Indoor and outdoor concentrations of nitrogen dioxide, volatile organic compounds, and polycyclic aromatic hydrocarbons among MICA-Air households in Detroit, Michigan

ABSTRACT

The Mechanistic Indicators of Childhood Asthma (MICA) study in Detroit, Michigan introduced a participant-based approach to reduce the resource burden associated with collection of indoor and outdoor residential air sampling data. A subset of participants designated as MICA-Air conducted indoor and outdoor residential sampling of nitrogen dioxide (NO_2), volatile organic compounds (VOCs), and polycyclic aromatic hydrocarbons (PAHs). This participant-based methodology was subsequently adapted for use in the U.S. National Children's Study. The current paper examines residential indoor and outdoor concentrations of these pollutant species among health study participants in Detroit, Michigan.

Pollutants measured under MICA-Air agreed well with other studies and continuous monitoring data collected in Detroit. For example, NO_2 and BTEX concentrations reported for other Detroit area monitoring were generally within 10-15% of indoor and outdoor concentrations measured in MICA-Air households. Outdoor NO_2 concentrations were typically higher than indoor NO_2 concentration among MICA-Air homes, with a median indoor/outdoor (I/O) ratio of 0.6 in homes that were not impacted by environmental tobacco smoke (ETS) during air sampling. Indoor concentrations generally exceeded outdoor concentrations for VOC and PAH species measured among non-ETS homes in the study. I/O ratios for BTEX species (benzene, toluene, ethylbenzene, and m/p- and o-xylene) ranged from 1.2 for benzene to 3.1 for toluene. Outdoor NO_2 concentrations were approximately 4.5 ppb higher on weekdays versus weekends. As expected, I/O ratios pollutants were generally higher for homes impacted by ETS.

These findings suggest that participant-based air sampling can provide a cost-effective alternative to technician-based approaches for assessing indoor and outdoor residential air pollution in community health studies. We also introduced a technique for estimating daily concentrations at each home by weighting 2- and 7-day integrated concentrations using continuous measurements from regulatory monitoring sites. This approach may be applied to estimate short-term daily or hourly pollutant concentrations in future health studies.

INTRODUCTION

Elevated exposures to air pollutant species commonly found in both indoor and outdoor residential environments have been implicated in a wide spectrum of adverse health outcomes. Volatile organic compounds (VOC) and polycyclic aromatic hydrocarbons (PAH) have been associated with reproductive, developmental, neurological, allergic and respiratory, cardiovascular, and cancer outcomes (ATSDR, 1995 ; ATSDR, 2000; Suh et al., 2000; Miller et al., 2004; ATSDR, 2005; ATSDR, 2007a; ATSDR, 2007b; ATSDR, 2007c; Hertz-Picciotto et al., 2007; Spengler et al., 2007; Bernstein et al., 2008; Hertz-Picciotto et al., 2008). Nitrogen dioxide (NO_2) has been identified as a respiratory irritant responsible for asthma exacerbation (D'Amato et al., 2005; Bernstein et al., 2008).

Concentrations and exposures to these pollutants can be measured by collecting indoor, outdoor and personal measurements, a task typically undertaken by trained technicians (Breysse et al., 2005; Diette et al., 2007; Mukerjee et al., 2009a; Williams et al., 2009). Technician-based air monitoring can be resource intensive and may impose a significant burden on study participants. Estimates of pollution concentrations and personal exposures can also be predicted using empirical statistical models, e.g., land-use regression models (Brauer et al., 2002; Jerrett et al., 2005; Ross et al., 2006; Smith et al., 2006) spatial interpolation techniques, e.g., kriging or splining methods (Jerrett et al., 2005); and physical or mechanistic modeling-based approaches, including atmospheric, indoor / outdoor / personal exposure, and hybrid models (Jerrett et al., 2005; Boothe et al., 2005; Isakov et al., 2006; McConnell et al., 2006; Isakov and Özkaynak 2007; Özkaynak et al., 2008). However, modeling studies may require detailed information on emissions, building, and exposure factors, posing technical challenges. In the absence of more comprehensive exposure information, epidemiology studies generally rely on simple surrogates of personal exposures such as central-site monitoring data, proximity to roadways or traffic volume near the home as indicators of exposure (Venn et al., 2001; Janssen et al., 2003; Nicolai et al., 2003; Lewis et al., 2005; Ryan et al., 2005).

