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A Total Human Exposure Model (THEM) for Respirable Suspended Particles (RSP)

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INTRODUCTION

The Total Human Exposure Model (THEM) is part of a new class of exposure models that combines activity pattern data, mass balance equations, Monte-Carlo sampling, and real microenvironmental monitoring data to predict exposure to any chemical or substance for any population. THEM was written in Microsoft Professional QuickBASIC v.7.1 and can be implemented on IBM-compatible personal computers. In this paper, we apply THEM to Respirable Suspended Particles (RSP) of 3.5 microns or less (PM-3.5). The current version of THEM includes two components of a person's RSP exposure over 24 hours: (1) the RSP caused by Environmental Tobacco Smoke (ETS), and (2) the ambient RSP exposures. In the future, THEM will be expanded to include other RSP sources such as wood smoke, motor vehicles, cooking, and cleaning.

The main objectives of THEM are to: (1) predict the frequency distribution of exposures to RSP across a population, (2) determine the relative contribution of RSP exposure from different sources, and (3) predict the effects on exposure of controlling different pollutant sources. Since calculations in THEM are based on the activities of actual populations, actual pollutant concentrations, and mass balance model parameters from real locations, THEM can predict the results of alternative control strategies. For example, if smoking were eliminated in public places and other exposure sources remained the same, THEM can calculate the resulting reduction in RSP exposure of the population. Otherwise this information would be available only by conducting two personal monitoring field studies, one before the smoking restriction went into effect and another after public smoking ceased.

BACKGROUND

Risk analysis requires information on the exposures received by members of the population. Especially useful for risk analyses is the frequency distribution of exposures across the population, since exposure to a given pollutant often differs greatly from person to person. Duan[1] makes a distinction between the "direct" and "indirect" approaches for determining the exposures of a population. In the direct approach, a large number of people -- usually a representative sample of the population of interest -- is equipped with personal exposure monitors (PEMs) and their air exposures are measured over a 24-hour period. A number of direct-approach field studies have been carried out over the last decade[2,3], often referred to as the Total Exposure Assessment Methodology (TEAM) studies, yielding many new findings about the causes of exposure and a rich data base for making risk analyses.

A complementary approach -- the indirect approach -- combines data on activity patterns with data from microenvironmental field investigations through an *exposure model*. Activity pattern data come from surveys based on diaries of each person's activities, while the microenvironmental data come from field measurements designed to determine the concentrations found in the microenvironments that people commonly visit (homes, stores, restaurants, offices, buses, automobiles, etc.). One of the earliest estimates of exposure through the indirect approach was by Fugas[4], who computed the average weekly exposures by weighting the concentrations found in various locations in Yugoslavia by the times people spend there during the week. This result gave an average exposure but did not allow for the variation in exposure from person to person. By using Monte-Carlo simulation to sample from concentration distributions and the activity patterns of the population, computer models such as the Simulation of Human Air Pollution Exposure (SHAPE) model[5,6,7] were able to generate estimates of the variability of exposures across the population. Traynor *et al.* [8] have developed a "macromodel" for assessing residential indoor concentrations from combustion-generated pollutants, including RSP. The National Ambient Air Quality (NAAQS) Exposure Model (NEM)[9] used by the Environmental Protection Agency to evaluate the distribution of exposures across the population for setting NAAQS is an evolving model that uses many of the concepts embodied in SHAPE. THEM is a further evolution of these concepts in that it uses real activity pattern data from large population surveys and it also uses, wherever possible, recent sub models of microenvironmental concentrations based on real experiments. While SHAPE was designed primarily for carbon monoxide (CO), THEM is designed to model RSP exposures, but in the future it should evolve to include other pollutants, ultimately becoming a multiple-pollutant exposure model that can run on a personal computer.

METHODOLOGY

Summary of THEM Program Flow

THEM inputs population activity patterns, ambient concentrations, frequency distributions of physical parameters, and frequency distributions of microenvironmental exposure; from these, THEM generates exposure "profiles" (concentration versus time) for each person and statistics for the whole population. As shown in the flowchart (Figure 1), THEM inputs the activity pattern data and ambient hourly data for each person. The ambient hourly RSP data -- input and processed via the $\mathcal{A}$-subprogram -- are obtained from new "real-time" monitors that provide continuous measurements of particles. Iterations over each person include calculations of RSP exposure for each minute of each person's day from microenvironmental sources such as smoking, motor vehicle emissions, cooking, and cleaning. The microenvironmental exposure subprograms that determine such RSP exposures are called $\mathcal{M}$-subprograms.

Activity Pattern Input Data

The California Activity Pattern (CAP) Survey [10,11] conducted by the California Air Resources Board (ARB) and the National Human Activity Pattern Survey (NHAPS)[12] are important, recent activity pattern surveys for assessing human exposure to environmental pollutants. THEM currently inputs CAP data consisting of 1762 adults and teenagers (age 12 and older; collected October 1987 to September 1988) and 1200 children (ages 1 to 11; collected April 1989 to February 1990). A recent Stanford University study[13] reformatted the ARB's CAP database by combining the original diary file and the questionnaire file (i.e., diary plus main file) into one general file for use in exposure modeling. Each diary line includes codes for the person identification (PID), the household identification, adult vs. youth code, the starting time of each location episode, the ending time, the duration, the cumulative time (over all location episodes), the location, passive smoking activity (presence of a smoker), the activity, day, year and day of the week.

Currently, THEM reduces the 42 standard location codes in the CAP database into six new codes: (1) "Inside Home", (2) "Office-Factory", (3) "Bar-Restaurant", (4) "Other Indoor", (5) "Outdoors", and (6) "Vehicle" (Table 1). These codes determine what physical parameters are used and how a microenvironmental RSP exposure calculation is performed in the $\mathcal{M}$-subprograms. After THEM reads in the diary lines for one person, it uses the duration, starting and ending times, location codes, and passive smoking activity codes to create location and passive smoking "profiles" containing the person's location codes and passive smoking codes for each minute of the entire day. In the example location profile (Figure 2), person #5 of the San Francisco Bay Area has spent most of the time between 12:00 am to 2:00 am (hours 1 and 2) at location code no. 4 (Other Indoor). The person was also in a vehicle briefly (between 12:45 and 12:49 am) while moving from one indoor location to another and then returned home (location code no. 1) by a vehicle from 1:50 am to 1:59 am. From 2:00 am (hour 3) to

8:59 am (hour 9), the person was at home, probably sleeping some of the time. A similar profile with smoking codes shows exactly for what minutes during the person's day a smoker was reported present (not shown). Future versions of THEM will create profiles for the 99 CAP activity codes (cooking, cleaning, etc.) in addition to location and passive smoking profiles.

Ambient Exposure ($\mathcal{A}$-Subprogram)

Determining the ambient component of RSP exposure relies on: (1) sufficient and complete data from outdoor fixed-station monitors, and (2) conversion of outdoor ambient data to predicted exposures inside buildings, homes, and vehicles. THEM uses the $\mathcal{A}$-Subprogram to process data collected from a fixed monitor. In the present version of THEM, the $\mathcal{A}$-subprogram assumes the ambient hourly RSP concentration is identical to the exposure experienced by people wherever they are; in the future, a lag time will be introduced to account for RSP infiltration into indoor settings. At present, the only adjustment of the ambient data in THEM is conversion from PM-10 RSP concentrations to the PM-3.5 concentrations by multiplying by a scaling factor.

