Air Pollution Exposure Model for Individuals (EMI) in Health Studies: Predicting Spatiotemporal Variability of Residential Air Exchange Rates

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Abstract

In health studies, traffic-related air pollution is associated with adverse respiratory effects. Due to cost and participant burden of personal measurements, health studies often estimate exposures using local ambient air monitors. Since outdoor levels do not necessarily reflect personal exposures, we developed the Exposure Model for Individuals (EMI) in health studies. A critical aspect of EMI is estimation of the air exchange rate (AER) for individual homes where people spend most of their time. The AER, which is the airflow into and out of buildings, can substantially impact indoor air pollutant concentrations and resulting occupant exposures. Our goal was to evaluate and apply an AER model to predict residential AER for the Near-Road Exposures and Effects of Urban Air Pollutants Study (NEXUS), which is examining traffic-related air pollution exposures and respiratory effects in asthmatic children living near major roads in Detroit, Michigan. We developed an AER model to predict AER from building characteristics related to air leakage; local airport temperatures and wind speeds; and open windows. Cross validation was used with a subset of NEXUS homes (N=24) with daily AER measured on five consecutive days during fall 2010 and spring 2011. Individual predicted and measured AER closely matched with median absolute differences of 36% and 24% for the fall and spring, respectively. The model was then applied to predict hourly AER for all NEXUS homes (N=193) during the study (Jan. 2010 - Dec. 2012). The AER predictions show (1) substantial house-to-house (spatial) variations (0.1 – 3.5 h^{-1}) from building leakage differences; (2) slow oscillations from seasonal temperature changes; and (3) large transients from wind speed fluctuations. This study demonstrates the ability to predict spatiotemporal variability of residential AER in support of improving health study exposure assessments.

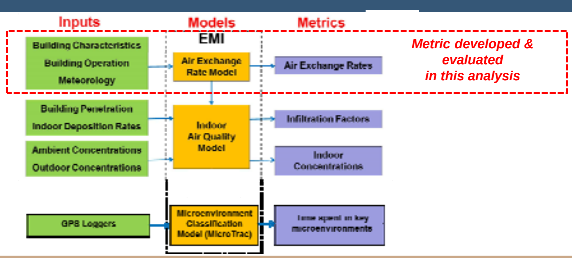
Near-Road Exposures and Effects Study (NEXUS)

- Investigating effects of traffic-related air pollution on the respiratory health of asthmatic children in Detroit, Michigan
- Using an integrated measurement and modeling approach for exposure assessment

Challenges of Air Pollution Health Studies

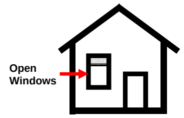
- Possible exposure misclassifications from using surrogates (e.g., central-site ambient monitors) can lead to uncertainty and bias to risk estimates
- Cost, participant burden of personal exposure monitoring

Exposure Model for Individuals (EMI) in NEXUS



Residential Air Exchange Rate (AER) Model

Air Leakage Pathways



Natural Ventilation Pathways

LBLX model*: accounts for air leakage, natural ventilation, meteorology

*Breen et al. Environ. Sci. Technol. 44:9349-9356, 2010.

- Determinant for entry of outdoor air pollutants and removal of indoor source emissions
- Substantial temporal and house-to-house AER variations from meteorology, building characteristics, and occupant behavior
- AER affects magnitude and time-course behavior of indoor pollutant concentrations
- Critical parameter for exposure models since people spend most of their time indoors at home

Cross Validation/Calibration of AER Model

- Measured daily AER in 24 NEXUS homes for 5 consecutive days in 2 seasons (fall 2010, spring 2011)
- Obtained LBLX model input data:
  - Building characteristics (e.g., home age, floor area) and daily operating conditions (e.g., indoor temperature, window opening)
  - Meteorology data: airport temperature and wind speed

