Exposure Model for Individuals (EMI) in Human Health Studies: Predicting Residential Indoor Exposures to Fine Airborne Particles

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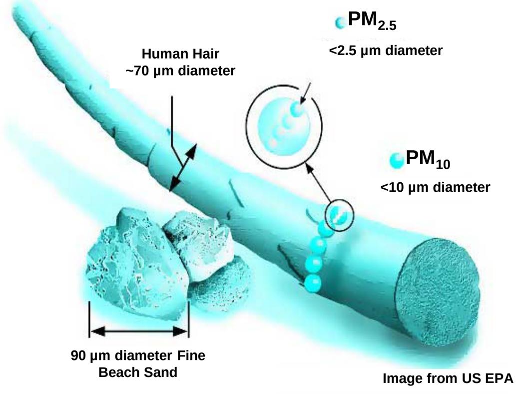
ABSTRACT

In many epidemiological studies, particulate matter (PM) is associated with increased risk for adverse cardiopulmonary events. Due to cost and participant burden of indoor and personal measurements, health studies often estimate exposures using ambient measurements. However, ambient levels do not necessarily reflect personal exposures since indoor levels can differ from ambient levels, and people spend considerable time indoors. To reduce this exposure error, which adds uncertainty and bias to risk estimates, we are developing an exposure model for individuals (EMI) in cohort health studies. A critical aspect of EMI is estimation of the ambient contribution to concentrations within individual homes, where people spend most of their time. A mass-balance indoor air quality (IAQ) model was linked to an air exchange rate (AER) model to predict ambient-generated indoor $PM_{2.5}$ mass from ambient concentrations, meteorology, and questionnaire data on housing characteristics and operation. First, AER model predictions were compared to 642 daily AER measurements across 31 detached homes in central North Carolina. For individual model-predicted and measured AER, median absolute difference was 43% (0.17 hr^{-1}). Second, IAQ model was evaluated with concurrent daily measurements of ambient and residential indoor-outdoor $PM_{2.5}$ mass. Using cross validation, model predictions were compared to measurements of ambient-generated indoor $PM_{2.5}$, which were derived from sulfate (outdoor tracer of $PM_{2.5}$). For individual model predictions and measurements, median absolute difference was 20%. This study demonstrates the ability of EMI to predict residential indoor $PM_{2.5}$ of ambient origin in support of developing exposure metrics for health studies.

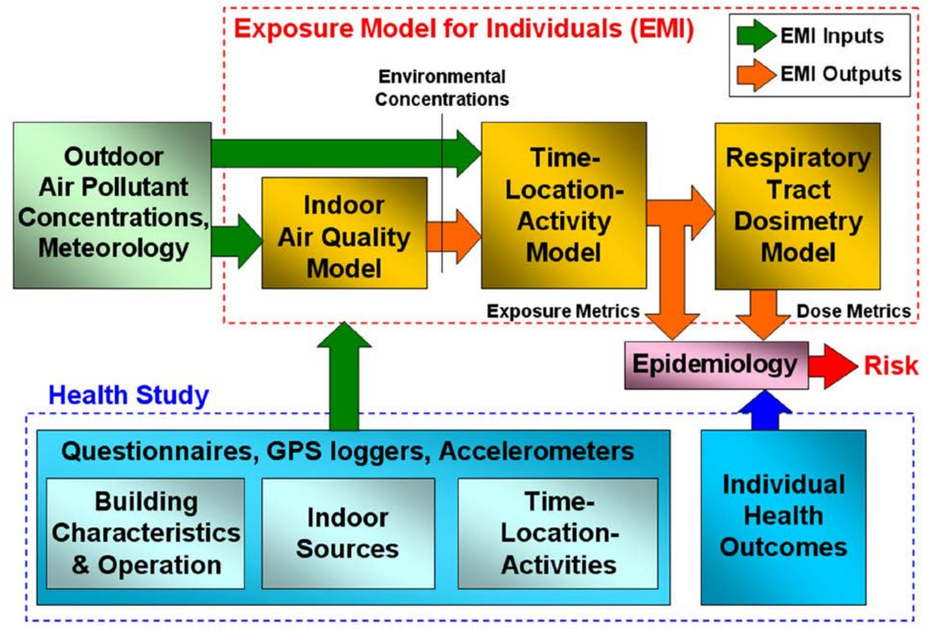
AIR POLLUTION HEALTH STUDIES



- Respiratory effects: reduced lung function, exacerbation of asthma
- Cardiovascular effects: myocardial ischemia, endothelial vasomotor dysfunction