The Mechanistic Indicators of Childhood Asthma (MICA) study introduced a participant-based approach to reduce the burden associated with collection of indoor and outdoor residential air monitoring data. Under this approach, a subset of participants designated as MICA-Air collected indoor and outdoor residential air samples. The development and application of participant-based indoor and outdoor air sampling for this study has been described in detail elsewhere (Johnson et al., 2008), and has been adapted for use in the U.S. National Children's Study. The current report describes indoor and outdoor NO_2, VOCs, and PAHs measured at MICA-Air households and compares air pollution measured under MICA-Air with results from other research and regulatory monitoring in Detroit, Michigan. We also introduce a technique for estimating daily ambient NO_2 concentrations based on 2- and 7-day household measurements coupled with continuous regulatory monitoring data. This approach may be used to estimate short term (daily or hourly) exposure in future health studies.

METHODS

MICA-Air Study Design

Gas-phase air sampling was conducted from November 1 – December 29, 2006 in a subset of homes concurrently enrolled in two EPA health studies, MICA and the Detroit Children's Health Study (Johnson et al., 2008). Passive samplers were shipped to participating households and deployed by the parents of study participants to collect simultaneous indoor and outdoor measurements of NO_2, VOC, and PAH species. Half of the homes deployed VOC and NO_2 samplers for a single 7-day sampling event; the other half deployed single event 2-day NO_2 samplers as well as 24 and 48 hour PAH samplers. Households were assigned to sampling groups based on several factors—primarily lead time between recruitment and scheduled clinical evaluation for the health studies. Participants received detailed pictoral and written instructions for sampler deployment and retrieval as well as sampling cages in which to set up the indoor and outdoor samplers. Participants were instructed to deploy indoor samplers in the bedroom of the child participating in the health study. Participants recorded start and stop times and dates, as well as indoor temperature based on their indoor thermometer or thermostat, at the beginning and end of the sampling period. Environmental tobacco smoke (ETS) was assessed via

questionnaire. MICA-Air design and protocols have been described in detail elsewhere (Johnson et al., 2008).

Passive Air Sampling

Integrated 2-day and 7 day concentrations of NO_2 were collected using Ogawa passive samplers. Integrated 7 day measures of concentration were collected using Perkin-Elmer tubes packed with Supelco Carbopack B adsorbent for the following VOCs: benzene, ethylbenzene, toluene, m/p-xylene, o-xylene, 2-methylhexane, 2-methylpentane, 2,2,4-trimethylpentane, 2,3-dimethylpentane, 3-methylhexane, methylcyclohexane, 1,1,1-trichloroethane, 1,3-butadiene, 1,4-dichlorobenzene, carbon tetrachloride, chloroform, hexane, methylene chloride, methyl t-butyl ether (MTBE), styrene, tetrachloroethene, and trichloroethene. Twenty-four hour concentrations were collected for the following gas-phase PAH species: naphthalene (NAP), acenaphthylene (ACEN), acenaphthene (ACE), anthracene (AN), fluorene (FLN), phenanthrene (PHE), fluoranthene (FL), and pyrene (PY) using Fan-Lioy passive PAH samplers (Fan et al., 2006). Further discussion of passive sampling technology and evaluation is provided in the online supplement.

Quality Control

To evaluate data quality, the study deployed field duplicates equal to at least 10% of the experimental samplers, and field blanks equal to at least 15% of the experimental samplers deployed in the study. Further details and evaluation of duplicate samplers and blanks is provided in the online supplement. Samples were blank corrected by subtracting the average pollutant concentration measured on field blanks for each chemical species. Pollutant levels reported in this paper represent net concentration. Duration-specific MDL values were calculated for each sample. Calculations for MDL are described in further detail in the online supplement. MDL was used to qualify rather than truncate data; therefore net pollutant concentrations below MDL were not replaced with zero or MDL/(sqrt 2), and values below MDL were included in all analyses reported in this paper unless otherwise noted. However, indoor/outdoor (I/O) ratios were not calculated for households with indoor or outdoor values below zero after blank correction.

