Indoor Residential Chemical Emissions as Risk Factors for Children’s Respiratory Health

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Thanks to Al Hodgson for help understanding indoor chemicals.
Indoor Residential Chemical Emissions and Children’s Health

- Introduction
- Available findings: indoor concentrations & sources
- Ventilation as modifier for risks from indoor sources
- Evaluation
- Existing conditions vs. risks
- Implications
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Indoor Chemical Emissions and Children’s Health -- Introduction

- U.S. research on respiratory health effects of residential indoor air primarily on:
  - allergens (dust mites, cockroach, animal dander)
  - mold, moisture, endotoxin
  - combustion products (ETS, cookstoves, heaters, outdoor pollutants)
Indoor Chemical Emissions and Children’s Health --
Introduction

- However, recent research outside U.S. shows associations between respiratory/allergic health effects and
  - indoor concentrations of chemicals
  - common indoor materials and finishes

- Most research, and strongest findings, in children

- Diverse findings not yet summarized
Indoor Residential Chemical Emissions and Children’s Health

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Indoor Chemical Emissions and Children’s Health – Available Findings

- Reported risk factors in 20 recent studies (last 10 yrs, except 2 U.S. 1989-90)
  - **specific organic compounds** –
    - formaldehyde
    - plasticizers
    - aromatic compounds
    - aliphatic compounds
  - **indoor finishes or materials** –
    - particleboard
    - flexible flooring and plastics
    - paint
    - carpet
    - Renovation
  - **excluded ETS, combustion** . . .
Indoor Chemical Emissions and Children’s Health: Available Findings

- Associated outcomes
  - asthma-related
  - allergy-related
  - altered T-cell cytokine profiles
  - pulmonary infections
### Indoor Chemical Emissions and Children’s Health: Table 1a. Odds Ratios (OR) from Reported Studies

<table>
<thead>
<tr>
<th>Risk Factors</th>
<th>Outcomes</th>
</tr>
</thead>
<tbody>
<tr>
<td>Plasticizers or Plastics</td>
<td>Asthma-Related: OR = 1.0 – 12.6* (1.0, 1.1, 1.4*, 1.4*, 1.5, 1.9*, 1.9*, 2.4*, 2.9, 2.9*, 3.4*, 12.6*)&lt;br&gt;</td>
</tr>
<tr>
<td></td>
<td>Allergy/Atopy: OR = 1.3* – 3.0* (1.3*, 1.6*, 2.0*, 2.6*, 3.0*)</td>
</tr>
<tr>
<td>Formaldehyde or Composite Wood</td>
<td>Asthma-Related: OR = 1.2 – 8.0* (1.2, 1.3, 1.4, 1.4*, 1.4*, 1.4*, 1.6, 1.7*, 1.8*, 2.0*, 8.0*)&lt;br&gt;</td>
</tr>
<tr>
<td></td>
<td>Allergy/Atopy: OR = 1.5* - 4.1 (1.5*, 1.8, 2.4, 4.1)</td>
</tr>
<tr>
<td>Paint or Painting</td>
<td>Asthma-Related: OR = 1.1 – 4.1* (1.1, 1.2, 1.3, 1.7*, 1.9*, 4.1*, 4.1*)&lt;br&gt;</td>
</tr>
<tr>
<td></td>
<td>Allergy/Atopy: OR = 1.2* (1.2*)</td>
</tr>
</tbody>
</table>

**KEY:** RANGE of ORs (specific reported ORs) <br> * p-value <0.05
### Indoor Chemical Emissions and Children’s Health: Table 1b. Odds Ratios (OR) from Reported Studies

<table>
<thead>
<tr>
<th>Risk Factors</th>
<th>Outcomes</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Asthma-Related</td>
</tr>
<tr>
<td>Aromatic VOCs</td>
<td>OR = 1.2*-10*</td>
</tr>
<tr>
<td></td>
<td>(1.2*, 1.3*, 2.4*, 6.4*, 8.0*, 10*, 10*)</td>
</tr>
<tr>
<td>Non-aromatic VOCs</td>
<td>OR = 8.1*–16*</td>
</tr>
<tr>
<td></td>
<td>(8.1*, 9.6*, 13*, 16*)</td>
</tr>
</tbody>
</table>

