

Modelling Exposure to Environmental Pollutants

Modelling Exposure to Air Pollutants

Mike Ashmore
Environment Department
University of York

Exposure and Health

- Epidemiological studies generally relate temporal and spatial variation in health outcomes to concentrations at monitoring stations
- Modelled or measured outdoor concentrations used to estimate and value levels of mortality and morbidity, and assess benefits of policies **BUT**
- Real effects of air pollution depend on exposures of individuals not of monitors

What determines exposure?

1. Time spent in indoor and outdoor micro-environments (MEs)
2. Indoor exposure
 - proximity of buildings to road
 - penetration and deposition of outdoor pollutants
 - indoor pollution sources
3. Outdoor exposure
 - variation in concentration through space and time

Three key elements of exposure

- Indoor exposure due to indoor sources
- Outdoor exposure due to outdoor sources
- Indoor exposure due to outdoor sources
- Also in some cases (e.g. UK cities in the 1950s) outdoor exposure due to indoor sources

Measurements vs. models

- Direct measurements essential to provide basis for useful models
- Often based on limited sample sizes and measurements
- Empirical analysis can identify key sources and predict exposure of others in same time and place
- Problem of extrapolation and 'what if' policy scenarios

Models of exposure

- Use of surrogates e.g. measured or modelled outdoor concentrations
- Empirical approaches – predict individual exposure from e.g. outdoor concentration and most important activities
- Micro-environmental time-activity-location models for every individual
- Population based time-activity-location models
- Micro-environmental concentrations may be based on empirical or physico-chemical models

Modelling Exposure to Environmental Pollutants

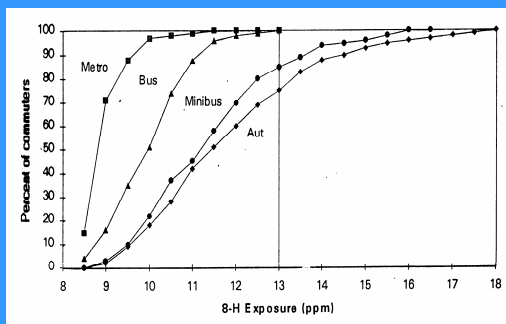
Which model is 'fit for purpose'?

- Choice of model driven by application
- Epidemiological studies require individual estimates to link to individual health outcomes
- Focus here on use of models for policy evaluation
- Broad UK policy assessment for cost-benefit analysis based on outdoor concentrations as a surrogate
- But is this adequate if exposure varies greatly within a population due to other drivers?

Population Exposure Frequency Distribution (PEFD)

- Key concept for a different modelling approach
- Expresses the distribution of personal exposures within population groups
- Can't predict individual exposures - relies on generic information for the city and population of interest

Modelled Effect of Mode on 8h CO Exposure in Mexico City



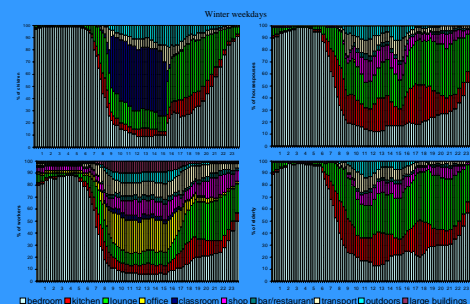
Probabilistic exposure modelling framework

- **INDAIR** - simulates diurnal profiles of frequency distributions of air pollutant concentrations
 - different indoor micro-environments (MEs)
 - function of outdoor concentrations, indoor sources, pollutant and building characteristics
- **EXPAIR** - simulates PEFDs based on time-activity patterns and probabilistic ME concentration profiles from INDAIR
- Simultaneous CO, NO₂, PM_{2.5}, PM₁₀

Indoor MEs: INDAIR-2

| Micro-environment | Default parameterisation | Additional factor 1 | Additional factor 2 |
|-----------------------|-------------------------------|---------------------|---------------------|
| Home - kitchen | No source | Cooking | Smoking |
| Home - liv. room | No source | Cooking | Smoking |
| Home - bedroom | No source | Cooking | Smoking |
| Transport | Bicycle/walk/public transport | Car | |
| School | No source | - | - |
| Office | Nat. ventilated | Mech. ventilated | |
| Shops/large buildings | No source | - | - |
| Bars/restaurants | No smoking | Smoking | Cooking |

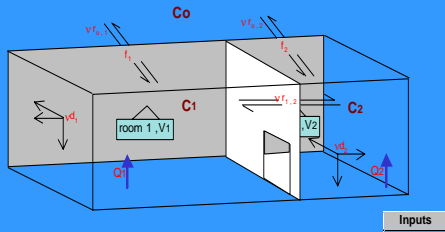
EXPAIR - 2 Time activity profiles - winter weekdays



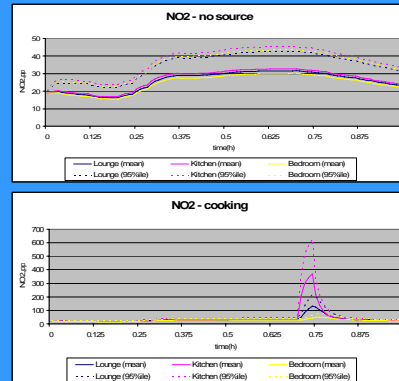
Modelling Exposure to Environmental Pollutants

How does INDAIR work?