Estimation of Daily NO2 Concentrations Based on 2- and 7-Day Measurements and Continuous Monitoring Data

We also estimated daily ambient NO_2 at MICA-Air homes by calibrating 2-day or 7-day average NO_2 concentration measured at each home using continuous monitoring data measured at MDEQ sites as follows. The 2-day or 7-day average NO_2 concentration measured at each home was assigned to each day that fell within the sampling period for that home. These daily values were then adjusted for day of the week effect by applying a calibration factor (CF), which was based on daily concentrations at regulatory monitoring sites during the study (Equation 1). Daily estimates for MICA-Air homes were calculated as the product of: daily value, daily calibration factor, and total number of sampling days at the home, divided by daily calibration factors for each of the days on which sampling was conducted at the home (Equation 2).

$$\mathbf{CF_{Sun\ldots Sat} = NO_{2\ MDEQ\ Sun\ldots Sat} / NO_{2\ MDEQ\ Total}} \quad \mathbf{(1)}$$

Where:

- $CF_{Sun\ldots Sat}$ = Daily calibration factors for each day of the week (Sunday…Saturday)
- $NO_{2\ MDEQ\ Sun\ldots Sat}$ = Average daily NO_2 at MDEQ sites in Detroit for each day of the week (Sunday…Saturday) during MICA-Air study period (Nov 1 - Dec 29, 2006)
- $NO_{2\ MDEQ\ Total}$ = Average daily NO_2 at MDEQ sites in Detroit for duration of MICA-Air study period (Nov 1 - Dec 29, 2006)

$$\mathbf{NO_{2\ Daily} = [NO_{2\ MICA\text{-}Air} * CF_{Day\ X} * N] / \sum CF_{1\ldots N}} \quad \mathbf{(2)}$$

Where:

- $NO_{2\ Daily}$ = Daily NO_2 for Day X based on 2-day or 7-day MICA-Air measurement
- $NO_{2\ MICA\text{-}Air}$ = Average NO_2 measured at 2-day or 7-day home
- $CF_{Day\ X}$ = Daily calibration factor for date of interest (Sunday…Saturday) from Equation 1
- $CF_{1\ldots N}$ = Daily calibration factors for each day during which sampling was conducted at the home (Day 1…Day N)
- N = Number of days in which sampling was conducted at the home

Regulatory Monitoring Data

Both estimated and unadjusted outdoor NO_2 concentrations for MICA-Air households were compared with continuous monitoring data collected by the Michigan Department of Environmental Quality–Air Quality Division (MDEQ) at MDEQ sites 16 and 19 (Linwood and East 7 Mile) in Detroit, Michigan. Daily concentrations at the two MDEQ sites were similar (mean difference in daily NO_2 = 0.6 ppb; mean standard deviation = 1.2 ppb); therefore mean concentrations at the two sites were used in these comparisons.

Statistical Analyses

Descriptive statistics were generated for indoor and outdoor concentrations of NO_2, VOCs, and PAHs. Percent differences between MICA-Air and regulatory monitoring data were based on unadjusted 2- or 7-day averages from the study homes and MDEQ concentrations averaged over matched time periods. We compared unadjusted NO_2 and BTEX measured under MICA-Air with results from technician-based studies in Detroit. Finally, we performed studentized t-tests to compare weekend versus weekday NO_2 concentrations (for both unadjusted and estimated concentrations) and indoor/outdoor pollutant ratios for ETS versus non-ETS homes. Analyses presented in this paper were limited to households providing complete sampling log data (Johnson et al., 2008). Statistical analyses were performed using SAS 9.1 (SAS Institute, Cary, North Carolina, USA).

RESULTS

Descriptive statistics for outdoor and indoor NO_2, VOC and PAH concentrations are provided in Tables 1a and 1b, respectively. Mean outdoor NO_2 was approximately 4.0 ppb higher among homes that conducted air sampling for 2 days compared with those that conducted 7-day sampling ($p < 0.05$). There was no observed difference in mean indoor NO_2 concentrations for 2-day versus 7-day homes ($p = 0.99$). Mean outdoor concentrations for BTEX species (benzene, toluene, ethylbenzene, and m/p- and o-xylene) ranged from 0.8 $\mu g/m^3$ for ethylbenzene to 4.4