**KEY:** RANGE of ORs (specific reported ORs)  
* p-value <0.05
Indoor Chemical Emissions and Children’s Health: Available Findings

- Many specific risk factor/health outcome associations only single findings
- Most frequently identified risk factors:
  - Formaldehyde or particleboard
  - Plasticizers or plastic materials
  - Recent painting
- Selected single findings of interest
  - Aliphatic hydrocarbons (unclear interpretation)
  - Aromatic compounds (~ETS, vehicle emission?)
Indoor Chemical Emissions and Children’s Health: Specific Available Findings

- **Risk factor**
  - Higher formaldehyde concentrations (>20, 22, 30, 36, 60, 61, 73 µg/m³) or presence of particleboard

- **→ increased**
  - diagnosed asthma (3 studies)
  - diagnosed chronic bronchitis (1 study)
  - exhaled nitric oxide (1 study)
  - wheeze, presence or frequency (2 studies)
  - respiratory symptoms (1 study; not in 2)
  - adverse changes in lung function (2 studies; not in 1)
  - atopy or allergy (2 studies)
Indoor Chemical Emissions and Children’s Health: Specific Available Findings

- **Example findings for formaldehyde**
  - Emergency treatment for asthma increased by 39% at formaldehyde concentrations >60 µg/m³, or by an estimated 3% per 10 µg/m³ increase over the observed range (Rumchev 2002)
  - Proportion of diagnosed asthmatic children, in categories of peak indoor formaldehyde of <20, 20-50, and >50 µg/m³, were 16%, 39%, and 44%, but p>0.05 (Garrett 1999)
Indoor Chemical Emissions and Children’s Health: Specific Available Findings

- **Risk factor**
  - Higher phthalate dust concentrations (BBzP $>0.25$ mg/g, DEHP $>0.13$ mg/g) or presence of plastic surfaces

- **Increased**
  - diagnosed asthma (ns, 2 studies)
  - bronchial obstruction (1 study)
  - wheeze (2 studies; not in 1)
  - cough (1 study)
  - phlegm (1 study)
  - allergy (2 studies)
  - rhinitis (1 study)
  - eczema (1 study)

BBzP = n-butyl benzyl phthalate
DEHP = diethyl hexyl phthalate
Indoor Chemical Emissions and Children’s Health: Specific Available Findings

- Risk factor
  - Recent painting or renovation
    - increased
      - wheeze (4 studies)
      - obstructive bronchitis (1 study)
      - pulmonary infection (1 study)
      - allergy (2 studies)
Indoor Chemical Emissions and Children’s Health: Specific Available Findings

- **Risk factor**
  - Higher concentrations of specific aliphatic hydrocarbon compounds (many intercorrelated)

- → increased
  - food-specific IgE (1 study)
    - (hexane, nonane, decane)
  - T-cell cytokine expression → Th2 (1 study)
    - (heptane, nonane, decane, dodecane)
Indoor Chemical Emissions and Children’s Health: Specific Available Findings

- Risk factor
  - Higher concentrations of specific aromatic compounds (many intercorrelated)
  
  → increased

  - diagnosed asthma (1 study)
    (benzene, toluene, dichlorobenzene, total aromatics)
  
  - food-specific IgE (1 study)
    (toluene, m,p-xylene, 4-ethyltoluene, chlorobenzene)
  
  - pulmonary infections (1 study)
    (benzene; styrene, not correlated with ETS)
# Indoor Chemical Emissions and Children’s Health: Available Findings

## Strong associations for indoor materials / activities

<table>
<thead>
<tr>
<th>Risk Factor</th>
<th>Age of Subjects</th>
<th>Outcome</th>
<th>Odds Ratio</th>
</tr>
</thead>
<tbody>
<tr>
<td>Recent painting of newborn’s room</td>
<td>6 wks</td>
<td>Pulmonary infections</td>
<td>5.6</td>
</tr>
<tr>
<td>Redecoration</td>
<td>up to age 2</td>
<td>Obstructive bronchitis</td>
<td>4.1</td>
</tr>
<tr>
<td>Plastic surfaces</td>
<td>up to age 2</td>
<td>Bronchial obstruction</td>
<td>2.9</td>
</tr>
</tbody>
</table>
### Indoor Chemical Emissions and Children’s Health: Available Findings

