Published in final edited form as:

*J Expo Sci Environ Epidemiol*. 2016 June ; 26(4): 341–348. doi:10.1038/jes.2015.26.

# Factors influencing time-location patterns and their impact on estimates of exposure: The Multi-Ethnic Study of Atherosclerosis and Air Pollution

**Elizabeth W. Spalt**[1], **Cynthia L. Curl**[1], **Ryan W. Allen**[2], **Martin Cohen**[1], **Kayleen Williams**[3], **Jana A. Hirsch**[4], **Sara Adar**[5], and **Joel D. Kaufman**[6]

[1]Department of Environmental and Occupational Health Sciences, University of Washington

[2]Faculty of Health Sciences, Simon Fraser University, Burnaby, British Columbia, Canada

[3]Collaborative Health Studies Coordinating Center, University of Washington

[4]Carolina Population Center, University of North Carolina, Chapel Hill, North Carolina

[5]Department of Epidemiology, University of Michigan, Ann Arbor, Michigan

[6]Departments of Environmental and Occupational Health Sciences, Epidemiology, and Medicine, University of Washington, Seattle, Washington

## Abstract

We assessed time-location patterns and the role of individual- and residential-level characteristics on these patterns within the Multi-Ethnic Study of Atherosclerosis and Air Pollution (MESA Air) cohort and also investigated the impact of individual-level time-location patterns on individual-level estimates of exposure to outdoor air pollution. Reported time-location patterns varied significantly by demographic factors such as age, gender, race/ethnicity, income, education, and employment status. On average Chinese participants reported spending significantly more time indoors and less time outdoors and in transit than white, black, or Hispanic participants. Using a tiered linear regression approach, we predicted time indoors at home and total time indoors. Our model, developed using forward selection procedures, explained 43 percent of the variability in time spent indoors at home, and incorporated demographic, health, lifestyle, and built environment

---

Elizabeth W. Spalt, MS, Department of Environmental and Occupational Health Sciences, University of Washington, Seattle, Washington, University of Washington, Campus Box 354695, 4225 Roosevelt Way NE, Suite 302, Seattle, WA 98105, Phone: 206-897-1436, Fax: 206-897-1991, espalt@uw.edu.
Cynthia L. Curl, PhD
Department of Environmental and Occupational Health Sciences, University of Washington, Seattle, Washington
Ryan W. Allen, PhD
Faculty of Health Sciences, Simon Fraser University, Burnaby, British Columbia, Canada
Martin Cohen, ScD
Department of Environmental and Occupational Health Sciences, University of Washington, Seattle, Washington
Kayleen Williams, MS
Collaborative Health Studies Coordinating Center, University of Washington
Jana Hirsch, PhD
Carolina Population Center, University of North Carolina, Chapel Hill, North Carolina
Sara D. Adar, ScD
Department of Epidemiology, University of Michigan, Ann Arbor, Michigan
Joel D. Kaufman, MD, MPH
Departments of Environmental and Occupational Health Sciences, Epidemiology, and Medicine, University of Washington, Seattle, Washington

factors. Time-weighted air pollution predictions calculated using recommended time indoors from USEPA(1) overestimated exposures as compared to predictions made with MESA Air participant-specific information. These data fill an important gap in the literature by describing the impact of individual and residential characteristics on time-location patterns and by demonstrating the impact of population-specific data on exposure estimates.

**Keywords**

epidemiology; exposure modeling; personal exposure; population based studies

## Introduction

A standard method to assess individual exposure to contaminants is to calculate a time-weighted average of microenvironmental concentrations by multiplying the concentration of a given chemical in an individual's environment by the amount of time spent in contact with contaminated media in that environment(2). Because pollutant concentrations can vary across microenvironments, exposure assessments require estimates of these concentrations and the time spent in each location.

Large-scale studies of time-location patterns include the National Human Activity Pattern Survey (NHAPS) and the Consolidated Human Activity Database (CHAD)(3). Data from these types of large-scale studies or databases can be a useful alternative to collecting study-specific data, which can be expensive and difficult to validate. However, such existing information may not be representative of unique populations. The Multi-Ethnic Study of Atherosclerosis and Air Pollution (MESA Air) cohort is comprised of individuals over the age of 45 from four racial/ethnic groups: white, black, Chinese, and Hispanic. Given the limited data on Chinese populations and USEPA's recent recommendations for the collection of additional time-location data for older populations(4), charactering time-location patterns in the MESA Air cohort helps to broaden the populations for which time-location patterns are understood.

MESA Air aims to quantify the relation between individual-level estimates of long-term outdoor air pollution exposure and the progression of subclinical atherosclerosis and the incidence of cardiovascular disease (CVD)(5). As we previously described(6), the questionnaire developed for and administered to MESA Air participants is a reliable method for estimating time spent in microenvironments. The aims of this analysis are to assess differences in time-location patterns among demographic groups, to understand how individual- and residential-level characteristics impact total time spent in specific microenvironments within this cohort, and to quantify the effect of incorporating participant-specific time-location data – as opposed to standard exposure factors – on outdoor air pollution exposure estimates.

## Methods

### Study population

MESA Air is an ancillary study to the Multi-Ethnic Study of Atherosclerosis (MESA(7)), a long-term study of the progression of CVD in adults. MESA included 6,814 participants from six US communities: Baltimore, MD; Chicago, IL; Forsyth County, NC; Los Angeles, CA; New York, NY; and St. Paul, MN Participants were aged 45–84 years at enrollment, with an approximately equal gender ratio, and were free of recognized CVD at baseline. Four ethnic/racial groups were targeted for inclusion: non-Hispanic white, non-Hispanic black, Hispanic, and Chinese. MESA Air includes 6,424 participants, primarily recruited between 2005 and 2007 from the parent MESA cohort. Additional participants were recruited from a second ancillary study to MESA, the MESA Family Study (n=490), and directly for MESA Air (n=257) in three additional areas near existing MESA communities, two areas in the Los Angeles basin and one area near New York City(5). An additional 1,127 MESA participants are included in MESA Air exposure modeling but did not complete all aspects of the MESA Air study and were not included in this analysis.