183 μg/m^3 for toluene; 2-methylpentane also contributed a high proportion of the overall pollutant
184 levels measured outside the homes.
185
186 For indoor BTEX species, mean concentrations ranged from 2.3 μg/m^3 for ethylbenzene to 18.0
187 μg/m^3 for toluene. Branched alkanes and 1,4-dicholorbenzene were also important contributors
188 to indoor pollution. Standard deviations were generally higher for indoor versus outdoor
189 concentrations for NO_2 and VOC species. NAP was the most predominant of the PAH species
190 for both indoor and outdoor measurements.
191
192 **Comparison of Unadjusted NO_2 and BTEX Measurements at MICA-Air Homes with**
193 **Regulatory and Technician-Based Monitoring**
194
195 Descriptive statistics for NO_2 and BTEX for Detroit area studies including MICA-Air are
196 provided in Table 2. Mean NO_2 measured at continuous MDEQ sites during the same time
197 period as the MICA-Air study (November 1- December 29, 2006) were within 5% of median
198 outdoor concentrations measured under MICA-Air. Mean outdoor NO_2 measurements at
199 DEARS homes in both winter and summer (Williams et al., 2009), and year round regulatory
200 measurements (Rizzo et al., 2002) were also within 10% of outdoor NO_2 concentrations
201 measured at MICA-Air homes.
202
203 Mean outdoor BTEX concentrations at MICA-Air homes were similar to outdoor winter
204 measurements at DEARS homes (within 10-15% for benzene, ethylbenzene, and xylenes).
205 Outdoor BTEX concentrations at MICA-Air homes were also consistent with annual average
206 BTEX concentrations (Le et al., 2007) and BTEX measurements collected under Detroit
207 Children's Health Study (DCHS) (Mukerjee et al., 2009b). Mean indoor BTEX concentrations
208 in DEARS homes collected in winter were similar to measurements collected under MICA-Air;
209 ethylbenzene, m/p-xylene and o-xylene concentrations were within 2%, 11% and 13% of MICA-
210 Air measurements, while benzene and toluene concentrations were within 22% and 28%.
211
212 Monitoring data from two continuous regulatory monitoring sites in Detroit was matched to each
213 MICA-Air home by averaging the daily NO_2 monitoring data for each day during which the

household deployed the passive samplers, and weighting the daily averages by the proportion of sampling time on each day. Unadjusted outdoor NO_2 concentrations at MICA-Air homes were within 15-20% of outdoor NO_2 measured at regulatory monitoring sites (median percent difference: 17%; mean percent difference: 20%). Unadjusted outdoor NO_2 at 7-day homes agreed more closely with concurrent measurements at regulatory monitoring sites, but were more likely to be lower than concentrations at regulatory monitoring sites (mean % difference: 10%; median 15%; range: -81 to 63%), while unadjusted outdoor NO_2 measurements at 2-day homes were generally higher than concurrent measurements at continuous regulatory monitoring sites (mean % difference: 34%; median: 20%; range -35 to 148%).

Comparison of Estimated Daily NO_2 at MICA-Air Homes with Continuous Regulatory Monitoring

Figure 1 shows daily outdoor NO_2 concentrations during the MICA-Air study period (November 1- December 29, 2006) for MICA-Air homes and regulatory monitoring sites in Detroit. MDEQ values reflect the daily averages measured at continuous regulatory monitoring sites in Detroit, while MICA-Air values represent estimated daily concentrations (as described in the methods section). Overall, daily outdoor NO_2 for MICA-Air homes was similar to daily NO_2 at MDEQ sites. The difference between daily NO_2 at MICA-Air and MDEQ monitoring sites was greater during the first and last days of the study period (Nov-1-2, and Dec 27-29), and during the American Thanksgiving holiday weekend (Nov 25-29). Standard error was not reported for these time periods because MICA-Air sampling was conducted at only one household during each of those dates.

Figure 2 shows estimated outdoor NO_2 concentrations at MICA-Air homes and MDEQ sites by day of the week. As with the unadjusted measurements, estimated daily concentrations at 7-day homes were similar to MDEQ sites, while estimated concentrations at 2-day homes were slightly higher. Average outdoor NO_2 was approximately 4.5 ppb higher during weekdays compared with weekends for both MDEQ sites and estimated daily MICA-Air concentrations ($p < 0.05$). Weekend versus weekday comparisons based on unadjusted concentrations for 2-day MICA-Air

homes that conducted sampling on weekends versus weekdays also showed significantly higher concentrations on weekdays versus weekends ($p < 0.05$).