INDAIR - a model for indoor levels of air pollutants



Importance of peak exposures indoors-NO₂



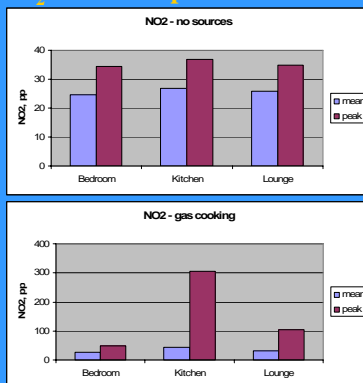
Key parameters

- Outdoor concentration
- Air exchange rate with outside
- Internal air exchange rates between rooms
- Room size
- Deposition velocity
- Emission rate
- Ventilation of sources

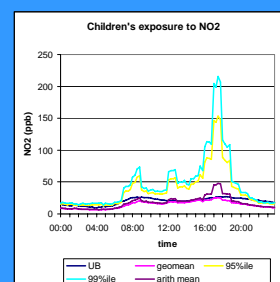
What are most important parameters for NO₂?

- **Without indoor sources:**
 - Outdoor concentrations
 - External air exchange rate
 - Deposition velocity
- **With indoor sources**
 - Room size
 - Emission rate
 - Deposition velocity

INDAIR Predictions - NO₂ mean and peak concentrations



Children's exposure to NO₂ - different parameters of exposure frequency distribution

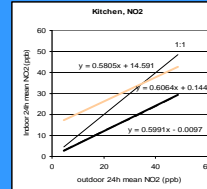


Modelling Exposure to Environmental Pollutants

Consistency with measured levels Dimtroulopoulou et al., 2005

- Mean I/O ratios
 - 0.5-0.6; NO₂, no gas cooking (model 0.53)
 - 0.7-0.8; NO₂, lounge with gas (model 0.66)
 - 0.9-1.0; NO₂, kitchen with gas (model 0.88)
- Hourly peak concentrations of NO₂
 - 88-245 ppb in lounge (model 103ppb)
 - 104-428 ppb in kitchen (model 304ppb)

Simple empirical predictions - models and measurements



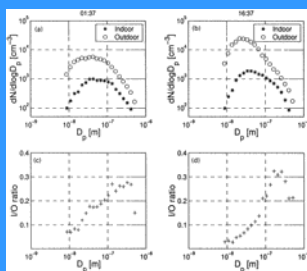
$$C_{in} = k.C_{out} + Q$$

Based on NO₂ measurements in Mumbai (Kulkarni & Patel, 2002)

k and Q depend on house size and cooking fuel

INDAIR model simulations

Particle size distribution changes indoors



Kopponen et al., 2001

Modelling PEFDs for Leicester

- Distribute MEs between four different road types with different concentration profiles
- Model frequency distributions of concentrations for each ME for each road type
- Run EXPAIR to simulate population exposure for each road type and across the city
- Compare mean and 95%iles of PEFD with urban background concentrations
- Compare population groups, seasons and days
- Consider different traffic and indoor policy interventions in terms of population exposure compared with outdoor concentrations

Leicester application: assign MEs to road type

- Traffic model used to assign roads to one of four categories based on traffic flow characteristics
- Outside model zone, roads assigned to background category
- MEs split between four categories based on data on specific locations (e.g. schools), traffic density (e.g. cars) and planning data (e.g. homes)
- About 25% of homes on roads with elevated air pollution levels

Outdoor road types - Leicester



Type 1: AURN background

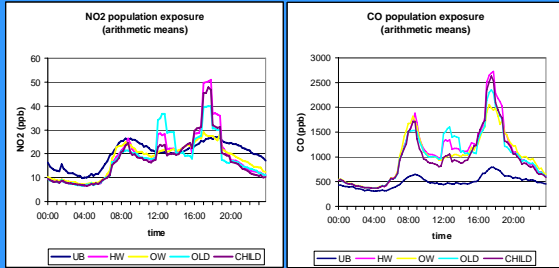
Type 2: Urban roads with high traffic - green

Type 3: Urban roads with medium traffic - blue

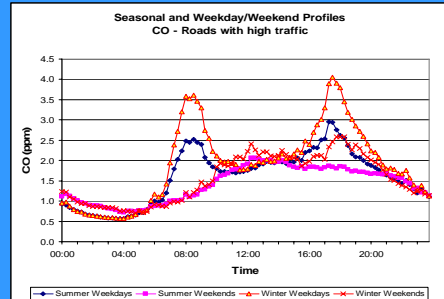
Type 4: Urban roads with low traffic - pink