### MESA Air Questionnaire (MAQ)

The MESA Air Questionnaire (MAQ, see supplemental materials) is described more thoroughly elsewhere(6). Briefly, every MESA Air participant was asked to complete a MAQ regarding residential characteristics and time-location patterns at study enrollment (hereafter referred to as the baseline MAQ and the focus of this analysis) and up to four more times. This baseline administration occurred in person, during a MESA clinic exam between 2005 and 2007, in English, Spanish, Mandarin, or Cantonese depending on the preferred language of the participant.

The MAQ collected information on home characteristics relevant to pollutant infiltration efficiencies and behaviors related to individual exposures. Participants were asked specific questions about their typical time-location patterns in winter and summer. For each day of the week, the MAQ included questions documenting time spent (rounded to the nearest hour) in each of seven locations: home indoors, home outdoors, work/volunteer/school indoors, work/volunteer/school outdoors, in transit, other indoors, and other outdoors. Participants also designated which days of the week they considered weekends and weekdays. The amount of time by transit mode, road types travelled, and traffic conditions experienced were also documented. Additional questions asked about home characteristics related to building type, building age, the presence of an attached garage, and other factors relevant to infiltration.

### Built Environment Parameters

Since previous research in this cohort has demonstrated associations between the built environment and physical activity(8-12), the built environment may also play a role on time-location patterns. To assess the impact of the built environment on time-location patterns, we evaluated the following variables distance to commercial land use (meters, 2006 data from the National Land Cover Database), distance to coast (meters), distance to city hall (meters), population density, and elevation (meters). Population density measures from the 2000 U.S

Census Bureau include buffers of 500, 1000, 1500, 2000, 2500, 3000, 5000, 10000, and 15000 meters. Built environment measures were also calculated during the MESA Neighborhood Ancillary Study. For the current analysis, we used density of popular walking destinations, intersection density, and network ratio, as these have been shown to be most associated with walking for transportation in this cohort(10). Details on these measures can be found elsewhere(10).

## Data Analysis

The first aim of this study was to assess differences in time-location patterns by demographic group. Differences by group were assessed using Kruskal Wallis tests due to skewness in the outcome.

The second aim was to understand the individual- and residential-level predictors of time-location patterns reported in the MAQ. For MESA Air, the primary use of the time-location section of the MAQ is to determine the fraction of time spent indoors, which is used to calculate individual time-weighted air pollution estimates (described in detail subsequently) for each location in MESA Air(13). For this reason, we were particularly interested in understanding predictors of time spent indoors. Because individuals spend such a large portion of their time indoors at home(1, 3, 14, 15), there is also broader utility in understanding the predictors of time spent in this microenvironment.

We conducted linear regression modeling in a tiered approach to estimate both total time indoors and time indoors at home. The model equation is as follows:

$$t_{indoors}=\alpha+\beta_1 X_1+\beta_2 X_2+\cdots+\beta_k X_k \quad \text{Equation 1}$$

where $t_{\text{indoors}}$ is the total time indoors (hours/week) or time indoors at home (hours/week), $\alpha$ is the intercept, $\beta$ is the estimate, and X is the independent variable. For each location, we averaged the reported times in summer and winter to obtain a yearly average result.

We selected a tiered modeling approach with the goal of developing relatively simple models for predicting time-location patterns. The minimally adjusted model incorporated race/ethnicity, gender, study site, and age. The second model added the following socioeconomic and demographic variables: employment status (full time, part time, or not employed), education (<high school, high school, college, graduate/professional school), household income (<$12,000, $12,000-$24,999, $25,000-$39,999, $40,000-$74,999, $75,000+), and marital status (married, not married). The third model was developed using forward-selection with 10-fold cross-validated RSME as the selection criteria. To build the third model, we tested the variables from the second model plus the following health- and lifestyle-related variables: body mass index (BMI) category (normal, overweight), diabetes status (normal, impaired fasting glucose, diabetes), individual perception of health compared to others of same age (better, same, worse), cigarette smoking status (current, former/never), cholesterol category (<200, 200-239, 240+), hypertension stage (normal, hypertensive), self-reported asthma, self-reported arthritis, self-reported emphysema, and yes/no from the question: “do you ever have to stop walking from breathlessness?.” The third model also included three housing-related questions: building type (single family/free-standing/manufactured, row house/townhouse/brownstone/duplex/triplex, high-rise apartment/low-rise apartment, other), whether the participant spent more than four weeks per year at a second home, and the presence of any air conditioning (e.g., central, window units). Variables tested in this third model also included the built environment parameters described above. Finally, we added the season of MAQ administration as a variable. The final third models only included parameters that improved predictability as determined by 10-fold cross validation. We also ran additional models excluding study site that may be more universally applied outside of MESA Air and provide these results in the Supplemental Materials.

The third aim of this study was to evaluate the impact of time-location patterns on individual outdoor-derived air pollution estimates. MESA Air focuses on air pollution of outdoor origin and estimates indoor concentrations of outdoor-derived air pollution using outdoor concentrations and participant-specific infiltration efficiencies. Outdoor-to-indoor infiltration efficiencies ($F_{inf}$) for fine particulate matter ($PM_{2.5}$) are based on housing characteristics obtained from the MAQ and weather patterns (16). Individual time-weighted $PM_{2.5}$ estimates in MESA Air represent exposure both indoors and outdoors and therefore incorporate outdoor concentration, infiltration efficiency, and the total time indoors with the following equation:

$$C_{ind}=\frac{(1-t_{indoors})}{24\frac{hrs}{day}}\times C_{out}+\frac{t_{indoors}}{24\frac{hrs}{day}}\times C_{out}\times F_{inf}\qquad\text{Equation 2}$$

