The Healthiness and Toxicity of Common Building Materials

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Based upon:
The Problem

World-wide
over 4,000,000 registered human-made chemicals
about 60-80,000 in common use
about 1,000 added every year

1945 – less than 10 million tons produced
‘now’ – over 110 million tons produced (about 10 years ago)

BUT
less than 2% tested for their effects on human health
more than 70% not tested at all
For 95% of chemicals used in construction products there are insufficient health assessments.

More new materials have been developed in the last 20 years than in the rest of history combined, with these making up about half of the materials in current use.
Recognition of problems with poor air quality since the World War Two

With increase of air-tightness of buildings since the 1970s, recognition of problems with insufficient air exchange and build-up of indoor toxicants

Recognition of Sick Building Syndrome in the early 1980s

Most people spend 80-93% of their time indoors

Materials are not alone in their negative contribution to indoor air quality, but are relevant

Research in this area has been developing since the World War Two, and especially in the last 20-30 years

Still, many consider that it is not keeping up with the needs for new knowledge in this area

This is problematic given the increases in modern diseases such as cancer, multiple allergy syndrome, allergies, asthma, autism, attention deficit disorder and similar
The Boiled Frog Syndrome: A frog jumps into a pot of water which is gradually being heated. As the water gets warmer, the frog adjusts its body temperature and continues to adjust to the increasing water temperature until, ultimately, the frog gets boiled alive.

(Thomas Saunders, *The Boiled Frog Syndrome*, 2002: 5)
Prudent avoidance or the precautionary principle:

‘Where there are threats of serious or irreversible damage, lack of full scientific certainty shall not be used as a reason for postponing cost-effective measures to prevent environmental degradation’ or in this case, human health

Good quasi-scientific sources
**First phase:**
On-going use, replacements, new materials and substances

**Second and third phase:**
VOCs, formaldehyde, vinyl and phthalate plasticisers

**Fourth phase:**
Lead and asbestos
First phase: Early recognition of risks

- More indications than complete assessments/proofs of adverse health effects;
- 1st generation risks, with the most obvious risks studied;
- Shorter term observations, e.g. studies that can be done in 1-2 years;
- Animal studies more than human subjects – problems of comparability with human bodies make conclusions difficult (especially for cognitive processes/behaviours);
- No proper longitudinal and prospective studies; and
- Often assessments of high level exposures, less work on long term low level exposures.
Second phase:
Beginning of regulation against a particular substance

- Stage of formalised acknowledgement that certain levels of the particular substance are harmful, and starting to limit exposure to these levels;
- Results of larger numbers of longitudinal and prospective studies become available;
- In addition to initially recognised risks, 1st generation risks, new 2nd generation risks are identified; and
- Regulated levels set higher than the subsequent ones.

Third phase:
Decrease seen in allowed levels over time

- More research results available, including results on both 1st and 2nd generation risks;
- Results from longitudinal and prospective studies start giving more evidence of the harmful mechanisms;
- For some substances 3rd generation risks are identified, often dealing with issues of much lower levels of exposure which can only be studied after the initial regulations have been set;
- The available research results are more conclusive; and
- Decrease in allowable levels regulated.
Fourth phase:
Ban on use of a particular substance

- Many conclusive results available for all three generations of risks;
- Results on lower levels of exposure becoming available;
- Enough factual information to ban the use of the particular substance;
- Limitations to existing knowledge are still observed, and more time needed for more complete understanding;
- Future of existing, built in materials under previous regulations is not dealt with by the ban; and
- Knowledge about the problem substance continues developing.
Phase 1
Observed health issues with a substance

Phase 2
Some efforts to limit its use

Phase 3
Increased regulation against it

Phase 4
Ban of the substance

Proto-phase 1
Development of a new substance to replace the eliminated

Proto-phase 2
Introduction of the new substance into use without much testing
Fourth phase: Lead and asbestos
Second and third phase: VOCs, formaldehyde, vinyl and phthalate plasticisers
First phase: On-going suspicion, replacement and new chemicals
Timeline of lead poisoning prevention policies and blood lead levels in children aged 1-5, by year, from National Health and Nutrition Examination Survey, United States, 1971-2008. Abbreviations: BLL = blood lead level; GM = geometric mean. (Source: Brown and Margolis 2012.)
Asbestos fibre types. Amphiboles (e.g., crocidolite, amosite, anthrocite, and others not shown) are straight, rod-like fibres, whereas serpentines (e.g., chrysotile) are curvilinear fibres. (Source: Liu, Cheresh and Kamp 2013.)
Aromatic compounds: benzene, toluene, ethylbenzene, xylenes, and styrene
Vinyl

