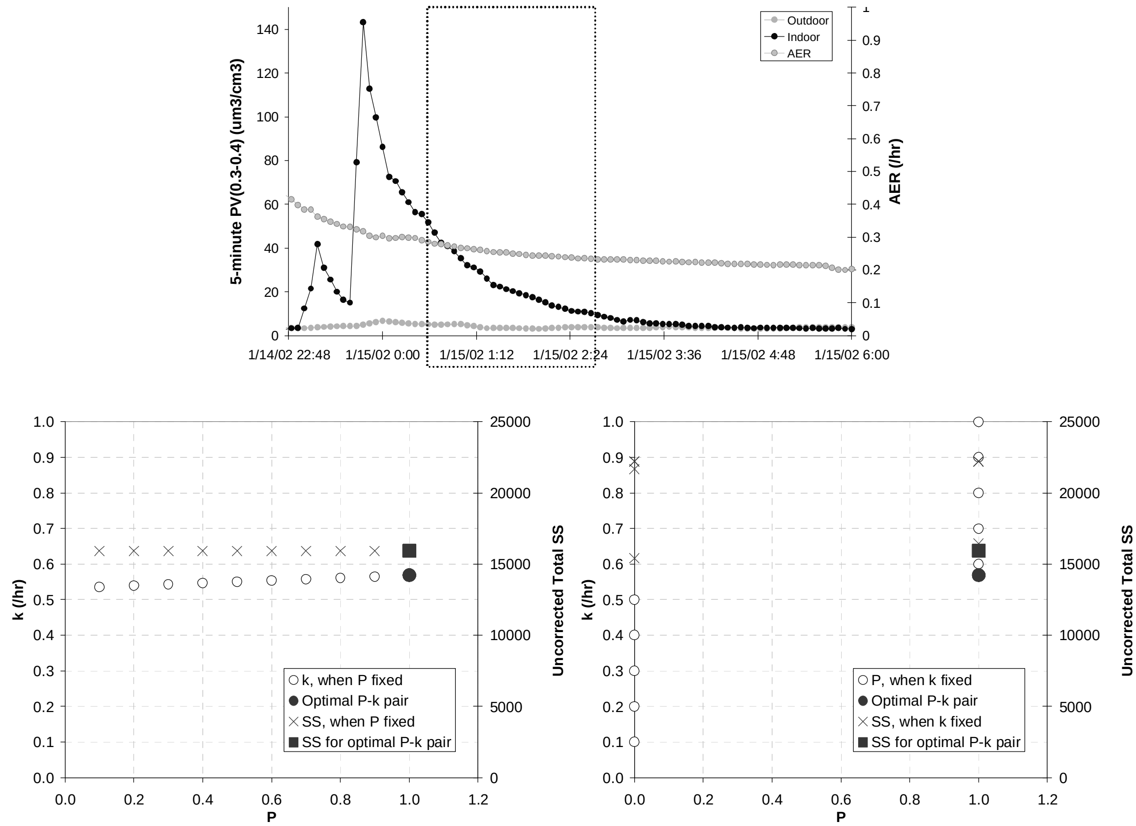
Corresponding estimates of *P* were unstable for the modeled post-source time period. As shown on Figure 75 (lower right-hand plots), possible values for *P* were generally equal either to zero or one, depending on whether the corresponding value for *k* was fixed to a value below or above its optimal range. The imprecise estimates for *P* are likely due to the use of data obtained during a time period when depositional losses were the dominating factor.

Figure 75. *P* and *k* Estimates and Errors: House 13 – Post-Indoor Source Period*

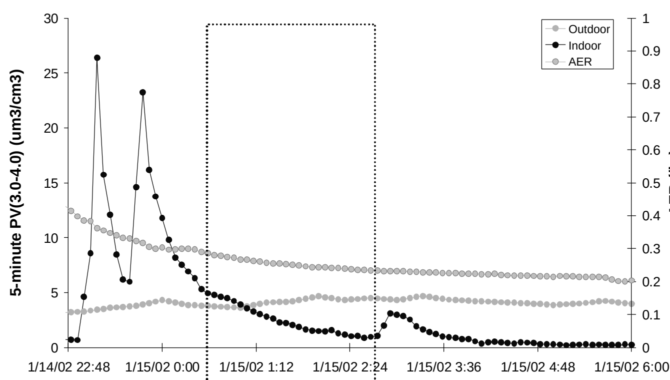
a) Size range: 0.03-0.04 µm

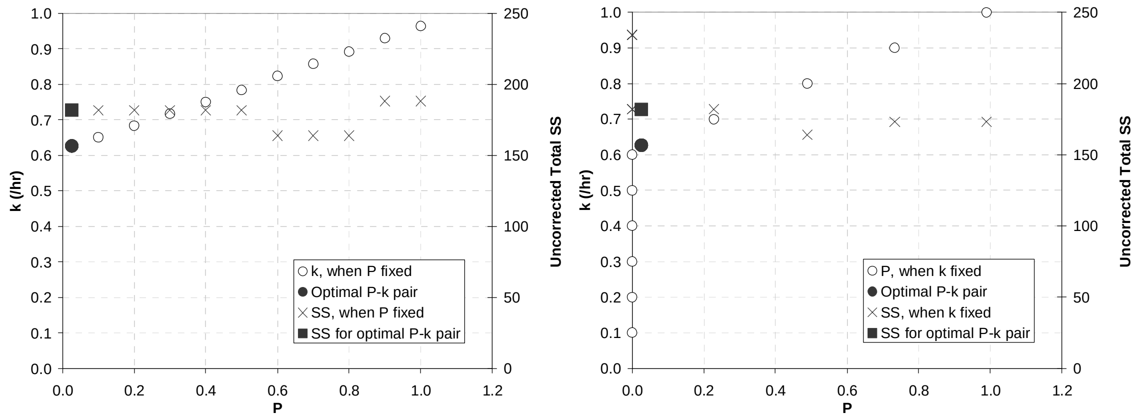


b) Size range: 0.3-0. 4 µm



c) Size range: 3.0-4.0 µm





[*] Post-indoor source event for House 13 on 01/15/02 for three size ranges; top plots show indoor and outdoor concentrations and air exchange rates for the modeled time period; lower left-hand plots show estimates of *k* when *P* is fixed; lower right-hand plots show estimates of *P* when *k* is fixed.

4.1.4.3 Non-steady nighttime, non-source data. Non-source periods during which indoor and outdoor concentrations varied were examined to determine whether robust estimates of *P* and *k* could be determined for these time periods. Results are illustrated using nighttime data from House 16 on February 10, 2002 from 12-6am. For this house and time period, indoor and outdoor concentrations were characterized by large changes in outdoor concentrations for each particle size range, with corresponding changes in indoor concentrations occurring slightly after those in outdoor concentrations (Figure 76a-c, top plots; Table 72).

Table 72. Indoor and Outdoor Particle Volume Concentrations ($\mu m^3/cm^3$) and Optimal *P* and *k* values: House 16, February 10, 2002 (12-6am)[1]

Size Bin (µm)	Location	N	Mean	SD	Min	Max	P (SE)	k (SE), hr^{-1}
0.03-0.04	Indoor	72	0.029	0.007	0.019	0.050	**0.64 (0.02)**	0.00*
	Outdoor	72	0.045	0.022	0.011	0.13		
0.3-0.4	Indoor	72	1.27	0.95	0.16	3.53	1.00*	0.00*
	Outdoor	72	1.18	1.18	0.13	4.50		
3.0-4.0	Indoor	72	2.24	1.18	0.71	5.30	**0.46 (0.05)**	0.13 (0.11)
	Outdoor	72	5.68	3.22	1.98	14.91		

P and *k* estimated using dynamic mass balance model. [1]Values in bold were significant at the 0.05 level. [*]Estimate was limited to the bounds set on the parameter.

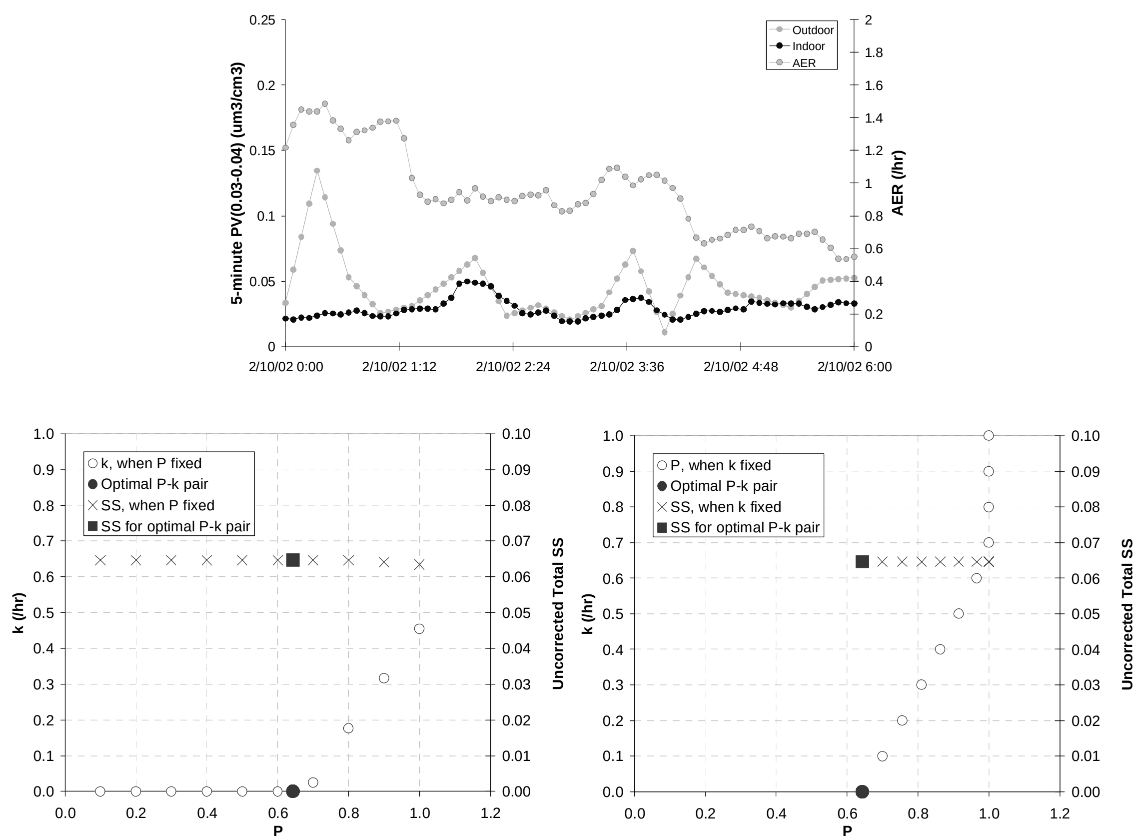
"Optimal" values for *P* found to vary by particle size, with again the value being highest for the accumulation mode particles $PV_{0.3\text{-}0.4}$ (Table 72). "Optimal" values for *k*, however, were near zero for each of the particle size intervals (Table 69). Estimates of *P* are consistent with particle theory, where deposition is greatest for ultra-fine and coarse particles and thus these particles are removed more readily as they penetrate the building shell, resulting in a lower value of *P*.

When values for P and k were estimated independently by holding the other value constant, model errors (as determined using the sum of squared differences) for many of the P and k pairs were similar, again suggesting that numerous "optimal" values existed for P and k (Figure 76). It should be noted, however, that resultant P and k pairs differed depending on which parameter was held constant. For example, when P was fixed at one, the k for $PV_{0.03\text{-}0.04}$ was estimated to equal 0.45 hr^{-1} (Figure 76, lower left-hand plot). Yet, when k was fixed at 0.45, the resulting estimate for P equaled 0.9 (Figure 76, lower right-hand plot). Although these differences may be relatively small, they are indicative of instability in the P and k estimates, which if true would also likely result in a wide range of possible P and k values.

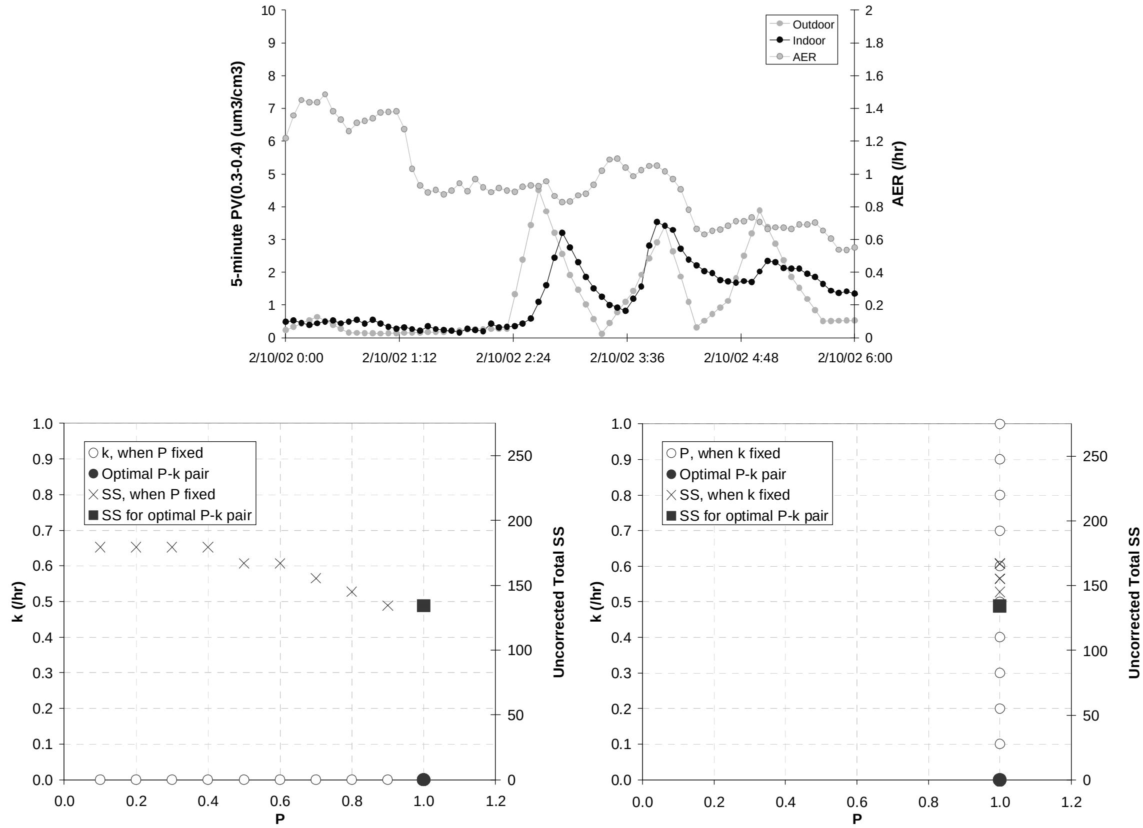
For P, possible values for $PV_{0.03\text{-}0.04}$ and $PV_{3\text{-}4}$ ranged between 0.65 and 1.0 and between 0.4 and 0.8, respectively (Figure 76). For $PV_{0.3\text{-}0.4}$, P was estimated to equal one for all examined k values. These results suggest that estimates of P obtained using non-steady, non-source data were more stable than those obtained using post-indoor source and to a lesser degree steady, non-source period data; however, estimates were still relatively imprecise. Possible values of k for all values of P, on the other hand, were either extremely low, with many bounded to zero, or rose steeply with P (Figure 76a-c, lower left-hand plots). These results are consistent with instability in estimates of k.

Figure 76. *P* and *k* Estimates and Errors: House 16 – Variable Non-Source Period*

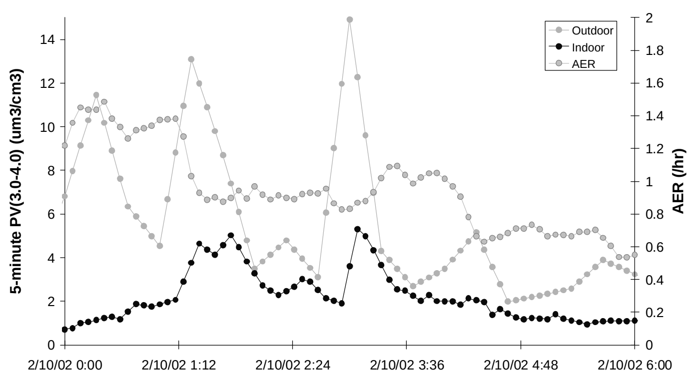
a) $PV_{0.03\text{-}0.04}$

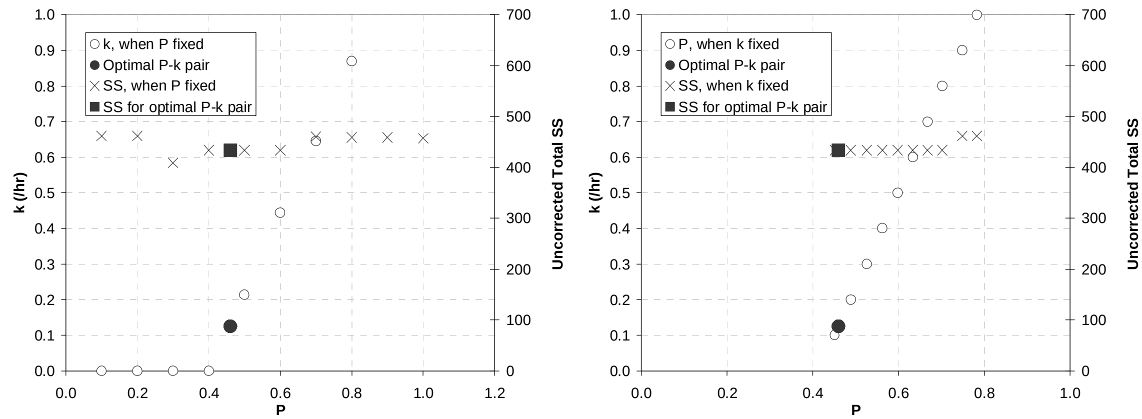


b) $PV_{0.3\text{-}0.4}$



c) $PV_{3\text{-}4}$





Examination of nighttime, non-source data for House 16 on February 10, 2002 across the three size ranges. Top plots show indoor and outdoor concentrations and air exchange rates for the modeled time period; lower left-hand plots show estimates of *k* when *P* is fixed; lower right-hand plots show estimates of *P* when *k* is fixed.

4.1.4.4 Summary. Estimates of *P* and *k* obtained using the dynamic mass balance model were generally imprecise, as for each time period and size, numerous *P* and *k* pairs were identified that were equivalent as measured by the model error. The inability of the model to distinguish values of *P* and *k* more precisely is likely due to the structure of our data as well as to our modeling methodology. In contrast to studies conducted in test homes, models were based on data sampled under real-life conditions; as a result, indoor particle concentrations and air exchange rates were not controlled, preventing deposition and penetration from being estimated under separate and distinct time periods. Precision of the estimates, as determined by estimating the parameters independently while holding the other constant, was greatest for post-indoor source time periods for *k* or and for non-source, varying outdoor concentration periods for *P*. During these time periods, it is likely that influences by either deposition or penetration dominated the indoor particle levels, respectively thus allowing greater precision in modeling the corresponding parameter. For any single time period, however, precise estimates for both *P* and *k* were not obtained.

Table 73. Estimates of *P* and *k* By Period: Dynamic Mass Balance Models[1]

Size Bin (µm)	Non-Source, Constant C_o		Post-Indoor Source		Non-Source, Varying C_o	
	P (SE)	k (SE) (hr^{-1})	P (SE)	k (SE) (hr^{-1})	P (SE)	k (SE) (hr^{-1})
0.03-0.04	**1.0[2]**	**0.39 (0.00)**	1.0[2]	**0.91 (0.03)**	**0.64 (0.02)**	0.00[3]
0.3-0.4	**0.63 (0.10)**	**0.14 (0.05)**	1.0[2]	**0.57 (0.01)**	1.0[2]	0.00[3]
3.0-4.0	**0.44 (0.16)**	**1.05 (0.41)**	0.03 (0.11)	**0.63 (0.04)**	**0.46 (0.05)**	0.13 (0.11)

[1]Bold indicates significance at the 0.05 level. Co represents outdoor concentration. [2]Estimate was bounded at one. [3]Estimates was bounded at zero.

Perhaps as a result of these imprecise estimates, estimates of *P* and *k* varied considerably with time period. For $PV_{0.03\text{-}0.04}$, for example, estimates of *P* equaled 0.64 when estimates were obtained using data from a non-source, varying outdoor concentration period, but equaled one when estimates were obtained using data from periods when outdoor concentrations were constant or from periods immediately following an indoor source event (Table 73). Similarly, estimates of k for this particle size interval also varied substantially by time period, with values ranging between zero and 0.90 hr^{-1}. Analogous differences in the estimates of P and k were found for other particle size intervals. As discussed above, these discrepancies may be the result of imprecise estimation methods, but could also indicate that P and k vary by time period and/or home, perhaps as the result of different air exchange rate or concentration conditions.