where $C_{ind}$ is the individual time-weighted $PM_{2.5}$estimate (μg/$m^3$), $t_{indoors}$ is the time spent indoors (hrs/day), $C_{out}$ is the outdoor $PM_{2.5}$estimate (μg/$m^3$) and $F_{inf}$ is the infiltration efficiency (dimensionless). For this analysis, we included all MESA Air participants who completed the time location portion of their baseline MAQ and did not report moving during the year prior to the baseline MAQ. $C_{out}$ represented annual average participant-specific outdoor $PM_{2.5}$ predictions for the year prior to the baseline MAQ. These predictions were calculated using a spatio-temporal model developed for MESA Air that incorporated $PM_{2.5}$ monitoring, geographic information, and weather patterns(17). Participant-specific infiltration efficiencies incorporate housing characteristics and vary by season. A single season-weighted $F_{inf}$ was calculated for each person. Summer and winter were differentiated based on average temperature over a two-week period. If the average temperature was greater than 18°C, the season for that two-week period was classified as summer; otherwise, the season was winter(16). Then we compared the time-weighted concentrations calculated using the recommended total time indoors estimate from USEPA's Exposure Factors Handbook(1) to those calculated using the total time indoors collected for each MESA Air participant. USEPA(1) provides a recommended total time indoors value of 19.2 hours per day for individuals over the age of 18 (average of 18-64 and 65+). USEPA derived their recommendations for time indoors by subtracting the time spent outdoors (for participants that spent any time outdoors only) reported in NHAPS.

All statistical analyses were conducted using SAS Software Version 9.3 of the SAS System for Windows (Copyright ©2010 SAS Institute Inc., Cary, NC).

## Results

A total of 5,996 participants completed the time-location section of the baseline MAQ, and Table 1 presents the demographic characteristics these participants. On average, participants spent 21.5 hours indoors per day, which is higher than USEPA's recommended exposure factor value of 19.2(1). We observed several significant differences in time-location patterns by demographic variables such as age, gender, race/ethnicity, site, income level, education, and job status (Table 2).

This study is the first to show that Chinese participants spend more time indoors and less time outdoors compared to whites, blacks, and Hispanics participants. Significant differences in total time spent indoors, and outdoors, and in transit were observed across each pair of race/ethnic groups ($p<0.05$), except for the comparisons between blacks and Hispanics indoors ($p=0.99$), blacks and Hispanics in transit ($p=0.06$), and whites and Hispanics in transit ($p=0.76$). Although the recruitment of ethnic/racial groups was not consistent across sites (white, black, Hispanic, and Chinese participants were recruited at six, five, three, and two sites, respectively) (7), significant differences in time location patterns by race/ethnicity remained after separating the results by site (Table 3, Supplemental Table 2). For total time indoors, all racial/ethnic pairs were significantly different ($p<0.0001$) from each other except for Hispanic:black. This trend was consistent by site ($p<0.05$) with a few exceptions. In Baltimore and Chicago, white and black participants were not significantly differently from each other, and in Los Angeles, the difference between black and Chinese participants was not significant ($p=0.09$).

Figure 1 presents the distributions of total time spent indoors and time spent indoors at home for MESA Air participants by employment status (full/part time vs. not employed). The mean values for time spent indoors at home are 109 hours/week and 135 hours/week, for participants that are employed (full/part time) and unemployed, respectively.

### Individual and Residential Predictors of Time-Location Patterns

Several models were developed to predict total time indoors. The first, a minimally-adjusted model, incorporated race/ethnicity, gender, study site, and age and had an $R^2$ of 0.15 (Table 4). The $R^2$ for the second model, which added socioeconomic and demographic variables, was 0.16. The final variables in the third model included all of the variables from model 2 plus the results from the question: "do you ever have to stop walking from breathlessness?," perceived health age, cholesterol category, building type, possession of a second home, presence of air conditioning, distance to commercial land use, elevation, and season of MAQ administration. This third model had a cross-validated $R^2$ value of 0.19. In all three models, age, gender, race/ethnicity, and site were significant ($p<0.0001$). Participants spent approximately 0.25 hours more per week indoors with each additional year of age. The amounts of time spent indoors by black and Hispanic participants were similar, whereas white and Chinese participants spent about 2 hours less and 3 hours more time indoors, respectively, than Hispanic participants. For model two, of the socioeconomic variables, employment status, education, and income were significant ($p<0.05$), but the model $R^2$ of model two was very similar to that of the minimally adjusted model. All variables except for air conditioning were significant ($p<0.05$) in model three. Site and gender, explained 12 percent of the variability in model three (Supplemental Table 2). Models developed without study site explained 12, 12, and 17 percent of the variability, for the minimally adjusted model, model two, and model three, respectively (Table 5p Supplemental Table 3). For all three models with and without study site, the average relative difference between observed and predicted values ranged between 6 and 7 percent.

We also developed several models to predict time spent indoors at home. The minimally-adjusted and model two had $R^2$ values of 0.27 and 0.40, respectively (Table 5, Supplemental Table 4). The variables selected for the third model included all model two variables plus asthma, arthritis, cigarette smoking status, the results from the question: “do you ever have to stop walking from breathlessness?,” cholesterol category, perceived health age, building type, possession of a second home, distance to main city hall, distance to commercial land use, elevation, and 1-mile buffer network ratio. The cross-validated $R^2$ value for this third model was 0.43, and the average relative difference between observed and predicted values was 13 percent (Table 5).

As with the models predicting the total amount of time spent indoors, age, gender, race/ethnicity, and site were all significant predictors of time spent at home indoors ($p<0.0001$). In model two, all of the socioeconomic variables were significant ($p<0.05$), and the addition of these variables improved model two’s $R^2$ compared with the minimally adjusted model. Employment status alone explained 32 percent of the variability in model three (Supplemental Table 5). Excluding study site as a variable from the three models reduced $R^2$ values modestly (Supplemental Table 6).

### Estimates of Exposure to Outdoor Air Pollutants

On average, the calculated time-weighted outdoor-derived $PM_{2.5}$ exposures were 0.56 μg/$m^3$ higher using the USEPA’s recommended total time indoors estimate compared to using the participant-reported information on patterns of time-location (Table 6). The differences were larger for women and Chinese participants and increased with age for older participants.