Real-time hourly average ambient PM-10 concentrations were obtained from a fixed-station continuous monitor in San Jose, CA, operated by the Bay Area Air Quality Management District (BAAQMD)[14]. The data were collected for the year 1993 but are used for the current calculations of THEM since they are high quality data collected hourly, 24 hours a day, that can be used to include seasonal and hourly variation in ambient RSP concentrations. THEM reads in the date on which each person was surveyed from the CAP data and then translates the date into the number of days after the 1st of the year (Julian format). The corresponding hourly ambient data for the 24-hour period is then read in from the BAAQMD PM-10 file.

As part of this project, real-time ambient particle data is also being collected from a residential, suburban location in the Bay Area[15]. This location uses a Radiance 901 integrating nephelometer and a Langan DataBear digital data logger to obtain RSP concentrations at 5-minute intervals. These recent data provide a good source to compare with BAAQMD data, since the size range (2.5 microns) is closer to our microenvironmental exposure measurements (3.5 microns).

Microenvironmental Exposure ($\mathcal{M}$-Subprograms)

A critical part of THEM are the $\mathcal{M}$-subprograms that calculate the RSP concentrations that a person experiences when they are in a microenvironment containing a smoker. As THEM goes through the location and passive smoking profiles on a minute-by-minute basis, it enters the RSP exposure into an exposure profile (Figure 3) for each minute that the person is in a location where a smoker is reported present. RSP microenvironmental exposures are determined by either: (1) mass balance equations with physical parameters as inputs, or (2) Monte-Carlo sampling from real microenvironmental data.

Mass Balance Equations. The mass balance equation for indoor RSP balances the indoor RSP source and RSP entering the room from outside with the RSP leaving the room, reacting, or being absorbed by objects inside the room[16]. The mass balance equation parameters include the air exchange rate, source strength, source duration or history, and room volume. THEM uses the Sequential Cigarette Exposure Model (SCEM)[17] -- a mass balance model that has been validated for a chamber and an automobile -- to calculate RSP concentrations from ETS.

Before SCEM can be fully incorporated into an $\mathcal{M}$-subprogram, it requires specification of the mass balance parameters for each reduced location category. In the current version of THEM, room air exchange rates are incorporated into SCEM calculations for the Home locations based on studies of residential air exchange rates across the United States[18] (Figure 4). Room volumes for the Home locations are from data on square footage (Figure 5) and number of rooms (Table 2) carried out by PG&E[19] with an assumed constant ceiling height of 10 feet. The home is assumed to be multi-compartmental, and room volumes are calculated by dividing the home's volume by the number of rooms. Because air exchange rate and room volume data specific to Office-Factory and Bar-Restaurant locations are unavailable, THEM uses the Home parameters for these locations with a single large volume instead of smaller compartments. Because representative surveys are currently lacking, distributions for source strengths, smoking rates, motor vehicle air exchange rates, and motor vehicle volumes are estimated by the user. Future versions of THEM will make more extensive use of parameters based on data.

THEM calls the SCEM subprogram whenever a new smoking episode is detected. Even if a person has reported a smoker present in only a few minutes of the time at a certain location, the entire location episode (up to 1 hour or more) is classified as a passive smoking episode. To get the parameters of SCEM, THEM uses the Monte-Carlo Inverse Transform Method[20,21] to sample from frequency distributions input by the user.

The SCEM-Based Exposure Profile. A separate paper[17] shows how to solve the mass balance equations to arrive at the time series of RSP concentration or exposure *E(t)* due to a single cigarette smoked at intervals. A future version of THEM may use the details of each smoking episode (starting time, duration etc.), but the current version uses a single average RSP concentration calculated from only source strength, smoking rate, air exchange rate, and room volume. The following equation for the average RSP concentration (in μg/m^3) over the whole smoking episode is derived from the original mass balance equations[17]:

(1) $$\overline{E} = \frac{GR}{\Phi V}$$

where

G = Source Strength (μg / cigarette)

R = Smoking Rate (cigarettes / hour)

Φ = Air Exchange rate (1 / hr)

V = Volume (m^3)

This value is the same as the RSP exposure that is used to fill in the exposure profile for each minute that the person spends at a location with a smoker present. The example exposure profile (Figure 3) for person #5 in the Bay Area activity pattern file has an RSP exposure of 161 μg/m^3 from 12:00 am to 12:44 am (hour 1) while a smoker was present in location code no. 4 (Other Indoor; see Figure 2). No smoker was present in the person's vehicle from 12:45 am to 12:49 am so these RSP exposures are 0 μg/m^3. Then, from 12:50 am to 1:49 am, the person was with a smoker in location code no. 4 again (assumed to be different from the first Other Indoor location) with an average exposure of 308 μg/m^3.

Monte-Carlo Sampling of Microenvironmental Experimental Data. For some activities and locations, it may be easier and more accurate to sample from a distribution of known microenvironmental concentrations. In the future, THEM will sample frequency distributions of real microenvironmental measurements of RSP collected in about 400 visits to over 200 different locations from a field study conducted at Stanford University of homes, restaurants, Bingo games, airports, and other locations. The reduced location codes will be reformulated to accommodate the diversity of locations in this new study. Sampling will be done via the Monte-Carlo Inverse Transform Method[20,21].

Structure of THEM

At the heart of THEM are the $\mathcal{M}$-subprograms that calculate the microenvironmental exposures to RSP that are entered into the 1440-minute exposure profiles for each person. Generally, microenvironmental exposure to RSP is a function of location, activity, and presence of a smoker -- all of which can be expressed as arrays consisting of person *i* and minute *j* dimensions:

(2) $$E_{\mathcal{M}}(i,j) = f\left[L(i,j), A(i,j), S(i,j)\right]$$

where

$E_{\mathcal{M}}(i,j)$ = *Microenvironmental exposure for person i at minute j*

$L(i,j)$ = *Location for person i at minute j*

$A(i,j)$ = *Activity for person i at minute j*

$S(i,j)$ = *Presence of smoker for person i at minute j*

THEM considers exposures only as a function of $L(i,j)$ and $S(i,j)$ because only microenvironmental exposures from ETS currently are considered. If, for a series of minutes *j* for person *i*, $L(i,j) = 1$ (Home) and $S(i,j) = 1$ (smoker present), then THEM branches to an $\mathcal{M}$-subprogram that fills in the corresponding elements of $E_{\mathcal{M}}(i,j)$ with appropriate microenvironmental RSP exposures.