4.2 Part 2: Characterization of 24-h Personal Particulate Exposures

24-h indoor, outdoor and personal particulate exposures were characterized together with time-activity patterns. Data used in these analyses were based only on 24-h integrated measurements. No continuous data were used in these analyses. Note that reflectance measurements were converted to a more standard measure of elemental carbon by regressing reflectance on 24-h aethalometer measurements. However, since the aethalometer measures black carbon and not elemental carbon concentrations, data are reported below as equivalent BC concentrations.

4.2.1 Time-Activity Patterns

Subjects who wore the personal monitor spent the majority of their time at home indoors (mean of 69%) (Table 74), with non-working subjects spending more time indoors at home (80-90%) as compared to employed participants, who spent between 2%-36% of their time at work. Time spent in other microenvironments ranged broadly, with the average time spent in non-home indoor environments ranging between 1% and 32% and outdoors or in a motor vehicle between 6-11%. Activity patterns were, however, shown to differ substantially by hour, as time spent in indoor non-home locations, outdoors and in transit occurred only during the waking hours (6am-10pm) (Table 75). It is possible that the early start of the workday is due to the erroneous inclusion by study participants of transit time as work time. While these findings are generally consistent with time-activity patterns of other population subgroups, participants in our study spent on average less time at home and more time at work and in transit as compared to healthy, older adults (Klepeis *et al.* 1996) and sensitive (Ebelt *et al.* 2000; Chang and Suh 2003) individuals.

4.2.2 24-h Particulate Exposures

Summary statistics for $PM_{2.5}$, black carbon, and NO_3^- stratified by sample type are presented in Figure 77, Figure 78 and Table 76. In general, outdoor $PM_{2.5}$ and NO_3^- concentrations measured at the homes (28.8$\pm$20.4 and 10.8$\pm$10.2 ug/m^3, respectively) were higher than those measured in indoor (17.6$\pm$11.4 and 3.0$\pm$4.0 ug/m^3, respectively) and personal (17.7$\pm$11.9 and 3.8$\pm$4.3 ug/m^3, respectively) environments, for which mean levels were comparable. For $PM_{2.5}$, indoor, outdoor, and personal concentration relationships differ from those found in our earlier study of individuals with COPD, which found personal $PM_{2.5}$ exposures to be higher than outdoor and indoor concentrations (Chang and Suh 2003). In contrast, indoor, outdoor, and personal concentration relationships for NO_3^- were similar to those found in the COPD study. Higher outdoor NO_3^- concentrations are consistent with the fact that motor vehicles are the major source of NO_3^-. Personal, indoor and outdoor BC levels were comparable, with the relationship between their levels similar to those found for indoor and outdoor BC measured using aethalometers and to those found for EC in our earlier COPD study.

Table 74. Activity Patterns: Average by House and Microenvironment[1]

House	# Days	Indoors – Home	Indoors - Work	Indoors - Other	Outdoors	In Transit
2	5	0.39	0.36 [2]	0.32 [2]	0.27 [2]	0.12 [2]
3	7	0.80	0.00	0.07	0.01	0.13
4	7	0.68	0.19	0.06	0.08	0.07
5	6	0.87	0.00	0.03	0.07	0.05
6	7	0.75	0.19	0.01	0.05	0.07
7	7	0.90	0.00	0.06	0.02	0.06
8	7	0.80	0.00	0.12	0.08	0.11
9	7	0.67	0.16	0.05	0.06	0.07
10	6	0.65	0.02	0.15	0.06	0.15
11	7	0.47	0.27	0.07	0.01	0.22
12	6	0.68	0.16	0.17	0.04	0.11
13	7	0.66	0.21	0.08	0.05	0.11
14	5	0.60	0.16	0.03	0.08	0.18
15	7	0.82	0.00	0.04	0.03	0.12
16	7	0.52	0.24	0.04	0.07	0.16
17	7	0.61	0.02	0.28	0.01	0.10
Mean	105	0.69	0.12	0.09	0.06	0.11
SD		0.19	0.17	0.13	0.08	0.08
Median		0.72	0.00	0.05	0.03	0.09
Max		1.00	0.51	0.51	0.37	0.42

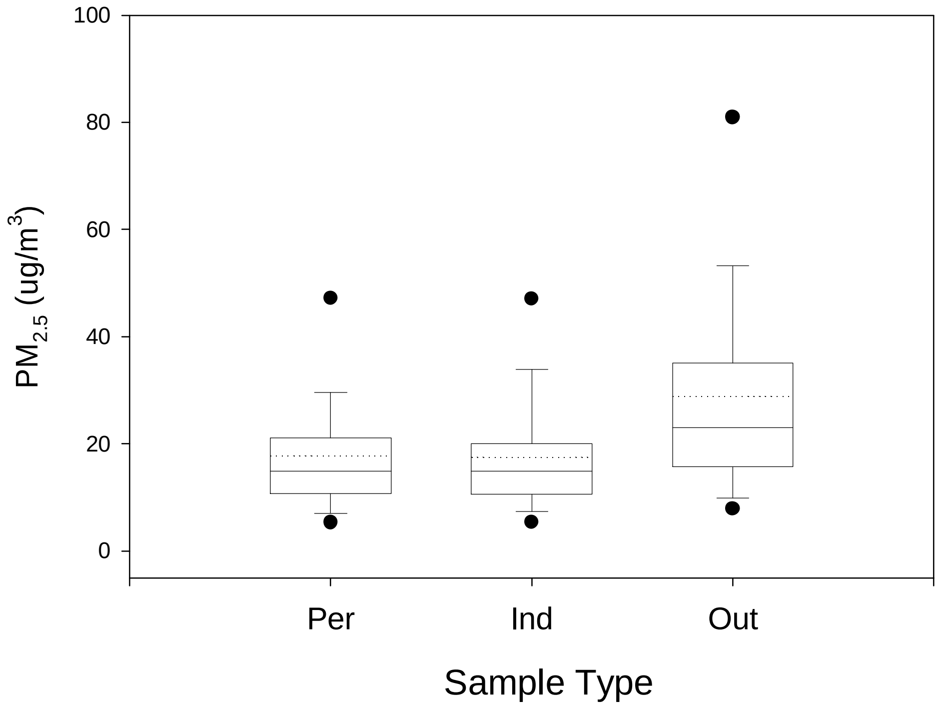
[1] Values were calculated from data from the participant-completed time-activity diaries. Values are expressed as fraction of time over a 24-hr period. Summary statistics (e.g., mean, standard deviation, median, minimum and maximums) were calculated using all data rather than mean values for the 16 participants.
[2] This subject double entered several locations for many 20-minute periods (i.e. multiple microenvironments during same 20-minutes).

Table 75. Activity Patterns: Average by Hour and Microenvironment[1]

Hour	N	Indoors – Home	Indoors – Work	Indoors - Other	Outdoors	In Transit
0	105	0.99	0.01	0.00	0.00	0.00
1	105	0.99	0.01	0.00	0.00	0.00
2	105	0.99	0.01	0.00	0.00	0.00
3	105	0.99	0.01	0.00	0.00	0.00
4	105	0.99	0.01	0.00	0.00	0.00
5	210	0.98	0.01	0.00	0.00	0.00
6	210	0.91	0.02	0.00	0.00	0.08
7	210	0.70	0.09	0.02	0.10	0.15
8	177	0.42	0.32	0.14	0.11	0.14
9	178	0.40	0.33	0.12	0.10	0.12
10	184	0.40	0.29	0.17	0.11	0.14
11	186	0.39	0.30	0.18	0.08	0.18
12	186	0.38	0.28	0.20	0.10	0.20
13	195	0.42	0.26	0.19	0.14	0.16
14	198	0.43	0.29	0.15	0.10	0.16
15	203	0.49	0.22	0.14	0.09	0.19
16	207	0.56	0.15	0.14	0.08	0.16
17	208	0.65	0.11	0.11	0.07	0.16
18	209	0.71	0.01	0.11	0.06	0.22
19	210	0.66	0.01	0.17	0.08	0.16
20	210	0.74	0.00	0.13	0.03	0.12
21	210	0.85	0.01	0.08	0.02	0.07
22	210	0.93	0.01	0.03	0.02	0.04
23	210	0.99	0.01	0.00	0.00	0.00
Mean		0.72	0.11	0.08	0.05	0.10
SD		0.43	0.31	0.26	0.20	0.25
Median		1.00	0.00	0.00	0.00	0.00

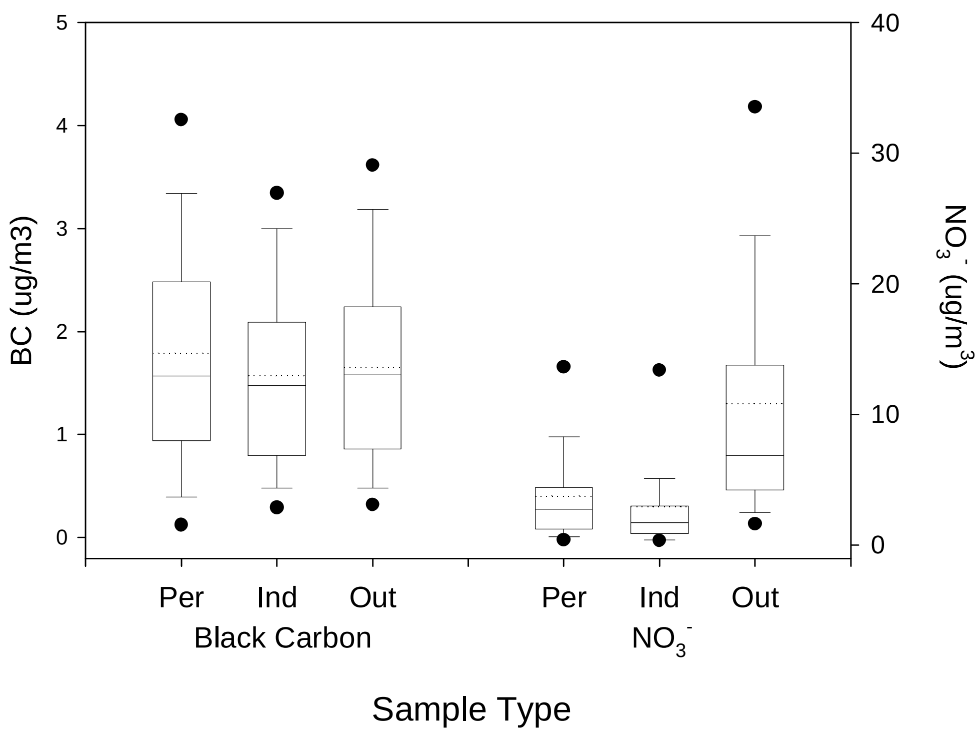
Values calculated from participant-completed time-activity diaries, with values expressed as fraction of time over a 24-hr period. Summary statistics (e.g., mean, standard deviation and medians) were calculated using all data rather than mean values for the 16 participants.

Figure 77. $PM_{2.5}$ Concentrations by Sample Type



Dotted line indicates mean value.

Figure 78. BC and NO_3^- Concentrations by Sample Type



Dotted line indicates mean value.

Table 76. Descriptive Statistics for Outdoor, Indoor, and Personal Samples

Pollutant/Location	n	Mean ± Std. Dev.	Maximum	Minimum
$PM_{2.5}$ ($\mu g/m^3$)				
Outdoor	103	28.82 ± 20.43	102.99	5.11
Indoor	106	17.56 ± 11.39	58.74	2.98
Personal	91	17.74 ± 11.90	68.10	1.47
NO_3^- ($\mu g/m^3$)				
Outdoor	99	10.84 ± 10.21	54.48	0.26
Indoor	102	2.95 ± 4.02	22.19	0.26
Personal	94	3.78 ± 4.25	24.08	0.19
BC ($\mu g/m^3$)				
Outdoor	103	1.66 ± 0.99	4.23	-0.10
Indoor	106	1.57 ± 0.95	4.12	-0.24
Personal	90	1.79 ± 1.27	7.07	-0.43

4.2.3 Composition

The composition of $PM_{2.5}$ differed by microenvironment (Figure 79 through Figure 81). NO_3^- (as ammonium nitrate) comprised approximately half of fine particle mass outdoors and comprised substantially smaller fractions of $PM_{2.5}$ in indoor (18%) and personal (26%) environments. As was the case with 6-hr averaged $PM_{2.5}$, the contribution of BC to $PM_{2.5}$ was relatively uniform across microenvironments, with BC comprising approximately 10% of $PM_{2.5}$ in all three microenvironments. "Other" non-measured $PM_{2.5}$ components comprised the largest fraction of $PM_{2.5}$ in indoor environments, followed by personal environments and finally by outdoor environments. The contributions of NO_3^- and BC to 24-h outdoor and indoor $PM_{2.5}$ were similar to their contributions to 6-h outdoor and indoor $PM_{2.5}$, especially in the afternoon and at night, providing further evidence of the robustness of our measurement methods. Again, the large contribution of "other" or non-measured $PM_{2.5}$ species points to the need for measurements of additional $PM_{2.5}$ components.

Figure 79. Composition of Outdoor $PM_{2.5}$

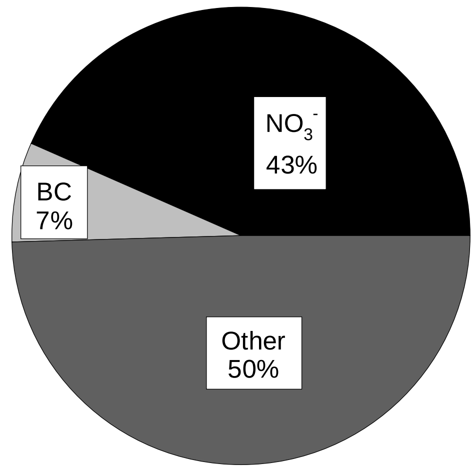


Figure 80. Composition of Indoor $PM_{2.5}$

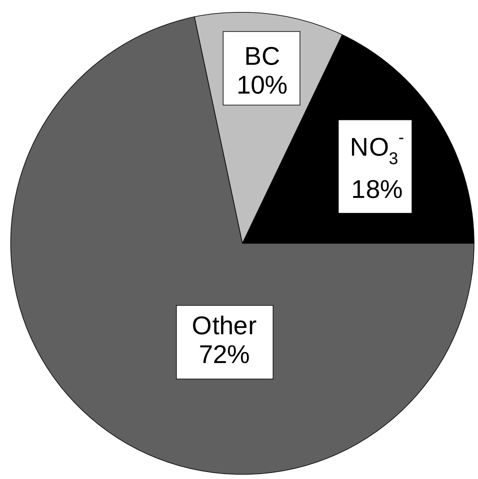
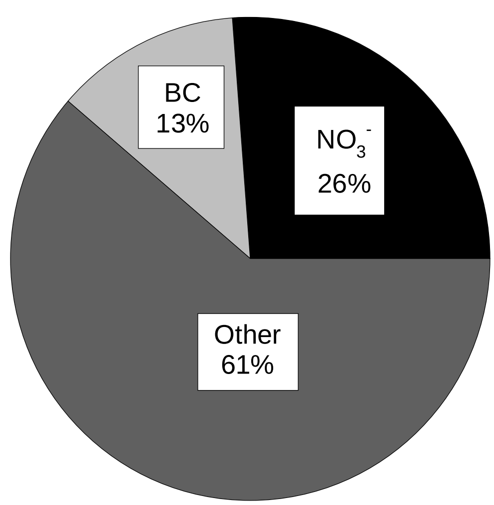


Figure 81. Composition of Personal $PM_{2.5}$



4.2.4 Personal Exposures, Indoor and Outdoor Concentration Relationship

For outdoor, indoor, and personal samples, correlations between $PM_{2.5}$ and both BC and NO_3^- were relatively strong, with correlation coefficients strongest for NO_3^- (Table 77). Correlations tended to be strongest among outdoor concentrations followed by indoor concentrations and personal exposures. Stronger associations among the pollutants outdoors as compared to indoors may reflect the fact that the sources of NO_3^-, BC, and to a lesser degree $PM_{2.5}$ are located primarily outdoors, including traffic and other motor vehicle-related pollution. The weaker associations among personal exposures as compared to among outdoor concentrations likely reflect the fact that individuals spend time both outdoors and indoors. For all 3 sampling types, associations were strongest between $PM_{2.5}$ and NO_3^-, especially in outdoor environments, followed by those between $PM_{2.5}$ and black carbon, and finally by those between NO_3^- and black carbon. Correlations between NO_3^- and BC were higher in personal and indoor environments as compared to outdoor environments, which was surprising given the fact that both particulate components originate primarily outdoors.

Table 77. Spearman Correlations (r_s) among $PM_{2.5}$, NO_3^-, and BC[1]

Type	Pollutant	NO_3^-	BC
Outdoor	**$PM_{2.5}$**	0.93	0.50
	NO_3^-		0.26
Indoor	**$PM_{2.5}$**	0.81	0.53
	NO_3^-		0.34
Personal	**$PM_{2.5}$**	0.72	0.48
	NO_3^-		0.37

1. All p-values<0.05

4.2.4.1 $PM_{2.5}$. When analyzed cross-sectionally, the association between personal $PM_{2.5}$ exposures and outdoor home concentrations was relatively strong, as outdoor concentrations explained approximately 50% of the variability in personal exposures (Figure 82). (The explained variability rose to 67% when one point, with substantially higher personal as compared to outdoor concentrations was excluded from the analysis.) The personal-outdoor association, however, varied widely by individual (Figure 83), with individual-specific correlation coefficients ranging between –0.97 to 0.97. Despite this, the median correlation coefficient was relatively high, equaling 0.68. This median value was substantially higher than that found in our earlier COPD study conducted in the metropolitan LA area (Chang and Suh 2003), but was comparable to those found in previous studies, including that conducted in Fresno, CA (R^2=0.70 for springtime personal-ambient associations (Evans *et al.* 2000)) and in other areas conducted in the eastern and Midwestern US (Rojas-Bracho *et al.* 2000; Sarnat *et al.* 2000). The slope of the personal on outdoor regression line equaled 0.39 (Table 75), indicating that individuals are exposed to approximately 40% of the $PM_{2.5}$ from outdoor environments.

Indoor-outdoor associations for $PM_{2.5}$ were higher than corresponding personal-outdoor associations. Outdoor concentrations explained 63% of the variability in indoor levels when analyzed cross-sectionally (Figure 84). (The explained variability rose to 76% when two points with substantially higher indoor as compared to outdoor levels were excluded from the analysis.) As was the case with personal-outdoor comparisons, the slope of the regression line of indoor on outdoor $PM_{2.5}$ equaled 0.42, suggesting an F_{INF} of 40% (Table 78). The similarity of the slopes for personal-outdoor and indoor-outdoor comparisons indicates that individuals' exposures to $PM_{2.5}$ occur primarily in indoor environments. The strong association between indoor and outdoor concentrations is consistent with that for 6-h concentrations, for which outdoor $PM_{2.5}$ concentrations explained 83% of the variability in 6-h nighttime indoor levels and for which F_{INF} was estimated to equal 40%. The median individual-specific correlation coefficient was also higher than that for personal-outdoor associations, equaling 0.76 (Figure 83). Again, substantial inter-personal variability in the correlation coefficients was observed, as values ranged between 0.07 and 0.96.

