AIR POLLUTION EXPOSURE MODEL FOR INDIVIDUALS (EMI) IN HEALTH STUDIES: EVALUATION OF INDOOR AIR QUALITY MODEL FOR PARTICULATE MATTER

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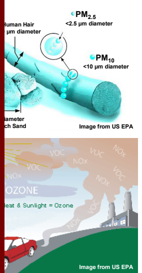
ABSTRACT

…us air pollution epidemiologic studies have observed associations …n ambient concentrations of particulate matter (PM) and increased … morbidity and mortality. These studies often use measurements from …site ambient monitors as exposure surrogates. To better understand …kages between ambient concentrations, exposures, and adverse …ascular and respiratory effects in diabetics and asthmatics, we are …ing an air pollution exposure model for individuals (EMI) in health … The EMI predicts personal exposures from ambient concentrations …estionnaire information such as indoor sources and time-activity …s. A critical aspect of the EMI is estimation of PM concentrations …omes where people spend most of their time. We developed a mass-… residential indoor air quality model to predict daily indoor $PM_{2.5}$ …oncentrations from outdoor concentrations and questionnaires. The …ange rate (AER), a critical model parameter, was estimated with a …istic AER model. Other parameters were set to reported literature … The model was evaluated with data from the Research Triangle Park …Particulate Matter Panel Study, which measured daily personal, …tial indoor and outdoor, and ambient $PM_{2.5}$ mass concentrations for …onsecutive days during each of four seasons in 36 homes within the …ea of North Carolina. For the model-predicted and measured indoor …trations of ambient-generated $PM_{2.5}$ mass, the median absolute …ce was 24% (2.2 µg/m³). Our study demonstrates the feasibility of … EMI to predict indoor $PM_{2.5}$ concentrations from ambient …ements in support of developing exposure-dose metrics for health …

…ALTH EFFECTS OF AIR POLLUTION



- Broad range of adverse effects associated with short and long-term exposures to particulate matter and gaseous copollutants
- Respiratory effects: reduced lung function, exacerbation of asthma
- Cardiovascular effects: myocardial ischemia, endothelial vasomotor dysfunction
- Adverse pregnancy outcomes: preterm births, low birth weight

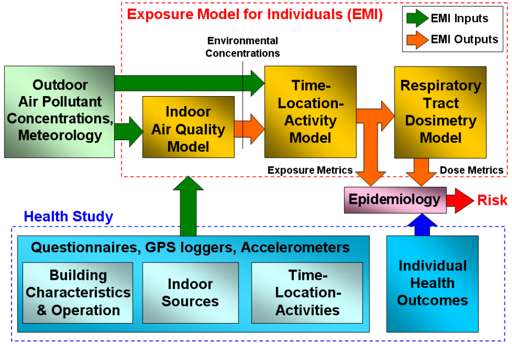
COHORT HEALTH STUDIES

…uate associations between health effects in …iduals and exposure to air pollutants

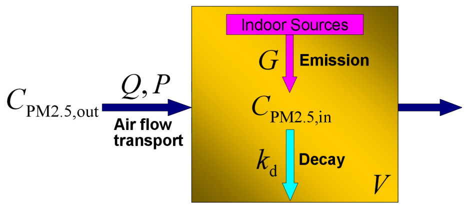
…antages:
- …ctual community exposures may not be easily replicated in …ontrolled chamber studies
- …ndividual health outcomes and questionnaires often available

…llenges:
- …ossible exposure misclassification of individuals from using …xposure surrogates (e.g. central site ambient measurements)
- …ost and participant burden of observational personal …xposure monitoring

EXPOSURE MODEL FOR INDIVIDUALS (EMI) IN HEALTH STUDIES



MASS BALANCE RESIDENTIAL INDOOR AIR QUALITY MODEL



Dynamic Mass Balance Equation

$$V\frac{dC_{PM2.5,in}}{dt} = \underbrace{Q\left(PC_{PM2.5,out} - C_{PM2.5,in}\right)}_{\text{Air flow transport through building}} - \underbrace{k_d V C_{PM2.5,in}}_{\text{Indoor Decay}} + \underbrace{G}_{\text{Indoor Sources}}$$

where:
- $C_{PM2.5,in}$ = residential indoor $PM_{2.5}$ concentration (µg/m³)
- $C_{PM2.5,out}$ = residential or central-site outdoor $PM_{2.5}$ concentration (µg/m³)
- P = $PM_{2.5}$ penetration coefficient (dimensionless)
- k_d = $PM_{2.5}$ indoor decay rate (h⁻¹)
- G = indoor-generated $PM_{2.5}$ source strength (µg/h)
- Q = air flow rate through building (m³/h)
- V = building volume (m³)

