Indoor environmental Quality related to comfort, health and productivity

Professor Bjarne W. Olesen, Ph.D.
Department of Civil Engineering

www.ie.dtu.dk

Technical University of Denmark
<table>
<thead>
<tr>
<th>Category</th>
<th>Cost</th>
</tr>
</thead>
<tbody>
<tr>
<td>People</td>
<td>100</td>
</tr>
<tr>
<td>Maintenance</td>
<td>10</td>
</tr>
<tr>
<td>Financing</td>
<td>10</td>
</tr>
<tr>
<td>Energy</td>
<td>1</td>
</tr>
</tbody>
</table>

COMFORT-PRODUCTIVITY

Building costs
Achieving Excellence in Indoor Environmental Quality

• Physical factors
  – Thermal Comfort
  – Air quality (ventilation)
  – Noise-Acoustic
  – Illumination

• Personal factors
  – Activity
  – Clothing
  – Adaptation
  – Expectation
  – Exposure time
INTAKE FOR A PERSON PER DAY

- 1 kg FOOD
- 2 kg LIQUID
- 15 kg AIR
Global impact on people

- In developing regions 5000 persons die per day due to poor IAQ
Hans Christian Andersen: The Princess on the Pea
Asthma and Allergy

In several industrial countries 50% of school children is suffering from Asthma or Allergy. This number has doubled within the last 20 years.
Odds ratio for being a “case”, i.e. children with at least two symptoms of possible three (wheezing, rhinitis, eczema) as a function of ventilation rates, in single family houses. (Bornehag et al., 2003).
Plasticizers from polyvinyl chloride in dwellings increase the risk of asthma among children.

Each column represents about 90 dwellings.

DEHP: di(2-ethylhexyl) phthalate.
PVC = Modern "Western" Lifestyle

- Furnitures
- Food package
- Cleaning products
- Cosmetics
- Toys
- Floor and walls
- Cables
- Paintings
STANDARDS

• ISO EN 7730-2005
  – Ergonomics of the thermal environment – Analytical determination and interpretation of thermal comfort using calculation of the PMV and PPD indices and local thermal comfort effects.

• ASHRAE 55-2004
  – Thermal environment conditions for human occupancy

• ASHRAE 62.1 and 62.2 -2004
  – Ventilation and indoor air quality

• CR 1752
  – Ventilation of buildings-Design criteria for the indoor environment

• EN 13779
  – Ventilation for non-residential buildings - performance requirements for ventilation and room-conditioning systems
EN15251
Indoor environmental input parameters for design and assessment of energy performance of buildings - addressing indoor air quality, thermal environment, lighting and acoustics
Temperature ranges for hourly calculation of cooling and heating energy in three categories of indoor environment

<table>
<thead>
<tr>
<th>Type of building/ space</th>
<th>Category</th>
<th>Operative Temperature for Energy Calculations °C</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Heating (winter season), ~ 1,0 clo</td>
<td>Cooling (summer season), ~ 0,5 clo</td>
</tr>
<tr>
<td>I</td>
<td>21,0 – 23,0</td>
<td>23,5 - 25,5</td>
</tr>
<tr>
<td>II</td>
<td>20,0 – 24,0</td>
<td>23,0 - 26,0</td>
</tr>
<tr>
<td>III</td>
<td>19,0 – 25,0</td>
<td>22,0 - 27,0</td>
</tr>
</tbody>
</table>

- Type I: Offices and spaces with similar activity (single offices, open plan offices, conference rooms, auditorium, cafeteria, restaurants, class rooms, Sedentary activity ~1,2 met)
- Type II: Offices and spaces with similar activity (single offices, open plan offices, conference rooms, auditorium, cafeteria, restaurants, class rooms, Sedentary activity ~1,2 met)
- Type III: Offices and spaces with similar activity (single offices, open plan offices, conference rooms, auditorium, cafeteria, restaurants, class rooms, Sedentary activity ~1,2 met)
PMV-values

Temperature (°C)

-1.5 -1.0 -0.5 0 0.5 1.0 1.5 2.0

Relative Performance

15 20 25 30 35

Composite weighted
Sample size weighted
Unweighted

from Seppänen and Fisk 2005a
Diagram based on studies with Danish subjects (Fanger et.al). Similar results obtained by North-American subjects (Cain et.al.) Similar results obtained with Japanese subjects (Tanabe)
Concept for calculation of design ventilation rate

Breathing Zone Outdoor Airflow

\[ V_{bz} = R_p P_z + R_s S_d + R_a A_z \]

- People Component:
  - Minimum l/s/Person
  - Number of People

- Building Component:
  - Ventilation per Smoker
  - Number of Smokers
  - Building Area

- Minimum l/s/m²
### Recommended ventilation rates for non-residential buildings for three categories (EN15251)