We may express the microenvironmental exposure to ETS for each person as a function of person *i* and minute *j* as follows:

(3) $$\textit{Smoker Present:}\quad ETS\left(L(i,j), S(i,j)\right)$$

Other microenvironmental exposures will be included in THEM in the future that are independent of the presence of a smoker $S(i,j)$:

(4)
$$\textit{Woodsmoke:}\quad W\left(L(i,j)\right)$$
$$\textit{Vehicular Emissions:}\quad Q\left(L(i,j)\right)$$
$$\textit{Cooking:}\quad C\left(L(i,j)\right)$$
$$\textit{Cleaning:}\quad K\left(L(i,j)\right)$$

These quantities are the pollutant time series for each individual from each RSP source. For each person's day, THEM calculates the microenvironmental exposure for each minute, the hourly average, and the 24-hour average as follows (currently only for ETS):

(5) $$E_{\mathcal{M}}(i,j) = \begin{bmatrix} ETS(L(i,j), S(i,j)) + \\ W(L(i,j)) + Q(L(i,j)) + \\ C(L(i,j)) + K(L(i,j)) \end{bmatrix}$$

(6) $$\overline{E}_{\mathcal{M}}(i,h) = \frac{1}{60} \sum_{j=(h-1)60+1}^{h60} E_{\mathcal{M}}(i,j), \quad h = 1, 2, 3, \ldots, 24^{th}\, hour$$

where

$$E_{\mathcal{M}}(i,j) = Microenvironmental\ exposure\ for\ person\ i\ at\ minute\ j$$

$$\overline{E}_{\mathcal{M}}(i,h) = Microenvironmental\ average\ exposure\ for\ person\ i\ at\ hour\ h$$

(7) $$\overline{E}_{\mathcal{M}}{}^{24}(i) = \frac{1}{24} \sum_{h=1}^{24} \overline{E}_{\mathcal{M}}(i,h)$$

where

$$\overline{E}_{\mathcal{M}}{}^{24}(i) = Microenvironmental\ 24\text{-}hour\ average\ exposure\ for\ person\ i$$

The ambient hourly average from the $\mathcal{A}$-subprogram is added to the microenvironmental hourly averages to give total hourly exposures for each person. Total 24-hour average exposures are then calculated from hourly averages:

(8) $$\overline{E}_{\mathcal{T}}(i,h) = \overline{E}_{\mathcal{M}}(i,h) + \overline{E}_{\mathcal{A}}(i,h)$$

(9) $$\overline{E}_{\mathcal{T}}{}^{24}(i) = \frac{1}{24} \sum_{h=1}^{24} \overline{E}_{\mathcal{T}}(i,h)$$

where

$$\overline{E}_{\mathcal{T}}(i,h) = Total\ average\ exposure\ for\ person\ i\ at\ hour\ h$$

$$\overline{E}_{\mathcal{A}}(i,h) = Average\ ambient\ exposure\ for\ person\ i\ at\ hour\ h$$

$$\overline{E}_{\mathcal{T}}{}^{24}(i) = Total\ 24\text{-}hour\ average\ exposure\ for\ person\ i$$

The 24-hour total average, microenvironmental average, ambient average, and hourly maximum total exposures are saved for each person. These data arrays are used to construct histograms of exposure for the entire population.

RESULTS AND DISCUSSION

THEM was run on data for 381 people from the CAP database who live in the San Francisco Bay Area to obtain distributions of microenvironmental 24-hour average exposures (Figure 6), ambient 24-hour average exposures (Figure 7), and total 24-hour average exposures (Figure 8). At present, the only exposure sources included in the model were those from: (1) ETS, and (2) ambient levels. The SCEM[17] model was used to calculate PM-3.5 RSP exposures for all six reduced locations (Table 2). All SCEM calculations used estimated parameters for source strengths and smoking rates. SCEM calculations for the Home location used surveys of real residential data for air exchange rates[18], square footage and number of rooms[19]. Calculations for Office-Factory and Bar-Restaurant locations used the same data as for the Home locations. For the Vehicle location, all air exchanges and volumes were estimated. Average hourly ambient PM-10 concentrations from the BAAQMD[14] monitoring station in San Jose, CA, were dependent on time but not location. The conversion factor from PM-10 ambient concentrations to PM-3.5 ambient concentrations was chosen as 0.6[22].

The microenvironmental 24-hour average RSP exposure (Figure 8) for all but the eight highest people ranges from 0 to 300 $\mu g/m^3$ with a mean of 42 $\mu g/m^3$. Most of the peoples' microenvironmental ETS exposures (70%) are clustered in the first interval (0-20 $\mu g/m^3$), with 80% below 40 $\mu g/m^3$ and a long tail to the right. One of the reasons for the large number of people in the first interval is the large proportion (49% of the whole population) with zero microenvironmental ETS exposure. In contrast, the ambient component of the 24-hour average RSP exposure (Figure 7) is more symmetrical; it has a small mean (16 $\mu g/m^3$) and a small range (0-45 $\mu g/m^3$) with a median of approximately 15 $\mu g/m^3$. The distribution of total exposures (Figure 8) of the population (a combination of ambient and microenvironmental components) retains the right-skewed appearance of the microenvironmental distribution (Figure 6). Its average is 58 $\mu g/m^3$. About 50% of the total exposures are in the 0-20 $\mu g/m^3$ range, and 80% of the population is still below 40 $\mu g/m^3$.

These preliminary results based only on the SCEM $\mathcal{M}$-subprogram and one fixed continuous ambient monitoring station imply that, at concentrations higher than 20 $\mu g/m^3$, ambient levels contribute more to total RSP exposures than the ETS microenvironmental exposures. ETS exposures may actually add very little to 24-hour RSP exposures for the Bay Area, but these results are very tentative and further analysis will be undertaken.

SUMMARY AND CONCLUSIONS

This paper summarizes the development of a new activity pattern-microenvironmental exposure model, the Total Human Exposure Model (THEM). THEM uses real activity pattern data from population studies such as the CAP[10,11] and NHAPS[12], along with measurements from microenvironmental field investigations. At present, THEM calculates the frequency distribution of exposures to RSP using the CAP, microenvironmental field investigations of ETS, and hourly RSP averages from real-time particle monitors. It calculates microenvironmental concentrations by either of two approaches: (1) the mass balance equation with its parameters (source strength, room volume, air exchange rates, etc.) sampled from frequency distributions, and (2) Monte-Carlo sampling of concentration distributions from field measurements. In the future, THEM will be extended to include wood smoke, motor vehicles, cleaning, and cooking.

The exercise of combining all the relevant sources of exposure from RSP into one model gives insight into the contributions that each source makes to total human exposure. In the future, a sensitivity analysis will be undertaken to evaluate the share that ETS contributes to one's total exposure to respirable particles, both the average contribution and the distribution of the ETS contributions across the population. Because there are uncertainties in the ambient data and in the various assumptions about the microenvironments, the sensitivity analysis will run the model several times with different sets of assumptions to determine the importance of each input variable over its most likely range. Used in this context, THEM can help *apportion* the sources of exposure and therefore can be useful in evaluating the effect of alternative regulatory policies and decisions.

