The health impact of poor IAQ & the need for holistic energy efficiency policies

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Disclaimer: Responsibility of the contents is the authors', contents does not represent the view of EAHC or EC
Reality checks: Housing in Europe

• 200 million residences, 700 million rooms, total floor area equal to Flanders
• Constructions, technologies and materials represent local histories, cultures, economies and ecologies of past 65 – 200 years
• Only 2…5 % of the residential building stock is replaced per year
• 300 000 Europeans share one room with 5 or more other occupants
• 5 million Europeans occupy 6 or more rooms only for themselves
• Country averages are meaningless for estimating the IAQ related health and welfare issues in any particular location
Time use of European adult urban populations in different environments through workdays

- Helsinki
- Athens
- Basel
- Oxford

Graphs show the percentage of time spent in various environments throughout the day for each city.
Hänninen et al., 2005
## European IAQ related health risk estimates in 3 recent assessments (DALY/100 000)

<table>
<thead>
<tr>
<th>Study Indoor Exposure</th>
<th>IAIAQ, 2011 (indoor)</th>
<th>EBoDE, 2013 (total exp)</th>
<th>WHO: EBD 2011 (inadeq housing)</th>
<th>note</th>
</tr>
</thead>
<tbody>
<tr>
<td>Countries</td>
<td>Eu-26</td>
<td>BeDeFiFrItNL(1)</td>
<td>Euro-45</td>
<td>1) representing EU-26</td>
</tr>
<tr>
<td>Fine PM</td>
<td>300</td>
<td>450 - 1000</td>
<td>80 (2)</td>
<td>2) indoor sources only</td>
</tr>
<tr>
<td>ETS</td>
<td>100 - 300(3)</td>
<td>60 - 120</td>
<td>81</td>
<td>3) with 2010 tobacco policies – without policies</td>
</tr>
<tr>
<td>Traffic noise</td>
<td></td>
<td>40 - 150</td>
<td>31</td>
<td></td>
</tr>
<tr>
<td>Lead</td>
<td></td>
<td>10 - 90</td>
<td>79</td>
<td></td>
</tr>
<tr>
<td>Damp &amp; Mould</td>
<td>50</td>
<td></td>
<td>38</td>
<td></td>
</tr>
<tr>
<td>Indoor cold</td>
<td></td>
<td></td>
<td>30 – 70 (4)</td>
<td>4) 11 European countries</td>
</tr>
<tr>
<td>Radon</td>
<td>34</td>
<td>45 - 110 (5)</td>
<td>25 (6)</td>
<td>5) discounted &amp; age adjusted 6) only Germany</td>
</tr>
<tr>
<td>Carbon monox</td>
<td>24</td>
<td></td>
<td>60 (7)</td>
<td>7) 28 European countries acute deaths only - underestimation</td>
</tr>
<tr>
<td>VOC</td>
<td>6</td>
<td>0.2 - 0.6 (8)</td>
<td></td>
<td>8) benzene and formaldehyde</td>
</tr>
</tbody>
</table>
A closer look at three different IAQ issues

• Contributions of indoor and outdoor sources to the overall IAQ burden of disease
• Roles of mechanical ventilation and air conditioning in exposure and risk
• Excess cold and heat – not just a comfort issue
IAQ associated DALY/million*a (2005) in 31 European countries, excl. ETS (total 2.2 MDALY/a)

Contribution of pollutants originating from outdoor air
Contribution of pollutants originating from indoor sources
A closer look at three different IAQ issues

• Contributions of indoor and outdoor sources to the overall IAQ burden of disease
• Roles of mechanical ventilation and air conditioning in exposure and risk
• Excess cold and heat – not just a comfort issue
Ventilation policy: PM$_{2.5}$ exposure reduction potential by post-1990 vs. pre-1990 building technology in Helsinki

A modest improvement in building envelope tightness and ventilation technology (to balanced mechanical) reduced population exposure by 20%.

Hänninen et al. JEA&EE 2005
During the cooling season:

In buildings with central AC, air is filtered, air exchange rate is low and population exposure to PM10 (and CVD incidence) is poorly related to outdoor air PM10 90% of time.