Modelling Exposure to Environmental Pollutants

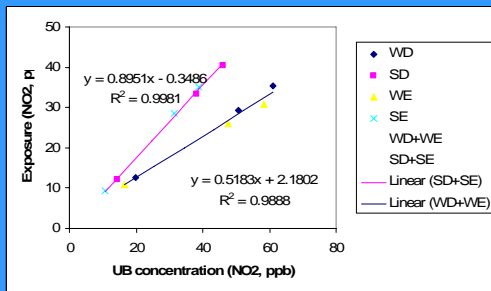
PEFD mean across the city for different groups - NO₂ and CO



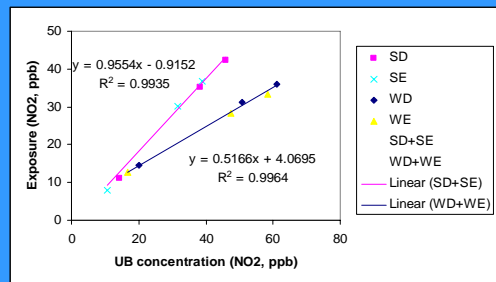
Seasonal variations - CO



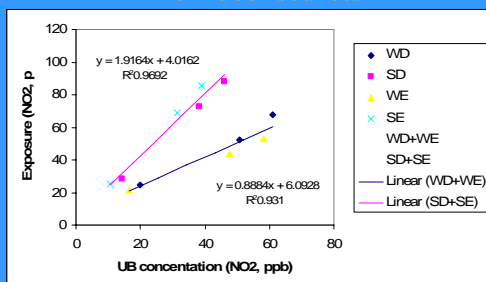
Relationship between UB and mean personal exposure: NO₂; elderly - no indoor sources



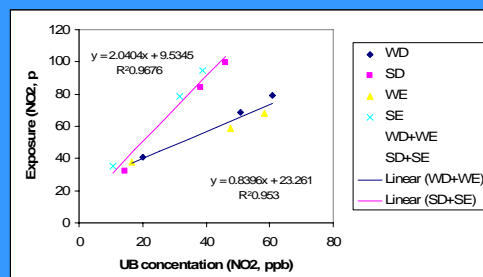
Relationship between UB and mean personal exposure: NO₂; elderly - with indoor sources



Relationship between UB and 95 percentile of mean personal exposure: NO₂; elderly - no indoor sources

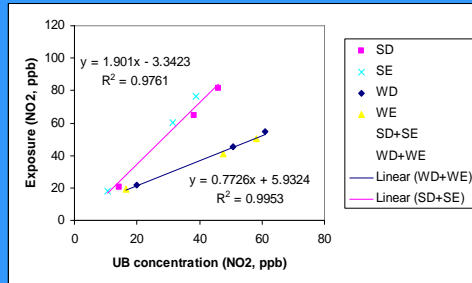


Relationship between UB and 95 percentile of mean personal exposure: NO₂; elderly - with indoor sources



Modelling Exposure to Environmental Pollutants

Relationship between UB and 95%ile PEFDs: NO₂; elderly - no HGVs



Policy assessment – mean & 95%ile PEFD; NO₂ (ppb) exposure of elderly

| | Winter mean | Winter 95%ile | Summer mean | Summer 95%ile |
|----------------------------|-------------|---------------|-------------|---------------|
| Baseline – home sources | 9.3 | 31.7 | 8.6 | 29.9 |
| AQM – home sources | 8.0 | 29.5 | 7.2 | 23.7 |
| Baseline – no home sources | 7.4 | 15.0 | 8.6 | 23.2 |
| No HGVs – no home sources | 7.0 | 13.7 | 7.6 | 15.7 |

Effects of modelled policy interventions

- Effects of traffic policies and home source removal greater on 95%ile exposures (and peak exposures during day)
- Effects of traffic policies on exposure greater in summer although roadside increment higher in winter
- CO exposure most influenced by traffic policies, NO₂ less, PM₁₀ least
- Exposure benefits differ between seasons because of air exchange rates and activity patterns
- Benefits of traffic policies in terms of PEFDs differ from those for outdoor concentrations

Assessing health impacts of indoor and outdoor air pollution

- Models that link indoor and personal exposure can provide new insights related to health effects of air pollution
- Models allow factors associated with highest indoor and outdoor exposures to be identified
- Relationship between UB levels and PEFD parameters varies in time – implications for time-series studies
- The greater frequency and size of peak exposures indoors needs to be considered in interpreting epidemiological studies
- Threshold – lack of population threshold can disguise individual thresholds if personal exposure not correlated with ambient levels
- PEFD approach allows policy evaluation considering indoor sources, outdoor sources and building design
- Policy assessment based on PEFD should be better focussed – but how much better given increased complexity and uncertainty?

Acknowledgements

- Contributions from many colleagues, especially Sani Dimitroulopoulou and Andrew Terry
- Contribution of Margaret Bell, Haibo Chen and Anil Namdeo (Institute of Transport Studies, Leeds) to traffic and pollution models in Leicester
- Leicester project supported by Department of Health
- Development of INDAIR/EXPAIR supported by Defra