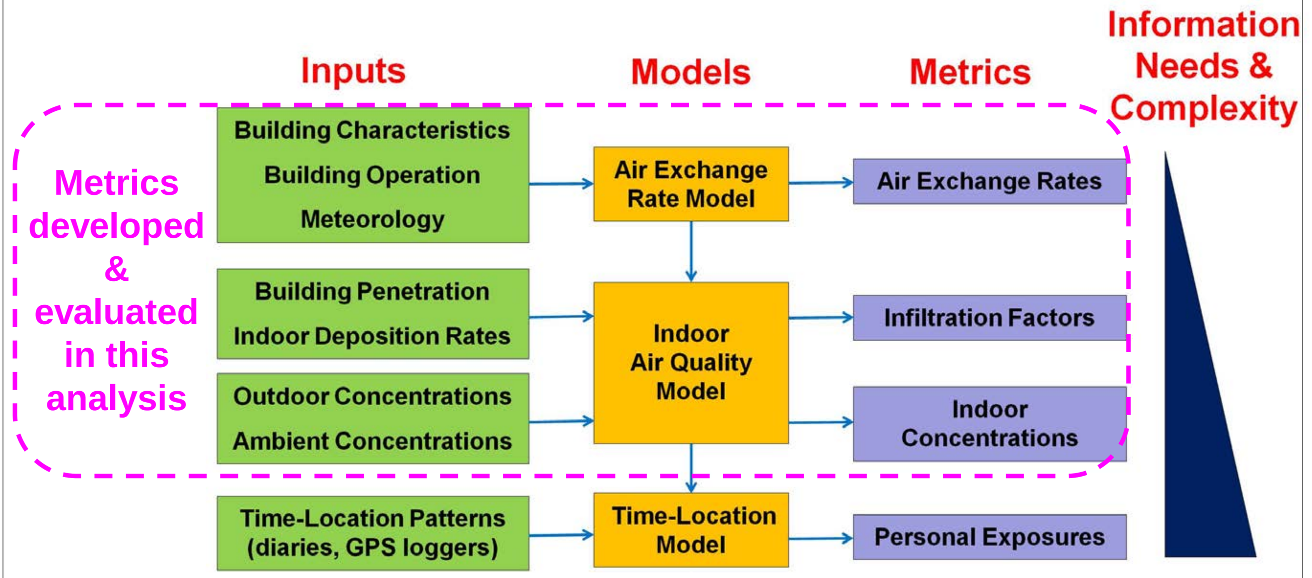
- Challenges of health studies:
  - Possible exposure errors from using surrogates (e.g., ambient levels) add uncertainty and potential bias to risk estimates
  - Cost, participant burden of personal exposure monitoring

EXPOSURE MODEL FOR INDIVIDUALS

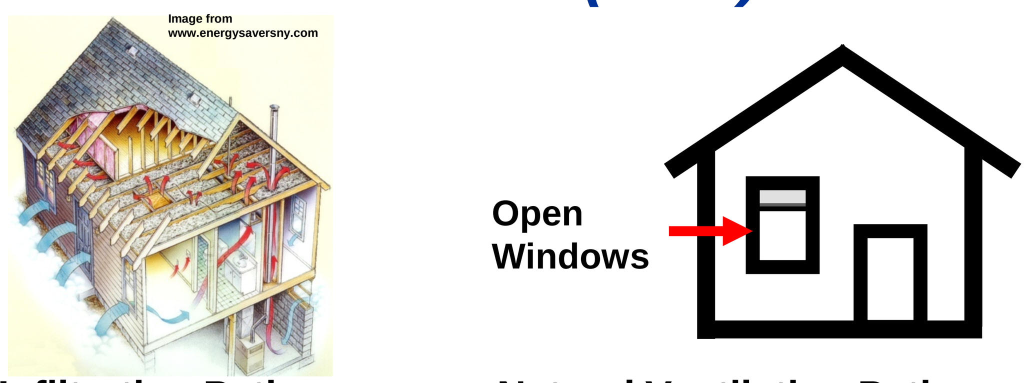


- Predicts exposure metrics for individuals in cohort health studies
- Inputs include outdoor concentrations, meteorology, and questionnaires