Figure 82. Personal vs. Outdoor Home $PM_{2.5}$ Concentrations

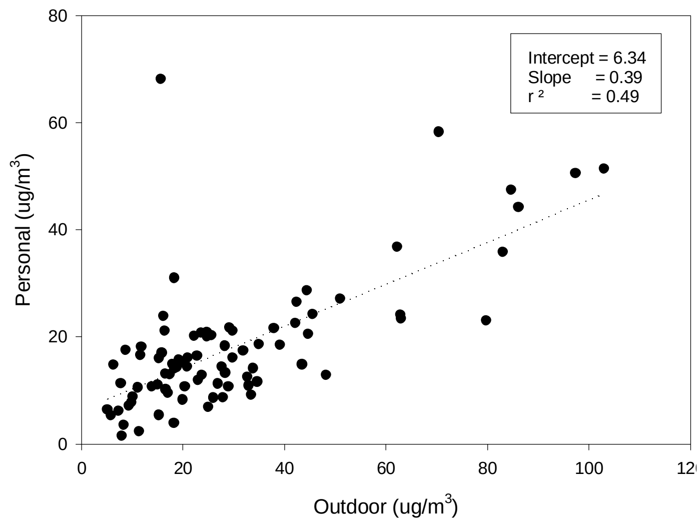
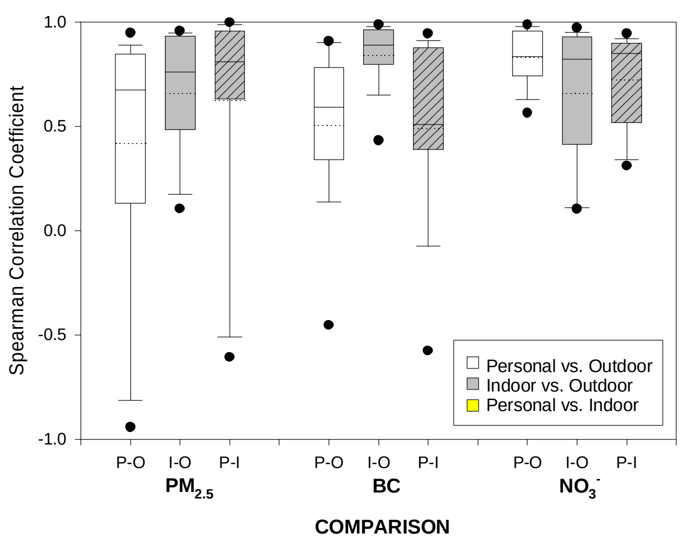
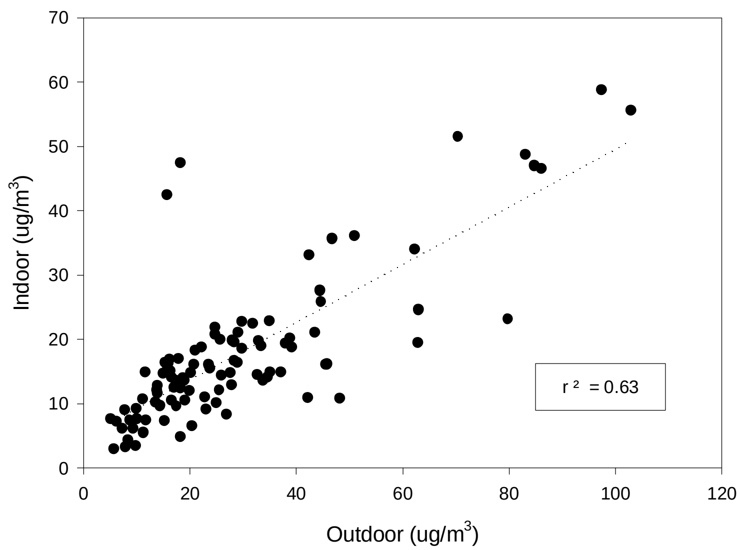


Figure 83. Individual-Specific Correlation Coefficients



* BC concentrations estimated from reflectance measurements and their relationship to indoor and outdoor aethalometer measurements. Dotted line shows mean concentrations.

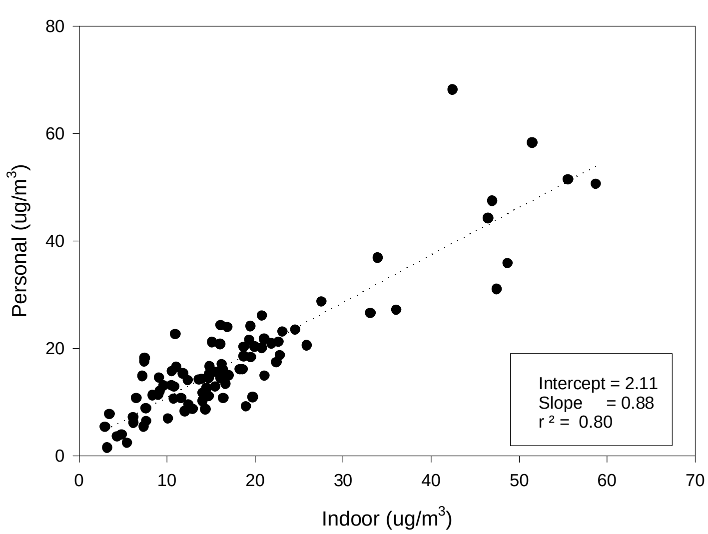
Figure 84. Indoor vs. Outdoor Home $PM_{2.5}$ Concentrations



Dotted line represents linear regression line of indoor on outdoor levels.

Individual-specific correlations for personal and indoor comparisons were highest, which was expected since participants spent the majority of their time indoors at home. The median correlation coefficient was 0.81, with a crude R^2 value of 0.80 (Figure 85). Despite this high median correlation and crude R^2 value, considerable inter-personal variability in the personal-indoor relationship was still observed, as coefficients ranged between –0.61 and 1.0 (Figure 83).

Figure 85. Personal vs. Indoor $PM_{2.5}$ Concentrations



Dotted line represents linear regression line of indoor on outdoor levels.

Table 78. Longitudinal Analysis for Pairwise Comparisons of Outdoor, Indoor and Personal Particulate Levels[1]

Pollutant	Comparison	n	Slope (SE)	Intercept (SE)
$PM_{2.5}$	Personal vs. Outdoor	84	0.39 (0.05)	6.70 (2.10)
	Indoor vs. Outdoor	100	0.42 (0.04)	5.72 (1.66)
	Personal vs. Indoor	88	0.92 (0.05)	1.58 (1.31)[2]
NO_3^-	Personal vs. Outdoor	88	0.34 (0.02)	0.15 (0.42)[2]
	Indoor vs. Outdoor	97	0.29 (0.02)	-0.09 (0.55)[2]
	Personal vs. Indoor	92	0.96 (0.05)	0.92 (0.33)
BC[3]	Personal vs. Outdoor	84	0.88 (0.12)	0.22 (0.25)[2]
	Indoor vs. Outdoor	101	0.83 (0.04)	0.02 (0.09)
	Personal vs. Indoor	88	0.99 (0.11)	0.15 (0.22)[2]

1. Results from mixed models using compound symmetry covariance matrix.
2. *Not significant at p=0.05.
3. BC concentrations estimated from reflectance measurements based on their relationship to indoor and outdoor aethalometer measurements.

When data were analyzed using repeated measures regression models, the relationships between personal exposures and indoor and outdoor home concentrations were found to follow similar patterns as has been observed in previous studies (Table 78). For personal-outdoor and indoor-outdoor comparisons for $PM_{2.5}$, for example, the slope of the regression lines was substantially lower than one with a significant intercept, with both slope and intercept values for the personal-outdoor similar to those for the indoor-outdoor comparisons. These comparable values are consistent with the fact that individuals spent the majority of their time indoors and suggest that indoor $PM_{2.5}$ concentrations reflect personal exposures well. Further support for this theory is provided by the observed relationship between personal $PM_{2.5}$ exposures and corresponding indoor concentrations, for which a slope close to one and an insignificant intercept was found. These results indicate that indoor concentrations are on average equivalent measures of personal $PM_{2.5}$ exposures.

Consistent with results from our studies of individuals with COPD conducted in Los Angeles and elsewhere, air exchange rates were found to affect both personal exposures and indoor concentrations. As shown on Figure 86 and Figure 87, at relatively high air exchange rates of around 1 exchange/hour and above, the indoor-outdoor ratios were generally close to one, which is consistent with penetration efficiencies close to one and a reduced influence of indoor sources. In contrast, at air exchange rates below 1 exchange/hour, indoor-outdoor ratios ranged widely with many values substantially greater than one, suggesting that indoor $PM_{2.5}$ sources can impact indoor concentrations and thus personal exposures at these lower air exchange rates. Air exchange rates, however, were not found to be significant predictors of either personal or indoor $PM_{2.5}$ when included as categorical variables in statistical models. This result was likely due in part to the relatively long averaging times of the $PM_{2.5}$ and air exchange rate measurements, which may obscure associations, since air exchange rates were found to be a significant predictor of 6-hr $PM_{2.5}$ measurements.

Figure 86. Personal/Outdoor $PM_{2.5}$ Ratios vs. Air Exchange Rates

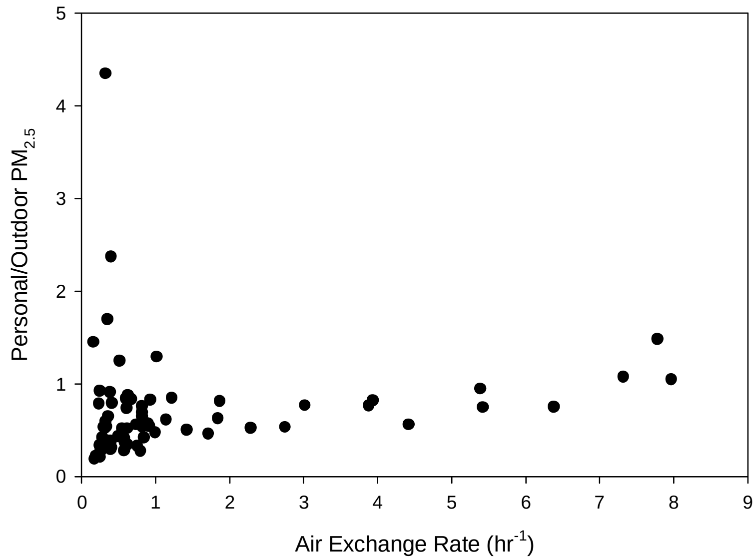
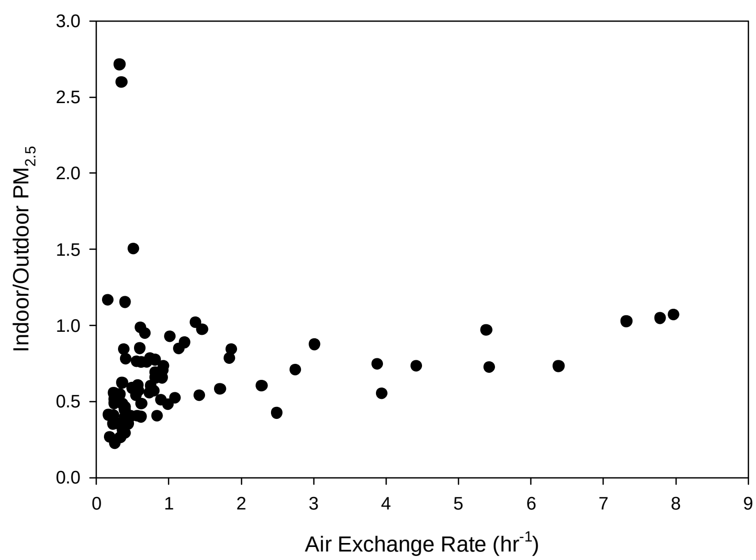


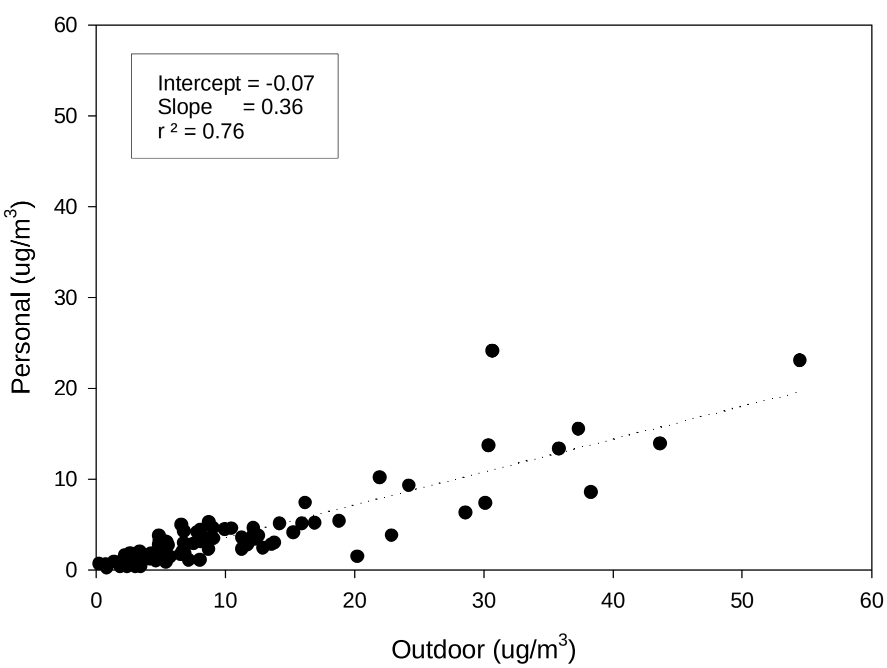
Figure 87. Indoor/Outdoor $PM_{2.5}$ Ratios vs. Air Exchange Rates



4.2.4.2 NO_3^-. When analyzed cross-sectionally, the associations among personal NO_3^- exposures and indoor and outdoor home concentrations were strong. Indoor and outdoor concentrations explained 84% and 76% of the variability in personal exposures, respectively (Figure 88, Figure 90), while outdoor concentrations explained 65% of the variability in indoor levels (Figure 89). Slopes of the regression lines for personal-outdoor (0.36) and indoor-outdoor (0.32) comparisons were comparable and substantially lower than one, which suggests an effective penetration efficiency of approximately 30% and that most of the exposures to outdoor NO_3^- occurs indoors. In contrast, the slope for the personal-indoor comparison was close to one, which is consistent with the fact that individuals spent the majority of their time indoors.

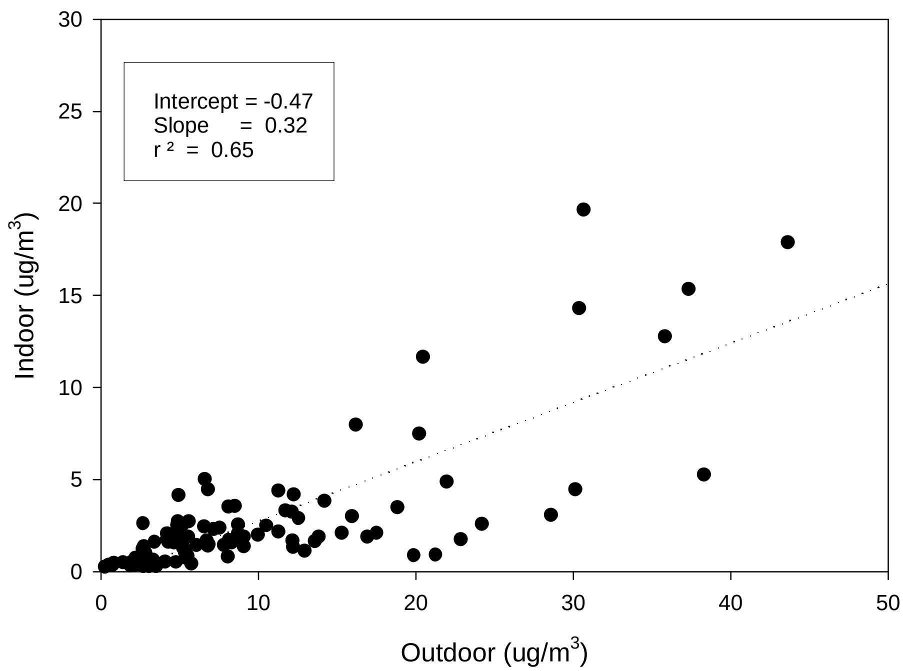
Unlike $PM_{2.5}$, the association between personal exposures and outdoor NO_3^- concentrations did not vary by individual, as individual-specific correlation coefficients for pair-wise personal-outdoor comparisons were higher and less variable than those for $PM_{2.5}$ (Figure 83). For indoor-outdoor and personal-indoor associations, however, correlations were lower and more variable when examined by individual, but were still relatively high and similar to those observed for $PM_{2.5}$. These lower and more variable indoor-outdoor and personal-indoor correlation coefficients may reflect the loss of NO_3^- in indoor environments, which may result in increased inter-personal variation in the observed correlations with indoor concentrations. When data were analyzed longitudinally, however, the slopes and intercepts of the pair-wise comparisons between personal, indoor, and outdoor concentrations were comparable to their respective comparisons in the cross-sectional analysis and were highly significant. The similarity in the results suggests that the slope and intercept did not vary with individual-specific characteristics. In addition, the non-significant intercepts for personal-outdoor and indoor-outdoor comparisons are consistent with the lack of NO_3^- sources in homes in Los Angeles. Both the slopes and intercepts are comparable to those found in our earlier study of individuals with COPD (Chang and Suh 2003).

Figure 88. Personal vs. Outdoor NO_3^-



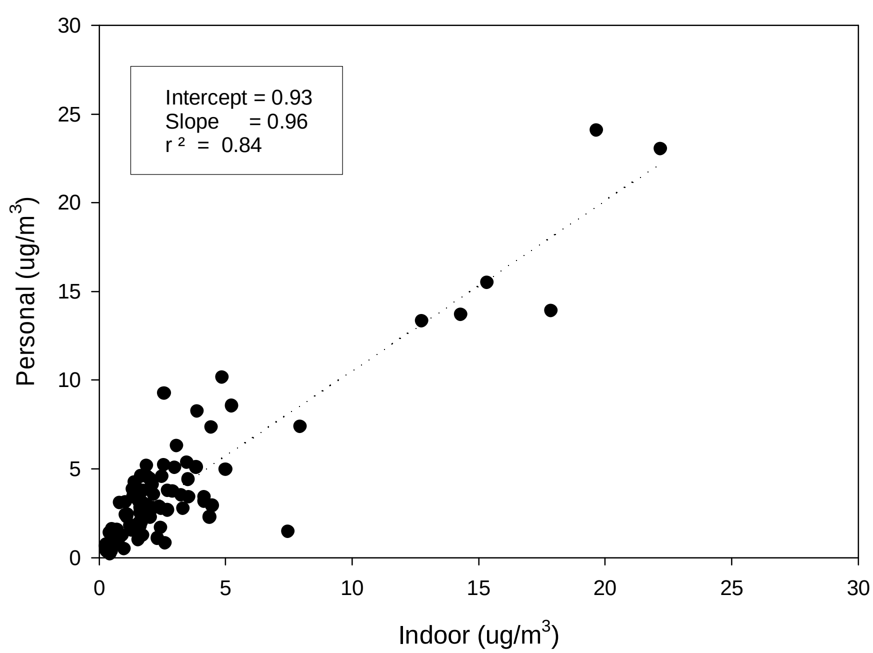
Dotted line represents linear regression line of indoor on outdoor levels.

Figure 89. Indoor vs. Outdoor NO_3^-



Dotted line represents linear regression line of indoor on outdoor levels.

Figure 90. Personal vs. Indoor NO_3^-



Dotted line represents linear regression line of indoor on outdoor levels.

The effect of air exchange rates on the ratio of personal and indoor to outdoor NO_3^- concentrations was not apparent (Figure 91 and Figure 92). When data were analyzed statistically, however, air exchange rates were an important effect modifier for both personal exposures and indoor concentrations, with an effective penetration efficiency for NO_3^- that increased with air exchange rates. The slope of the regression of personal on outdoor NO_3^- concentrations was lower for individuals who lived in homes with low air exchange rates (0.28±0.03) as compared to those who lived in homes with high air exchange rates (0.42±0.03). Intercepts for the two groups were both statistically insignificant (p=0.92 and 0.90, respectively). The relationship between indoor and outdoor concentrations was similar to that between personal and outdoor levels, with slopes of 0.24±0.03 for poorly-ventilated and 0.35±0.03 for well-ventilated homes. Again, intercepts for both groups were not significant. These results agree well with those found in our analysis of 6-h indoor and outdoor NO_3^- data, which found comparable slopes for well and poorly ventilated homes and insignificant intercepts for both groups. Furthermore, the higher slopes found for individuals living in well-ventilated homes and the insignificant intercepts are consistent with the fact that NO_3^- sources are located outdoors in Los Angeles and also with findings from our earlier study of individuals with COPD, in which air exchange rates were found to be important modifiers of both the effective penetration efficiency and indoor source contribution (Chang and Suh 2003).