Indoor/Outdoor Ratios for MICA-Air Homes

Figure 3 depicts I/O ratios for NO_2 and BTEX species. Mean I/O ratios for NO_2 did not vary significantly between ETS and non-ETS homes ($p = 0.79$). Mean I/O ratios for BTEX were greater in ETS homes ($p < 0.05$ for all BTEX species except toluene). Among non-ETS homes, I/O ratios for NO_2 (N=60) ranged from 0.2 to 3.4 with a median of 0.6. Median I/O ratios for BTEX species in non-ETS homes (N=29) were slightly higher, ranging from 1.2 for benzene to 3.2 for toluene, while median I/O ratios for ethylbenzene, o-xylene, and m/p-xylene were 1.7, 1.7, and 1.6, respectively. I/O ratios for other VOCs and PAHs are provided in the online supplements.

DISCUSSION

MICA-Air introduced a participant-based approach to exposure characterization in which participants conducted indoor and outdoor air sampling without assistance or oversight from trained technicians. Analyses of participant-based NO_2, VOC, and PAH measurements indicate that concentrations and trends observed in the current study agreed well with concurrent regulatory air monitoring data as well as active and passive monitoring results reported by technician-based studies. These findings suggest that participant-air sampling utilized under MICA-Air was a feasible strategy for measuring indoor and outdoor residential air pollution among health study participants. We also estimated daily ambient concentrations at each home by weighting integrated 2- and 7-day residential measurements with continuous regulatory monitoring data. Trends and associations reported for estimated daily concentrations were consistent with those based on unadjusted measurements, suggesting that this approach may be useful for estimating short-term ambient concentrations in future health studies.

NO_2, VOC, and PAH Measurements at MICA-Air Homes

Mean outdoor NO_2 was approximately 4.0 ppb higher among homes that conducted air sampling for 2 days compared with those that conducted 7-day sampling ($p < 0.05$), while indoor NO_2 did not vary between 2-day and 7-day homes. It is unlikely that sampling methodology and analysis could explain the differences between 2 and 7-day homes. Badges were prepared and analyzed using identical procedures, with the exception of sampling duration. NO_2 levels measured in the current study were well below the capacity of the samplers, eliminating the possibility of saturation. Also, Ogawa badges have additional filters and reduced surface area for nitrous acid deposition on tube walls; therefore volatilization, storage loss, and rate of sample accumulation would not be expected to vary with sampling duration as with Palmes tubes.

If air sampling were carried out predominantly during weekends at 2-day homes, higher weekday concentrations could potentially explain the difference in outdoor NO_2 concentrations measured at 2-day versus 7-day homes. However, the number of 2-day households conducting air sampling on weekends versus weekdays was similar, and average outdoor NO_2 measured by 2-day homes that conducted air sampling on weekends was higher than average NO_2 measured by 7-day homes (data not shown). It is also possible that outdoor NO_2 was higher among 2-day homes due to higher levels of ambient pollution near these homes. However, preliminary analysis of spatial land-use variables did not suggest significant differences in source proximity between the two groups (data not shown). Outdoor concentrations are also impacted by seasonality; however it is unlikely that seasonality could explain differences between 2-day and 7-day homes. There was also no evidence to suggest that month of sampler deployment (November versus December) differed between 2-day versus 7-day homes, or that ambient outdoor temperature differed between 2- and 7-day homes ($p=0.88$). Finally, the difference between mean outdoor NO_2 at 2-day versus 7-day homes persisted in sensitivity analyses which assumed constant temperature across households.

Average NO_2 and BTEX concentrations measured under MICA-Air were similar to concentrations measured by continuous regulatory monitoring and technician based studies in Detroit. NO2 measured at regulatory sites during the same time period as the MICA-Air study

was within 5% of outdoor NO_2 measured under MICA-Air, and ambient NO_2 for most Detroit studies were within 10% of outdoor NO_2 concentrations measured under MICA-Air. Indoor and outdoor BTEX concentrations measured at MICA-Air homes were generally consistent (within 15%) with residential DEARS measurements collected during the winter, and lower compared with concentrations reported at DEARS homes during the summer (Williams et al., 2009). Average BTEX concentrations were generally higher in summer (July-August) versus winter (January-March) in other Detroit area studies (Mukerjee et al., 2009b; Williams et al., 2009). MICA-Air conducted air sampling in fall/winter (November-December); therefore mean BTEX concentrations measured under MICA-Air that were similar to, or slightly higher than, winter means in other studies were consistent with the expected influence of seasonality.