In buildings cooled via open windows, air exchange rate is high with no filtration and population exposure to PM10 is close to (and CVD incidence related to) outdoor air PM10.
A closer look at three different IAQ issues

- Contributions of indoor and outdoor sources to the overall IAQ burden of disease
- Roles of mechanical ventilation and air conditioning in exposure and risk
- Excess cold and heat – not just a comfort issue
Hot August 2003 & mortality

Excess daily mortality in 16 European Countries. June 1. to Sept. 30. 2003

Areal excess mortality distribution August 3.–16.

Age and gender distortion of the excess mortality, which increased with age and was 50% higher for females than males.

Daily mortality vs. outdoor T of people aged 65-74

Keating et al. BMJ 2000

- Physiologically people adapt only marginally to ambient temperature.
- Instead people adapt via housing, clothing and behaviour.
- No mortality response to outdoor cold in Northern Finland, but indoor heat increases mortality above 20°C outdoor T. Buildings are poorly designed for cooling.
- In Athens indoor cold increases mortality below 15°C outdoor T but heat only above 30°C. Buildings are poorly designed for heating.
Energy efficiency of buildings vs. IAQ

Energy efficiency ≠ GHG efficiency

• Some energy conservation measures improve some others deteriorate IAQ, yet some do both

• GHG efficiency of a city depends on:
  – energy efficiency of the buildings (kWh/m³/a),
  – total built volume (m³/cap),
  – urban structure & transport modes
  – efficiency of the heat and power generating and distributing systems (% losses), and
  – GHG emissions of the primary sources of energy (gCO₂/kWh)
Energy efficiency of buildings

Wasted/used energy
- Thermal leaks through building envelope
- Thermal loss via ventilation
- Electric power consumption

Conservation solution
- Tight/sealed building envelope and thick insulation
- Elimination of indoor sources
- Reduced air exchange
- Balanced mechanical ventilation with PM 2.5 and heat recovery from exhaust to intake air
- Natural ventilation, no air conditioning
- Maximum utilisation of passive solar heat

IAQ issue (+ -)
- Moisture may migrate through leaks, condense in the insulation and promote mold
- Improves IAQ with no sacrifice
- Increases risk of poor IAQ and dampness
- Ensures set air exchange rate, reduces outdoor pollution penetration
- Outdoor air pollution penetrates indoors, air exchange is insufficient and heat builds up during the warm season
- Excessive heat may result from spring to autumn

Neither the conservation nor the IAQ optima are the same across Europe!
Energy efficiency of buildings vs. IAQ
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  – efficiency of the heat and power generating and distributing systems (% losses), and
  – GHG emissions of the primary sources of energy (gCO$_2$/kWh)

*Two ongoing EU-RTD projects, URGENCHE and PURGE, are doing just this.*
Residential use of fuels and energy (toe/cap*a), central heat and power generation and total residential GHG contribution (CO$_2$/cap*a) in four EU countries

**Denmark**, 0.82 toe, 3.80 tCO$_2$/cap*a

**Austria**, 0.83 toe, 2.70 tCO$_2$/cap*a

**Czech Rep**, 0.57 toe, 2.41 tCO$_2$/cap*a

**France**, 0.94 toe, 1.96 tCO$_2$/cap*a

Data: OECD/IEA, 2009
My home town, Kuopio, FINLAND
Holistic view: in addition to the energy need of each building, the GHG impact of a city is determined by:

- **Sources of heat and power**
  - Sources of power for the national grid
    - Proportions of fuels, hydro, nuclear, wind, solar
  - Local heat and power cogeneration
    - Fuels, thermal power plant or industrial waste heat
  - Energy generated in buildings
    - Gas, fuel oil, coal/coke, wood/pellets, solar

- **Urban planning**
  - Total volume of the building stock
    - Increasing both transport distances and heat/power demand
  - Availability of solar heat for buildings in the winter and shading in the summer
  - District heating network
  - Urban density; commuting distances, routes and means
    - Transport fuel use, congestion, biking, walking, physical activity

Two ongoing EU-RTD projects, URGENCHE and PURGE, are doing just this.
# ETS: CVD impact of the 2005 public smoking ban in Rome

Cesaroni et al. Circulation 2008

## Results of Additional Adjusted Analyses and Subgroup Analyses of the Association Between the Italian Smoking Ban and Acute Coronary Events in 35- to 64-Year-Olds and 65- to 74-Year-Olds