Vinyl = polyvinyl chloride (PVC) + plasticisers (often phthalate plasticisers)

PVC was first invented in 1872, more actively used from 1926

In 1933 vinyl flooring was displayed at the Century of Progress Exposition in Chicago

Vinyl became commercially available after the World War Two
PVC produced through polymerisation of vinyl chloride monomer (VCM)

VCM is known human carcinogen, genotoxic, toxic for immune and cardiovascular systems, liver, and organ development

Manufacturing of PVC, its burning and final decomposition create dioxins (highly toxic and persistent environmental pollutants)

The Greenpeace group has advocated the complete, global phasing-out of PVC
Vinyl is the second largest plastic by volume in the world (after polyethylene (PE))

About 70% of PVC used in construction industry

Plasticised PVC (pPVC) – in flooring, wiring, wallpaper
Unplasticised PVC (uPVC) – in pipes, cladding

In 2011, some reductions were observed in the world consumption of PVC

Most of those were in developed countries

Asian countries contributed about 80% of world consumption of PVC in 2011
For indoor air quality, the most significant concern for vinyl are the phthalate plasticisers.

Phthalates are a group of aromatic chemicals containing a phenyl ring with two attached and extended acetate groups.

They are added to PVC (or other plastics) to increase their flexibility and transparency.

Because they are not part of the chain of polymers that make plastics, plasticisers can be slowly released from these products.

Phthalates can be 10-60% of final PVC products/ vinyl.

pPVC accounts for 80-90% of world plasticiser consumption.

Some reductions in use of phthalate plasticisers in recent years, but still China accounted for nearly 38% of their world consumption in 2012.
<table>
<thead>
<tr>
<th>Phthalate</th>
<th>Year of classification</th>
<th>Reason for inclusion</th>
<th>More specific reasons</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bis(2-ethylhexyl)phthalate (DEHP)</td>
<td>2008</td>
<td>Toxic for reproduction</td>
<td>May impair fertility; May cause harm to the unborn child</td>
</tr>
<tr>
<td>Dibutyl phthalate (DBP)</td>
<td>2008</td>
<td>Toxic for reproduction</td>
<td>May cause harm to the unborn child</td>
</tr>
<tr>
<td>Benzyl butyl phthalate (BBP)</td>
<td>2008</td>
<td>Toxic for reproduction</td>
<td>May cause harm to the unborn child</td>
</tr>
<tr>
<td>Diisobutyl phthalate (DIBP)</td>
<td>2009</td>
<td>Toxic for reproduction</td>
<td>May cause harm to the unborn child</td>
</tr>
<tr>
<td>Bis(2-methoxyethyl) phthalate</td>
<td>2011</td>
<td>Toxic for reproduction</td>
<td></td>
</tr>
<tr>
<td>n-pentyl-isopentylphthalate</td>
<td>2012</td>
<td>Toxic for reproduction</td>
<td>May impair fertility; May cause harm to the unborn child</td>
</tr>
<tr>
<td>Diisoentylphthalate (DIPP)</td>
<td>2012</td>
<td>Toxic for reproduction</td>
<td>May impair fertility; May cause harm to the unborn child</td>
</tr>
<tr>
<td>Diethyl phthalate (DPP)</td>
<td>2013</td>
<td>Toxic for reproduction</td>
<td></td>
</tr>
</tbody>
</table>

Based on: European Chemicals Agency (ECHA), 2013

The US Agency for Toxic Substances and Disease Registry (ATSDR) only lists 4 phthalate plasticisers
In 2005, European Union has banned use of all phthalates in toys that can be put into a baby’s mouth.

A similar regulation took effects in the US in 2009.
Di(2-ethylhexyl)phthlate (DEHP) is a short chain phthalate often found in older PVC products and most researched.

There is still limited epidemiological evidence related to phthalates.