Figure 91. Personal/Outdoor NO_3^- Ratios vs. Air Exchange Rates

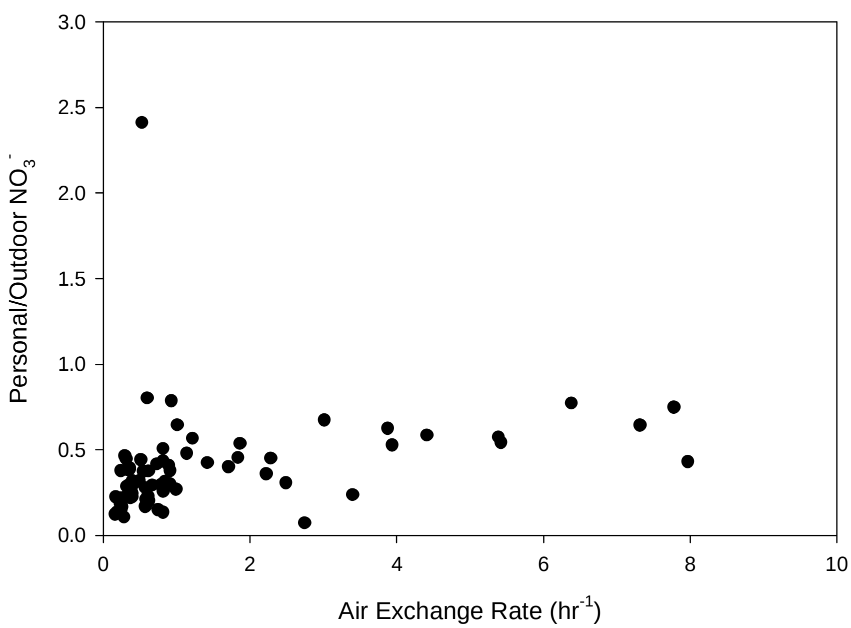
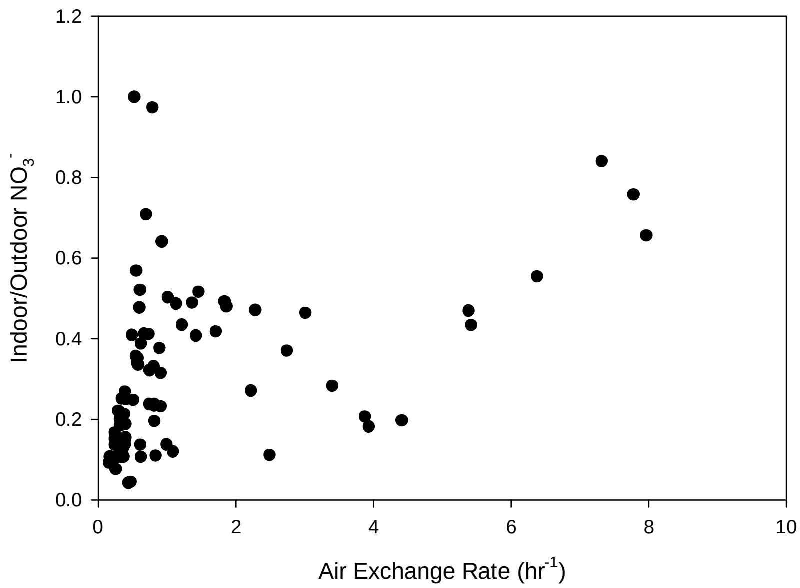


Figure 92. Indoor/Outdoor NO_3^- Ratios vs. Air Exchange Rates

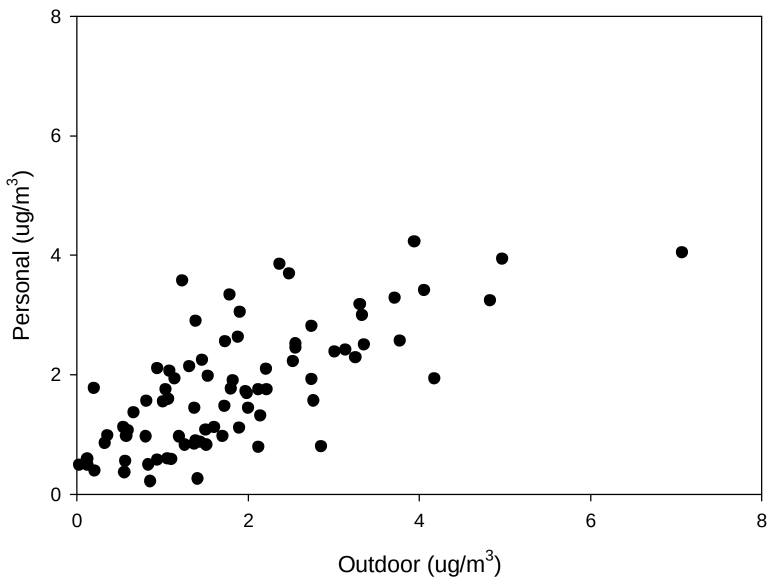


4.2.4.3 Black Carbon. The association between personal BC exposures and corresponding outdoor home concentrations was relatively strong, as outdoor concentrations explained approximately 50% of the variability in personal exposures when data were analyzed cross-sectionally (Figure 93). The slope of the regression line indicated an average effective penetration efficiency of approximately 85%, while the insignificant intercept suggests that indoor BC sources were not important contributors to indoor BC levels. Consistent with the observed strong cross-sectional associations, the median individual-specific correlation coefficient was relatively high, equaling 0.60; however, individual-specific coefficients ranged widely, between –0.70 and 0.91 (Figure 83). The median value and observed inter-personal variation are consistent with results from our earlier COPD study conducted in the metropolitan LA area (Chang and Suh 2003).

The association between indoor and outdoor black carbon concentrations was stronger than that between personal exposures and outdoor concentrations, as outdoor concentrations accounted for 87% of the variability in indoor levels when data were analyzed cross-sectionally (Figure 94). Consistent with these findings, the association between indoor exposures and outdoor BC concentrations did not vary by individual, as individual-specific correlation coefficients for pair-wise indoor-outdoor comparisons were higher and less variable than those for personal-outdoor, individual-specific comparisons (Figure 83). The slope of the regression line for the cross-sectional analysis was similar to that for personal-outdoor regression line, with a non-significant intercept as well. The similarity in the indoor-outdoor and personal-outdoor associations suggests that indoor BC concentrations are able to reflect personal BC exposures with a high degree of accuracy.

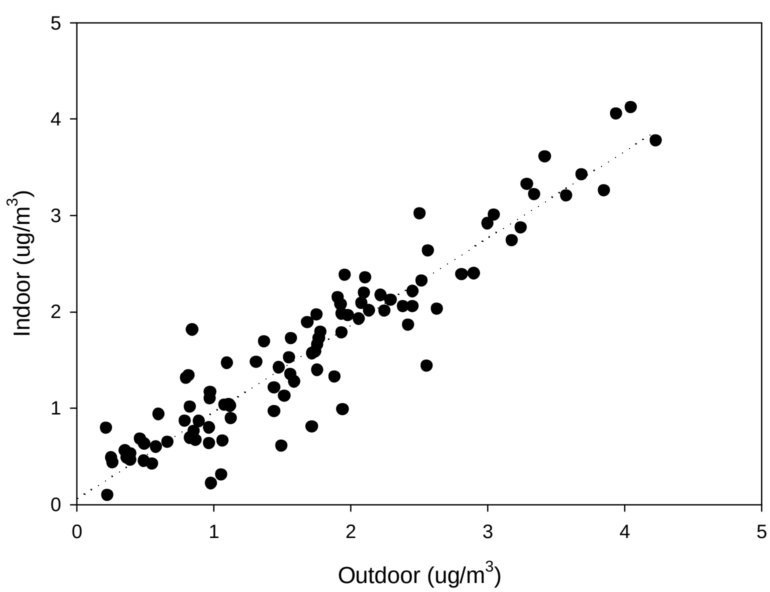
Further support for this theory is provided by the observed cross-sectional association between personal and indoor BC levels, which resulted in a slope of approximately one. Individual-specific correlation coefficients for personal-indoor comparisons were similar to that for personal-outdoor comparisons in terms of both the median value and the observed distribution of the coefficients and were lower and more variable than indoor-outdoor comparisons (Figure 83).

Figure 93. Personal vs. Outdoor BC*



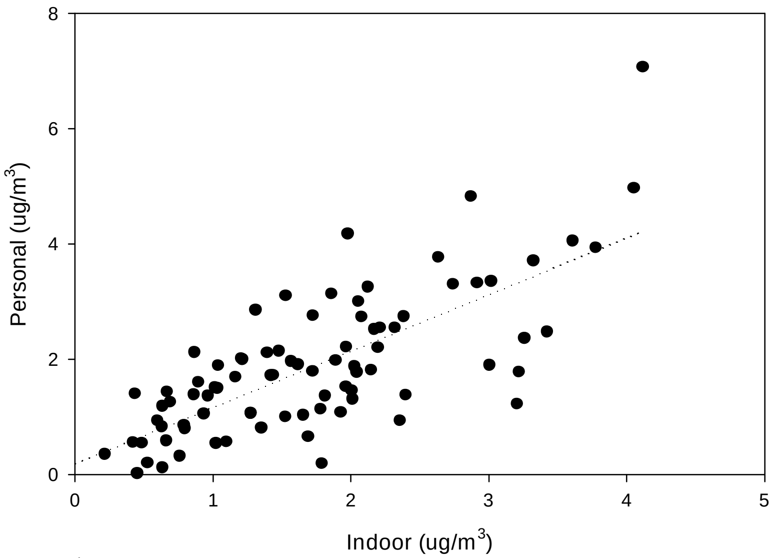
* BC concentrations estimated from reflectance measurements.

Figure 94. Indoor vs. Outdoor BC*



BC concentrations estimated from reflectance measurements.

Figure 95. Personal vs. Indoor BC*



* BC concentrations estimated from reflectance measurements.

When data were analyzed longitudinally, the slopes of the pair-wise comparisons between personal, indoor, and outdoor concentrations were comparable to their respective comparisons in the cross-sectional analysis and were highly significant (Table 78). The similarity in the results suggests that the slope did not vary with individual-specific characteristics. The intercepts for all three associations were insignificant, suggesting that the contribution of non-ambient sources to personal and indoor BC concentrations was negligible. The slope of the regression line for indoor and outdoor BC concentrations was lower than observed in our longitudinal analysis of corresponding 6-h data, which showed a slope approximately equal to one. These observed differences are likely due to the measurement difference between the indoor and outdoor aethalometer, where measurements obtained using the indoor aethalometer were on average 25% higher than outdoor measurements.

Consistent with this observed lack of inter-individual variability, air exchange rates appeared to have no effect on ratio of indoor to outdoor BC concentrations when data were examined graphically, as ratios were generally near or below one irrespective of the air exchange rate (Figure 97). Similarly, air exchange rates were not found to modify the relationship between personal and outdoor or between indoor and outdoor BC concentrations, as neither the effective penetration efficiency (p=0.47 and 0.41, respectively) nor the indoor source contribution (p=0.77 for both comparisons) differed by air exchange rate category for either comparison. The lack of an air exchange rate effect on the personal-outdoor and indoor-outdoor relationship may result from the fact that BC tends to be comprised of particles between 0.1 and 0.5 µm in size (Hogan *et al.* 1984; Horvath 1993), which tend to have high penetration efficiencies and low deposition rates (Long *et al.* 2001). As a result, the majority of BC may be able to penetrate from outdoor to indoor environments, regardless of the air exchange rate. Similar results were found in our earlier study of individuals with COPD, for which neither air exchange rates nor open window frequency (as continuous or categorical variables) were found to affect the association between indoor and outdoor EC concentrations or the association between personal exposures and outdoor EC concentrations (Chang and Suh 2003). Air exchange rates, however, were found to modify the F_{INF} for 6-hr BC, with slopes increasing with increasing air exchange rates. Reasons for these differences may again be due to differences in averaging times.

Figure 96. Personal/Outdoor BC vs. Air Exchange Rates

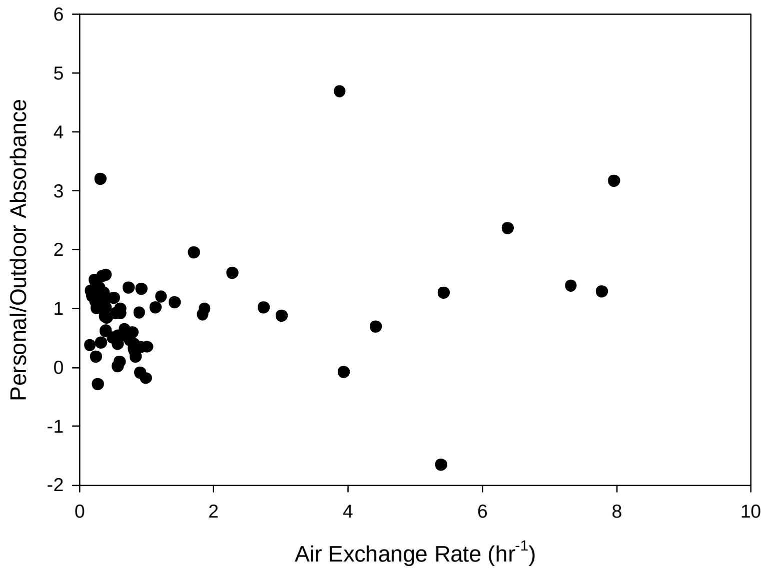


Figure 97. Indoor/Outdoor Black Carbon vs. Air Exchange Rates

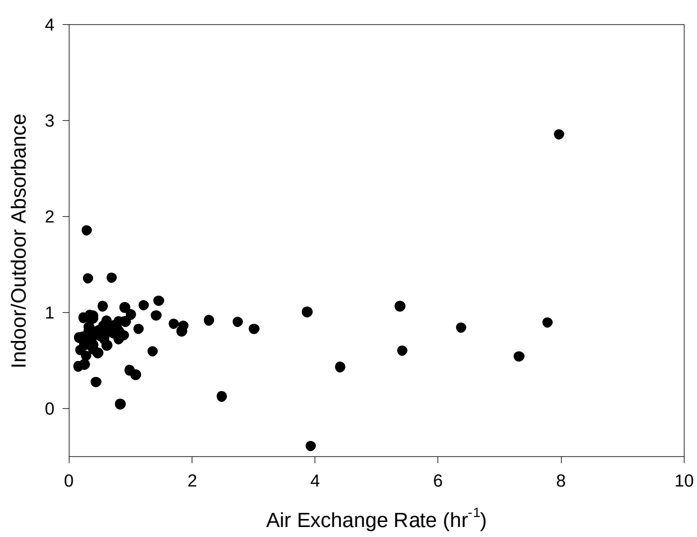


Table 79. Micro-Environmental Model Results

Pollutant	Model	N	Crude R^2	Slope (SE)	Intercept (SE)
$PM_{2.5}$	Micro-environmental	84	0.80	0.82 (0.05)	3.68 (1.23)
	Outdoor alone	84	0.49	0.39 (0.05)	6.70 (2.10)
	Indoor alone	88	0.80	0.92 (0.05)	1.58 (1.31)*
NO_3^-	Micro-environmental	88	0.90	0.93 (0.04)	0.69 (0.25)
	Outdoor alone	88	0.76	0.34 (0.02)	0.15 (0.42)*
	Indoor alone	92	0.84	0.96 (0.05)	0.92 (0.33)
BC	Micro-environmental	83	0.53	0.96 (0.11)	0.34 (0.21)*
	Outdoor alone	83	0.49	0.88 (0.12)	0.22 (0.25)*
	Indoor alone	87	0.55	0.99 (0.11)	0.15 (0.22)*

[1] Crude R^2 calculated using cross-sectional regression analyses. Sample size (n), slopes, and intercepts determined using mixed models with compound symmetry covariance matrix. Model estimates were calculated using time-weighted exposures, where all indoor concentrations (except for workplace) was assumed to equal measured indoor home levels and all outdoor concentrations (excluding transit) was assumed to measured outdoor home levels. [2] *Not significant at p=0.05.

4.2.5 Micro-environmental exposure models

Time-weighted micro-environmental models were found to be more accurate predictors of personal $PM_{2.5}$, NO_3^- and BC exposures as compared to indoor or outdoor concentrations alone (Table 79). For $PM_{2.5}$, time-weighted micro-environmental models explained 80% of the variability in measured personal exposures when data were analyzed cross-sectionally (Figure 90). Furthermore, the accuracy of the model was high, resulting in a slope of 0.83±0.05 and an intercept of 3.34±1.02 when mixed models were used to compare measured and estimated concentrations. For NO_3^-, time-weighted exposure models estimated personal exposures with even higher accuracy and precision (Figure 91). Models explained 90% of the variability in personal NO_3^- exposures (cross-sectional analysis), with mixed models resulting in a slope near one (0.96±0.04) and a low but significant intercept (0.59±0.19) when measured exposures were regressed on estimated exposures. Model performance was weakest for BC, with the precision of model estimates (crude R^2=0.53) similar to that observed for outdoor (crude R^2=0.51) and indoor (crude R^2=0.56) concentrations alone (Figure 92). The accuracy of model estimates, however, was extremely high, resulting in a slope comparable to one (0.98±0.11) and an insignificant intercept (0.25±0.17). For all models, model performance decreased slightly when information about time spent in transit and at work was incorporated into the model.

Figure 98. Micro-Environmental Model: Measured vs. Estimated $PM_{2.5}$

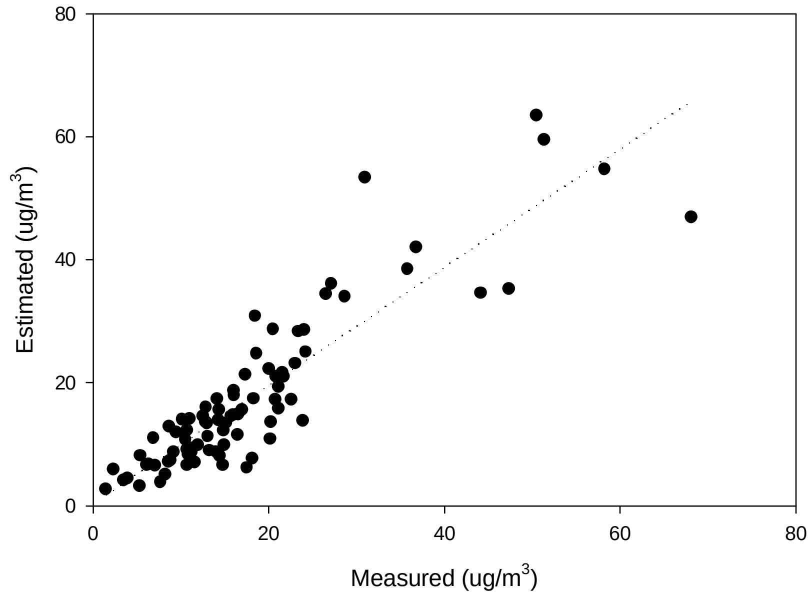


Figure 99. Micro-Environmental Model: Measured vs. Estimated NO_3^-

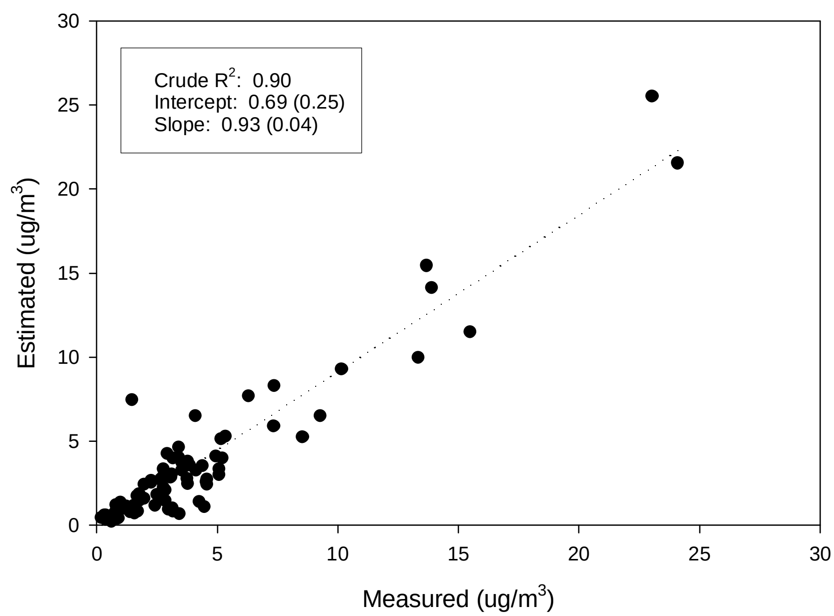
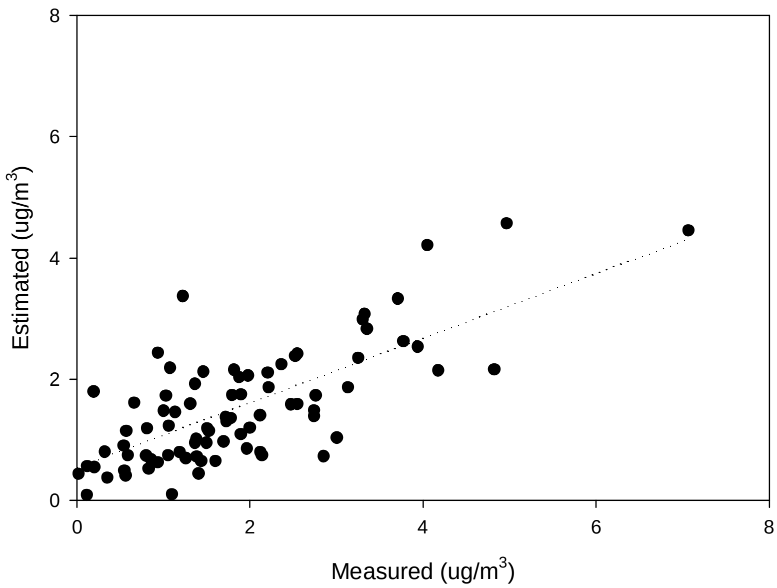
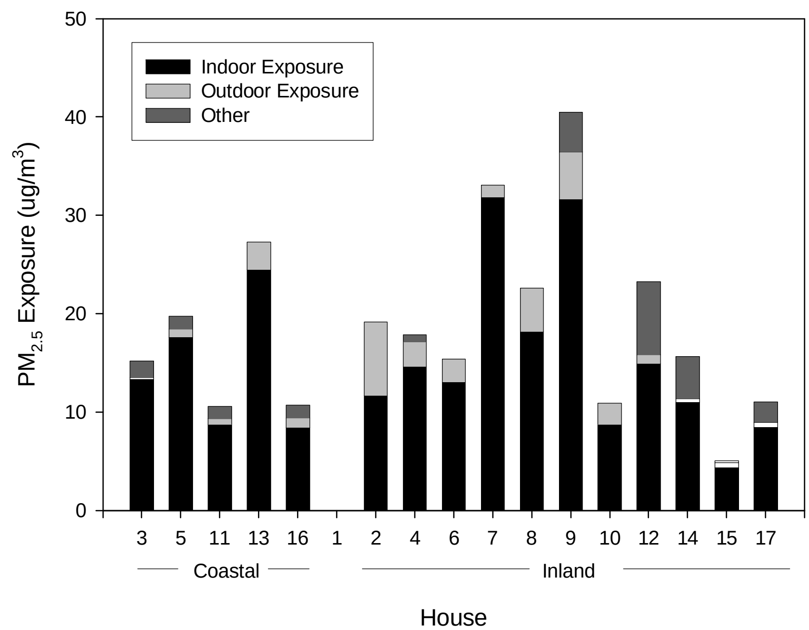


Figure 100. Micro-Environmental Model: Measured vs. Estimated BC



* "Measured" personal BC exposures estimated using personal reflectance and collocated indoor BC concentrations. Dotted line represents linear regression line.

