Standards for Ventilation, IAQ, and Thermal Comfort

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EVALUATION OF THE INDOOR ENVIRONMENT

• DESIGN LEVEL
• COMMISSIONING
• TESTING
• COMPLAINTS

INDOOR ENVIRONMENT

• THERMAL
• AIR QUALITY
• ACOUSTIC
• LIGHT

THERMAL ENVIRONMENT

• ISO EN 11399 Principles and application of international standards
• ISO EN 13731 Definitions, symbols and units
• ISO EN 7730 Moderate thermal environments: determination of PMV and PPD indices and specification of the conditions for thermal comfort.
• ISO EN 7730rev 1 Scope
• The purpose of this International Standard is to present a method for predicting the general thermal sensation and the degree of discomfort (thermal dissatisfaction) of people exposed to moderate thermal environments.
• to specify acceptable thermal environmental conditions for general and local thermal comfort
• ISO EN 13732 Definitions, symbols and units
• ISO EN 7730rev 2 Scope
• The International Standard applies to healthy men and women. The standard applies to people exposed to indoor environments where the aim is to attain thermal comfort, or indoor environments where moderate deviations from comfort occur.
• in extreme thermal environments other International Standards apply (ISO 7243, ISO 7933, ISO TR 11079)
• Deviations may occur for sick and disabled people (ISO TS 14415)
• ISO EN 13732 Part 1 Hot environments: estimation of the heat stress on working man, based on the WBGT index (wet bulb globe temperature)
• ISO EN 13732 Part 2 Moderate environments: determination of cold environments: determination of required clothing insulation (IREQ)
• ISO EN 13732 Part 3 Cold environments: estimation of the heat stress on working man, based on the WBGT index (wet bulb globe temperature)
• ISO EN 7243 Hot environments: estimation of the heat stress on working man, based on the WBGT index (wet bulb globe temperature)
• ISO EN 7933 Hot environments: analytical determination and interpretation of thermal stress using calculation of required sweat rate
• ISO EN 8996 Determination of metabolic rate
• ISO EN 9920 Estimation of the thermal insulation and evaporative resistance of a clothing ensemble
• ISO TR 11079 Evaluation of cold environments: determination of required clothing insulation (IREQ)
• ISO EN 10551 Assessment of the influence of the thermal environment using subjective judgement scales.
• ISO EN 10551-1 Measurement of the subjective sensation of thermal comfort using the thermal sensation scale
• ISO EN 10551-2 Measurement of the degree of discomfort (thermally of discomfort)
• ISO EN 10551-3 Measurement of the degree of discomfort (thermally of discomfort)
• ISO 9886 Evaluation of thermal strain by physiological measurements
• ISO TS 14415 Medical supervision of individuals exposed to extreme hot or cold environments
• ISO EN 14505 Method for the assessment of human responses to contact with surfaces
• Part 1 Hot surfaces
• Part 2 Moderate surfaces
• Part 3 Cold surfaces
• ISO DIS 12894 Medical supervision of individuals exposed to extreme hot or cold environments
• ISO NP 13732 Method for the assessment of human responses to contact with surfaces
• Part 1 Hot surfaces
• Part 2 Moderate surfaces
• Part 3 Cold surfaces
• ISO NP 15265 Risk of stress or discomfort in thermal working environments
• ISO/NP 14505 Evaluation of the thermal environment in vehicles
• ISO EN 7726 Instruments and methods for measuring physical quantities (under revision)
The present International Standard may be used in the design of new environments or in assessing existing ones.

The standard has been prepared for working environments but can be applied to any kind of environment.

In non-conditioned spaces ethnic and national-geographic deviations may occur.

**ISO EN 7730**

**MODERATE THERMAL ENVIRONMENT**

- ISO EN 7730 Moderate thermal environments: determination of PMV and PPD indices and specification of the conditions for thermal comfort.

- ASHRAE 55-92R Thermal environment conditions for human occupancy.

**MODERATE ENVIRONMENTS**

- **GENERAL THERMAL COMFORT**
  - PMV / PPD, OPERATIVE TEMPERATURE

- **LOCAL THERMAL DISCOMFORT**
  - Radiant temperature asymmetry
  - Draught
  - Vertical air temperature difference
  - Floor surface temperature

**GENERAL THERMAL COMFORT**

- Personal factors
  - Clothing
  - Activity

- Environmental factors
  - Air temperature
  - Mean radiant temperature
  - Air velocity
  - Humidity

**PMV-index**

-3 Cold
-2 Cool
-1 Slightly cool
0 Neutral
+1 Slightly warm
+2 Warm
+3 Hot
GENERAL THERMAL COMFORT

- OPERATIVE TEMPERATURE
  - -0.5 < PMV < +0.5 ; PPD < 10 %
- SPACES WITH MAINLY SEDENTARY OCCUPANTS:
  - SUMMER CLOTHING: 0.5 clo
  - ACTIVITY LEVEL: 1.2 met
- 23 °C < t < 26 °C.