TIERED EXPOSURE METRICS



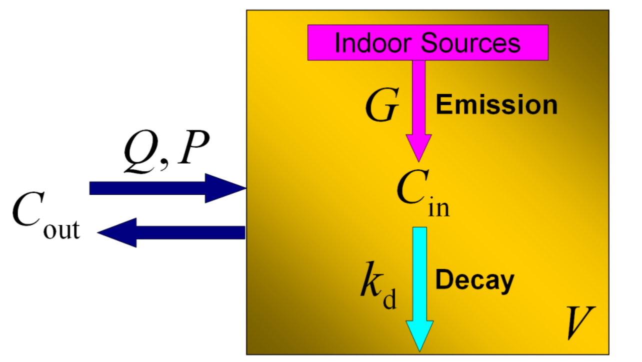
AIR EXCHANGE RATE (AER) MODELS



Air Infiltration Pathways — Natural Ventilation Pathway

Models	Air Infiltration	Nat. Vent.	Meteorology
SF (Breen et al)	Yes	No	No
LBL (Breen et al)	Yes	No	Yes
LBLX (Breen et al)	Yes	Yes	Yes

INDOOR AIR QUALITY MODEL



Steady-State Mass Balance Equation

$$C_{in} = \underbrace{\frac{k_a P}{k_a + k_d}}_{\text{Infiltration factor}} C_{out} + \frac{G}{V(k_a + k_d)}$$

Outdoor-generated — Indoor-generated

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

where:
- C_{in} = home indoor $PM_{2.5}$ concentration (µg/m³)
- C_{out} = home or ambient outdoor $PM_{2.5}$ concentration (µg/m³)
- P = $PM_{2.5}$ penetration coefficient (dimensionless)
- k_d = $PM_{2.5}$ indoor decay rate (h^{-1})
- k_a = air exchange rate (h^{-1}) = Q/V
- G = indoor-generated $PM_{2.5}$ source strength (µg/h)
- Q = air flow rate through building (m³/h)
- V = building volume (m³)

CASE STUDY: RTP PM PANEL STUDY

Daily measurements (24 h avg.) at 31 detached homes for 7 consecutive days in 4 consecutive seasons (2000-2001)

- $PM_{2.5}$ mass: ambient, home outdoor & indoor
- Sulfate: home outdoor & indoor
- Home air exchange rates
- Questionnaires (e.g., building characteristics)