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Table 1. Location Codes Used in the CAP Survey[11,12] and Reduced Codes Used in THEM

Standard Location Codes		Reduced Location Codes		
Code	Location	Code	Location	Standard Codes
1	IN KITCHEN	1	INSIDE HOME	1-9, 12-13, 32
2	IN LIVING ROOM			
3	IN DINING ROOM	2	OFFICE-FACTORY	21-22, 38
4	IN BATHROOM			
5	IN BEDROOM IN GARAGE	3	BAR-RESTAURANT	28-29
6	IN STUDY			
7	IN GARAGE	4	OTHER INDOOR	23-27,30,31, 33,35-37,39
8	IN BASEMENT			
9	IN UTILITY ROOM			
10	POOL, SPA	5	OUTDOORS	10, 11, 34, 40, 53, 54, 59
11	IN YARD			
12	ROOM TO ROOM			
13	OTHER HOUSEHOLD ROOM	6	VEHICLE	51, 52, 55-58,
21	AT OFFICE			
22	AT PLANT			
23	AT GROCERY STORE			
24	AT SHOPPING MALL			
25	AT SCHOOL			
26	OTHER PUBLIC PLACE			
27	AT HOSPITAL			
28	AT RESTAURANT			
29	AT BAR-NIGHTCLUB			
30	AT CHURCH			
31	AT INDOOR GYM			
32	AT SOMEONE ELSE'S HOME			
33	AT AUTO REPAIR			
34	AT PLAYGROUND			
35	AT HOTEL-MOTEL			
36	AT DRY CLEANERS			
37	AT BEAUTY PARLOR			
38	AT WORK:MOVING AMONG LOCATIONS			
39	OTHER INDOOR			
40	OTHER OUTDOOR			
51	IN CAR			
52	IN VAN			
53	WALKING			
54	AT BUS STOP			
55	ON BUS			
56	ON RAPID TRAIN			
57	OTHER TRUCK			
58	ON AIRPLANE			
59	ON BICYCLE			
60	ON MOTORCYCLE			
61	OTHER TRANSPORTATION			
99	UNKNOWN			

Table 2. Cumulative Frequency for Number of Rooms in a House[19]