In rats DEHP is an endocrine disruptor with antiandrogenic activity, suppressing testosterone-related processes.

Combination of phthalates (BPA, DEHP, and DBP) have been found to have increased impact in subsequent generations, suggesting that ancestral environmental exposures could be generating trans-generational inheritance of disease, often with adult onset.
75% of US population had phthalate or their metabolites in blood

95% of US population had phthalate or their metabolites in urine

Also found in semen, saliva, amniotic fluid, umbilical cord, blood, human milk, and baby formula

3-30µg/kg/day estimated current exposure levels of most humans
Studies of what happens in space have found:

A very small area/amount of pPVC emits almost as many phthalates as a large area, and this did not change with increased ventilation rates.

Once emitted into indoor air, phthalates settle into household dust, increasing exposure for children, especially toddlers.
In addition vinyl/PVC industry are very active in financing rebuttal of relevance of these issues

In 2013, the *Indoor Air* journal published in the same issue two articles on vinyl:

One, report on uptake of phthalates in babies exposed to vinyl flooring in bedrooms

The other industry rebuttal focused on procedural imperfections
Linoleum

Made by mixing oxidized linseed oil with resins from pine trees, wood flour, cork, and limestone fillers, with added pigments, pressed onto a backing.

When new, linoleum can continue to the process of oxidation of linseed oil, leading to persistent odours (due to release of various aldehydes).

Some linoleums were found to have very high emissions levels of acetaldehyde.

Farming of flax/linseed is associated with the use of environmentally persistent pesticides and run off of nutrients (eutrophication).

Research indicates that these problems could be avoided through development of industry which was neglected for decades: in mid the 1980s only three linoleum producers in the world operated.
Comparison of mean material health ratings for three general samples, compared to NZ architects ratings and 'I don't know' responses in general samples.

Means from general samples only (61 from NZ, 60 from US, 61 from UK)

Means from 65 NZ architects

Overall general mean 3.46

Overall NZ architects mean 3.05

Actual number 'I don't know' responses from general samples
Health ratings for vinyl and linoleum from the NZ general sample.

Health ratings for vinyl and linoleum from the NZ architects sample.

Health ratings for vinyl and linoleum from the US sample.

Health ratings for vinyl and linoleum from the UK sample.
Health ratings for vinyl and linoleum from practitioners

How often practitioners specify vinyl and linoleum

Health ratings for particleboard and MDF normal and low/zero formaldehyde from the NZ architects sample.

Health ratings for particleboard and MDF normal and low/zero formaldehyde from the US sample.

Health ratings for particleboard and MDF normal and low/zero formaldehyde from the UK sample.
First phase:
On-going suspicion, replacement and new chemicals

Table 3
Requirements by various labeling schemes for emissions (or test chamber concentrations) by building materials

<table>
<thead>
<tr>
<th></th>
<th>AgBB</th>
<th>CESAT</th>
<th>M1</th>
<th>LQAI</th>
<th>Natureplus</th>
<th>Blue Angel</th>
<th>Austrian Ecolabel</th>
<th>GUT</th>
<th>Emicode EC1</th>
</tr>
</thead>
<tbody>
<tr>
<td>TVOC</td>
<td>3d: 10000 µg m(^{-3})</td>
<td>3d: 5000 µg m(^{-3})</td>
<td>28d: 200 µg m(^{-2}) h(^{-1})</td>
<td>3d: 5000 µg m(^{-2}) h(^{-1})</td>
<td>28d: 200–500 µg m(^{-3})</td>
<td>3d: 1200 µg m(^{-3})</td>
<td>28d: 380 µg m(^{-2}) h(^{-1})</td>
<td>3d: 300 µg m(^{-3})</td>
<td>10d: 500 µg m(^{-3})</td>
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<tr>
<td></td>
<td>28d: 1000 µg m(^{-3})</td>
<td>28d: 200 µg m(^{-3})</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>28d: 10 µg m(^{-3})</td>
<td>28d: 50 µg m(^{-3})</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>HCHO</td>
<td>28d: 120 µg m(^{-3})</td>
<td>28d: 10 µg m(^{-3})</td>
<td>28d: 50 µg m(^{-3})</td>
<td>28d: 10 µg m(^{-3})</td>
<td>28d: 36 µg m(^{-3})</td>
<td>28d: 60 µg m(^{-3})</td>
<td>–</td>
<td>10 µg m(^{-3})</td>
<td>1d: 50 µg m(^{-3})</td>
</tr>
</tbody>
</table>

\(^a\) Also acetaldehyde should not exceed the same chamber concentration.