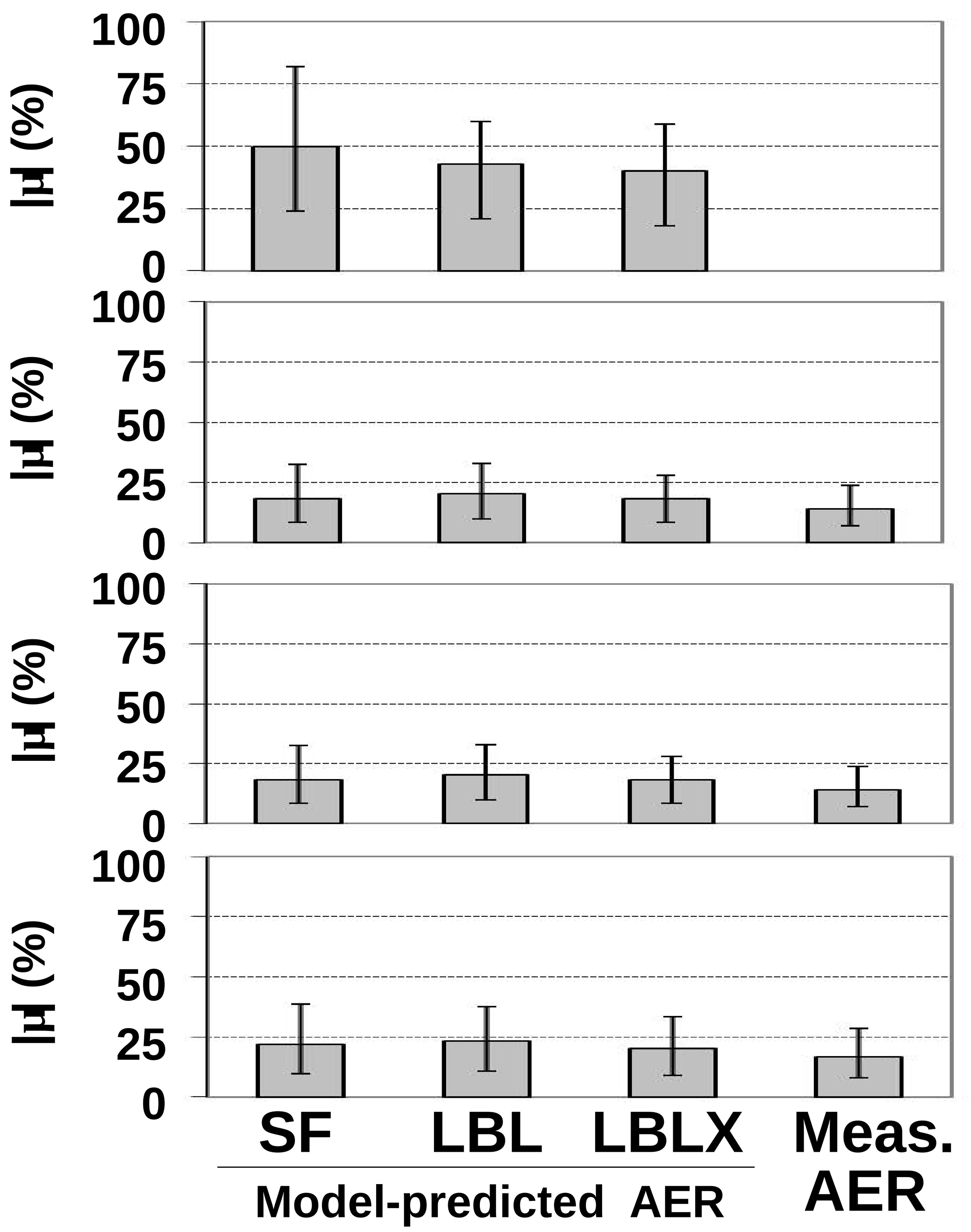
CROSS VALIDATION FOR PREDICTIVE INDOOR AIR QUALITY MODEL

- Method to (1) evaluate model *output uncertainty* with independent data not used for parameter estimation, and (2) estimate *parameter uncertainty*
- Parameter uncertainty
  - Removed samples from one home at a time (validation sample), and estimate parameters with remaining data
  - Evaluated model with validation sample
  - Calculated Jackknife estimates and confidence intervals for parameters (P, k_d)

Number of homes	Number of samples	P	95% CI of P	k_d	95% CI of k_d
31	591	0.84	(0.74, 0.93)	0.21	(0.13, 0.29)

Exposure Metric	Models	Model Evaluation Metric
Air exchange rates (AER)	SF, LBL, LBLX (Breen et al)	$\lvert\mu\rvert = \frac{\lvert\hat{k}_a - k_a\rvert}{k_a} \times 100$
PM2.5 mass infiltration factors	$\hat{F}_{inf} = \frac{k_a P}{k_a + k_d}$	$\lvert\mu\rvert = \frac{\lvert\hat{F}_{inf} - F_{inf}\rvert}{F_{inf}} \times 100$ where: $F_{inf} = \frac{C_{sulfate,in}}{C_{sulfate,out}}$
Indoor PM2.5 mass concentrations (from home outdoor meas.)	$\hat{C}_{in}^{home\_out} = \hat{F}_{inf} C_{home\_out}$	$\lvert\mu\rvert = \frac{\lvert\hat{C}_{in}^{home\_out} - C_{in}\rvert}{C_{in}} \times 100$ where: $C_{in} = F_{inf} C_{home\_out}$
Indoor PM2.5 mass concentrations (from ambient outdoor meas.)	$\hat{C}_{in}^{amb\_out} = \hat{F}_{inf} C_{amb\_out}$	$\lvert\mu\rvert = \frac{\lvert\hat{C}_{in}^{amb\_out} - C_{in}\rvert}{C_{in}} \times 100$

Output Uncertainty



CONCLUSION

- Demonstrates feasibility of developing tiered exposure metrics for individuals in health studies
- Sensitivity analysis showed 40% error of predicted AER yields only 12% error for predicted indoor conc.
- Median |μ| for indoor conc. increased by 2-4% using ambient, instead of home, outdoor meas.
- Median |μ| for indoor conc. varied by 2-3% using different AER models

REFERENCES

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