To further evaluate the efficacy of participant-based air sampling, unadjusted measurements collected at individual MICA-Air homes were compared with temporally matched (2- and 7-day average) concentrations collected at MDEQ sites in Detroit. The median percent difference between unadjusted outdoor NO_2 concentrations measured at MICA-Air homes and concurrent outdoor NO_2 measured at regulatory monitoring sites was approximately 17%. Percent difference was lower for 7-day homes (13%) compared with 2-day homes (20%).

Estimated Daily NO_2 at MICA-Air Homes

Estimated daily NO_2 at MICA-Air homes was also compared with daily averages from regulatory monitoring sites. Differences between MICA-Air and MDEQ were greater where daily estimates were based on measurements from only one household. Comparisons between MDEQ monitoring and integrated measurements of NO_2 at MICA-Air homes were consistent with comparisons between MDEQ monitoring and estimated daily NO_2 at the study homes. While some differences between MICA-Air homes and MDEQ sites would be expected due to differences in pollutant concentrations across the urban area, good agreement between continuous monitoring data and MICA-Air (both estimated and unadjusted measurements) suggests that participant based air sampling was reasonable approach for collecting residential monitoring data.

Outdoor NO_2 concentrations at study homes were higher on weekdays compared with weekends for both daily estimated concentrations at all MICA-Air homes and for unadjusted measurements at 2-day homes that conducted sampling on weekdays versus weekends. These findings are consistent with patterns observed in MDEQ data for Detroit, and in previous studies in the U.S. (Marr and Harley, 2002; Thoma et al., 2008) and abroad (Karar et al., 2005; Tsai et al., 2007; Khoder, 2008) which reported higher levels of NO_2 in urban areas during weekdays versus weekends due to rush hour and commercial truck traffic. In addition, the agreement between weekend versus weekday trends in estimated and unadjusted values suggests that the approach used in this paper to estimate daily concentrations by weighting integrated measurements with continuous monitoring data could be used to estimate short-term air pollution levels in future health studies. In this paper we demonstrate the use of this approach to estimate daily concentrations. However, the technique could potentially be used to estimate hourly pollutant concentrations based on 1-day measurements.

Indoor/Outdoor Ratios at MICA-Air Homes

I/O ratios showed greater concentrations of outdoor versus indoor NO_2 for most MICA-Air households. In contrast, indoor BTEX concentrations were typically greater than outdoor concentrations. Relationships between indoor and outdoor NO_2 reported in previous studies varied considerably; studies in southern California and Boston have reported I/O ratios between 1 and 2 for NO_2 (Lee et al., 1998; Baxter et al., 2007). I/O ratios for BTEX among non-ETS homes in MICA-Air were comparable to I/O ratios reported by the DEARS study in Detroit. For example, median I/O ratios for benzene, ethylbenzene, m/p- and o-xylene among non-ETS MICA-Air homes fell within 10% of median I/O ratios for non-ETS homes in DEARS (Williams et al., 2009). I/O ratios for other VOC species and PAHs are discussed in greater detail in the online supplement.

I/O ratios for BTEX species among non-ETS homes in MICA-Air were slightly higher than I/O ratios reported in other geographic areas. Relationships of Indoor, Outdoor, and Personal Air (RIOPA) reported median I/O ratios for BTEX species ranging from 1.12 benzene to 1.54 for toluene for multi-season air sampling in Los Angeles, CA; Houston, TX; and Elizabeth, NJ