# Rooms	Cumulative Frequency
1	0.002
2	0.007
3	0.033
4	0.132
5	0.396
6	0.680
7	0.840
8	0.933
9	0.969
10	0.986
15	1.000

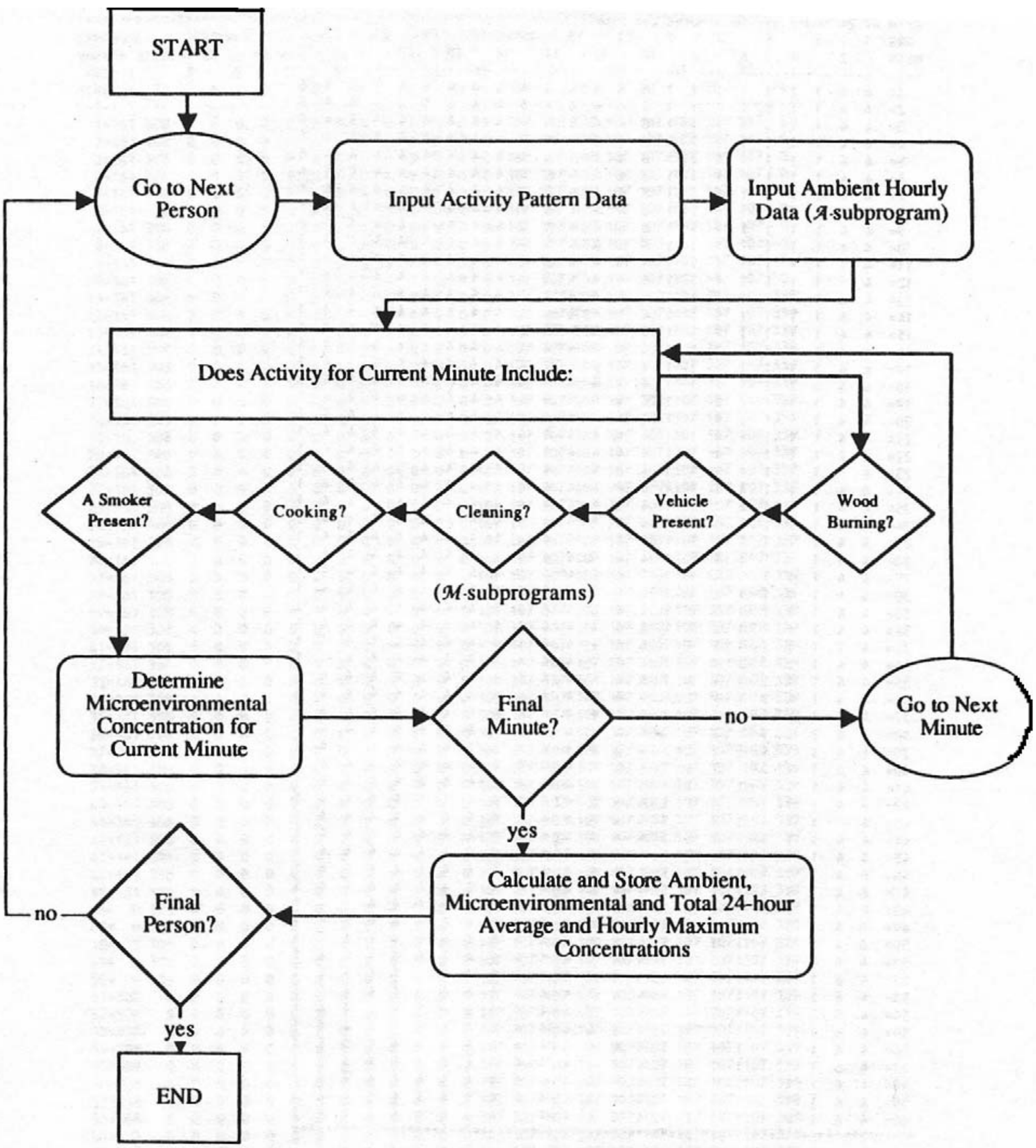

Figure 1. The flow of THEM includes two basic iterations. One loop runs over each person, inputing activity pattern data and hourly ambient exposure data (𝒜-subprogram), and saving statistics for each individual, while the other loop runs over each minute of each person's day calculating RSP exposure from smoking, wood burning, cooking, cleaning or motor vehicles (ℳ-subprograms).

```
******************************************************************************
LOCATION FOR PERSON #  5 / PID # 101 / d:\californ\BAY.DAT
Grid of 24 hours vs. 60 minutes per hour
 HRS- 1     3     5     7     9    11    13    15    17    19    21    23
MINS     2     4     6     8    10    12    14    16    18    20    22    24
--|--------------------------------------------------------------------
  1=  4  4  1  1  1  1  1  1  1  6  4  4  4  4  4  4  4  4  4  4  4  4  4  6
  2=  4  4  1  1  1  1  1  1  1  6  4  4  4  4  4  4  4  4  4  4  4  4  4  6
  3=  4  4  1  1  1  1  1  1  1  6  4  4  4  4  4  4  4  4  4  4  4  4  4  6
  4=  4  4  1  1  1  1  1  1  1  6  4  4  4  4  4  4  4  4  4  4  4  4  4  6
  5=  4  4  1  1  1  1  1  1  1  6  4  4  4  4  4  4  4  4  4  4  4  4  4  6
  6=  4  4  1  1  1  1  1  1  1  6  4  4  4  4  4  4  4  4  4  4  4  4  4  6
  7=  4  4  1  1  1  1  1  1  1  6  4  4  4  4  4  4  4  4  4  4  4  4  4  6
  8=  4  4  1  1  1  1  1  1  1  6  4  4  4  4  4  4  4  4  4  4  4  4  4  6
  9=  4  4  1  1  1  1  1  1  1  6  4  4  4  4  4  4  4  4  4  4  4  4  4  6
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 11=  4  4  1  1  1  1  1  1  1  4  4  4  4  4  4  4  4  4  4  4  4  4  4  1
 12=  4  4  1  1  1  1  1  1  1  4  4  4  4  4  4  4  4  4  4  4  4  4  4  1
 13=  4  4  1  1  1  1  1  1  1  4  4  4  4  4  4  4  4  4  4  4  4  4  4  1
 14=  4  4  1  1  1  1  1  1  1  4  4  4  4  4  4  4  4  4  4  4  4  4  4  1
 15=  4  4  1  1  1  1  1  1  1  4  4  4  4  4  4  4  4  4  4  4  4  4  4  1
 16=  4  4  1  1  1  1  1  1  1  4  4  4  4  4  4  4  4  4  4  4  4  4  4  1
 17=  4  4  1  1  1  1  1  1  1  4  4  4  4  4  4  4  4  4  4  4  4  4  4  1
 18=  4  4  1  1  1  1  1  1  1  4  4  4  4  4  4  4  4  4  4  4  4  4  4  1
 19=  4  4  1  1  1  1  1  1  1  4  4  4  4  4  4  4  4  4  4  4  4  4  4  1
 20=  4  4  1  1  1  1  1  1  1  4  4  4  4  4  4  4  4  4  4  4  4  4  4  1
 21=  4  4  1  1  1  1  1  1  1  4  4  4  4  4  4  4  4  4  4  4  4  4  4  1
 22=  4  4  1  1  1  1  1  1  1  4  4  4  4  4  4  4  4  4  4  4  4  4  4  1
 23=  4  4  1  1  1  1  1  1  1  4  4  4  4  4  4  4  4  4  4  4  4  4  4  1
 24=  4  4  1  1  1  1  1  1  1  4  4  4  4  4  4  4  4  4  4  4  4  4  4  1
 25=  4  4  1  1  1  1  1  1  1  4  4  4  4  4  4  4  4  4  4  4  4  4  4  1
 26=  4  4  1  1  1  1  1  1  1  4  4  4  4  4  4  4  4  4  4  4  4  4  4  1
 27=  4  4  1  1  1  1  1  1  1  4  4  4  4  4  4  4  4  4  4  4  4  4  4  1
 28=  4  4  1  1  1  1  1  1  1  4  4  4  4  4  4  4  4  4  4  4  4  4  4  1
 29=  4  4  1  1  1  1  1  1  1  4  4  4  4  4  4  4  4  4  4  4  4  4  4  1
 30=  4  4  1  1  1  1  1  1  1  4  4  4  4  4  4  4  4  4  4  4  4  4  4  1
 31=  4  4  1  1  1  1  1  1  1  4  4  4  4  4  4  4  4  4  4  4  4  4  4  1
 32=  4  4  1  1  1  1  1  1  1  4  4  4  4  4  4  4  4  4  4  4  4  4  4  1
 33=  4  4  1  1  1  1  1  1  1  4  4  4  4  4  4  4  4  4  4  4  4  4  4  1
 34=  4  4  1  1  1  1  1  1  1  4  4  4  4  4  4  4  4  4  4  4  4  4  4  1
 35=  4  4  1  1  1  1  1  1  1  4  4  4  4  4  4  4  4  4  4  4  4  4  4  1
 36=  4  4  1  1  1  1  1  1  1  4  4  4  4  4  4  4  4  4  4  4  4  4  4  1
 37=  4  4  1  1  1  1  1  1  1  4  4  4  4  4  4  4  4  4  4  4  4  4  4  1
 38=  4  4  1  1  1  1  1  1  1  4  4  4  4  4  4  4  4  4  4  4  4  4  4  1
 39=  4  4  1  1  1  1  1  1  1  4  4  4  4  4  4  4  4  4  4  4  4  4  4  1
 40=  4  4  1  1  1  1  1  1  1  4  4  4  4  4  4  4  4  4  4  4  4  4  4  1
 41=  4  4  1  1  1  1  1  1  1  4  4  4  4  4  4  4  4  4  4  4  4  4  4  1
 42=  4  4  1  1  1  1  1  1  1  4  4  4  4  4  4  4  4  4  4  4  4  4  4  1
 43=  4  4  1  1  1  1  1  1  1  4  4  4  4  4  4  4  4  4  4  4  4  4  4  1
 44=  4  4  1  1  1  1  1  1  1  4  4  4  4  4  4  4  4  4  4  4  4  4  4  1
 45=  4  4  1  1  1  1  1  1  1  4  4  4  4  4  4  4  4  4  4  4  4  4  4  1
 46=  6  4  1  1  1  1  1  1  1  4  4  4  4  4  4  4  4  4  4  4  4  4  4  1
 47=  6  4  1  1  1  1  1  1  1  4  4  4  4  4  4  4  4  4  4  4  4  4  4  1
 48=  6  4  1  1  1  1  1  1  1  4  4  4  4  4  4  4  4  4  4  4  4  4  4  1
 49=  6  4  1  1  1  1  1  1  1  4  4  4  4  4  4  4  4  4  4  4  4  4  4  1
 50=  6  4  1  1  1  1  1  1  1  4  4  4  4  4  4  4  4  4  4  4  4  4  4  1
 51=  4  6  1  1  1  1  1  1  1  4  4  4  4  4  4  4  4  4  4  4  4  4  4  1
 52=  4  6  1  1  1  1  1  1  1  4  4  4  4  4  4  4  4  4  4  4  4  4  4  1
 53=  4  6  1  1  1  1  1  1  1  4  4  4  4  4  4  4  4  4  4  4  4  4  4  1
 54=  4  6  1  1  1  1  1  1  1  4  4  4  4  4  4  4  4  4  4  4  4  4  4  1
 55=  4  6  1  1  1  1  1  1  1  4  4  4  4  4  4  4  4  4  4  4  4  4  4  1
 56=  4  6  1  1  1  1  1  1  1  4  4  4  4  4  4  4  4  4  4  4  4  4  4  1
 57=  4  6  1  1  1  1  1  1  1  4  4  4  4  4  4  4  4  4  4  4  4  4  4  1
 58=  4  6  1  1  1  1  1  1  1  4  4  4  4  4  4  4  4  4  4  4  4  4  4  1
 59=  4  6  1  1  1  1  1  1  1  4  4  4  4  4  4  4  4  4  4  4  4  4  4  1
 60=  4  6  1  1  1  1  1  1  1  4  4  4  4  4  4  4  4  4  4  4  4  4  4  1
******************************************************************************
```