## Discussion and Conclusions

For the MESA Air cohort, Chinese participants spent more time indoors and less time outdoors and in transit than white, black, or Hispanic participants. Employment status was the single best predictor of time spent indoors at home. Using participant-specific time location information in place of standard exposure factors demonstrated that standard factors can overestimate air pollution predictions and that the overestimation may increase with age. This analysis highlights important limitations of the existing literature regarding the time-location habits of U.S. adults. Although studies of time spent in microenvironments are available in the literature and summarized in USEPA’s Exposure Factors Handbook(1), none of these studies focused on a population like the one found in MESA Air. MESA Air participants were intentionally recruited to be over the age of 45 years and to be racially/ethnically diverse. Additionally, much of the available time-location data dates back more than twenty years, whereas MESA Air is more recent. Because no population comparable to MESA Air was available in the literature, obtaining time-activity information directly from participants was desirable for conducting exposure assessment for this unique population. Further, these results add recent key data on these demographic groups to the relatively sparse body of literature on time-location information. Recent recommendations by USEPA highlighted the need for the collection of time-location data on older populations(4).

Older MESA Air participants spent more time at home and less time at work than younger participants, and compared to males, females spent more time indoors at home and other locations indoors and less time in all other locations. Participants with higher incomes or higher education spent less time indoors at home and more time in other locations, in transit, and at work indoors than participants with lower incomes or lower education. Moreover, this study was the first to report that older Chinese participants spend significantly more time indoors and less time outdoors and in transit than older white, black, or Hispanic participants. Chinese participants in MESA Air were recruited from only two of the MESA sites (Los Angeles and Chicago), so it is somewhat more difficult to draw larger population conclusions about this group’s time-location patterns.

Although we were only able to explain a small portion of the variability, the minimally-adjusted models reported in this paper were highly significant and provide methods for estimating time spent indoors and time indoors at home using only a few key demographic variables. Models without study site that incorporate only gender, race, and age may be applicable to other study populations (Supplemental Tables 3 and 6).

The variation in total time indoors for the majority of participants is low with 86 percent of participants reporting spending 82-100 percent of their time indoors and 93 percent reporting 76-100 percent. Given this low variability in total time indoors across the population, the low predictive ability of the models presented here is not surprising. For time indoors at home, the minimally adjusted model was able to explain 27 percent of the variability. However, the forward selection approach in model three indicated that employment status alone was able to predict even more of the variability (32 percent, Supplemental Table 5).

Most air pollution epidemiology relies on the assumption that residential outdoor concentrations of air pollutants are good proxies for individual exposure(18-25), but because participants spend the majority of their time indoors, most of the exposure to outdoor air pollution may actually be due to the portion of air pollution that infiltrates indoors. In MESA Air, we found that infiltration of $PM_{2.5}$ varied by study site and season with an overall average across all sites of 62 percent(16). Better understanding of time-location patterns can lead to better estimates of exposures to outdoor air pollution. In addition, although not explicitly evaluated by MESA Air, better understanding of the time spent indoors can lead to better estimates of exposures to indoor air pollutants.

This is one of the first studies to use a wide range of built environment measures to predict time-location patterns. Ultimately, however, while the built environment has been shown in this cohort to be associated with physical activity, most measures of the built environment did not end up in most of the models. The models predicting time indoors at home, with and without study site, did include the 1-mile network ratio and the 5-mile density of popular walking destinations, respectively (Supplemental Tables 4 and 6).

Standard exposure factors from sources like USEPA(1) provide researchers with key information for making exposure estimates but may not be applicable to all populations. We found that the time-weighted outdoor-derived air pollution predictions calculated using recommended time indoors from USEPA(1) overestimated predictions relative to those made with MESA Air information. Importantly, the magnitude of the overestimation was inconsistent across important demographic characteristics, which could easily lead to biases in health analyses relying on these data. In particular, for female, Chinese, and older participants, the use of a standard exposure factor resulted in an over-prediction of air pollution estimates, and for older participants, this over-prediction increased with age.

According to Air Quality System (AQS) data collected by the USEPA, annual average $PM_{2.5}$ levels across the U.S. range from <5 to 23 $\mu g/m^3$(26). Note that this report incorporates data from 2005-2007, and levels of $PM_{2.5}$ have been decreasing over time(26). The magnitude of difference between the individual time-weighted air pollution predictions using the USEPA estimate of time indoors and the mean reported value for Chinese participants is approximately 6 percent. This difference is the same as the decline in 75th percentile outdoor $PM_{2.5}$ between 2005 and 2007 (from 17 $\mu g/m^3$ to 16 $\mu g/m^3$)(26).

In summary, this analysis adds key time-location data to the literature by providing more recent information on an older and more ethnically/racially diverse population and describing potential demographic, socioeconomic, health, and built environment predictors of total time indoors and time indoors at home. This study is also the first to show that Chinese participants spend more time indoors and less time outdoors compared to whites, blacks, and Hispanics. Low population variability likely hampered our ability to develop a model that could explain most variability for total time indoors, but several variables were important and highly significant. The greatest predictor of time spent indoors at home was employment status, and the parsimonious model developed using forward-selection was able to explain 43 percent of the variability (41 percent without study site). Further, this analysis demonstrates that the use of standard exposure factors for the time spent in microenvironments may slightly overestimate time-weighted air pollution exposures.

## Supplementary Material

Refer to Web version on PubMed Central for supplementary material.

## Acknowledgements

This publication was developed under a STAR research assistance agreement, No. RD831697 (MESA Air) and grant No. RD-83479601-0 (CCAR) by the U.S. Environmental Protection Agency. It has not been formally reviewed by the EPA. The views expressed in this document are solely those of the authors and the EPA does not endorse any products or commercial services mentioned in this publication. Support for MESA is provided by contracts N01-HC-95159, N01-HC-95160, N01-HC-95161, N01-HC-95162, N01-HC-95163, N01-HC-95164, N01-HC-95165, N01-HC-95166, N01-HC-95167, N01-HC-95168, and N01-HC-95169 and CTSA UL1-RR-024156. Funding for the MESA Family study is provided by grants R01-HL-071051, R01-HL-071205, R01-HL-071250, R01-HL-071251, R01-HL-071252, R01-HL-071258, R01-HL-071259, UL1-RR-025005 by the

National Center for Research Resources, Grant UL1RR033176, and is now at the National Center for Advanced Translational Sciences, Grant UL1TR000124. Funding for MESA Neighborhood was supported by National Institutes of Health (NIH) National Heart, Lung, and Blood Institute (NHLBI) (Grant NIH 2R01 HL071759) and from the Robert Wood Johnson Foundation (RWJF), Active Living Research Program (Grant #52319). Additional support was provided from the National Institute of Environmental Health Sciences through grants K24ES013195, P50ES015915, and P30ES07033. This research received support from the Population Research Training grant (T32 HD007168) and the Population Research Infrastructure Program (R24 HD050924) awarded to the Carolina Population Center at The University of North Carolina at Chapel Hill by the Eunice Kennedy Shriver National Institute of Child Health and Human Development.