<table>
<thead>
<tr>
<th></th>
<th>35–64 y</th>
<th></th>
<th>65–74 y</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>n</td>
<td>RR*</td>
<td>95% CI</td>
<td>n</td>
</tr>
<tr>
<td>All events</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Main analysis</td>
<td>2136</td>
<td>0.89</td>
<td>0.85–0.93</td>
<td>2126</td>
</tr>
<tr>
<td>Adjusted for time trend</td>
<td>2136</td>
<td>0.93</td>
<td>0.88–0.99</td>
<td>2126</td>
</tr>
<tr>
<td>Adjusted for all-cause hospitalization rates</td>
<td>2136</td>
<td>0.90</td>
<td>0.86–0.95</td>
<td>2126</td>
</tr>
<tr>
<td>Adjusted for time trends and all-cause hospitalization rates</td>
<td>2136</td>
<td>0.94</td>
<td>0.88–1.01</td>
<td>2126</td>
</tr>
<tr>
<td>By gender</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Only men</td>
<td>1712</td>
<td>0.88</td>
<td>0.84–0.93</td>
<td>1408</td>
</tr>
<tr>
<td>Only women</td>
<td>424</td>
<td>0.90</td>
<td>0.81–1.00</td>
<td>718</td>
</tr>
<tr>
<td>By socioeconomic position (quintiles)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1 (High)</td>
<td>340</td>
<td>0.92</td>
<td>0.82–1.03</td>
<td>342</td>
</tr>
<tr>
<td>2</td>
<td>383</td>
<td>0.90</td>
<td>0.81–1.01</td>
<td>388</td>
</tr>
<tr>
<td>3</td>
<td>408</td>
<td>0.88</td>
<td>0.79–0.98</td>
<td>465</td>
</tr>
<tr>
<td>4</td>
<td>470</td>
<td>0.90</td>
<td>0.81–0.99</td>
<td>417</td>
</tr>
<tr>
<td>5 (Low)</td>
<td>535</td>
<td>0.85</td>
<td>0.77–0.93</td>
<td>514</td>
</tr>
<tr>
<td>By type of event</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Out-of-hospital deaths</td>
<td>224</td>
<td>0.85</td>
<td>0.74–0.99</td>
<td>312</td>
</tr>
<tr>
<td>Hospital events</td>
<td>1912</td>
<td>0.89</td>
<td>0.85–0.94</td>
<td>1814</td>
</tr>
<tr>
<td>Only incident cases</td>
<td>1680</td>
<td>0.93</td>
<td>0.88–0.98</td>
<td>1528</td>
</tr>
</tbody>
</table>

*All rate ratios comparing 2005 vs 2000–2004 are adjusted for PM$_{10}$, flu epidemics, holidays, and apparent temperature.
Public health impact from ETS exposure with and without the 2010 public and workplace smoking bans (DALY/million*a)

Scaled to other countries from the results of Cesaroni et al. 2008 from Rome, Italy.
<table>
<thead>
<tr>
<th>Data quality range: good *** ... poor * nil ○</th>
<th>Indoor and common occupational sources for personal air pollution exposure [in addition to tobacco]</th>
<th>Significance for the highest individual exposures</th>
<th>Contribution for population air pollution exposure (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>PM$<em>{2.5}$ *** PM$</em>{10-2.5}$ ○</td>
<td>solid fuel combustion, candles</td>
<td>dominant</td>
</tr>
<tr>
<td></td>
<td>O$_3$ **</td>
<td>ozonators, electrostatic air cleaners, laser printers</td>
<td>rare or weak</td>
</tr>
<tr>
<td></td>
<td>NO$_2$ **</td>
<td>unvented gas appliances</td>
<td>significant</td>
</tr>
<tr>
<td></td>
<td>CO **</td>
<td>unvented, faulty and/or improperly operated combustion equipment</td>
<td>dominant</td>
</tr>
<tr>
<td></td>
<td>SO$_2$ ○</td>
<td>residential coal burning, paraffin heaters &amp; lamps</td>
<td>rare but dominant</td>
</tr>
<tr>
<td></td>
<td>C$_6$H$_6$ ***</td>
<td>Attached garages and solvents in some domestic chemicals</td>
<td>dominant</td>
</tr>
<tr>
<td></td>
<td>BaP * Naphth**</td>
<td>solid fuel combustion - naphthalene also in mothballs and coal tar based waterproofing</td>
<td>dominant rare but dominant</td>
</tr>
<tr>
<td></td>
<td>As ○, Cd ○, Ni ○, Pb*</td>
<td>some old paints &amp; accumulated dust</td>
<td>some</td>
</tr>
<tr>
<td></td>
<td>Hg ○</td>
<td>breaking thermometers and fluorescent tubes, amalgam fillings</td>
<td>high</td>
</tr>
</tbody>
</table>
The EnVIE concept, linking health impact to exposure, source and policy.
Daytime cooling in the summer in Europe is possible without refrigeration