Figure 2. Example of location profile. Minutes run vertically and hours run horizontally over grid containing location codes for person #5 of Bay Area activity file.

```
***************************************************************************************
EXPOSURE FOR PERSON #  5 / PID # 101 / d:\californ\BAY.DAT
Vector grid of 24 hours vs. 60 minutes per hour
 HRS- 1     3     5     7     9    11    13    15      17      19      21      23
MINS    2     4     6     8    10    12    14      16      18      20      22      24
--|------------------------------------------------------------------------------
  1=161 308  0  0  0  0  0  0  0  0  0  0  0  0  0  107 107 107 107 107 107 107 107   0
  2=161 308  0  0  0  0  0  0  0  0  0  0  0  0  0  107 107 107 107 107 107 107 107   0
  3=161 308  0  0  0  0  0  0  0  0  0  0  0  0  0  107 107 107 107 107 107 107 107   0
  4=161 308  0  0  0  0  0  0  0  0  0  0  0  0  0  107 107 107 107 107 107 107 107   0
  5=161 308  0  0  0  0  0  0  0  0  0  0  0  0  0  107 107 107 107 107 107 107 107   0
  6=161 308  0  0  0  0  0  0  0  0  0  0  0  0  0  107 107 107 107 107 107 107 107   0
  7=161 308  0  0  0  0  0  0  0  0  0  0  0  0  0  107 107 107 107 107 107 107 107   0
  8=161 308  0  0  0  0  0  0  0  0  0  0  0  0  0  107 107 107 107 107 107 107 107   0
  9=161 308  0  0  0  0  0  0  0  0  0  0  0  0  0  107 107 107 107 107 107 107 107   0
 10=161 308  0  0  0  0  0  0  0  0  0  0  0  0  0  107 107 107 107 107 107 107 107   0
 11=161 308  0  0  0  0  0  0  0  0  0  0  0  0  0  107 107 107 107 107 107 107 107 339
 12=161 308  0  0  0  0  0  0  0  0  0  0  0  0  0  107 107 107 107 107 107 107 107 339
 13=161 308  0  0  0  0  0  0  0  0  0  0  0  0  0  107 107 107 107 107 107 107 107 339
 14=161 308  0  0  0  0  0  0  0  0  0  0  0  0  0  107 107 107 107 107 107 107 107 339
 15=161 308  0  0  0  0  0  0  0  0  0  0  0  0  0  107 107 107 107 107 107 107 107 339
 16=161 308  0  0  0  0  0  0  0  0  0  0  0  0  0  107 107 107 107 107 107 107 107 339
 17=161 308  0  0  0  0  0  0  0  0  0  0  0  0  0  107 107 107 107 107 107 107 107 339
 18=161 308  0  0  0  0  0  0  0  0  0  0  0  0  0  107 107 107 107 107 107 107 107 339
 19=161 308  0  0  0  0  0  0  0  0  0  0  0  0  0  107 107 107 107 107 107 107 107 339
 20=161 308  0  0  0  0  0  0  0  0  0  0  0  0  0  107 107 107 107 107 107 107 107 339
 21=161 308  0  0  0  0  0  0  0  0  0  0  0  0 107 107 107 107 107 107 107 107 107 339
 22=161 308  0  0  0  0  0  0  0  0  0  0  0  0 107 107 107 107 107 107 107 107 107 339
 23=161 308  0  0  0  0  0  0  0  0  0  0  0  0 107 107 107 107 107 107 107 107 107 339
 24=161 308  0  0  0  0  0  0  0  0  0  0  0  0 107 107 107 107 107 107 107 107 107 339
 25=161 308  0  0  0  0  0  0  0  0  0  0  0  0 107 107 107 107 107 107 107 107 107 339
 26=161 308  0  0  0  0  0  0  0  0  0  0  0  0 107 107 107 107 107 107 107 107 107 339
 27=161 308  0  0  0  0  0  0  0  0  0  0  0  0 107 107 107 107 107 107 107 107 107 339
 28=161 308  0  0  0  0  0  0  0  0  0  0  0  0 107 107 107 107 107 107 107 107 107 339
 29=161 308  0  0  0  0  0  0  0  0  0  0  0  0 107 107 107 107 107 107 107 107 107 339
 30=161 308  0  0  0  0  0  0  0  0  0  0  0  0 107 107 107 107 107 107 107 107 107 339
 31=161 308  0  0  0  0  0  0  0  0  0  0  0  0 107 107 107 107 107 107 107 107 107 339
 32=161 308  0  0  0  0  0  0  0  0  0  0  0  0 107 107 107 107 107 107 107 107 107 339
 33=161 308  0  0  0  0  0  0  0  0  0  0  0  0 107 107 107 107 107 107 107 107 107 339
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 38=161 308  0  0  0  0  0  0  0  0  0  0  0  0 107 107 107 107 107 107 107 107 107 339
 39=161 308  0  0  0  0  0  0  0  0  0  0  0  0 107 107 107 107 107 107 107 107 107 339
 40=161 308  0  0  0  0  0  0  0  0  0  0  0  0 107 107 107 107 107 107 107 107 107 339
 41=161 308  0  0  0  0  0  0  0  0  0  0  0  0 107 107 107 107 107 107 107 107 107 339
 42=161 308  0  0  0  0  0  0  0  0  0  0  0  0 107 107 107 107 107 107 107 107 107 339
 43=161 308  0  0  0  0  0  0  0  0  0  0  0  0 107 107 107 107 107 107 107 107 107 339
 44=161 308  0  0  0  0  0  0  0  0  0  0  0  0 107 107 107 107 107 107 107 107 107 339
 45=161 308  0  0  0  0  0  0  0  0  0  0  0  0 107 107 107 107 107 107 107 107 107 339
 46=  0 308  0  0  0  0  0  0  0  0  0  0  0  0 107 107 107 107 107 107 107 107 107 339
 47=  0 308  0  0  0  0  0  0  0  0  0  0  0  0 107 107 107 107 107 107 107 107 107 339
 48=  0 308  0  0  0  0  0  0  0  0  0  0  0  0 107 107 107 107 107 107 107 107 107 339
 49=  0 308  0  0  0  0  0  0  0  0  0  0  0  0 107 107 107 107 107 107 107 107 107 339
 50=  0 308  0  0  0  0  0  0  0  0  0  0  0  0 107 107 107 107 107 107 107 107 107 339
 51=308   0  0  0  0  0  0  0  0  0  0  0  0  0 107 107 107 107 107 107 107 107 107 339
 52=308   0  0  0  0  0  0  0  0  0  0  0  0  0 107 107 107 107 107 107 107 107 107 339
 53=308   0  0  0  0  0  0  0  0  0  0  0  0  0 107 107 107 107 107 107 107 107 107 339
 54=308   0  0  0  0  0  0  0  0  0  0  0  0  0 107 107 107 107 107 107 107 107 107 339
 55=308   0  0  0  0  0  0  0  0  0  0  0  0  0 107 107 107 107 107 107 107 107 107 339
 56=308   0  0  0  0  0  0  0  0  0  0  0  0  0 107 107 107 107 107 107 107 107 107 339
 57=308   0  0  0  0  0  0  0  0  0  0  0  0  0 107 107 107 107 107 107 107 107 107 339
 58=308   0  0  0  0  0  0  0  0  0  0  0  0  0 107 107 107 107 107 107 107 107 107 339
 59=308   0  0  0  0  0  0  0  0  0  0  0  0  0 107 107 107 107 107 107 107 107 107 339
 60=308   0  0  0  0  0  0  0  0  0  0  0  0  0 107 107 107 107 107 107 107 107 107 339
***************************************************************************************
```

Figure 3. Example exposure profile. Minutes run vertically and hours run horizontally over grid containing average microenvironmental RSP concentrations ($\mu g/m^3$) for person #5 of Bay Area activity file.