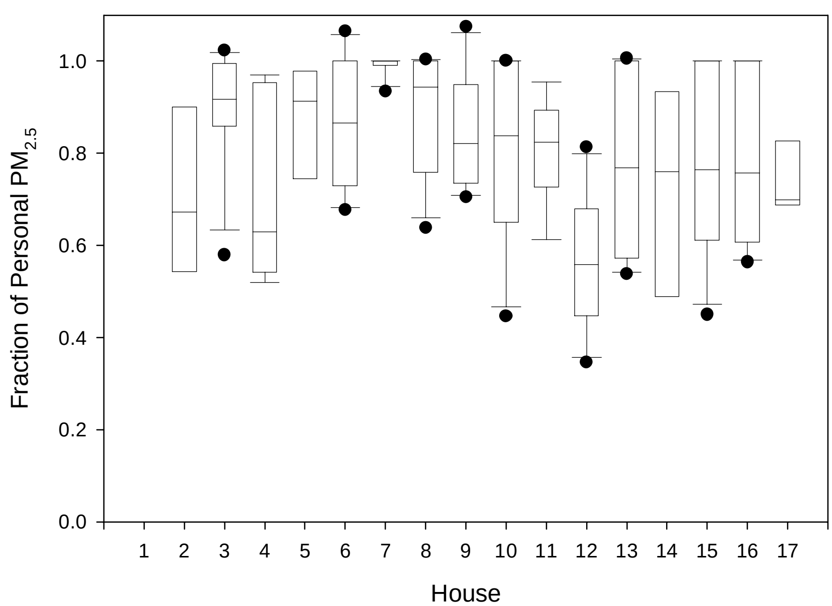
Figure 101. Contribution of Indoor and Outdoor Exposures to Personal $PM_{2.5}$ Exposures*



Contributions estimated using the mean ratio of time-weighted indoor or outdoor concentrations and personal $PM_{2.5}$ exposures multiplied by the personal $PM_{2.5}$ exposure. "Other" represents personal $PM_{2.5}$ that was not accounted for by time-weighted indoor and outdoor concentrations.

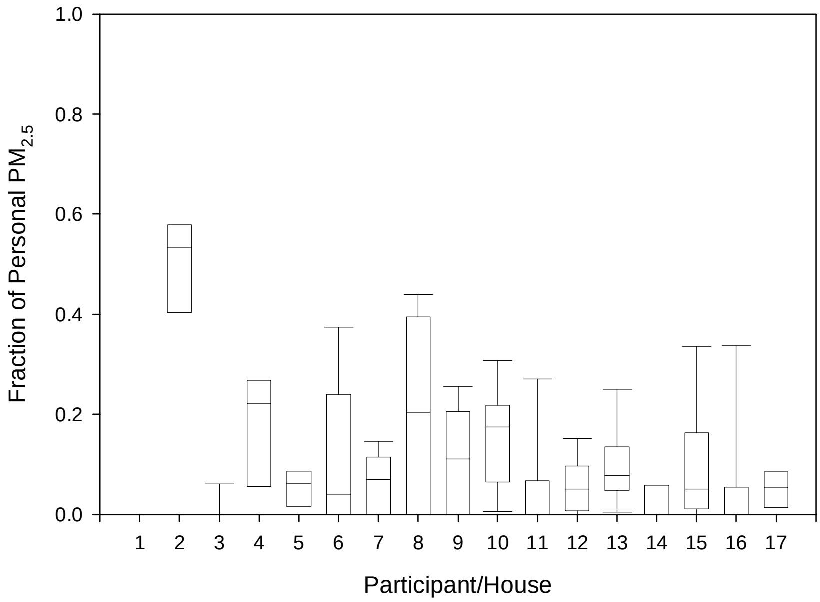
The strong performance of the time-weighted micro-environmental models allowed the contribution of indoor and outdoor exposures to personal particulate exposures to be assessed. Consistent with the fact that individuals spent the majority of their time indoors, indoor exposures were the largest contributor on average to personal $PM_{2.5}$ exposures, as estimated using the ratio of the time-weighted indoor or outdoor concentrations and the measured personal $PM_{2.5}$ exposure (Figure 101). [Note that the contribution of indoor $PM_{2.5}$ includes $PM_{2.5}$ that originated from indoor sources and that penetrated from outdoor environments.] The mean contribution of indoor $PM_{2.5}$, however, did vary slightly by home, with mean contributions ranging from approximately 65% to nearly 100%, possibly due to individual-specific differences in activity patterns (Figure 102). Correspondingly, the contribution of outdoor $PM_{2.5}$ (from time spent outdoors) to personal exposures was low for the majority of individuals, except for the individual living in House 2, who spent a large fraction of time outdoors. Although not possible to examine quantitatively, the mean contribution of indoor $PM_{2.5}$ to personal exposures did not appear to vary by whether the home was located in a coastal or inland location.

Figure 102, Fraction of Personal $PM_{2.5}$ Exposures from Indoor Exposures



* Time-weighted indoor concentrations were used to estimate the contribution of indoor concentrations to personal exposures. Note since model estimates were not exact, estimated contributions (and thus fractions) were greater than the measured personal exposure for some periods. For this plot, fractions greater than one were capped at one.

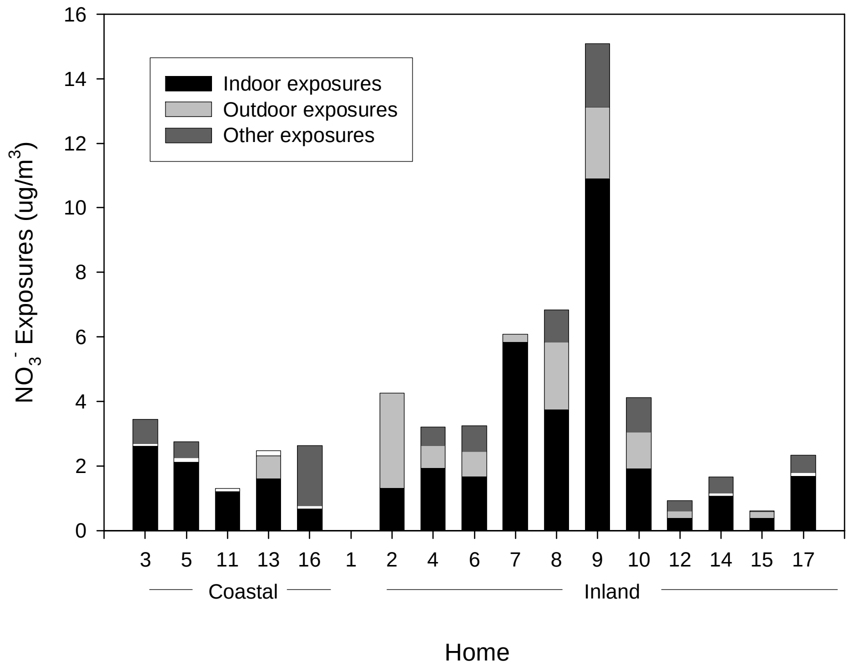
Figure 103. Fraction of Personal $PM_{2.5}$ Exposures from Outdoor Exposures



* Contributions assessed using the ratio of time-weighted outdoor concentrations to personal exposures. Note that this method does not consider exposures to outdoor PM2.5 that occur indoors as the result of penetration from outdoor to indoor environments.

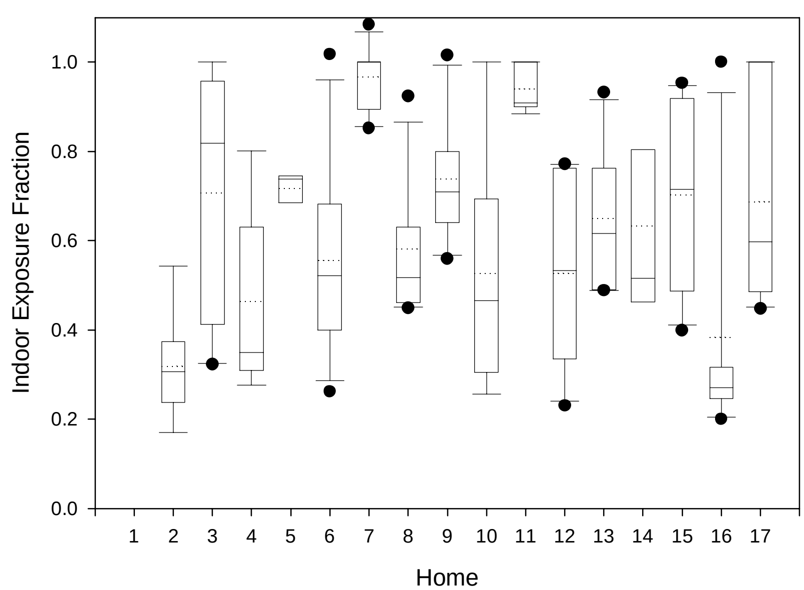
For NO_3^-, indoor exposures also comprised the largest fraction of personal exposures for most of the homes, although outdoor and other exposures comprised the largest average fraction of personal exposures for Homes 2 and 16, respectively (Figure 104, Figure 106). For all homes, the contribution of indoor exposures was generally smaller than that observed for $PM_{2.5}$, probably as the result of generally low indoor NO_3^- concentrations. Since outdoor NO_3^- concentrations were much higher than that indoors, the contribution of outdoor NO_3^- exposures to personal NO_3^- was relatively large especially given the low amount of time spent outdoors. The contribution of indoor and outdoor NO_3^- to personal exposures did not appear to differ by whether the home was located in a coastal or inland location. As was the case with $PM_{2.5}$, significant intra-home variability in the contribution of indoor to personal exposures was found, as ratios of indoor to personal NO_3^- exposures ranged broadly for a given home (Figure 105).

Figure 104. Contribution of Indoor and Outdoor Exposures to Personal NO_3^- Exposures*



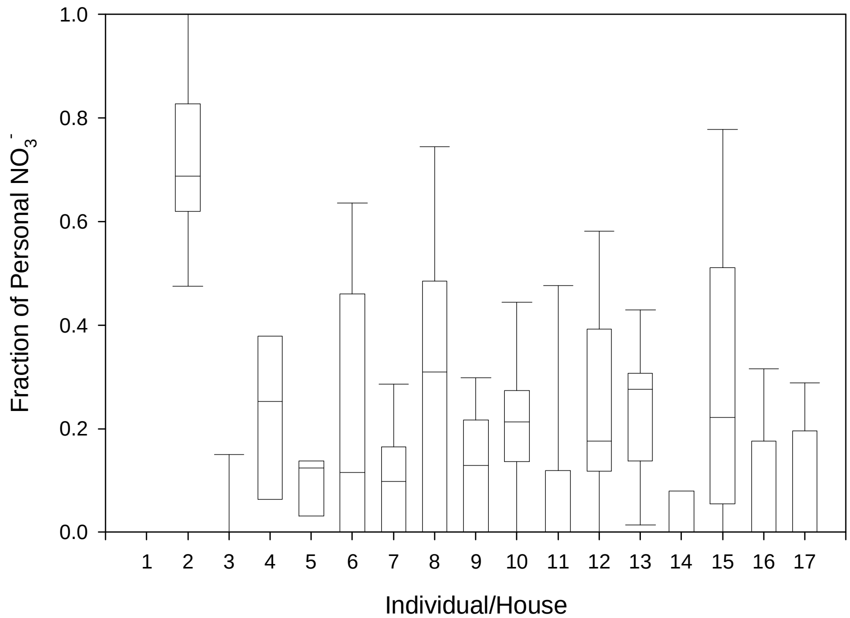
* Contributions estimated using the mean ratio of time-weighted and personal NO_3^- exposures multiplied by the personal NO_3^- exposure. "Other" includes personal NO_3^- that was not accounted for by time-weighted indoor and outdoor concentrations.

Figure 105. Fraction of Personal NO_3^- Exposures from Indoor Exposures



Fraction of personal exposures from indoors estimated using time-weighted indoor exposures. Since time-weighted indoor levels are estimates, some fractions were greater than the measured personal exposure.

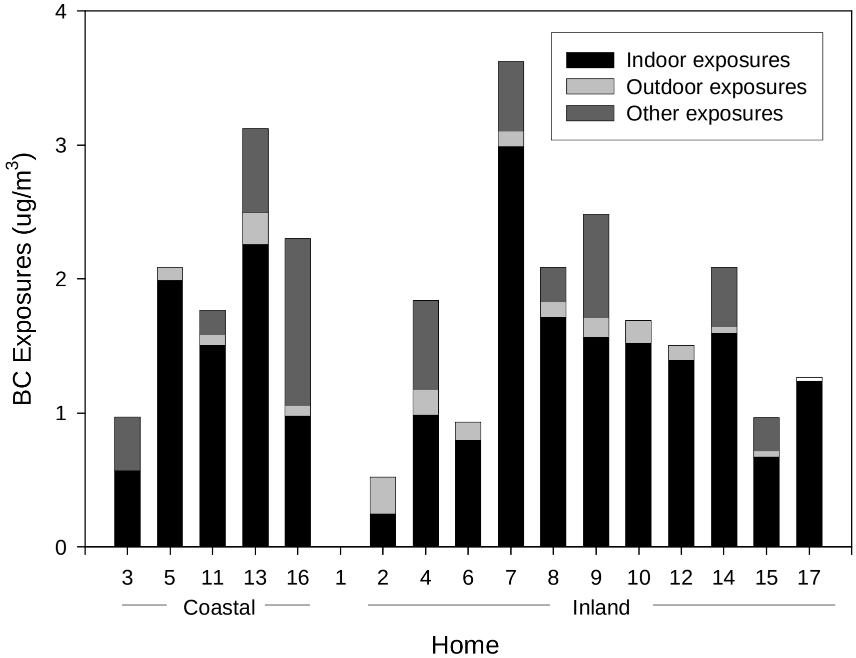
Figure 106. Fraction of Personal NO_3^- Exposures from Outdoor Exposures



Fraction of personal exposures from outdoors estimated using time-weighted outdoor exposures. Note that this method does not consider exposures to outdoor NO_3^- that occur indoors through penetration of outdoor particles to indoor environments.

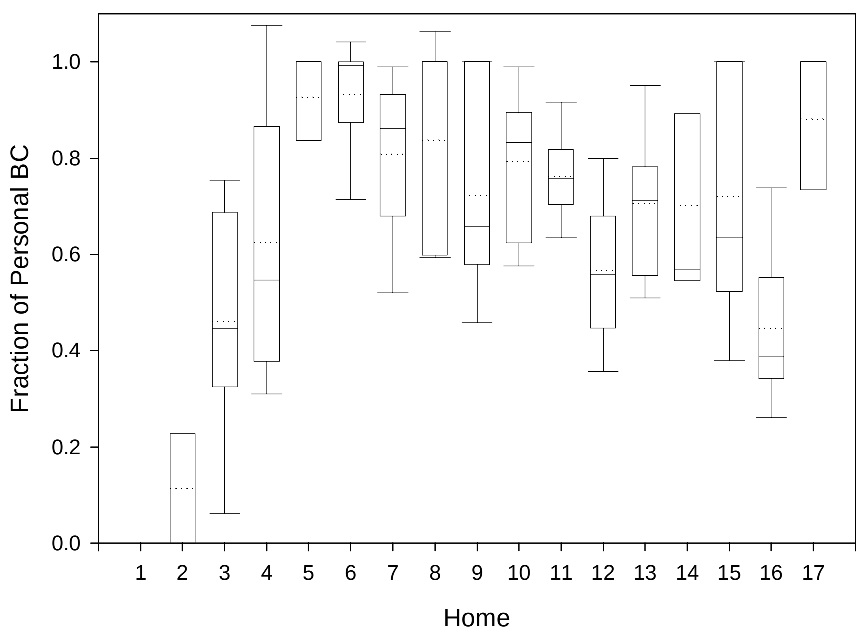
Indoor exposures contributed the largest fraction to personal BC exposures, although for some individuals (e.g., individuals living in Homes 3, 4, 9, 13, 16), "other" exposures also contributed substantially to personal BC levels. These "other" exposures may be due to time spent in motor vehicles, which are major sources of BC; however, time spent in motor vehicles did not appear to be associated with the contribution of "other" exposures, suggesting that other BC sources may also be important contributors to personal BC exposures. As was the case for $PM_{2.5}$, outdoor exposures contributed relatively small fractions to corresponding personal BC exposures, except for the individual living in House 2, who spent a relatively large amount of time outdoors.

Figure 107. Contribution of Indoor and Outdoor Exposures to Personal BC Exposures



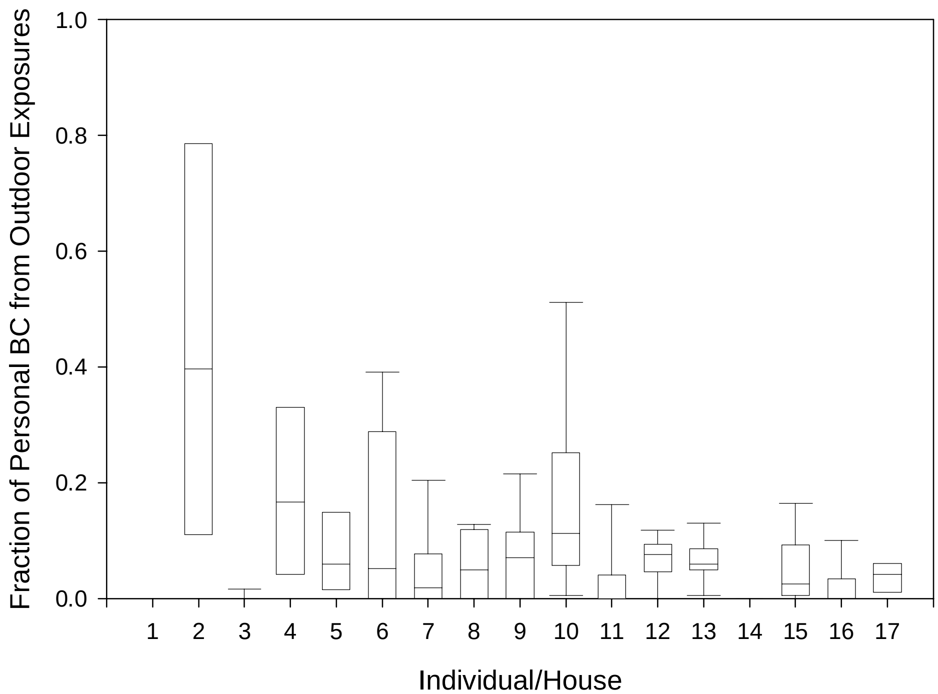
* Contributions estimated using the mean ratio of time-weighted and personal BC exposures multiplied by personal BC exposure. "Other" includes personal BC that was not accounted for by time-weighted indoor and outdoor concentrations. BC concentrations estimated from reflectance and aethalometer measurements.

Figure 108. Fraction of Personal BC Exposures from Indoor Exposures



* Fraction of personal exposures from indoors estimated using time-weighted indoor exposures. Since time-weighted indoor levels are estimates, some fractions were greater than the measured personal exposure.

Figure 109. Fraction of Personal BC Exposures from Outdoor Exposures



* Fraction of personal exposures from indoors estimated using time-weighted outdoor exposures. Note that this method does not consider exposures to outdoor BC that occur indoors through penetration of outdoor particles to indoor environments.

4.3 Part 3: Surface Dust

The table below compares the mean values of the three samples sent for analysis with comparison values (median, and maximum) taken from a survey of phthalates in house dust, collected in 120 homes in Cape Cod, Massachusetts[1]. Mean values of the phthalate species in the three house dust samples with values above the analytical limit of detection of 0.5 μg/g dust ranged between 0.23 and 314.3 ug/g. For the compounds for which concentrations were above the analytical detection limit of 0.5 μg/g dust and for which comparison values were available, the levels measured in this study were similar to those measured in Cape Cod.