With air exchange rate, $k_a = \frac{Q}{V}$,

$$\frac{dC_{PM2.5,in}}{dt} = k_a P C_{PM2.5,out} - (k_a + k_d) C_{PM2.5,in} + \frac{G}{V}$$

Steady-State Mass Balance Equation

Assume all concentrations and parameters remain constant at daily average values across 24 h; set derivative to zero

$$C_{PM2.5,in} = \underbrace{\overbrace{\frac{k_a P}{k_a + k_d}}^{PM_{2.5}\text{ infiltration factor}} C_{PM2.5,out}}_{\text{Outdoor-generated}} + \underbrace{\frac{G}{V(k_a + k_d)}}_{\text{Indoor-generated}}$$

Only outdoor-generated $PM_{2.5}$ considered in this analysis

PREDICTING AIR EXCHANGE RATES

$$k_a = \frac{Q}{V} = \frac{A_{inf}\sqrt{k_s\left|T_{in} - T_{out}\right| + k_w U^2}}{V}$$

Ref: ASHRAE; Chan

where:
- k_s = stack coefficient (m²/°C-h²)
- k_w = wind coefficient (dimensionless) } Lookup tables
- A_{inf} = air infiltration leakage area (m²)
- T_{in} = indoor temperature (°C) } Housing characteristics
- T_{out} = outdoor temperature (°C)
- U = wind speed (m/h) } Meteorology

Previously evaluated with measured air exchange rates (Ref: Breen): Median model error = 41% (0.17 h⁻¹)

SENSITIVITY ANALYSIS

Relative sensitivity coefficient for air exchange rate:

$$R_{k_a}\left(C_{PM2.5,in}, k_a\right) = \left(\frac{k_a}{C_{PM2.5,in}}\right)\frac{\partial C_{PM2.5,in}}{\partial k_a} = 1 - \left(\frac{k_a}{k_a + k_d}\right)$$

Represents percent change in model output ($C_{PM2.5,in}$) per unit (1%) change in parameter (k_a)

Typical values for $k_d = 0.27\,h^{-1}$ and $k_a = 1.1\,h^{-1}$ yield $R_{k_a} = 0.20$
Implies 41% error in k_a yields 8% (0.20x41%) error in $C_{PM2.5,in}$

MODEL EVALUATION OF OUTDOOR-GENERATED INDOOR $PM_{2.5}$

RTP Particulate Matter Panel Study

Daily measurements (24 h average) at 36 residences for 7 consecutive days in 4 consecutive seasons (2000-2001)

- $PM_{2.5}$ mass: ambient, residential outdoor & indoor
- Sulfur: residential outdoor & indoor
- Air exchange rates

Outdoor-Generated Indoor PM2.5 Derived from Sulfur

$$C^{sulfur\_ratio}_{PM2.5,in} = \overbrace{\frac{C_{sulfur,residential\_in}}{C_{sulfur,residential\_out}}}^{PM_{2.5}\text{ infiltration factor}} C_{PM2.5,residential\_out} \quad \text{Outdoor-generated}$$

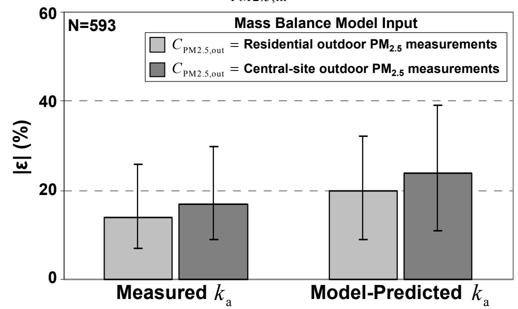
- Few or no indoor sources of sulfur (Ref: Sarnat)
- Physical properties of sulfur and $PM_{2.5}$ are similar

Model Parameters

k_a = measured and model-predicted (h⁻¹)
k_d = 0.27 h⁻¹
P = 0.95

Model Evaluation Metric

$$|\varepsilon| = \frac{C_{PM2.5,in} - C^{sulfur\_ratio}_{PM2.5,in}}{C^{sulfur\_ratio}_{PM2.5,in}} \times 100$$



CONCLUSION

- Median |ε| increased by 3-4% when using central-site, instead of residential, outdoor $PM_{2.5}$ measurements
- Median |ε| increased by 6-7% when using model-predicted, instead of measured, air exchange rates
- Indoor air quality model could be useful to develop exposure metrics for individuals in health studies

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