THERMAL COMFORT

PPD = 100 - 0.05 * exp ( -0.03563 * PMV^3 - 0.2179 PMV^2 )

GENERAL THERMAL COMFORT

<table>
<thead>
<tr>
<th>Category</th>
<th>Thermal state of the body as a whole</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>PPD</td>
</tr>
<tr>
<td>A</td>
<td>&lt; 6</td>
</tr>
<tr>
<td>B</td>
<td>&lt; 10</td>
</tr>
<tr>
<td>C</td>
<td>&lt; 15</td>
</tr>
</tbody>
</table>

GENERAL THERMAL COMFORT

<table>
<thead>
<tr>
<th>Type of Building/Space</th>
<th>Category</th>
<th>Activity Level</th>
<th>Operational Temperature</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td>Cooling Season (clo)</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Heating Season (clo)</td>
</tr>
<tr>
<td>Office</td>
<td>A</td>
<td>1.0</td>
<td>24.5 ± 0.5</td>
</tr>
<tr>
<td></td>
<td>B</td>
<td>2.0</td>
<td>22.0 ± 0.5</td>
</tr>
<tr>
<td></td>
<td>C</td>
<td>3.0</td>
<td>20.0 ± 0.5</td>
</tr>
<tr>
<td>Commercial/Restaurant</td>
<td>A</td>
<td>1.4</td>
<td>21.5 ± 0.5</td>
</tr>
<tr>
<td></td>
<td>B</td>
<td>2.0</td>
<td>20.0 ± 0.5</td>
</tr>
<tr>
<td></td>
<td>C</td>
<td>3.0</td>
<td>19.0 ± 0.5</td>
</tr>
<tr>
<td>Department Store</td>
<td>A</td>
<td>1.4</td>
<td>20.5 ± 0.5</td>
</tr>
<tr>
<td></td>
<td>B</td>
<td>2.0</td>
<td>19.0 ± 0.5</td>
</tr>
<tr>
<td></td>
<td>C</td>
<td>3.0</td>
<td>17.0 ± 0.5</td>
</tr>
</tbody>
</table>

GENERAL THERMAL COMFORT

- HUMIDITY
  - Low humidity, eye irritation, skin dryness
  - High humidity, wettedness
  - Combined with perception of air quality

HUMIDITY

- Low humidity, eye irritation, skin dryness
- High humidity, wettedness
- Combined with perception of air quality

Maximum Recommended Upper Humidity Limit
Minimum Recommended Lower Humidity Limit
Humidity limits according to ASHRAE-55


GENERAL THERMAL COMFORT

• AIR VELOCITY
  - Preferred air velocity at increased temperature
  - Direction of air velocity
  - Large individual differences
  - Personal control (fans, windows)

ADAPTATION

• Behavioural
  - Clothing, activity, posture
• Psychological
  - Expectations

The following text can be found in ASHRAE Handbook 1936, Chapter 3:

"It should be kept in mind that southern people, with their more sluggish heat production and lack of adaptability, will demand a comfort zone several degrees higher than those given here for the more active people of northern climates."
Adaptation

- In determining the acceptable range of operative temperature from sec 4 to 6, a clo-value that correspond to the local clothing habits and climate shall be used.
- In warm or cold environments there may often be an influence of adaptation. Other forms of adaptation, than clothing, like body posture and decreased activity, which are difficult to quantify, may result in acceptance of higher indoor temperatures.
- People used to working and living in warm climates can more easily accept and maintain a higher work performance in hot environments than people from colder climates.
- Extended acceptable environments as given in Section 6 and Annex A may be applied for natural ventilated building and houses in warm areas. In this case it may be designed for higher PMV-values.

Non-steady thermal environments

- Temperature cycles
- Temperature drifts or ramps
- Transients

Temperature cycles
- Temperature cycles may occur due to the control of the temperature in a space. If the peak to peak variation is less than 1 K, there will be no influence on the comfort and the recommendations for steady state may be used. Higher peak variations may decrease comfort.

Temperature drifts or ramps
- If the rate of temperature change for drift or ramps are lower than 2.0 K per hour, the methods for steady state variation apply.