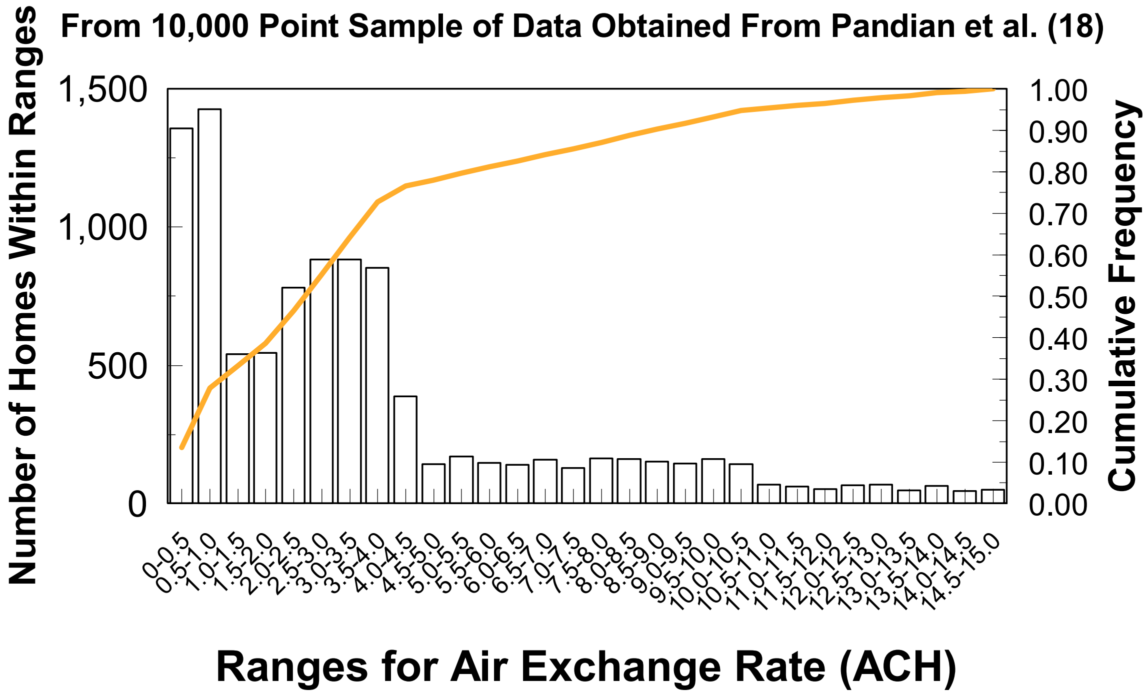

Figure 4. A plot of the histogram and cumulative frequency of the air exchange rate per home This distribution is randomly sampled for input into the SCEM model.

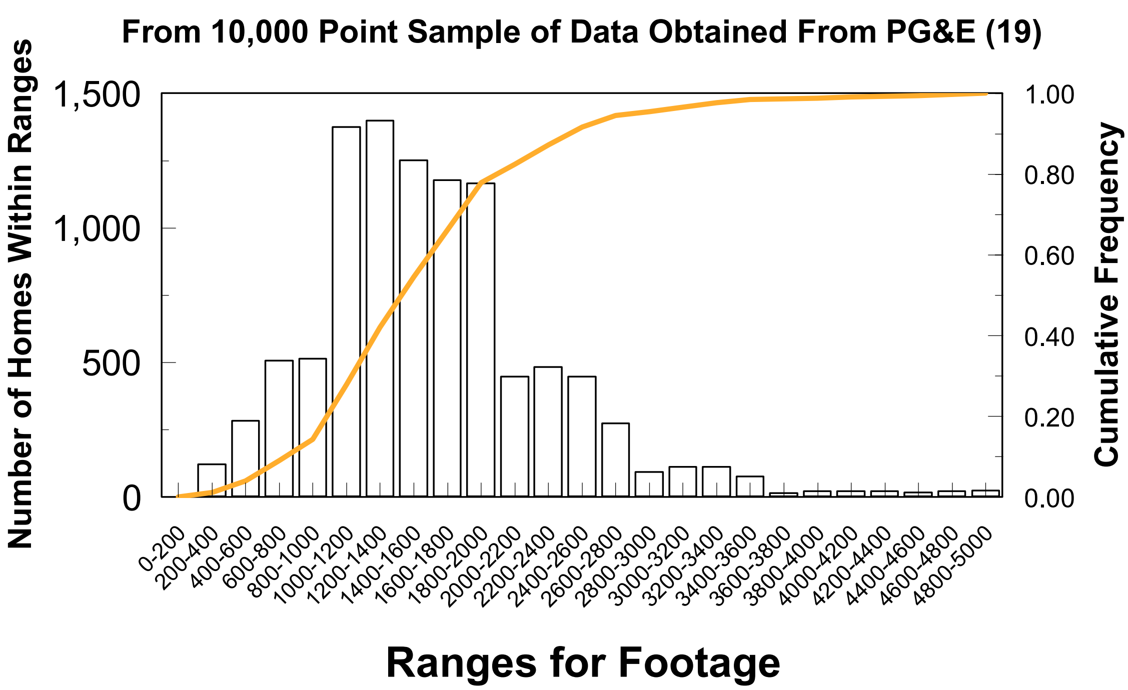

Figure 5. A plot of the histogram and cumulative distribution for home footage. This distribution is randomly sampled by the SCEM model.