LBLX Model

$$AER_{LBLX} = \frac{\sqrt{Q_{leak}^2 + Q_{nat}^2}}{V}$$

where: $Q_{leak} = A_{leak}\sqrt{k_s|T_{in} - T_{out}| + k_w U^2}$

Leakage Area (see model below) — Stack effect — Wind effect

- 2 literature-reported parameters from house height and sheltering: (k_s, k_w)
- 2 inputs from airport temperature and wind speed: (T_{out}, U)
- 3 inputs from building characteristics and indoor temperature: (A_{leak}, V, T_{in})

Model for Leakage Area

Leakage area: $$A_{leak} = \frac{NL}{NF} = \frac{\exp(\beta_0 + \beta_1 Y_{built} + \beta_2 A_{floor})}{NF}$$

where: $$NF = \frac{1000}{A_{floor}}\left(\frac{H_{height}}{2.5}\right)^{0.3}$$

- 3 inputs from housing characteristics: $(Y_{built}, A_{floor}, H_{height})$
- 3 parameters we estimated using cross validation: $(\beta_0, \beta_1, \beta_2)$

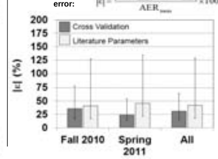
Estimated Parameters for Leakage Area Model

Parameter	Jackknife Estimate
β_0: low income intercept	6.34E+01
β_1: low income year built	-3.29E-02
β_2: low income floor area	-7.09E-04
β_0: conventional intercept	5.54E+01
β_1: conventional year built	-2.83E-02
β_2: conventional floor area	-5.87E-03

- Estimate parameters using leave-one-home-out (jackknife) cross validation
- Two sets of parameters: low-income homes and conventional homes
- Minimized sum of squared difference between modeled and measured AER

LBLX Model Evaluation with Measurements

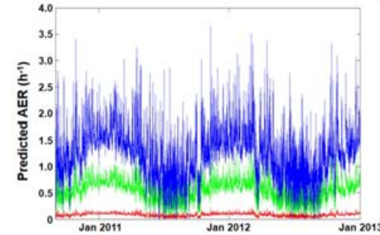
Prediction error: $|\varepsilon| = \frac{|AER_{LBLX} - AER_{meas}|}{AER_{meas}} \times 100$



- Prediction errors (quartiles are shown) are lower with cross validation parameters, as compared to literature-reported parameters
- Demonstrates value of NEXUS study design with subset of AER measurements to allow for model calibration

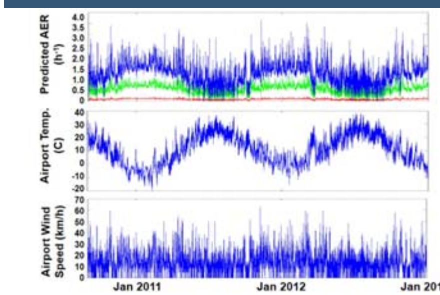
Predicted AER for NEXUS Homes

- Used estimated parameters from cross validation
- Predicted hourly AER for 193 NEXUS homes across 3 years



- Selected 3 homes with low (red), medium (green), high (blue) AER
- Substantial house-to-house AER variability due to building characteristics (e.g., higher AER for older and smaller homes)
- Substantial temporal AER variability due to weather (temperature, wind speed)

Temporal Variability of Predicted AER



- Selected 3 homes with low (red), medium (green), high (blue) AER
- Slow AER oscillations correspond to seasonal temperature changes (e.g., higher AER in winter due to larger indoor-outdoor temperature differences)
- Large AER transients correspond to wind speed fluctuations

Summary of AER Modeling

- Reduced AER model uncertainty with calibration of AER model
- Predicted house-to-house (spatial) and temporal (hourly) AER variations for 193 NEXUS homes
- AER predictions will be used to develop refined tiers of exposure metrics (e.g., residential indoor pollutant conc.), which account for spatial and temporal variations of traffic-related pollutants