**Strong associations for indoor chemical concentrations**

<table>
<thead>
<tr>
<th>Risk Factor</th>
<th>Age of Subjects</th>
<th>Outcome</th>
<th>Odds Ratio</th>
</tr>
</thead>
</table>
| **Formaldehyde**  
(> 75 µg/m³)       | 6-15 yrs         | Chronic bronchitis | 8 |
| **Decane**  
(> 5.7 µg/m³)     | 3 yrs            | Increased IgE, milk | 9.6 |
|              | 3 yrs            | Reduced IFN-γ producing T-cells | 22.8 |
| **Benzene**  
(above median)   | 6 mo-3 yrs       | Diagnosed asthma | 8 |
| **DEHP in dust**  
(top quartile)    | 1-6 yrs          | Diagnosed asthma | 2.9 |
Indoor Chemical Emissions and Children’s Health: Available Findings

- Example study of strong design:

- Nested case control study in infants 0-2 years old -- development of bronchial obstruction, w/excellent case ascertainment + validation

- Standardized environmental assessment
  - a priori index of child exposure to plasticizer emissions from indoor surfaces
  - ventilation measurements w/passive tracers

- Rigorous analysis adjusting for many confounders
Results (Oie et al. 1999 and Jaakkola et al. 1999)

- Plasticizer exposure index had dose-response relationship with risk of bronchial obstruction
  - Categorical (below median, 3rd quartile, 4th quartile)
    ORs = 1.0, 1.34, 2.70*
  - Continuous (per unit increase on 1-8 scale)
    OR = 1.65*
  - For PVC flooring, OR=1.90*
  - For PVC wallpaper, OR=0.72

- Risk of plasticizer exposure increased in homes with low ventilation rate (to be described)
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Indoor Chemical Emissions and Children’s Health: Ventilation as modifier of risks from indoor sources

- Risks from sources of indoor chemical emissions expected to increase at lower ventilation rates, because indoor concentrations would increase.
Indoor Chemical Emissions and Children’s Health:

Modeled indoor air concentration of a chemical compound as ventilation rate varies, for different emission strengths (H. Levin)

![Graph showing modeled indoor air concentration for different emission strengths (EF) and ventilation rates (ach). The graph demonstrates how concentration decreases as ventilation rate increases.]
Indoor Chemical Emissions and Children’s Health: Ventilation as modifier of risks from indoor sources

- Oie et al (1999) found the risk of bronchial obstruction in infants associated with indoor plasticizer-emitting materials was greatly increased in homes with low ventilation rates (less than 0.5 / hour)
Indoor Sources as Risks for Bronchial Obstruction in Infants, and Risk Modification by Residential Ventilation Rate (Oie et al. 1999)

- Plasticizer Exposure Index
  - Low ventilation: 12.6
  - High ventilation: 2.6

- Dampness
  - Low ventilation: 9.6
  - High ventilation: 2.3
Indoor Chemical Emissions and Children’s Health: Ventilation as modifier of risks from indoor sources

- Home ventilation rates decreasing over time, as newer houses built more tightly and older houses tightened, to save energy.
- Thus, average exposures from even unchanging sources likely to continue increasing over time.
Evidence that Houses are Becoming More Air Tight: U.S. Houses 1910-1990*

* WR Chan et al, 2005
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Indoor Chemical Emissions and Children’s Health: Evaluation 1

Explanation of findings?