Table 80. Comparison of Phthalate Levels in Dust in Three Los Angeles homes with Homes in Cape Cod, Massachusetts

Analyte	Mean (n=3) mg/g	Comparison Values[1]		
		Median mg/g	Max mg/g	Count
Dimethyl phthalate	0.23	¥		
Diethyl phthalate	1.37	4.98	111	119
Diisobutyl phthalate	2.05	1.91	39.1	119
Di-n-butyl phthalate	31.17	20.1	352	119
Dihexyl phthalate	2.36	5.97	391	119
Benzyl butyl phthalate	14.27	45.4	1310	119
Dicyclohexyl phthalate	0.70	1.88	62.7	101
Bis(2-ethylhexyl)phthalate	314.26	340	7700	101
Di-n-octyl phthalate	20.51	¥		
Dinonyl phthalate	24.33	¥		
Compounds not detected <0.5mg/g				
Bis(2-methoxyethyl)phthalate				
Bis(4-methyl-2-pentyl)phthalate				
Bis(2-ethoxyethyl)phthalate				
Diamyl phthalate				
Hexyl 2-ethylhexyl phthalate				
Bis(2-butoxyethyl)phthalate				

[1] From: Rudel et al. (2003)..

¥ Reference value not available.

5.0 CONCLUSIONS

Significant diurnal variation in indoor concentrations was observed for each of the measured particulate species, with this diurnal variation generally related to corresponding diurnal variation in outdoor levels. 20-minute mean outdoor concentrations were comparable or greater than mean indoor levels for each species, with differences greatest for NO_3^-, for which indoor levels tended to be low, and for coarse particles. Nighttime F_{INF} values showed patterns across the measured particle species that were consistent with particle theory. F_{INF} was highest for BC, which was not surprising given its non-reactive nature and its typical size (~0.1-0.5 um). Correspondingly, F_{INF} was lowest for fine particle NO_3^-, a highly reactive pollutant that in LA may consist primarily of particles larger than 1.0 um and thus may have greater gravitational losses. Nighttime F_{INF} for $PM_{2.5}$ fell between those for BC and NO_3^-, which can be attributed to the fact that both BC and NO_3^- are major components of $PM_{2.5}$ in Los Angeles. Nighttime F_{INF} values for the particle size intervals were consistent with those for $PM_{2.5}$ and its components, where F_{INF} values were highest for the smallest size fractions $PV_{0.02\text{-}0.1}$ and $PV_{0.1\text{-}0.5}$ and were lowest for the largest size fractions $PV_{0.7\text{-}2.5}$ and $PV_{2.5\text{-}10}$.

Similarly, estimates of ***P*** and ***k*** obtained using steady state models for nighttime periods were also consistent with particle theory and with results from previous studies. As was the case with estimated F_{INF} values, the estimated value of ***P*** was highest for BC. ***P*** was also once more lowest for NO_3^- and was furthermore statistically insignificant (0.18±0.13). The estimated ***P*** for $PM_{2.5}$ (0.42±0.11) was consistent with that for the size-resolved particles, with its low value relative to Boston likely due to the high outdoor NO_3^- concentrations in Los Angeles. Penetration efficiencies were highest for particles between 0.08 and 0.4 um and was lowest for particles between 2.5 and 10 um. Estimated values for ***P*** were consistent with wintertime estimates and were lower than summertime estimates from our Boston study. Again, this is likely due to the fact the NO_3^- comprises a much greater fraction of outdoor $PM_{2.5}$ in Los Angeles as compared to Boston.

Estimates of ***P*** and ***k*** obtained using the dynamic mass balance model were generally imprecise, as for each time period and size, numerous ***P*** and ***k*** pairs resulted in similar model error. Precision of the estimates, as determined by estimating the parameters independently while holding the other constant, was greatest for post-indoor source time periods for ***k*** or and for non-source, varying outdoor concentration periods for ***P***. During these time periods, it is likely that either deposition or penetration, respectively, were the dominant influence on indoor particle levels, thus allowing greater precision in modeling the corresponding parameter. For any single time period, however, simultaneous, precise estimates for both ***P*** and ***k*** were not obtained.

24-h personal exposures to $PM_{2.5}$, NO_3^- and BC were significantly associated with indoor and outdoor levels. Slopes of the indoor-outdoor longitudinal regressions for all three particulate species were comparable to those found in the analysis of 6-h averaged data, suggesting that estimates of the F_{INF} for $PM_{2.5}$, NO_3^- and BC are robust and stable. In addition, the slopes of the personal-outdoor and indoor-outdoor longitudinal regressions for $PM_{2.5}$ and NO_3^- were substantially lower than one, with a maximum for indoor-outdoor $PM_{2.5}$ comparisons of 0.42±0.04, while personal-outdoor and indoor-outdoor slopes for BC were higher, with values of 0.82±0.11 and 0.78±0.04, respectively. The slopes and intercepts for personal-outdoor regressions for all particulate species were similar to those for the indoor-outdoor associations, suggesting that indoor concentrations are on average equivalent measures of personal particulate exposures. Air exchange rates were significant modifiers of the personal-outdoor and indoor-outdoor associations for NO_3^- but not for the other particulate measures.

6.0 RECOMMENDATIONS

Further research should be conducted to assess the impact of the tape change artifact on 20-minute and hourly BC concentrations measured by aethalometers and to determine the variability in this artifact and in potential measurement biases between instruments. In addition, research should be conducted to evaluate the effects of season on penetration efficiencies and deposition rates in LA by measuring LA homes in multiple seasons. In addition, research should be conducted to characterize intra-home spatial variability in air exchange rates as well as hourly indoor and personal $PM_{2.5}$, EC, and NO_3^- exposures in other cities and for other populations. In particular, this research should focus on the impact of volatilization of NO_3^- on $PM_{2.5}$ penetration and decay. Such research should also be conducted using scripted activities to allow the contribution of specific indoor particle sources to be estimated, the effect of air exchange rates on penetration efficiencies to be examined in more detail, and decay rates to be determined more accurately. In this regard, targeted research studies intended to address specific issues conducted in test homes or in otherwise controlled environments may be necessary. Finally, further research should be conducted to characterize the effects of housing characteristics and operations on the dynamics of indoor PM and its components to allow generalization of results from this and other studies to other homes. By modeling for houses with different physical characteristics, this research would provide a cost-effective alternative to monitoring PM under controlled conditions in a large number of homes.

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GLOSSARY OF TERMS, ABBREVIATIONS, AND SYMBOLS

AC	Air conditioning
AER	Air exchange rate
APS	Aerodynamic particle sizer
BC	Black carbon
CAMM	Continuous aerosol mass monitor
CATs	Capillary absorption tubes
C_i	Indoor concentrations
C_o	Outdoor concentrations
COPD	Chronic obstructive pulmonary disease
C_p	Personal exposure levels
EC	Elemental carbon
ETS	Environmental tobacco smoking
F_i	Fraction of time spending indoors in each day
F_o	Fraction of time spending outdoors in each day
HAD	Housing activity diary
HI	Harvard Impactor
HNO_3	Nitric acid
HONO	Nitrous acid
HSPH	Harvard School of Public Health
LOD	Limit of detection
LPM	Liter per minute
n	Sample number
Na_2CO_3	Sodium carbonate
NO_3^-	Nitrate
PEM	Personal exposure monitor
$PM_{2.5}$	Particulate mass (d_a<2.5)
$PV_{0.02-0.1}$	Particulate volume ($0.02<d_a<0.1$)
$PV_{0.1-0.5}$	Particulate volume ($0.1<d_a<0.5$)
$PV_{0.7-2.5}$	Particulate volume ($0.7<d_a<2.5$)
$PV_{2.5-10}$	Particulate volume ($2.5<d_a<10$)
PFT	Perfluorocarbon tracer
R^2	Coefficient of determination
r_s	Spearman correlation coefficient
SAM	Stationary ambient monitoring
SD	Standard deviation
SE	Standard error
SMPS	Scanning mobility particle sizer
SO_2	Sulfur dioxide
TAD	Time-activity diary
TOR	Thermal optical reflectance
WUAQL	Washington University Air Quality Laboratory

APPENDICES

APPENDIX A: STUDY QUESTIONNAIRES

Housing Characteristics: Instructions and Questionnaire

TECHNICIAN INSTRUCTIONS FOR COMPLETING THE HOUSING CHARACTERISTICS QUESTIONNAIRE

The Housing Characteristics Questionnaire asks for information about any housing characteristic or feature that may affect particle levels inside and immediately outside the study home. The questionnaire is to be completed by the field technician.

When should the questionnaire be completed?

The field technician will complete the questionnaire using his/her observations and as necessary, by asking one or more of the study participants. The technician should try to complete the questionnaire during the set-up and first sampling day; however, due to the amount of information requested in the questionnaire, this may not be possible. If so, the technician may complete the questionnaire throughout the seven-day sampling period.

Who should I ask for information about household characteristics?

In completing the questionnaire, the technician may need to ask the household residents for information. It is likely that the technician may have to ask several household residents to obtain all of the needed information, as different household residents may be knowledgeable about different aspects of the house.

How do I complete the questionnaire?

For each questionnaire, the technician should make sure to include home identifier information and the date of sampling. Also, the technician who completed the questionnaire should write his or her name on the first page of the questionnaire.

As often as possible, the questionnaire asks for questionnaire responses in the form of checklists. These checklists were provided to ensure appropriate responses and to facilitate the questionnaire completion. Technicians should check all appropriate boxes.

In many of the checklists, the location or other descriptive information is requested. If so, the technician should write the relevant information on the line next to the appropriate checklist item.

If a question is intentionally left blank, the technician should note this on the questionnaire. A second technician should review the completed questionnaire. This review should be completed while sampling is still on-going at the house. Any answers that are unclear or incorrect should be clarified or corrected.

How do I draw or obtain the floor plan?

Included in the questionnaire is the request for a detailed floor plan. This floor plan will be used to calculate air exchange rates. As a result, it is important to record the height, width, and length of each room in the house, so that the square footage and volume of the home can be determined.

It is possible that the household residents already have a detailed floor plan, as the result of recent renovations or home construction activities. If so, the technician should make a copy of the floor plan and augment this copy as necessary.

HOUSE CHARACTERISTICS

House Characteristics Log Sheet **Version 1.4**
Harvard School of Public Health—Los Angeles Indoor 2001 **Date: 9/21/2001**

Date Setup:___/___/_____ Operator's initials: _______

HOUSE ID__________ Respondents ID: _______

ZIP CODE__________

1. Describe members of the household. (Check all that apply for each person. Use supplemental sheets if necessary.)

a. Sex: Male / Female   Age:_____   Health Conditions: asthma / allergy / cold or flu / other _______________

b. Sex: Male / Female   Age:_____   Health Conditions: asthma / allergy / cold or flu / other _______________

c. Sex: Male / Female   Age:_____   Health Conditions: asthma / allergy / cold or flu / other _______________

d. Sex: Male / Female   Age:_____   Health Conditions: asthma / allergy / cold or flu / other _______________

2. What best describes this building?
- One family detached home
- One family attached home
- A building for 2 families
- A building for 3-5 families
- An apartment building (6-10 families)
- An apartment building (10+ families)
- A mobile home or trailer
- Other (describe): _________________________

3. Does the home have a crawl space? Yes No

4a. Does the home have a basement? Yes No

4b. Does the home have a garage?
- Attached
- Underneath
- Detached
- None

5. What year was the house originally built? _____________

HOUSE CHARACTERISTICS

6. Have there been any major construction, repairs, or renovations in the house within the last year (e.g., remodeling, repairs, painting, carpeting, lead paint remediation, plumbing repairs, heating or cooling systems)?
____

7. Is the house located within about 2 blocks of any of the following sources? (check all that apply)

Busy surface street or freeway	Bus or truck depot
Construction or road work	Open field or crops
Gravel or dirt road	Other: _______________
Restaurant	
Industrial activity	None

8. List the number of pets that live in or enter the house:

Dogs ______	Other: ______________
Cats ______	None

9a. Cooking appliances: (Please check appropriate boxes)

Gas stove	Microwave
Electric stove	Bread maker
Toaster	Second oven
Toaster oven	Other: ______________

Note: Include in other faxes or copier machines.

9b. Stove venting: (Please check appropriate boxes)

Range hood with <u>vented</u> exhaust fan	None
Range hood with <u>unvented</u> exhaust fan	
Downdraft range exhaust	Other: ______________
Ceiling exhaust fan	

9c. Dirtiness of oven and stove-top burners:

Heavy Medium Light None.

9d. Dirtiness of toaster and toaster ovens (spills and debris inside):

Heavy Medium Light None.

9e. What kind of kitchen room is present regarding the rest of the house:
Open (kitchen contained in a large room or large opening between kitchen and other rooms)
Close (doorway connecting kitchen and other areas)

10. What is your primary heating system? (Check all that apply):

a. Fuel Type:	b. Appliance Type (note location where appropriate):
Gas	Central
Electric	Wall ________________________________
Kerosene	Floor ________________________________
Wood	Baseboard ___________________________
Other: ______________	Wood stove _____________________
	Fireplace ______________________
	Other: ___________________________

if Fireplace was chosen provide:

Fuel type:	Natural Gas	Wood
Ventilation type:	Sealed combustion	Unsealed combustion

HOUSE CHARACTERISTICS

If unsealed: Open flue Closed flue
Exhaust:____

10c. Secondary heat sources (note room location):
- Kerosene space heater _______________
- Propane space heater __________________
- Electric space heater __________________
- Oven or stove
- Other: _______________
- None

11. Cooling System: (Please check appropriate boxes. Where appropriate, indicate room location)
- Central AC
- Room AC ______________
- Swamp cooler
- No AC
- Other _______________

12. Fans (Please check all that apply)
- Whole house fan
- Ceiling fan ________________
- Attic fan
- Window fan _______________
- Portable room fan __________________
- Exhaust fan _____________
- Other __________________
- None

13. Central air duct work (check all that apply):

a. Is it primarily inside the living space? Yes No Unknown Not applicable

b. If Yes, <u>where</u> does the return duct lead back to the air handler (central fan; mark on the house diagram). Mark all that apply (mark even if they are nor currently using the duct):
- crawlspace
- attic
- garage
- Other: _____________________________
- interior closet or wall
- outside (e.g., roof)
- slab

c. Central air filter type: Enter brand and model: ______________________________________
coarse mesh 1” pleated 2” pleated HEPA Other None

d. Filter condition:
Clean Moderately dirty Very Dirty NA

14. Furnace condition (if a gas furnace is present, check all that apply)
a. Signs of corrosion in flue or other areas? Yes No
b. Signs of moisture or condensate buildup? Yes No
c. Has the home had a combustion safety test, as part of a furnace replacement or a weatherization job?
Yes If yes, when: ________ No
Don’t know

15. List any other major appliances and their fuel type:
a. Water Heater gas electric other_______________ None
b. Clothes dryer: gas electric other_______________ None
c. Other: ______________________

d. If a clothes dryer is used, is it vented outside the house? Yes No
If Yes, does the vent duct appear intact (no signs of breakage or leakage of lint): Yes No

HOUSE CHARACTERISTICS

16. Air cleaners and Humidifiers: (Check all that apply. Where appropriate, please indicate location of device, manufacturer and model number, CFM or CADR specifications, and general cleanliness of uthe unit)

a. Air cleaners: general type
Central ________________________ Portable __________________________

b. Air cleaners: PM removal method (Also note whether Central, Portable, or Both)
Electrostatic ____________________ Ozone-generating __________________
Filter-based _____________________ Combination ______________________
Other: _________________________

c. Humidifiers: General type
Ultra-sonic ______________________ Other: ____________________________

d. Humidifiers: Water type
Distilled water Tap water Other: ________________

e. Dehumidifiers: Yes ________________ No

17. Floor covering (check all that apply and indicate percent coverage)

a. Main room (where samplers are placed)
Carpeting low pile medium pile shag
Area rugs ____________
Other: ________________

b. Other rooms of first floor (or the floor where samplers are placed).
Carpeting low pile medium pile shag
Area rugs ____________
Other: ________________

c. Kitchen.
Carpeting low pile medium pile shag
Area rugs ____________
Other: ________________

d. Second floor
Carpeting low pile medium pile shag
Area rugs ____________
Other: ________________

e. Are shoes usually worn in the house? Yes No

f. Are walk-off or door mats placed outside the doors? Yes No

18. What kind of floor cleaning devices are used in the house? (Check all that apply)

a. Vacuum types: Upright Handheld Central vacuum
Canister Heavy duty Other: ____________

b. What type of special features does the primary vacuum have?
Beater brush Unknown
HEPA filter Other: ____________
Cyclone None

HOUSE CHARACTERISTICS

Dust sensor

c. Sweepers: Broom Dust mop Carpet sweeper Other ____________________

d. Other: Carpet cleaner Floor buffer Other: ____________

e. When was carpet last vacuumed (# days)? ____________

f. When was carpet last cleaned (steam or dry) (#days)? __________

g. What is the general level of cleanliness, clutter, and dust buildup?
1 = Very clean 2 3 4 5 = very dusty and cluttered,

h. Are there blankets or comforters over sofas?
Yes No

19. What car the subject usually use?
Model:
Age:
Fuel Type: Gasoline Diesel

Attach an approximate drawing of the floor where samplers are placed. Include windows, doors, AC units, and vented exhaust fans, clothes dryers and range fans. Also, include heating devices, fans, air cleaners, kitchen, and garage. Include an indicator for North direction.

20. Attach photos (or electronic file names for photos) of each side of the house, looking toward the house and away from the house. Note any potential sources of dust, smoke, or other aerosols.
____
____

COMMENTS (enter any notes re: sources or activities of potential interest, both indoor and outdoors)
____
____
____
____
____
____

House-Activity Diary: Instructions and Diary

Harvard School of Public Health
Detailed Characterization of
Indoor and Personal Particulate Matter Concentrations
Los Angeles, CA 2001-2002.

Subject Instructions for completing the
Home Activities Diary

Why do we ask you to fill these diaries?
In this study we are interested in two things. The first is to learn how the air pollution enters your house from outside. The second is to learn what activities you perform in your house that can generate pollutants inside the house.

In order to learn how air pollution enters your house from outside, we will need some information about your house. This will include information about the physical characteristics of your house, the appliances present in your house, and the kind of activities that are performed in your home. We are very interested in understanding how these factors can affect how pollution enters your home.

To help us understand these issues, we will ask you to provide information about the **ventilation** conditions in your home, for example, whether you used **air conditioning or other cooling devices, fans,** and whether you **opened windows or doors** in your house. We will also you to give us information about activities that may produce particulate air pollution. Some examples of these types of activities are: **cleaning, cooking, lawn mowing, and use of heating devices**.

What activities should you fill in the diary?
The diary consists of several columns, with each row representing a time window. What we would like to know when you perform certain activities. The activities we are interested in answer the following questions:

For Ventilation:
Did you turn on or off your AC or swamp cooler?
Did you turn on or off fans in your house?
Did you open or close windows or doors?
If applicable, indicate where the AC or fan is located.
What windows or doors were opened or closed.

For Heating
Did you turn on a heating device?
Which one and where?
Did you use other heating devices, such as **central heaters, space heaters, baseboard heaters, wood stoves, or fireplaces**.

For Cooking
Did somebody cook at home?
How did they cook the food? For example, did you t**oast, fry, sauté, bake, broil, BBQ outside, or use your microwave?**

For cleaning:
Did somebody clean inside your home?
How? For example, did you **dust, vacuum, sweep the floor?**
If possible, provide information on what was used for vacuuming or sweeping.

For Others:
Were other activities performed that may affect pollution inside your home? For example, did a **guest smoke;** did you **burn candles or incense**; did you **barbeque, weld, solder, have a party, mow your lawn, run your car in the garage**?

Was there any major source of smoke in or outside your house or at your neighbors' house? If so, describe what happened and where.

How do you fill the diary?
You should write in your diary every time you perform a new activity or the ventilation conditions in your home change. Entries should be made in the space that corresponds to the time that you started the activity or when the ventilation conditions changed inside the home. In addition, entries should be made in the space that corresponds to the relevant kind of activity.

For example, if you bake a cake from 8:05 to 8:35, write under the column **Cooking: "Baking cake"** in both slots 8:00 and 8:20. If the activity occurs over a long time period, for example baking from 6:00 to 8:30, just write down **"Baking cake"** at 6:00 row and draw an arrow down until the 8:20 row.

The same should be done for the rest of the columns. For the ventilation columns, record when you change ventilation conditions in your home. For example, if you leave home at 7:00 AM and you close all windows and door before you leave, write in **windows and doors** column **"Close all windows and doors"** in the 7:00 AM row. Later when you arrive home at 6:00 PM and open all the living room windows, write "**Open all living room windows"** in the 6:00 PM row.

The field staff will show you some example diaries and will review the diary with you after you complete them.