Emissions requirements (or test chamber concentrations) of leading European voluntary labelling schemes for carpet materials. (Source: Katsoyiannis, Leva and Kotzias 2009.)
<table>
<thead>
<tr>
<th>Substance Description</th>
<th>AU ACCS Max emiss. (24 hr)</th>
<th>NZ Env. Choice for synth. carpets</th>
<th>US green label plus Max emiss. (24 hr)</th>
<th>Classification by:</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>µg/h/m²</td>
<td>µg/m³</td>
<td>µg/h/m²</td>
<td>ECHA</td>
</tr>
<tr>
<td>Benzene C₆H₆</td>
<td>55</td>
<td>30</td>
<td>55</td>
<td>IARC</td>
</tr>
<tr>
<td>Formaldehyde CH₂O</td>
<td>10</td>
<td>16</td>
<td>16</td>
<td>CAL/OSHA</td>
</tr>
<tr>
<td>Toluene C₆H₅ – CH₃</td>
<td>280</td>
<td>150</td>
<td>280</td>
<td></td>
</tr>
<tr>
<td>Styrene C₆H₆</td>
<td>410</td>
<td>220</td>
<td>410</td>
<td></td>
</tr>
<tr>
<td>Acetaldehyde C₂H₄O</td>
<td>20</td>
<td>4.5</td>
<td>130</td>
<td></td>
</tr>
<tr>
<td>Vinyl Acetate C₄H₆O₂</td>
<td>400</td>
<td>100</td>
<td>190</td>
<td></td>
</tr>
<tr>
<td>Naphthalene C₁₀H₈</td>
<td>20</td>
<td>4.5</td>
<td>8.2</td>
<td></td>
</tr>
</tbody>
</table>

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<thead>
<tr>
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<td></td>
<td>µg/h/m²</td>
<td>µg/m³</td>
<td>µg/h/m²</td>
<td>ECHA</td>
</tr>
<tr>
<td>Caprolactam C₆H₁₁NO</td>
<td>120</td>
<td>100</td>
<td>130</td>
<td>IARC</td>
</tr>
<tr>
<td>1-Methyl-2-Pyrrolidone C₆H₈NO</td>
<td>300</td>
<td>160</td>
<td>300</td>
<td>CAL/OSHA</td>
</tr>
<tr>
<td>Nonanal C₉H₁₈O</td>
<td>24</td>
<td>13</td>
<td>24</td>
<td></td>
</tr>
<tr>
<td>Octanal C₈H₁₆O</td>
<td>24</td>
<td>7.2</td>
<td>13</td>
<td></td>
</tr>
<tr>
<td>2-Ethylhexanoic Acid C₈H₁₆O</td>
<td>46</td>
<td>25</td>
<td>46</td>
<td></td>
</tr>
<tr>
<td>4-Phenylcyclohexene C₁₂H₁₄</td>
<td>50</td>
<td>2.5</td>
<td>50</td>
<td></td>
</tr>
</tbody>
</table>

Based on: ECHA, IARC, CAL/OSHA 2013.
On-going use
4-Phenyloctyloxycyclohexene (4PCH)
2-Butoxyethanol

Replacements
For fire retardants change from polybrominated diphenyl ether (PBDE) to tris(1,3-dichloroisopropyl) phosphate (TDCPP) which is suspected human carcinogen

For phthalates, change from shorter chain phthalates such as DEHP to longer chain phthalates such as DINP, and non-phthalate plasticizers, all less researched

New materials and substances
Nanotechnology
Conclusions

Natural and less changed materials less likely to be harmful, but use them wisely

Many natural chemicals can negatively impact human health if used in un-natural proportions/distorted

Highly inert materials, such as aluminum, steel or glass, pose no health risks once installed, but should be evaluated for their total impact on the natural environment

More transparency on what is in the materials and products is needed

Testing prior to introduction on the market is needed, but uncommon

This is rapidly changing and there is much room for leadership