## References

1. U.S EPA. EPA Report. Exposure factors handbook 2011 edition (final). 2011 600/EPA/R-09/052F.
2. U.S EPA. EPA Report. Washington, DC: Risk assessment guidance for superfund volume I: Human health evaluation manual (Part F, supplemental guidance for inhalation risk assessment): Final. 2009 EPA/540/-R-070/002
3. Graham SE, McCurdy T. Developing meaningful cohorts for human exposure models. Journal of Exposure Science and Environmental Epidemiology. 2004; 14(1):23–43.
4. U.S EPA. EPA Report. Data Sources Available for Modeling Environmental Exposures in Older Adults. 2011 EPA/600/R-12/013
5. Kaufman JD, Adar SD, Allen RW, Barr RG, Budoff MJ, Burke GL, et al. Prospective study of particulate air pollution exposures, subclinical atherosclerosis, and clinical cardiovascular disease: The Multi-Ethnic Study of Atherosclerosis and Air Pollution (MESA Air). American journal of epidemiology. 2012; 176(9):825–37. [PubMed: 23043127]
6. Spalt EW, Curl CL, Allen RW, Cohen M, Adar SD, Hinkley-Stukovsky K, Avol E, Castro C, Nunn C, Mancera-Cuevas K, Kaufman JD. Time-Location Patterns of a Diverse Population of Older Adults: The Multi-Ethnic Study of Atherosclerosis and Air Pollution (MESA Air). submitted for publication.
7. Bild DE, Bluemke DA, Burke GL, Detrano R, Diez Roux AV, Folsom AR, et al. Multi-ethnic study of atherosclerosis: objectives and design. American journal of epidemiology. 2002; 156(9):871–81. [PubMed: 12397006]
8. Hirsch JA, Moore KA, Evenson KR, Rodriguez DA, Roux AVD. Walk Score® and Transit Score® and Walking in the Multi-Ethnic Study of Atherosclerosis. American journal of preventive medicine. 2013; 45(2):158–66. [PubMed: 23867022]
9. Hirsch JA, Diez Roux AV, Moore KA, Evenson KR, Rodriguez DA. Change in walking and body mass index following residential relocation: the multi-ethnic study of atherosclerosis. American journal of public health. 2014; 104(3):e49–e56. [PubMed: 24432935]
10. Hirsch JA, Moore KA, Clarke PJ, Rodriguez DA, Evenson KR, Brines SJ, et al. Changes in the built environment and changes in the amount of walking over time: longitudinal results from the Multi-Ethnic Study of Atherosclerosis. American journal of epidemiology. 2014; 180(8):799–809. [PubMed: 25234431]
11. Ranchod YK, Roux AVD, Evenson KR, Sánchez BN, Moore K. Longitudinal associations between neighborhood recreational facilities and change in recreational physical activity in the multi-ethnic study of atherosclerosis, 2000–2007. American journal of epidemiology. 2014; 179(3):335–43. [PubMed: 24227016]
12. Rodríguez DA, Evenson KR, Roux AVD, Brines SJ. Land use, residential density, and walking: the multi-ethnic study of atherosclerosis. American journal of preventive medicine. 2009; 37(5):397–404. [PubMed: 19840694]
13. Cohen MA, Adar SD, Allen RW, Avol E, Curl CL, Gould T, et al. Approach to estimating participant pollutant exposures in the Multi-Ethnic Study of Atherosclerosis and Air Pollution (MESA Air). Environmental science & technology. 2009; 43(13):4687–93. [PubMed: 19673252]
14. U.S EPA. Descriptive Statistics Tables from a Detailed Analysis of the National Human Activity Pattern Survey (NHAPS) Data. Environmental Protection Agency; Las Vegas, NV: U.S.: 1996.
15. Leech JA, Nelson WC, Burnett RT, Aaron S, Raizenne ME. It's about time: a comparison of Canadian and American time-activity patterns. Journal of Exposure Analysis and Environmental Epidemiology. 2002; 12(6):427–32. [PubMed: 12415491]

16. Allen RW, Adar SD, Avol E, Cohen M, Curl CL, Larson T, et al. Modeling the residential infiltration of outdoor PM(2.5) in the Multi-Ethnic Study of Atherosclerosis and Air Pollution (MESA Air). Environmental health perspectives. 2012; 120(6):824–30. [PubMed: 22534026]

17. Keller JP, Olives C, Kim S-Y, Sheppard L, Sampson PD, Szpiro AA, Oron AP, Lindstrom J, Vedal S, Kaufman JD. A unified spatiotemporal modeling approach for prediction of multiple air pollutants in the Multi-Ethnic Study of Atherosclerosis and Air Pollution. Environmental health perspectives. 2014

18. Dockery DW, Pope CA 3rd, Xu X, Spengler JD, Ware JH, Fay ME, et al. An association between air pollution and mortality in six U.S. cities. The New England journal of medicine. 1993; 329(24):1753–9. [PubMed: 8179653]

19. Miller KA, Siscovick DS, Sheppard L, Shepherd K, Sullivan JH, Anderson GL, et al. Long-term exposure to air pollution and incidence of cardiovascular events in women. The New England journal of medicine. 2007; 356(5):447–58. [PubMed: 17267905]

20. Pope CA 3rd, Burnett RT, Thun MJ, Calle EE, Krewski D, Ito K, et al. Lung cancer, cardiopulmonary mortality, and long-term exposure to fine particulate air pollution. JAMA : the journal of the American Medical Association. 2002; 287(9):1132–41. [PubMed: 11879110]

21. Hoek G, Brunekreef B, Goldbohm S, Fischer P, van den Brandt PA. Association between mortality and indicators of traffic-related air pollution in the Netherlands: a cohort study. The Lancet. 2002; 360(9341):1203–9.