Home Activities Diary						**Version 1.2**
Harvard School of Public Health-LA INDOOR 2001						
House No:	________	**House ID:** ________ **Staff Initials:** ____________				**Sampling Day (circle one): 1 2 3 4 5**
Date:	____/____/____					**Day of Week: Mo Tu We Th Fr Sa S**

Start Time	Heating	Cooling	Fans	Windows and Doors	Cooking	Cleaning	Other
8:00 AM							
8:20 AM							
8:40 AM							
9:00 AM							
9:20 AM							
9:40 AM							
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6:40 AM							
7:00 AM							
7:20 AM							
7:40 AM							

Start Time	Heating	Cooling	Fans	Windows and Doors	Cooking	Cleaning	Other
	Did you use any **heating appliance?** Please indicate type and where you used it: Central heater Space heater Baseboard Fireplace	**Did you use AC** **or swamp cooling?**	**Did you use Fan?** Central Fan Living Room Fan	**Did you open** **windows or doors?** **Which one?**	**Did you cook?** Please indicate cooking type: Toasting Frying Sauteing Baking Broiling BBQ outside Using Microwave	**Did you clean?** Please indicate location and type of cleaning. Dusting counters and walls Vacuuming Sweeping floor	**Any major source** **of smoke in your hou** **or neighborhood?** Please indicate locatic and type of activity Guest smoked burn candles burn incense barbecue next door welding Air fresheners Cleaning products soldering in garage Party at home Lawn mower Car running in the gara

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Detailed Characterization of
Indoor and Personal Particulate Matter Concentrations
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TECHNICIAN INSTRUCTIONS FOR REVIEWING THE HOME ACTIVITIES DIARY

Start of Personal Sampling

At the start of the first sampling day, the technician should give a clipboard containing (1) a copy of the instructions for completing the home activities diary, (2) an example of a completed home activities diary, and (3) a copy of the home activities diary for the participant to complete. Also attached to the clipboard should be a pen.

The technician should review the instructions with all members of the household that would participate filling the diary. The participant, using the example diary to illustrate how to complete the diary and to highlight information that is particularly relevant to the study. In his or her instructions, the technician should stress the importance of making diary entries as the participant begins each new activity of interest, as this method will maximize the accuracy of diary entries.

After the technician has completed this review, the technician should ask the participant if he or she has any questions. The technician should then ask the participant to complete the first diary entries (e.g., start of personal sampling).

Start of Each Sampling Day

At the beginning of each sampling day, the technician should review the instructions briefly with the participant (as necessary) and give the participant a new copy of the home activities diary. The technician should ask the participant if he or she has any questions.

End of Personal Sampling Day

At the end of each sampling day (which may coincide with the start of a new sampling day), the technician should review the completed time-activity diary. After this review, the technician should bring the completed diary to the lab and place it in the appropriate folder.

The technicians should ask the subjects about the main activities during the last day. Specifically ask:
Have anybody use AC or cooler?
Have anybody use fans?
Have anybody open windows and doors?
Have anybody cooked?
Have anybody do cleaning?
Have anybody perform or seen any activity that can generate fumes or dust?

The technician should ask the participant for clarification about any activities or entries that (1) last more than two hours, (2) if diaries lack entries for ventilation or cooking and/or (3) seem inconsistent or are unclear.

In addition, the technician should ask participants for more information about location and conditions for any unusual entry (other column).

Time-Activity Diary: Instructions and Diary

Harvard School of Public Health
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SUBJECT INSTRUCTIONS FOR COMPLETING THE TIME-ACTIVITY DIARY

What is a Time-Activity Diary?

A Time-Activity Diary describes what you did and where you were throughout your day. This information will be used to help us characterize your exposures to various air pollutants and identify important factors that influence your exposures. To help you fill out your diary, we have attached an example of a completed time activity diary.

How do I complete the diary?

The diary asks you for your activities over a 24-hour period. Since it is easy to forget the details of your day, you should try to make entries into the diary throughout the day. In general, it may be easiest to write in your diary each time you begin a new activity or each time you change your location.

During the hours when most people are awake, the diary asks you to describe your activities and general location for each half-hour. Since you may perform two or more activities lasting for only 10 or 15 minutes, your entry for a given half-hour period may include 2 or more activities. During the night when you are likely to be asleep, the diary asks you about your activities and locations for each hour.

For activities that occur over long time periods, you can write a description of the activity and its location in its starting time block and simply draw an arrow from that time through to the start of the next new activity.

What kind of information should I include in the diary?

The diary is divided into several columns. The first column contains the start time of each time block. The second column asks for a short description of your activity. Examples of entries into this column include: sleeping, reading, shopping at the mall, eating at a restaurant, cutting the grass, or cooking dinner. Since people often do many things in a given half-hour, you can include multiple activities into each time block, especially if they involve dust, smoke, or odors.

The six numbered columns ask you where you were for this time block. For example, were you inside your home? Were you outside in your yard? In your car? At work? For each location, you should include a check inside the appropriate box. If you were at multiple locations, please indicate the number of minutes you were inside each location. Also, if you are away from your home, please write down the town and/or your general location. If you used a car or bus, please include the time you were outside walking to the car or waiting for the bus.

The last three columns ask yourself whether you were near any air pollution sources, such as cigarette smoke, cooking, or other sources such as cleaning, motor vehicles or construction. If so, please place a check in the appropriate box. In the *Near Other Dust, Smoke, or Odor Sources* column, please indicate the type of source you were near. Sources of "smoke" are sources that produce visible and sometimes odorous pollutants, while sources of "odor" tends to produce less visible pollution (diesel, ammonia, heating appliances, cooking, mold, cleaning products, fires, etc.)

TECHNICIAN INSTRUCTIONS FOR REVIEWING THE TIME-ACTIVITY DIARY

Start of Personal Sampling

At the start of the first personal sampling day, give a clipboard containing (1) a copy of the subject's instructions for completing the Time-Activity Diary, (2) an example of a completed Time-Activity Diary, and (3) a blank copy of the Time-Activity Diary for the participant to complete. Attach a pen to the clipboard.

Review the instructions with the participant, using the example diary to illustrate how to complete the diary and to highlight information that is particularly relevant to the study. Stress the importance of making diary entries as the participant begins each new activity, as this method will maximize the accuracy of diary entries.

After completing this review, ask the participant if he or she has any questions. Then ask the participant to complete the first diary entries (e.g., start of personal sampling).

Start of Each Personal Sampling Day

At the beginning of each personal sampling day, review the instructions briefly with the participant.

Give the participant a new copy of the Time-Activity Diary and ask the participant to complete the first diary entry.

Ask the participant if he or she has any questions.

End of Personal Sampling Day

Review the continuous indoor and outdoor monitoring data and list any peaks or anomalous values and their time of day.

At the end of each personal sampling day (which may coincide with the start of a new personal sampling day), review the completed Time-Activity Diary.

Ask the participant for clarification if any activity other than sleeping (1) lasts more than two hours, (2) lacks a transit activity between Home and Away from Home locations, (3) lacks information on how the person went from home to the transit activity (e.g. did he have to go outside to get to the car or was it parked in an attached garage?) and/or (4) seems inconsistent or unclear.

Ask participants for more information about location, particle sources, or type of cooking, as appropriate. Prompt the participant for information about location, especially for cases where the indoor/outdoor location is not obvious, such as in the workplace, restaurants, banks, and schools. Note responses on the side of the diary, in the activity column, or on the back of the diary using footnotes.

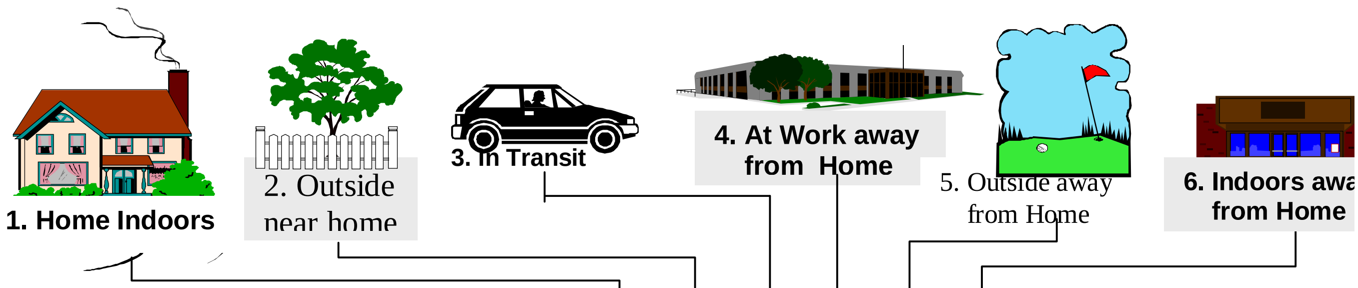
Ask the participant about the type of transit (e.g., bus, car, van/truck, bike, walking, etc.) as appropriate.

Ask about the location (e.g., town, street address, and/or zip code) of any activity performed away from home and ask whether the participant took the monitor with them.

Ask the Subject about their activities, other's activities, and possible pollutant sources during the times when peak pollutant levels were observed that day. Note relevant responses on the side of the diary, in the activity column, or on the back of the diary using footnotes.

Bring the completed diary to the lab and place it in the folder containing that participant's completed diaries and questionnaires.

Make a back-up copy and store in a box to be sent to HSPH for storage in a secure, locked file cabinet.



Start Time	Activity Description	1	2	3	4	5	6	Near Smoker	Near Cooking	Other
8:00 AM										
8:30 AM										
9:00 AM										
9:30 AM										
10:00 AM										
10:30 AM										
11:00 AM										
11:30 AM										
12:00 PM										
12:30 PM										
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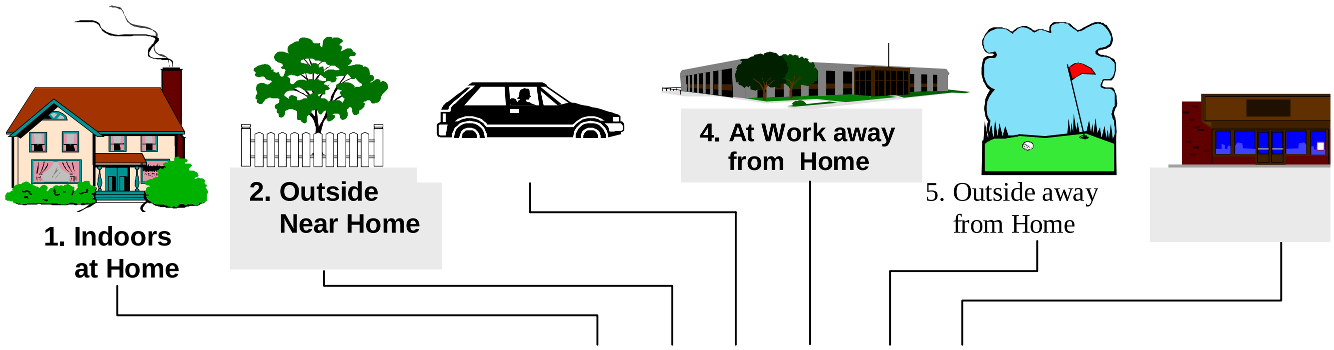
7:00 PM										
7:30 PM										



Start Time	Activity Description	1	2	3	4	5	6	Near Smoker	Near Cooking	Other
8:00 PM										
8:30 PM										
9:00 PM										
9:30 PM										
10:00 PM										
10:30 PM										
11:00 PM										
11:30 PM										
12:00 AM										
1:00 AM										
2:00 AM										
3:00 AM										
4:00 AM										
5:00 AM										
5:30 AM										
6:00 AM										
6:30 AM										
7:00 AM										
7:30 AM										