- In the Mediterranean region cooling has been traditionally been carried out by building characteristics and occupant activities
  - Narrow building frame allows natural ventilation through all residences
  - Wide eaves shade the walls from high midday sun
  - Window shutters let through air but not sun or insects
  - Walls and floors made of heat buffering mineral materials
  - Shutters are kept closed on the sunny side of the building
  - From morning till evening the windows and are kept closed
  - Through the night the shutters are kept closed but windows open

This way the afternoon peak indoor temperature remains easily 5.. 8 °C below the peak outdoor temperature
Radon exposure and lung cancer cases estimated by relative risk model across Europe

Data from EU Radonmapping 2005 and Darby et al. 2006
Example of an EnVIE MT IAQ policy impact assessment: Radon and lung cancer in Finland

Policy reduces indoor Rn by 30%

Policy reduces lung cancer DALYs from exposure to indoor Rn by 30% = 80 #/a

Policy reduces total lung cancer DALYs by 80 #/a = 6%
IAQ associated BoD in DALY/a attributed to diseases – in total 2.2 MDALY/a, excluding ETS
IAQ associated BoD in DALY/a attributed to exposure agents

- Combustion particless
- Building dampness
- Bio-aerosols from outdoor air (seasonality)
- Radon
- Carbon monoxide
- VOCs

EUROPE-26

Combustion particless: 1,425,504
Building dampness: 224,414
Bio-aerosols from outdoor air (seasonality): 182,448
Radon: 173,248
Carbon monoxide: 122,169
VOCs: 27,776

Total: 1,425,504
IAQ associated BoD in DALY/a attributed to sources of exposure

EUROPE-26

- Ambient air quality: 1,447,541
- Heating and combustion equipment/appliances: 292,836
- Water systems, leaks, condensation: 224,414
- Building site (radon from soil): 173,248
- Furnishings, decoration materials and electrical appliances: 7,276
- Cleaning and other household products: 6,226
- Building materials: 40,176
Distribution of the public health benefits of IAQ policies within 31 European countries, (DALY/a*million)

- Radon safe construction
- Extract ventilation for kitchens, extract ventilation and waterproofed surfaces for bathrooms
- European protocols for IAQ testing & labelling for materials, equipment and products
- European moisture control guidelines to prevent persistent dampness and mould growth.
- Mandatory flues, CO detectors & regular maintenance/inspection for all combustion devices
- European health based ventilation guidelines to control pollution, moisture and temperature
- Regular inspection and maintenance for all ventilation and AC systems
- Tight building envelopes, balanced ventilation, air cleaning when AAQ below WHO AQG
- Documentation, operating, inspection and maintenance manuals for buildings and installations, & qualified and trained person with responsibility for building tasks
- Integrate IAQ into the EPBD procedure for buildings

DALY/million*a:  Min - 1st Quart - Med - 3rd Quart - Max

Min – 1st Quart – Med – 3rd Quart - Max
Estimated distribution of the total EU-27 population into households (1 ... 6 or more occupants), and residences (1 ... 6 or more rooms)

<table>
<thead>
<tr>
<th># of persons in residence</th>
<th>Estimated population division into households in the EU-27 residence stock</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>1 Room</td>
</tr>
<tr>
<td>1</td>
<td>10 000 000</td>
</tr>
<tr>
<td>2</td>
<td>3 300 000</td>
</tr>
<tr>
<td>3</td>
<td>1 100 000</td>
</tr>
<tr>
<td>4</td>
<td>810 000</td>
</tr>
<tr>
<td>5</td>
<td>320 000</td>
</tr>
<tr>
<td>6</td>
<td>130 000</td>
</tr>
<tr>
<td>Total</td>
<td>16 000 000</td>
</tr>
</tbody>
</table>

Half of the EU population lives in 2..4 person households occupying 3..5 room residences