22. Ostro B, Lipsett M, Reynolds P, Goldberg D, Hertz A, Garcia C, et al. Long-term exposure to constituents of fine particulate air pollution and mortality: results from the California Teachers Study. Environmental health perspectives. 2010; 118(3):363–9. [PubMed: 20064787]

23. Gehring U, Heinrich J, Krämer U, Grote V, Hochadel M, Sugiri D, et al. Long-term exposure to ambient air pollution and cardiopulmonary mortality in women. Epidemiology. 2006; 17(5):545–51. [PubMed: 16755270]

24. Rosenlund M, Berglind N, Pershagen G, Hallqvist J, Jonson T, Bellander T. Long-term exposure to urban air pollution and myocardial infarction. Epidemiology. 2006; 17(4):383–90. [PubMed: 16699471]

25. Puett RC, Hart JE, Yanosky JD, Paciorek C, Schwartz J, Suh H, et al. Chronic fine and coarse particulate exposure, mortality, and coronary heart disease in the Nurses' Health Study. Environmental health perspectives. 2009; 117(11):1697–701. [PubMed: 20049120]

26. U.S EPA. EPA Report. Research Triangle Park, NC: Integrated science assessment for particulate matter. 2009 EPA/600/R-08/139F

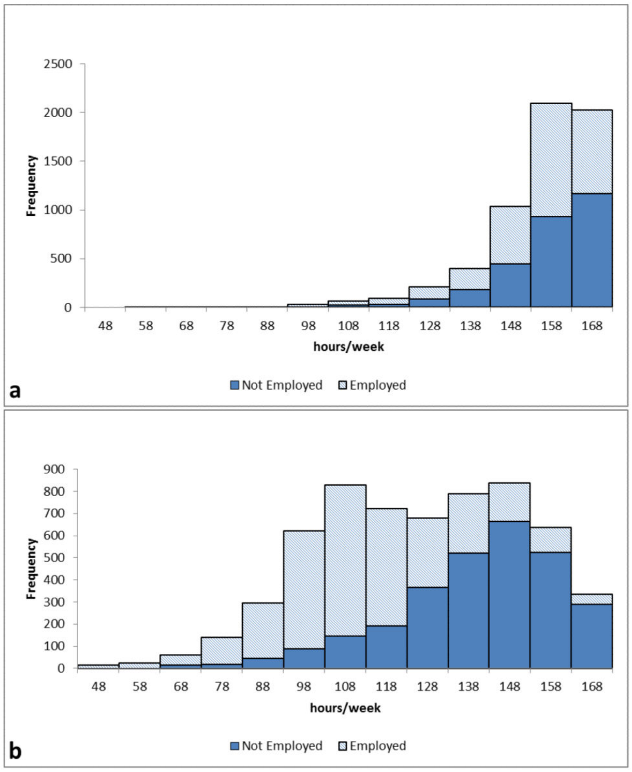

**Figure 1.**

Distribution of (a) total time spent indoors and (b) indoors at home (hours/week) by MESA Air participants with total frequencies broken out by employment status. The employed category includes participants employed full and part time.

## Table 1

Characteristics of MESA Air Participants Who Completed the Baseline MAQ (n=5,996)[1]

| | Number | % |
|---|---|---|
| **Gender** | | |
| Female | 3,194 | 53% |
| Male | 2,802 | 47% |
| **Race/ethnicity** | | |
| White | 2,258 | 38% |
| Chinese | 650 | 11% |
| Black | 1,667 | 28% |
| Hispanic | 1,421 | 24% |
| **Age Category** | | |
| 39-44[2] | 18 | 0% |
| 45-54 | 976 | 16% |
| 55-64 | 1,967 | 33% |
| 65-74 | 1,815 | 30% |
| 75-84 | 1,079 | 18% |
| 85+ | 141 | 2% |
| **Site** | | |
| Forsyth County | 888 | 15% |
| New York[2] | 1,195 | 20% |
| Baltimore | 721 | 12% |
| St. Paul | 872 | 15% |
| Chicago | 1,136 | 19% |
| Los Angeles[3] | 1,184 | 20% |
| **Socioeconomic Status** | | |
| High School Education or More[4] | 4,999 | 84% |
| Family Income ≥$30,000/year[5] | 3,671 | 65% |
| Single Family Home[6] | 3,266 | 54% |

[1] Between 2005 and 2007.

[2] MESA Family included a small number of participants <45, and 18 completed MAQs.

[2] Includes Rockland County

[3] Includes Riverside

[4] Values missing for 13 participants

[5] Values missing for 340 participants

[6] Values missing for 3 participants

## Table 2

Average Percent Time in Microenvironments by Demographic Group. All groups had significant differences ($p<0.05$) by location by the Kruskal-Wallis test except for Home Outdoors for <65/65+ and Other Outdoors for employed/not employed.