- Causal relationships with studied risk factors ??
- Strong correlation with unmeasured causal indoor exposures
- Confounding by non-indoor factors (SES . . . ?)
- Reporting bias on activities/materials (only for subjective reports in retrospective or cross-sect)
- Systematic measurement error
- Chance findings among multiple comparisons
Indoor Chemical Emissions and Children’s Health: Evaluation 2

- **Weaknesses**
  - All studies observational, with usual weaknesses
  - multiple findings for only a few specific relationships
  - Insufficient findings to distinguish causation/exacerbation
  - Associations with specific risks often not adjusted for other potentially correlated indoor chemical risks (e.g., benzene – ETS, vehicle emissions)

- **Strengths**
  - Many studies well-designed, without major flaws
  - Major common weakness = potential confounding by unmeasured indoor causal risk factors

- Difficult to identify alternative explanation not involving adverse effects by *some* indoor chemicals
Indoor Chemical Emissions and Children’s Health: Evaluation 3

- Most persuasive findings (multiple, consistent, absence of plausible correlated alternatives)
  1. Formaldehyde

- Next most persuasive findings
  2. Plastics and plasticizers
  3. New paint

- Other suggestive findings
  - Aliphatic hydrocarbons (or correlated exposure)
  - Dichlorobenzene (no strong correlates)
Indoor Chemical Emissions and Children’s Health: Evaluation 3

- **Example mechanisms**
  - Respiratory tract inflammation (e.g., phthalates may have prostaglandin-like activity)
  - Increased sensitization, non-inflammatory
  - Direct effects on developing immune system (Th2 vs. Th1)
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Indoor Chemical Emissions and Children’s Health: Existing Conditions vs. Risks

**Formaldehyde**

<table>
<thead>
<tr>
<th>Study</th>
<th>Concentrations in air (µg/m³)</th>
<th>Median</th>
<th>Mean</th>
<th>Max</th>
</tr>
</thead>
<tbody>
<tr>
<td>Existing conditions:</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Garrett 1999</td>
<td>16</td>
<td></td>
<td></td>
<td>139</td>
</tr>
<tr>
<td>Venn 2003</td>
<td>22</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Krzyzanowski 1990</td>
<td>32</td>
<td></td>
<td>175</td>
<td></td>
</tr>
<tr>
<td>Rumchev 2002</td>
<td>30</td>
<td></td>
<td>224</td>
<td></td>
</tr>
<tr>
<td>Quackenboss 1989</td>
<td>35</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Risks reported:</td>
<td>&gt; 20, 22, 30, 36, 60, 61, 73</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
### Indoor Chemical Emissions and Children’s Health: Existing Conditions vs. Risks

#### Phthalates

<table>
<thead>
<tr>
<th>Phthalates*</th>
<th>Concentrations in dust (mg/g dust)</th>
<th>Median</th>
<th>90th %</th>
<th>Max</th>
</tr>
</thead>
<tbody>
<tr>
<td>BBzP*</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Existing conditions:</td>
<td></td>
<td>0.04</td>
<td>0.28</td>
<td>1.3</td>
</tr>
<tr>
<td>Risk reported:**</td>
<td></td>
<td><strong>&gt;0.25</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>DEHP*</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Existing conditions:</td>
<td></td>
<td>0.34</td>
<td>0.85</td>
<td>7.7</td>
</tr>
<tr>
<td>Risk reported:**</td>
<td></td>
<td><strong>&gt;0.13</strong></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

* Rudel 2003  
** Bornehag
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Indoor Chemical Emissions and Children’s Health: Implications

- Some common materials and emissions in modern homes associated with adverse respiratory and allergic health effects in infants and children
- Findings most persuasive for formaldehyde, strongly suggestive for plastics/plasticizers and new paint, and suggestive for other risk factors
- Use of these products likely to increase, and home ventilation rates likely to decrease over time, increasing exposures and any true adverse effects
- Causal connections, biologic mechanisms, and role of these risk factors in recent rise of asthma and allergies is uncertain
Indoor Chemical Emissions and Children’s Health: Implications

- These questions receiving no research attention in the U.S.
- Important to confirm or disprove
- If ubiquitous home exposures increase preventable, serious respiratory health effects in children, urgent need to –
  - identify causal exposures
  - quantify risks to motivate and guide policies or consumer choices
  - Identify preventive strategies