Effects of urban pollution on IAQ in energy-efficient buildings in the UK

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Background

- 80% CO2 reduction by 2050 required
- 78% of current housing stock will still be in existence by 2050
Consequences of building energy efficient retrofit

Unintended consequences of building energy efficient retrofit

IAQ

Reduce energy

Warm homes

Building energy efficient retrofit

Reduce energy

IAQ

Consequences of building energy efficient retrofit

Unintended consequences of building energy efficient retrofit
Unintended consequence: IAQ

• Reductions in envelope permeability without mechanical ventilation produced increases in indoor PM2.5 concentrations (Shrubsole et al, 2012).

• Mean indoor radon concentrations increase by an estimated 56.6% and additional annual burden of 4700 life years lost when increasing airtightness (Milner et al, 2014)
Is there an optimum ventilation strategy for IAQ?

Building tight, ventilation right!

- Ventilation to dilute indoor pollutants
- Ventilation to reduce outdoor ingress
Research question

- In which location is the weatherization retrofit (airtightness improvement) encouraged?

- Is there a balance of ventilation between penetration of outdoor pollution and dilution of indoor-generated pollutants?
One-compartment IAQ model

\[ V \frac{dC_i}{dt} = P\alpha VC_o - \alpha VC_i - kVC_i + \dot{m} \]

\[ C_i = \frac{P\alpha C_o}{\alpha + k} + \frac{\dot{m}}{V(\alpha + k)} = F_{inf} C_o + C_{ig} \]

Ref.: WW Nazaroff, Indoor Air 14 (Suppl. 7), 175, 2004.
Case study in London

<table>
<thead>
<tr>
<th>Scenarios</th>
<th>Concentration (µg/m³)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Urban roadside (Marylebone road)</td>
<td>22</td>
</tr>
<tr>
<td>Urban background (Bloomsbury)</td>
<td>11</td>
</tr>
<tr>
<td>Rural (Rochester)</td>
<td>9</td>
</tr>
</tbody>
</table>
### Indoor emission

<table>
<thead>
<tr>
<th>Scenarios</th>
<th>Emission rate</th>
</tr>
</thead>
<tbody>
<tr>
<td>No indoor source</td>
<td>0</td>
</tr>
<tr>
<td>Medium indoor source</td>
<td>0.95 (mg/h)</td>
</tr>
<tr>
<td>Heavy indoor source (cooking, smoking etc)</td>
<td>1.7 (mg/min) for cooking period</td>
</tr>
</tbody>
</table>

### Airtightness

<table>
<thead>
<tr>
<th>Scenarios</th>
<th>Airtightness</th>
</tr>
</thead>
<tbody>
<tr>
<td>Before Part L1 2002</td>
<td>20m³/(m²h) @50 Pa (0.8 ACH)</td>
</tr>
<tr>
<td>After Part L1 2002</td>
<td>10m³/(m²h) @50 Pa (0.4 ACH)</td>
</tr>
<tr>
<td>Passivhaus</td>
<td>0.6 ACH@50 Pa (0.03ACH)</td>
</tr>
</tbody>
</table>
Urban location

Urban background

Rural location
Health and economic implications

The change in health outcomes due to the change in indoor PM2.5 concentration

C-R function: \[ \Delta y = y_0 P(e^{\beta \Delta x} - 1) \]

<table>
<thead>
<tr>
<th>Pollutant</th>
<th>Outcome</th>
<th>Concentration change $\beta$ coefficient (95% CI)</th>
<th>$\beta$-coefficient standard deviation</th>
<th>Baseline prevalence of illness per year $y_0$</th>
<th>Reference</th>
</tr>
</thead>
<tbody>
<tr>
<td>PM2.5 [$\mu g/m^3$]</td>
<td>Total mortality</td>
<td>5.8E−3 (2.0E−3, 1.0E−2)</td>
<td>1.9E−03</td>
<td>7.40E−3</td>
<td>Pope et al. [6]</td>
</tr>
<tr>
<td></td>
<td>Chronic bronchitis</td>
<td>9.1E−2 (7.8E−2, 1.1E−1)</td>
<td>6.8E−03</td>
<td>4.00E−4</td>
<td>Abbey et al., [34]</td>
</tr>
<tr>
<td></td>
<td>Asthma attack</td>
<td>1.4E−3 (3.1E−4, 2.5E−3)</td>
<td>5.6E−04</td>
<td>2.70E−2</td>
<td>Whittenmore and Korn [35]</td>
</tr>
<tr>
<td></td>
<td>Minor restricted activity days</td>
<td>7.4E−3 (6.0E−3, 8.8E−3)</td>
<td>7.0E−04</td>
<td>2.14E−2</td>
<td>Ostro and Rothschild [36]</td>
</tr>
<tr>
<td></td>
<td>All hospital admissions—all respiratory</td>
<td>1.5E−3 (0, 5.0E−3)</td>
<td>1.8E−03</td>
<td>2.58E−5</td>
<td>Burnett et al. [37]</td>
</tr>
<tr>
<td></td>
<td>Non-fatal stroke</td>
<td>2.5E−2 (2.0E−3, 4.8E−2)</td>
<td>1.2E−02</td>
<td>2.00E−4</td>
<td>Peters et al. [38]</td>
</tr>
</tbody>
</table>
Urban location

Mortality

Annual total incident health outcome

1. No indoor sources
2. Medium indoor sources
3. Heavy indoor sources

Outcome cost in millions of English pounds


No indoor sources Medium indoor sources Heavy indoor sources
• When we should increase airtightness?

• When we should open windows?
Balance-point concentration

\[
\frac{C_i}{C_o} = \frac{P\alpha}{\alpha + k} + \frac{\dot{m}}{V(\alpha + k)C_o} = P
\]

Balance-point outdoor concentration

\[
C_{oe} = \frac{\dot{m}}{kVP}
\]

\[
\frac{C_i}{C_o} = P + \frac{KP(C_{o,e} - C_o)}{C_o(a + K)}.
\]

If \( C_{o,e} > C_o \) then \( \frac{C_i}{C_o} > P \),

If \( C_{o,e} < C_o \) then \( \frac{C_i}{C_o} < P \).

Li et al. 2003
Conclusions

• Building tight, ventilate right. Indoor and outdoor fight.

• The increase of airtightness level by more stringent insulation towards Passivhaus standard in UK can lead to either increase or decrease of indoor pollution concentration depending on the relative strength of outdoor concentration and indoor emission rate.

• Balance-point concentration will be an important parameter to determine when open the window.
THANK YOU