<table>
<thead>
<tr>
<th>Type of building or space</th>
<th>Category</th>
<th>Per person l/s,person</th>
<th>Per floor area l/s, m²</th>
<th>Per person l/s,person</th>
<th>Per floor area l/s, m²</th>
<th>Per person l/s,person</th>
<th>Per floor area l/s, m²</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Very low polluted building, revision</td>
<td>I</td>
<td>5,0</td>
<td>1,5</td>
<td>10,0</td>
<td>2,0</td>
<td>20,0</td>
<td>3,0</td>
</tr>
<tr>
<td></td>
<td>II</td>
<td>3,0</td>
<td>1,0</td>
<td>7,0</td>
<td>1,4</td>
<td>14,0</td>
<td>2,1</td>
</tr>
<tr>
<td></td>
<td>III</td>
<td>2,0</td>
<td>0,0</td>
<td>4,0</td>
<td>0,0</td>
<td>8,0</td>
<td>1,2</td>
</tr>
<tr>
<td>Low polluted building, revision</td>
<td>I</td>
<td>7,5</td>
<td>1,5</td>
<td>15,0</td>
<td>1,7</td>
<td>30,0</td>
<td>2,7</td>
</tr>
<tr>
<td></td>
<td>II</td>
<td>4,5</td>
<td>1,0</td>
<td>10,5</td>
<td>1,2</td>
<td>21,0</td>
<td>1,9</td>
</tr>
<tr>
<td></td>
<td>III</td>
<td>3,0</td>
<td>0,6</td>
<td>6,0</td>
<td>0,7</td>
<td>12,0</td>
<td>1,1</td>
</tr>
<tr>
<td>Non-low polluted building, revision</td>
<td>I</td>
<td>1,0</td>
<td>1,5</td>
<td>2,0</td>
<td>6,0</td>
<td>4,0</td>
<td>7,0</td>
</tr>
<tr>
<td></td>
<td>II</td>
<td>0,6</td>
<td>1,0</td>
<td>1,4</td>
<td>4,2</td>
<td>2,8</td>
<td>4,9</td>
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<tr>
<td></td>
<td>III</td>
<td>0,4</td>
<td>0,6</td>
<td>0,8</td>
<td>2,4</td>
<td>1,6</td>
<td>2,8</td>
</tr>
</tbody>
</table>
## Residential buildings

<table>
<thead>
<tr>
<th>Category</th>
<th>Air change rate $^1)$</th>
<th>Living room and bedrooms, mainly outdoor air flow</th>
<th>Exhaust air flow, l/s</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>l/s,m$^2$ (1)</td>
<td>ach</td>
<td>l/s, pers$^2)$ (2)</td>
</tr>
<tr>
<td>I</td>
<td>0.49</td>
<td>0.7</td>
<td>10</td>
</tr>
<tr>
<td>II</td>
<td>0.42</td>
<td>0.6</td>
<td>7</td>
</tr>
<tr>
<td>III</td>
<td>0.35</td>
<td>0.5</td>
<td>4</td>
</tr>
</tbody>
</table>
Ventilation vs performance

(R²=0.777; P=0.009)
The effect of the indoor environment on student performance
Performance of schoolwork as a function of classroom ventilation

Doubling ventilation rate ~14.5% higher performance

\[ R^2 = 0.59 \]
Indoor Environment in Schools

**CO₂-koncentrationer for hele landet (743 klasser, 320 skoler)**

- 385-1000 ppm (Acceptabelt niveau): 44%
- 1001-2000 ppm: 14%
- 2001-3000 ppm: 36%
- 3001-4000 ppm: 6%

**Temperaturer for hele landet**

- Start forsøg: n=740
- Slut forsøg: n=500
- Gennemsnit
Indoor Environment in Schools

- Balanced Ventilation
- Exhaust Ventilation
- Natural Ventilation

CO$_2$ Concentration

- Balanced Ventilation: n=223
- Exhaust Ventilation: n=133
- Natural Ventilation: n=380
Indoor Environment in Schools
Indoor Air Quality and Thermal Comfort in near Zero Energy Buildings

• Thermal Comfort
  – More uniform conditions (radiant asymmetry, vertical air temperature differences)
  – Less draught risk (reduced heat supply, no cold surfaces)
  – Less difference between air and operative temperature
  – Is individual room control important?
    » Comfort
    » Energy

• Indoor Air Quality
  – Tighter buildings
  – Cannot rely on infiltration
  – Can you heat with the ventilation system?
    » Air distribution
    » Ventilation effectiveness
    » Individual room control
Indoor Air Quality and Thermal Comfort in near Zero Energy Buildings

If an energy efficient measure also improve the indoor environment it will

• Lower Health Risk
• Increase Comfort
• Increase Productivity
• Always be cost efficient.