| | Home Indoors | Home Outdoors | Work Indoors | Work Outdoors | Other Indoors | Other Outdoors | Transit |
|---|---|---|---|---|---|---|---|
| **All Participants** | 72% | 2% | 9% | 1% | 8% | 3% | 4% |
| **White** | 71% | 3% | 9% | 1% | 9% | 3% | 4% |
| **Chinese** | 77% | 1% | 9% | 1% | 7% | 1% | 4% |
| **Black** | 71% | 2% | 10% | 1% | 8% | 3% | 5% |
| **Hispanic** | 73% | 2% | 9% | 1% | 7% | 2% | 5% |
| **<65** | 66% | 2% | 15% | 2% | 7% | 2% | 5% |
| **65+** | 78% | 2% | 4% | 0% | 9% | 3% | 4% |
| **Female** | 74% | 2% | 9% | 0% | 8% | 2% | 4% |
| **Male** | 70% | 3% | 10% | 2% | 8% | 3% | 5% |
| **Employed** | 65% | 2% | 17% | 2% | 7% | 2% | 5% |
| **Not Employed** | 80% | 3% | 2% | 0% | 9% | 3% | 4% |
| **<High School** | 78% | 2% | 6% | 1% | 7% | 2% | 4% |
| **≥High School** | 71% | 2% | 10% | 1% | 8% | 3% | 5% |
| **<$30,000/yr** | 78% | 2% | 5% | 1% | 8% | 2% | 4% |
| **≥30,000/yr** | 69% | 3% | 12% | 1% | 8% | 3% | 5% |
| **Forsyth County** | 73% | 3% | 9% | 1% | 8% | 1% | 4% |
| **New York** | 72% | 1% | 10% | 1% | 8% | 2% | 5% |
| **Baltimore** | 68% | 3% | 9% | 1% | 9% | 6% | 4% |
| **St. Paul** | 68% | 5% | 11% | 1% | 8% | 3% | 4% |
| **Chicago** | 73% | 1% | 10% | 1% | 8% | 2% | 5% |
| **Los Angeles** | 76% | 2% | 7% | 1% | 7% | 2% | 4% |

## Table 3

Summary of Reported Time (hours/week, mean±SD) by Location, Race/Ethnicity, and Site (n=5,996)

| | | **All Sites** | **Forsyth County** | **New York** | **Baltimore** | **St. Paul** | **Chicago** | **Los Angeles** |
|---|---|---|---|---|---|---|---|---|
| Total Indoors | White | 149 ± 14 | 149 ± 13 | 151 ± 12 | 145 ± 18 | 146 ± 15 | 153 ± 10 | 149 ± 15 |
| | Chinese | 156 ± 9 | -- | -- | -- | -- | 157 ± 7 | 156 ± 10 |
| | Black | 151 ± 14 | 153 ± 12 | 152 ± 13 | 144 ± 17 | -- | 152 ± 14 | 153 ± 13 |
| | Hispanic | 151 ± 14 | -- | 153 ± 13 | -- | 147 ± 16 | -- | 152 ± 15 |
| Total Outdoors | White | 12 ± 13 | 12 ± 12 | 9 ± 11 | 17 ± 17 | 16 ± 14 | 6 ± 9 | 12 ± 14 |
| | Chinese | 5 ± 8 | -- | -- | -- | -- | 4 ± 5 | 6 ± 9 |
| | Black | 9 ± 13 | 8 ± 10 | 7 ± 10 | 17 ± 16 | -- | 6 ± 12 | 8 ± 12 |
| | Hispanic | 9 ± 12 | -- | 7 ± 10 | -- | 13 ± 12 | -- | 10 ± 13 |
| In Transit | White | 7 ± 5 | 7 ± 5 | 9 ± 5 | 6 ± 5 | 7 ± 4 | 8 ± 5 | 7 ± 5 |
| | Chinese | 6 ± 5 | -- | -- | -- | -- | 7 ± 5 | 6 ± 5 |
| | Black | 8 ± 7 | 7 ± 5 | 9 ± 8 | 7 ± 6 | -- | 10 ± 7 | 7 ± 6 |
| | Hispanic | 8 ± 7 | -- | 9 ± 8 | -- | 8 ± 7 | -- | 7 ± 5 |

## Table 4

Results of the generalized linear model showing the relationship between demographic, socioeconomic, health, housing, and built environment variables and total time spent indoors (hrs/wk). “Estimates” can be interpreted as indicating the difference in number of hours spent indoors based on a 1-unit change in the parameter. For example model 2, for each additional year of age, a participant spends an additional 0.24 hours/week indoors and participants in Baltimore spend 6.2 fewer hours/week indoors than participants in Los Angeles.

| | **Min. Adj. Model ($R^2$=0.15)** | | **Model 2 ($R^2$=0.16)** | | **Model 3 ($R^2$=0.19)** | |
|---|---|---|---|---|---|---|
| | **Estimate** | **SE** | **Estimate** | **SE** | **Estimate** | **SE** |
| **Intercept** | 132 | 1.2 | 133 | 1.4 | 130 | 2.02 |
| **Age** | **p** | **<0.0001** | **p** | **<0.0001** | **p** | **<0.0001** |
| | 0.25 | 0.02 | 0.24 | 0.02 | 0.23 | 0.02 |
| **Gender (ref:male)** | **p** | **<0.0001** | **p** | **<0.0001** | **p** | **<0.0001** |
| Female | 6.77 | 0.33 | 6.70 | 0.35 | 6.34 | 0.38 |
| **Race/Ethnicity (ref:Hispanic)** | **p** | **<0.0001** | **p** | **<0.0001** | **p** | **<0.0001** |
| White | −2.23 | 0.50 | −1.59 | 0.55 | −1.66 | 0.61 |
| Chinese | 3.23 | 0.68 | 3.32 | 0.70 | 2.89 | 0.75 |
| Black | −0.64 | 0.55 | 0.06 | 0.59 | −0.44 | 0.64 |
| **Site (ref:Los Angeles)** | **p** | **<0.0001** | **p** | **<0.0001** | **p** | **<0.0001** |
| Forsyth County | 0.49 | 0.65 | 0.58 | 0.66 | 1.05 | 0.87 |
| New York | 0.73 | 0.56 | 0.58 | 0.57 | −0.35 | 0.81 |
| Baltimore | −6.18 | 0.68 | −6.05 | 0.69 | −5.89 | 0.79 |
| St. Paul | −3.85 | 0.62 | −3.64 | 0.63 | −3.36 | 0.83 |
| Chicago | 2.47 | 0.57 | 2.56 | 0.59 | 1.60 | 0.70 |
| **Employment Status (ref:emp. full time)** | -- | -- | **p** | **0.02** | **p** | **0.004** |
| Not employed | -- | -- | −0.59 | 0.47 | −1.10 | 0.52 |
| Employed part time | -- | -- | −1.63 | 0.52 | −2.09 | 0.56 |
| **Education (ref:graduate/prof.)** | -- | -- | **p** | **0.01** | **p** | **0.0012** |
| Less than high school | -- | -- | 0.27 | 0.61 | 0.06 | 0.66 |
| High school | -- | -- | −0.78 | 0.53 | −1.41 | 0.57 |
| College | -- | -- | −1.09 | 0.44 | −1.58 | 0.47 |
| **Income (reference:$75,000+)** | -- | -- | **p** | **0.007** | **p** | **0.04** |
| < $12,000 | -- | -- | 2.21 | 0.71 | 2.27 | 0.80 |
| $12,000-$24,999 | -- | -- | 0.95 | 0.60 | 0.81 | 0.67 |
| $25,000-$39,999 | -- | -- | 1.33 | 0.55 | 1.57 | 0.60 |
| $40,000-$74,999 | -- | -- | 0.04 | 0.47 | 0.57 | 0.51 |
| **Marital status (ref:married)** | -- | -- | **p** | **0.65** | **p** | **0.05** |
| Unmarried | -- | -- | −0.2 | 0.65 | −1.04 | 0.42 |