APPENDIX B: TIME-SERIES PLOTS FOR CONTINUOUS PARTICLE MEASURES

Figure 110. Indoor Hourly $PM_{2.5}$ Data By Date

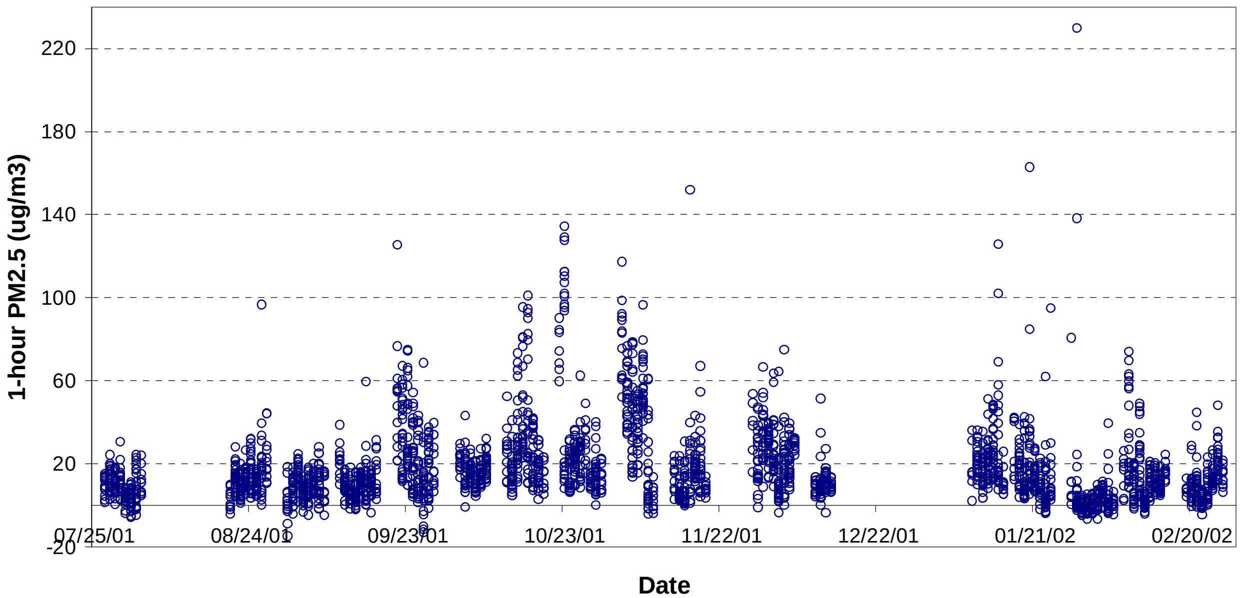


Figure 111. Outdoor Hourly $PM_{2.5}$ Data By Date

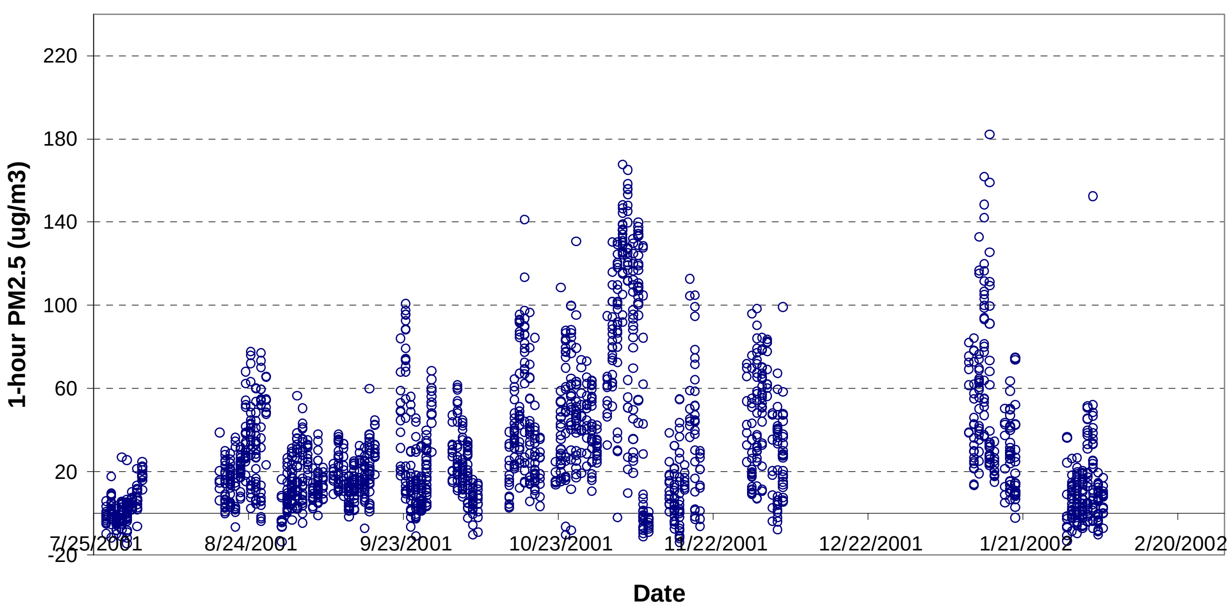


Figure 112. Indoor 20-Minute BC Data by Date

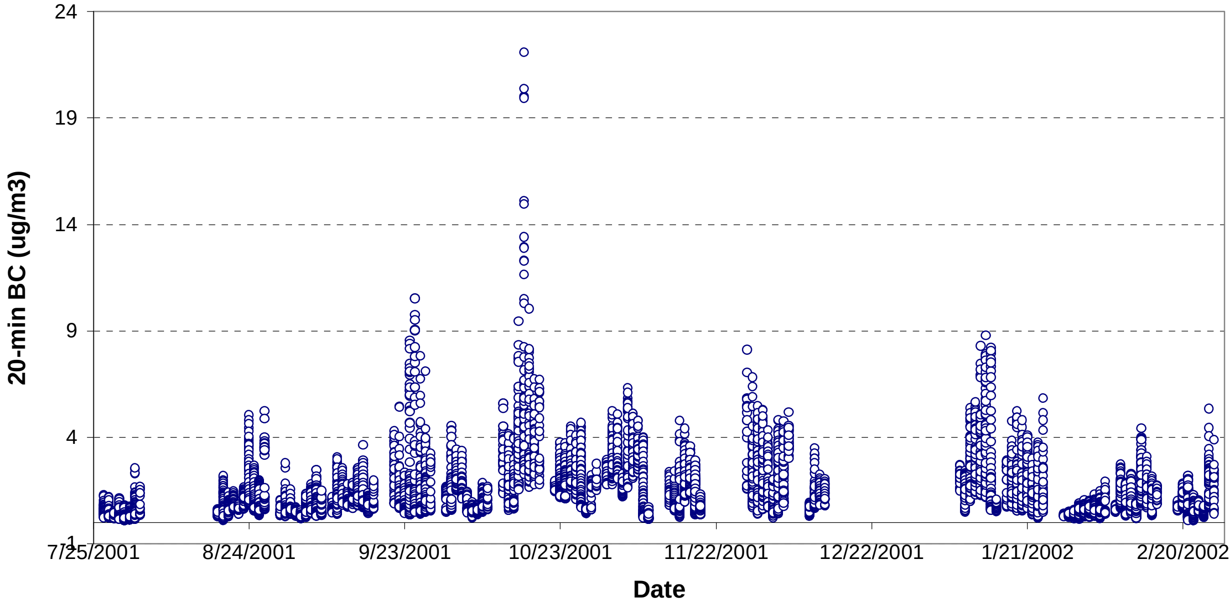


Figure 113. Outdoor 20-Minute BC Data by Date

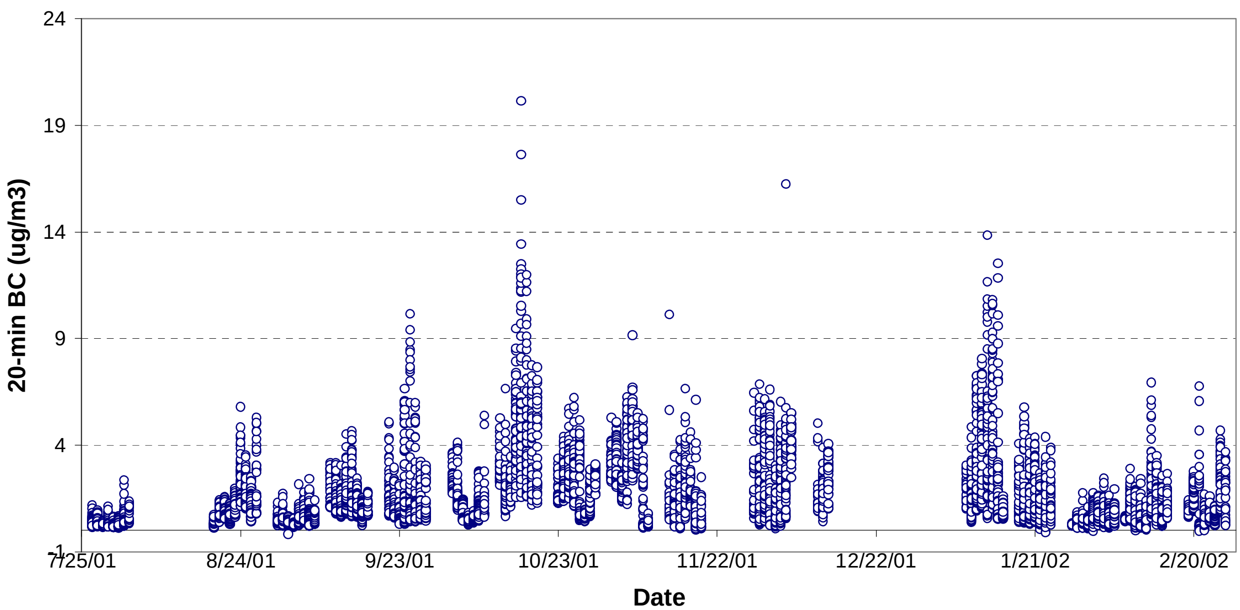


Figure 114. Indoor 20-Minute NO_3^- Data By Date

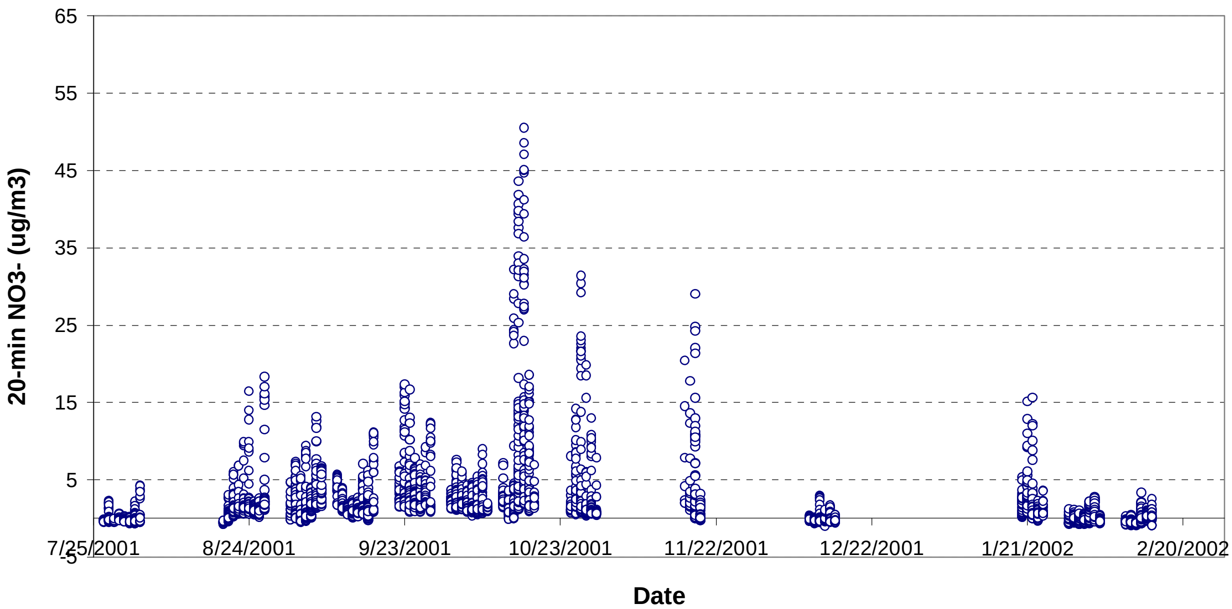


Figure 115. Outdoor 20-Minute NO_3^- Data By Date

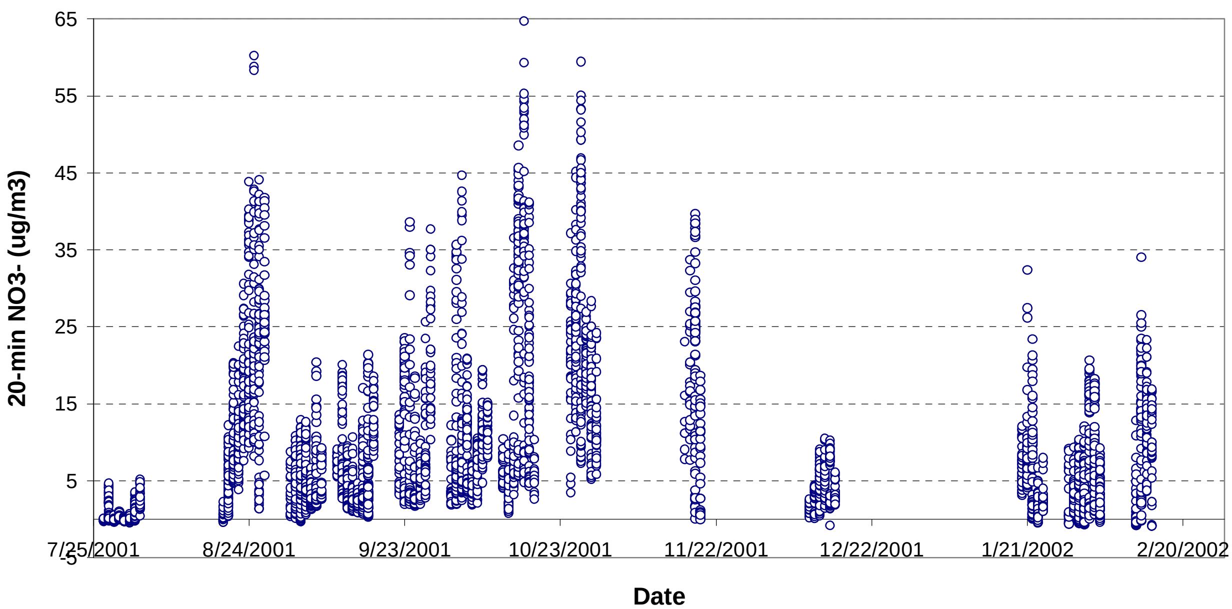


Figure 116. Indoor 20-Minute $PV_{0.02-0.1}$ Data by Date

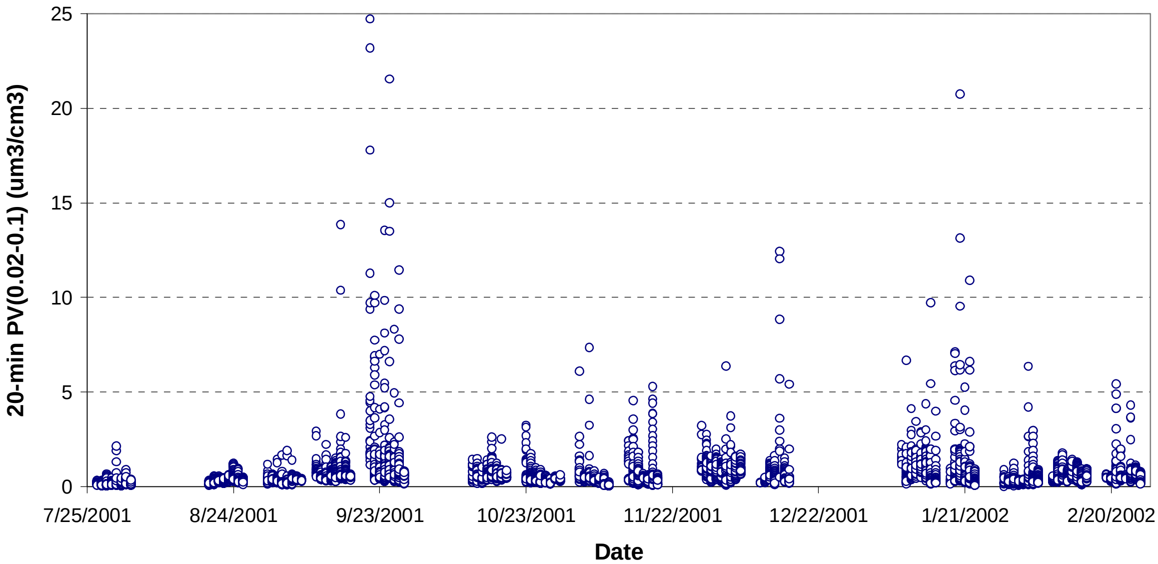


Figure 117. Outdoor 20-Minute $PV_{0.02-0.1}$ Data by Date

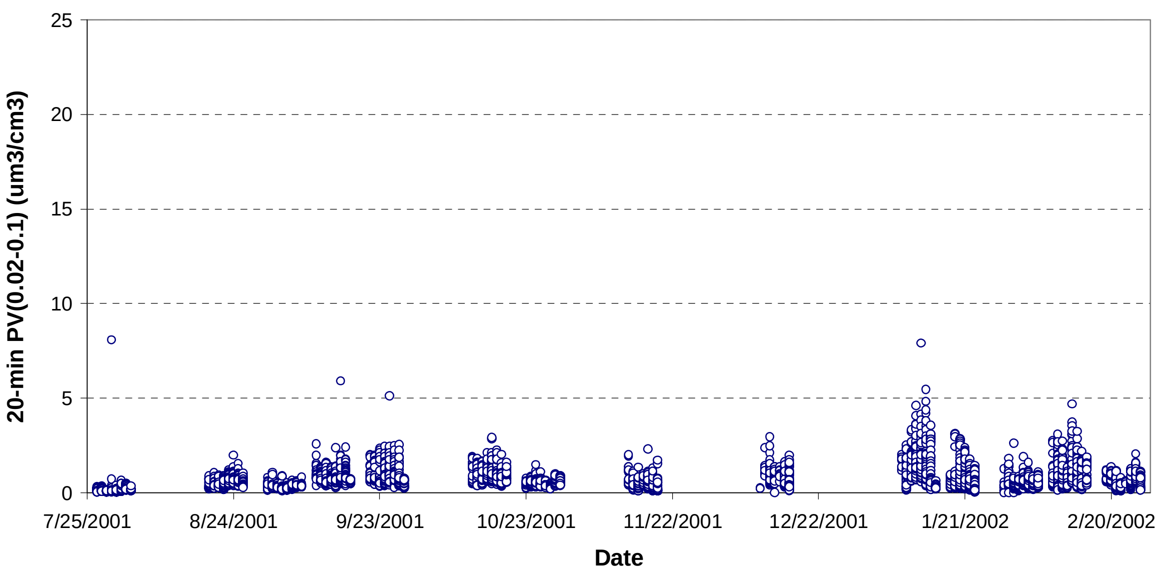


Figure 118. Indoor 20-Minute $PV_{0.1-0.5}$ Data by Date

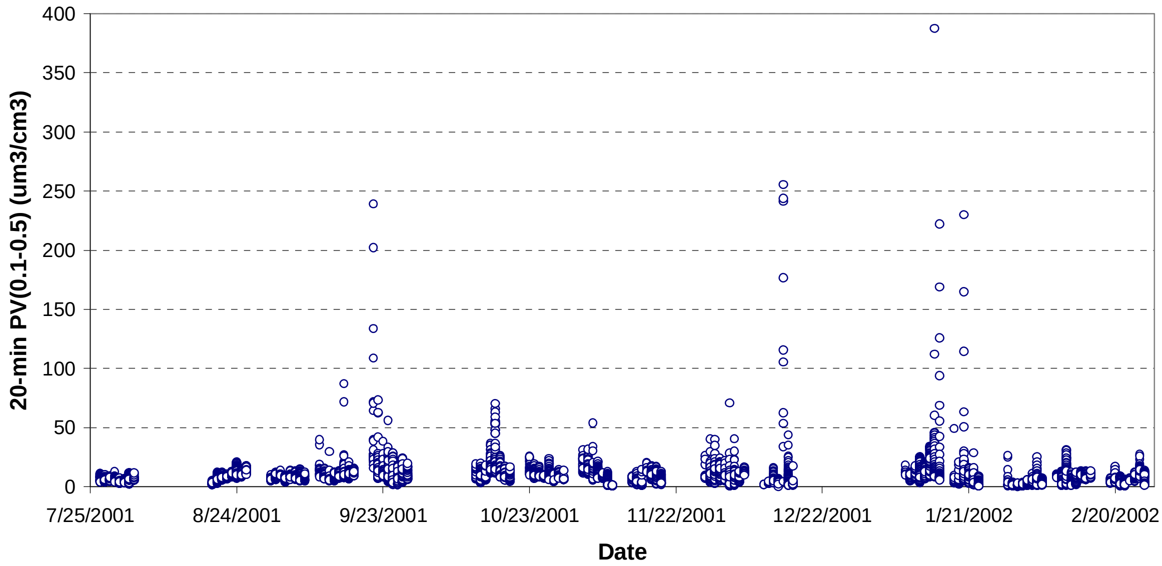


Figure 119. Outdoor 20-Minute $PV_{0.1-0.5}$ Data by Date

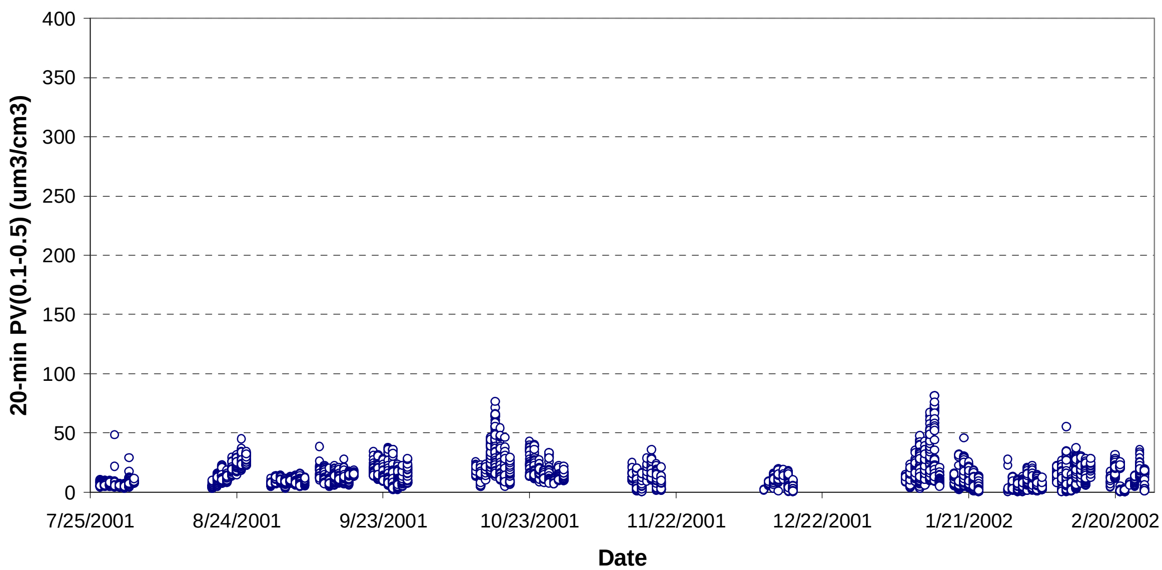


Figure 120. Indoor 20-Minute $PV_{0.7\text{-}2.5}$ Data by Date

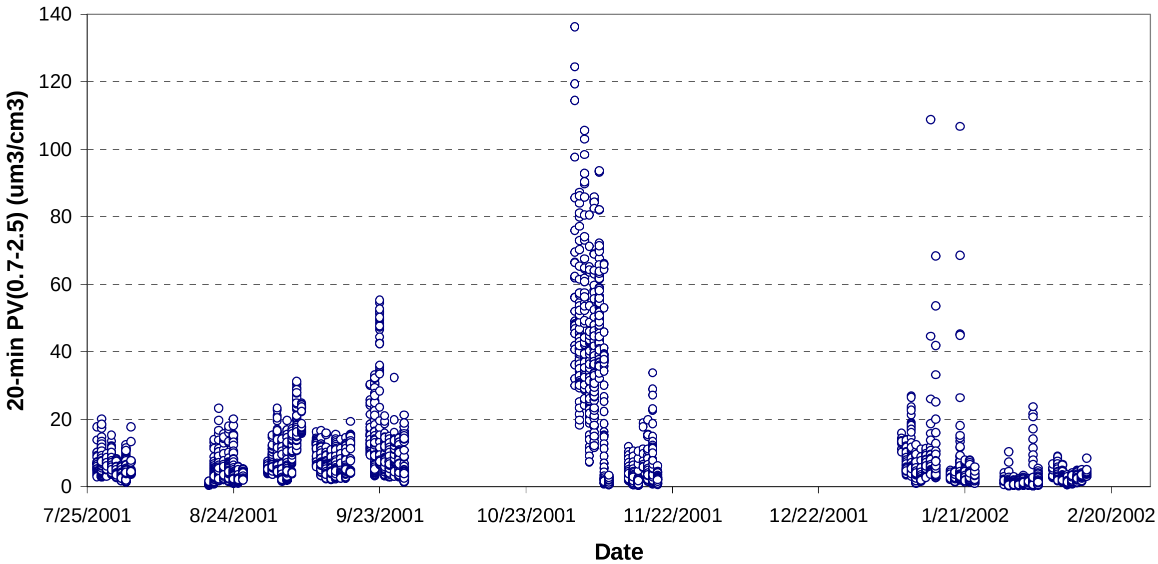


Figure 121. Outdoor 20-Minute $PV_{0.7\text{-}2.5}$ Data by Date

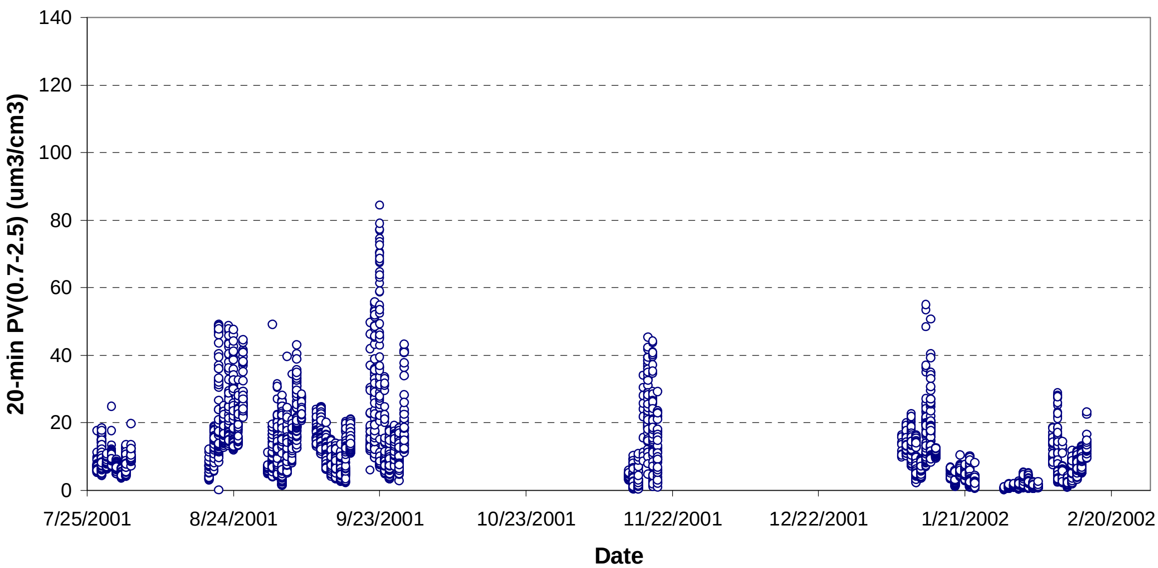


Figure 122. Indoor 20-Minute $PV_{2.5-10}$ Data by Date

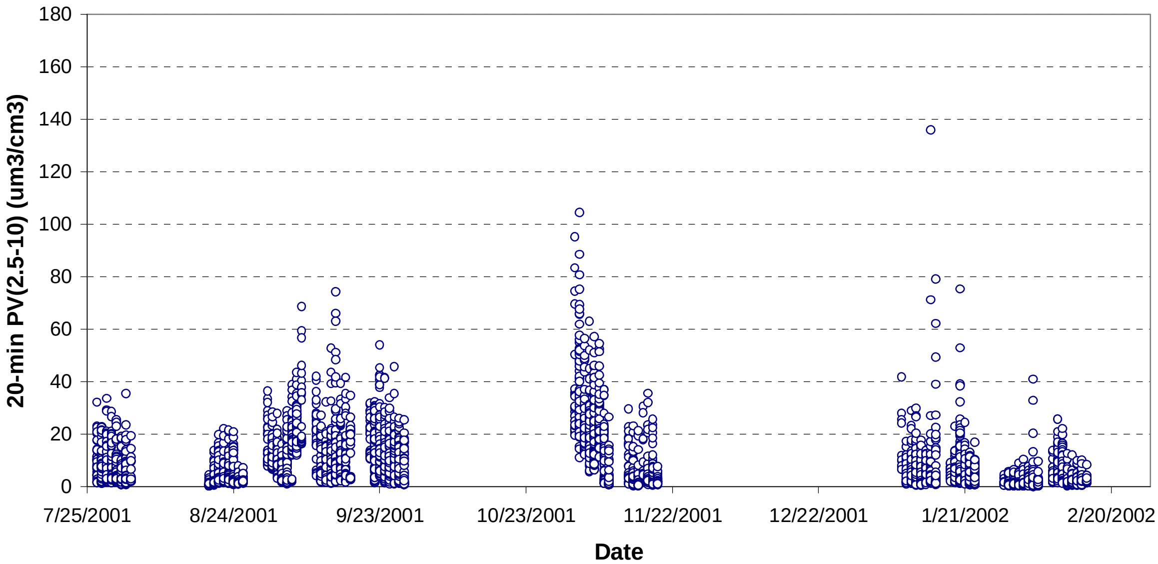


Figure 123. Outdoor 20-Minute $PV_{2.5-10}$ Data by Date