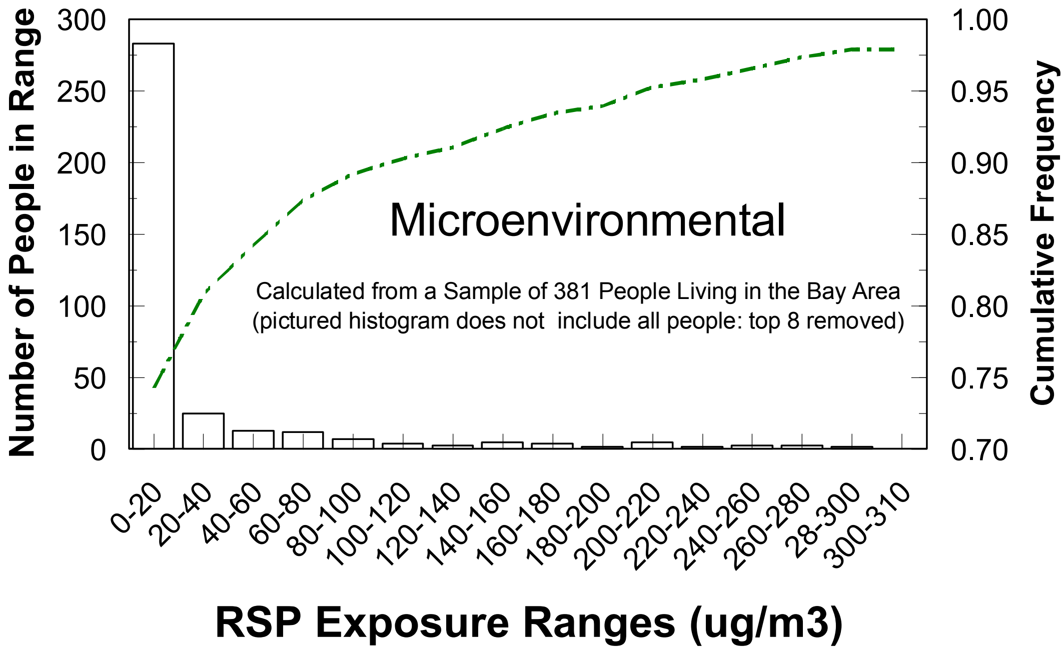

Figure 6. Histogram and frequency distribution of microenvironmental part of the 24-hour average exposure for the Bay Area population.

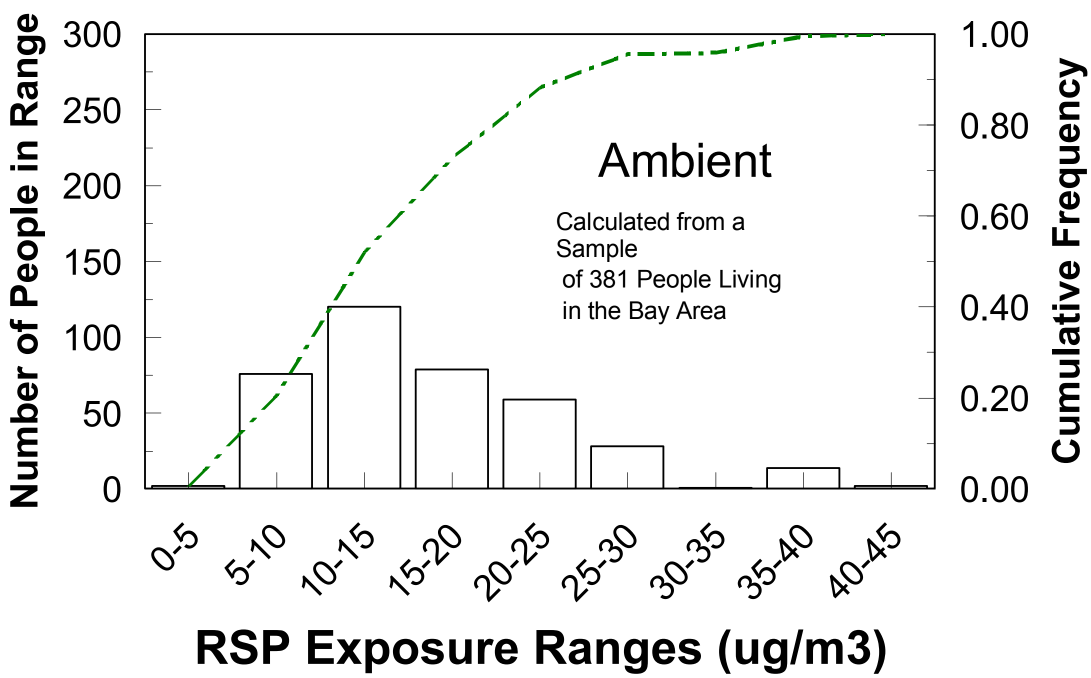

Figure 7. Histogram and cumulative frequency of ambient part of the 24-
average RSP exposure for the Bay Area population.

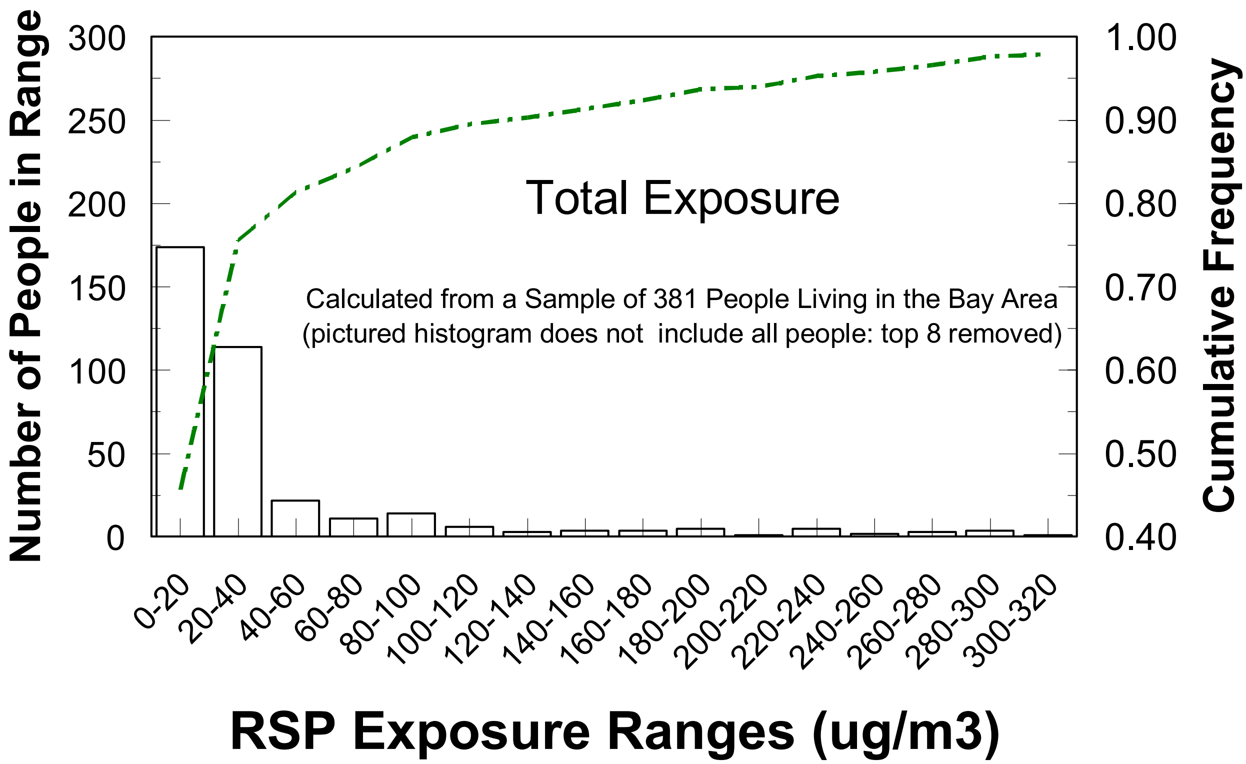

Figure 8. Histogram and cumulative frequency of 24-hour total average RSP exposure for the Bay Area population.