| | **Min. Adj. Model ($R^2$=0.15)** | | **Model 2 ($R^2$=0.16)** | | **Model 3 ($R^2$=0.19)** | |
|---|---|---|---|---|---|---|
| | **Estimate** | **SE** | **Estimate** | **SE** | **Estimate** | **SE** |
| **Stop walking from breathlessness (ref:yes)** | -- | -- | -- | -- | **p** | **0.01** |
| No | -- | -- | -- | -- | −1.42 | 0.61 |
| **Health age (ref:worse)** | -- | -- | -- | -- | **p** | **0.0007** |
| Better | -- | -- | -- | -- | −2.16 | 0.89 |
| Same | -- | -- | -- | -- | −1.32 | 0.89 |
| **Cholesterol Category (ref:240+)** | -- | -- | -- | -- | **p** | **0.02** |
| <200 | -- | -- | -- | -- | 1.72 | 0.67 |
| 200-239 | -- | -- | -- | -- | 0.94 | 0.71 |
| **Building type (ref:single family)** | -- | -- | -- | -- | **p** | **<0.0001** |
| Rowhouse/townhouse/duplex/triplex | -- | -- | -- | -- | 3.30 | 0.51 |
| Apartment | -- | -- | -- | -- | 1.59 | 0.67 |
| Other | -- | -- | -- | -- | −1.70 | 2.43 |
| **Second Home (reference:yes)** | -- | -- | -- | -- | **p** | **<0.0001** |
| No | -- | -- | -- | -- | 3.99 | 0.59 |
| **A/C (ref:yes)** | -- | -- | -- | -- | **p** | **0.20** |
| No | -- | -- | -- | -- | −0.74 | 0.58 |
| **Meters to commercial (continuous)** | -- | -- | -- | -- | **p** | **0.0008** |
| | -- | -- | -- | -- | −0.0009 | 0.0003 |
| **Elevation in meters (continuous)** | -- | -- | -- | -- | **p** | **0.02** |
| | -- | -- | -- | -- | 0.007 | 0.003 |
| **MAQ Season (ref:winter)** | -- | -- | -- | -- | **p** | **0.02** |
| Fall | -- | -- | -- | -- | 1.15 | 0.51 |
| Spring | -- | -- | -- | -- | −0.01 | 0.50 |
| Summer | -- | -- | -- | -- | 1.10 | 0.53 |

## Table 5

Summary of Model Parameters by Microenvironment and Model

| **Modeled Location** | | **Minimally Adjusted** | **Model 2** | **Model 3** |
|---|---|---|---|---|
| Total Indoors | $R^2$ | 0.15 | 0.16 | 0.19 |
| | Average Relative Difference | 6.7% | 6.7% | 6.4% |
| Total Indoors (excluding site) | $R^2$ | 0.12 | 0.12 | 0.17 |
| | Average Relative Difference | 6.9% | 6.8% | 6.5% |
| Home Indoors | $R^2$ | 0.27 | 0.40 | 0.43 |
| | Average Relative Difference | 15.5% | 13.7% | 13.2% |
| Home Indoors (excluding site) | $R^2$ | 0.26 | 0.39 | 0.41 |
| | Average Relative Difference | 15.7% | 13.9% | 13.3% |

## Table 6

The Absolute Difference in Time-Weighted $PM_{2.5}$ Concentrations ($\mu g/m^3$) Calculated with the USEPA Default Value for Time Indoors and MESA Air Participant-Specific Values for Time Indoors. For example, the overall average time-weighted concentration calculated using the USEPA default is 9.87 $\mu g/m^3$ (IQR: 7.96-12.22), while the average using participant-specific values in MESA Air is 9.33 $\mu g/m^3$ (IQR: 7.21-11.72).

| | N | Mean | 5th | Median | 95th |
|---|---|---|---|---|---|
| All | 5440 | 0.56 | 0.51 | 0.55 | 0.39 |
| Gender | | | | | |
| Female | 2916 | 0.65 | 0.61 | 0.67 | 0.43 |
| Male | 2524 | 0.45 | 0.40 | 0.49 | 0.28 |
| Race/Ethnicity | | | | | |
| White | 2065 | 0.56 | 0.43 | 0.50 | 0.40 |
| Chinese | 593 | 0.69 | 1.14 | 0.73 | 0.31 |
| Black | 1510 | 0.58 | 1.02 | 0.46 | 0.41 |
| Hispanic | 1272 | 0.46 | 0.49 | 0.51 | 0.36 |
| Age | | | | | |
| 39-44 | 12 | 0.11 | 0.39 | 0.16 | −0.29 |
| 45-54 | 861 | 0.45 | 0.46 | 0.42 | 0.23 |
| 55-64 | 1774 | 0.52 | 0.48 | 0.55 | 0.29 |
| 65-74 | 1644 | 0.58 | 0.51 | 0.60 | 0.48 |
| 75-84 | 1017 | 0.66 | 0.57 | 0.63 | 0.39 |
| 85+ | 132 | 0.73 | 0.55 | 0.75 | 0.54 |