(Weisel et al., 2005); while the Toxic Exposure Assessment Columbia/Harvard (TEACH) reported median winter I/O ratios between 1 and 2 for most BTEX species in New York, NY, with a median I/O ratio of approximately 2.5 for toluene (Kinney et al., 2002). Median I/O ratios were even lower for TEACH homes in Los Angeles (Sax et al., 2004). Although average BTEX concentrations varied between the RIOPA cities, median outdoor concentrations at RIOPA homes were higher compared with MICA-Air homes while indoor concentrations in RIOPA were lower than indoor concentrations reported by non-ETS homes in MICA-Air (Weisel et al., 2005). These results suggest that indoor sources had a greater impact on indoor concentration among MICA-Air homes compared with households in previous studies. I/O ratios may vary between cities due to differences in indoor sources, housing stock and factors that influence penetration of outdoor pollutants. Differences between urban sources and spatial distribution of study homes in relation to those pollutant sources can also contribute to inter-city differences in I/O ratios. However, because ETS was assessed using questionnaire versus analytical methods in this study, it is also possible that higher I/O ratios in MICA-Air were due to misclassification of some ETS homes.

Seasonality can have a major influence on the contribution of outdoor pollution to indoor concentration. Outdoor concentrations may exert a greater impact on indoor concentrations during the summer due to increased air exchange, while indoor contributions may be lower due to decreased use of indoor sources such as gas appliances and portable heaters. Higher I/O ratios are expected in winter versus summer due to reduced clearance of pollutants generated inside the home (Kinney et al., 2002). For example, Zhu et al. (2005) reported much higher I/O ratios for BTEX species (ranging from 7.7 for benzene to 16 for m/p-xylene) based on air sampling conducted in Ottawa, Canada during fall and winter seasons (November-March); this study also included homes impacted by ETS. MICA-Air measurements were collected during the winter, while the DEARS, RIOPA and TEACH measurements were collected during multiple seasons. Although seasonal variation may have contributed to differences in average I/O ratios between the studies, I/O ratios in MICA-Air were elevated compared to winter I/O ratios for TEACH. Finally, I/O ratios in RIOPA may have been lower than MICA-Air because the RIOPA study over-sampled homes that were heavily impacted by ambient air pollution sources, while MICA-Air sampled homes of participants in a health study (Weisel et al., 2005).

Limitations

The analyses in this paper were limited by several factors. MICA-Air participants conducted air sampling without oversight from trained technicians, and preliminary analyses suggest that participants were able to conduct air sampling according to study protocol and provide useful data (Johnson et al., 2008); however, there may be greater uncertainty associated with these measurements compared with data collected by trained technicians. Other design factors such as small sample size, particularly for PAH measurements, and non-synchronization of the sampling periods may also have impacted the analyses. Also, ETS was assessed through questionnaire rather than air sampling which may have led to misclassification of smoking households.

Comparison of MICA-Air results with other Detroit area monitoring data was limited by disparate sampling technology (e.g., active versus passive), integration periods, sampler analysis and sampling seasons. Furthermore, co-location of samplers by technicians was not possible in MICA-Air because technicians did not visit the homes. Thus, while the current results are promising, further evaluation is needed to elucidate the strengths and limitations participant-based air sampling.

Conclusions

MICA-Air collected indoor and outdoor air sampling data among participants of a health study conducted in Detroit, Michigan using a participant-based approach that has been adapted for use in the U.S. National Children's Study. The current paper characterizes indoor and outdoor concentrations of NO_2, VOC and PAH species in MICA-Air homes. Indoor concentrations generally exceeded outdoor concentrations for most VOC and PAH species measured in the study, and outdoor NO_2 concentrations were higher among homes that conducted air sampling on weekdays compared with weekends. Participant-based NO_2, VOC, and PAH measurements agreed well with previous studies and continuous monitoring data collected in Dearborn and Detroit. For example, average NO_2 and BTEX concentrations reported for other Detroit area monitoring generally fell within 10-15% of average indoor and outdoor concentrations measured at MICA-Air households. These findings suggest that participant-based air sampling might

provide a cost-effective alternative to technician-based approaches for assessing indoor and outdoor residential air pollution in health studies among diverse populations.

We also introduced an approach for estimating short term outdoor pollutant concentrations by weighting residential measurements using continuous regulatory monitoring data. Trends observed in estimated NO_2 concentrations were similar to trends based on unadjusted residential concentrations at MICA-Air homes (e.g., comparisons between weekend and weekday concentrations). Further research is needed to fully evaluate this approach, but preliminary findings suggest that this technique may be useful for estimating short term (e.g., daily or hourly) ambient concentrations in future health studies.

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