Transients
- In general the following statements regarding transients can be made:
  - A step-change of operative temperature is felt instantaneously.
  - After an up-step in temperature the new steady-state thermal sensation is experienced immediately, i.e. the PMV-PPD can be used to predict the comfort.
  - After a down-step in temperature the thermal sensation drops to a level cooler than the later steady-state sensation (in approx. 30 min.), i.e. the PMV-PPD predicts two high values the first 30 min.
LOCAL THERMAL DISCOMFORT

- FLOOR SURFACE TEMPERATURE
- VERTICAL AIR TEMPERATURE DIFFERENCE
- DRAUGHT
- RADIANT TEMPERATURE ASYMMETRY

LOCAL THERMAL COMFORT

<table>
<thead>
<tr>
<th>Draught Rate, DR</th>
<th>Vertical Air Temp. difference</th>
<th>Warm or Cool Floor</th>
<th>Radiant Temperature Asymmetry</th>
</tr>
</thead>
<tbody>
<tr>
<td>%</td>
<td>%</td>
<td>%</td>
<td>%</td>
</tr>
<tr>
<td>&lt;15</td>
<td>&lt;3</td>
<td>&lt;10</td>
<td>&lt;5</td>
</tr>
<tr>
<td>&lt;20</td>
<td>&lt;5</td>
<td>&lt;10</td>
<td>&lt;5</td>
</tr>
<tr>
<td>&lt;25</td>
<td>&lt;10</td>
<td>&lt;15</td>
<td>&lt;10</td>
</tr>
</tbody>
</table>

RADIANT TEMPERATURE ASYMMETRY

DRAUGHT

- DRAUGHT RATING, DR
- MEAN AIR VELOCITY
- TURBULENCE
- AIR TEMPERATURE

DR = (34.4v)(v>0.05)^1.5(0.37v Tu + 3.14)
VERTICAL AIR TEMPERATURE DIFFERENCE

- Local discomfort caused by vertical air temperature difference

<table>
<thead>
<tr>
<th>Category</th>
<th>Vertical temp. diff.</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>&lt; 2</td>
</tr>
<tr>
<td>B</td>
<td>&lt; 3</td>
</tr>
<tr>
<td>C</td>
<td>&lt; 4</td>
</tr>
</tbody>
</table>

VERTICAL AIR TEMPERATURE DIFFERENCE

FLOOR TEMPERATURE

- Difference Space - Floor K Standing vs. Sedentary

PERSONAL CONTROL

<table>
<thead>
<tr>
<th>Garment Description</th>
<th>Thermal Insulation clo</th>
<th>Change of Operative Temp. K</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sleeveless vest</td>
<td>0.12</td>
<td>0.8</td>
</tr>
<tr>
<td>Thin sweater</td>
<td>0.20</td>
<td>1.3</td>
</tr>
<tr>
<td>Light jacket</td>
<td>0.25</td>
<td>1.6</td>
</tr>
<tr>
<td>Normal jacket</td>
<td>0.35</td>
<td>2.2</td>
</tr>
</tbody>
</table>
VENTILATION AND IAQ STANDARDS OR GUIDELINES

- CR1752
- ASHRAE 62.1
- ASHRAE 62.2
- ISO/TC205 WG4

CEN TC156 Ventilation for Buildings

- CR 12782 Symbols, units and terminology
- prEN 13465 Residential ventilation - Simplified calculation method
- CR 1782 Design criteria for the indoor environment
  - Thermal, PMV-PPD, Different classes
  - IAQ, ventilation, health, comfort
  - Acoustic

VENTILATION

- COMFORT
- HEALTH

Ventilation Rate History

Office spaces...

TWO PATHWAYS

- Ventilation Rate Procedure
  - Prescriptively Based
  - Rates by Space Type
  - Equipment Requirements
  - 8-16 cfm/p

- Indoor Air Quality Procedure
  - Performance Based
  - Concentration Targets
  - Occupant Acceptability
  - Air Cleaning Allowed

Standard 62 Definitions:
What is "Acceptable IAQ"?

- Standard 62-1989: "Air in which there are no known contaminants at harmful concentrations as determined by cognizant authorities and with which a substantial majority (80% or more) of the people exposed do not express dissatisfaction."

- Standard 62R: "Air in an occupied space toward which a substantial majority of occupants express no dissatisfaction and in which there are not likely to be known contaminants at concentrations leading to exposures that pose a significant health risk."
**INDOOR CONTAMINANTS**

- People and their activity (smoking)
- Building
- Furnishing
- HVAC system
- Outdoor

**Perceived air quality**

**CO2 as reference**

\[ PD = 395 \times \exp (-0.15 \times C_{CO2}^{-0.8}) \]

**What about CO2?**

**CO2: The Great Misconception**

- CO2 is not a dangerous pollutant at levels found in non-industrial buildings
- CO2 cannot be used to accurately determine space ventilation rates
- CO2 is not a reliable indicator of acceptable indoor air quality
- CO2 at 1000 ppm is not a requirement of Standard 62-1989

**Required ventilation rate for smoking**

<table>
<thead>
<tr>
<th></th>
<th>Un-adapted (m³/cig)</th>
<th>Adapted (m³/cig)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Non-smokers</td>
<td>160</td>
<td>110</td>
</tr>
<tr>
<td>Smokers</td>
<td>40</td>
<td>30</td>
</tr>
</tbody>
</table>

**Required ventilation rate for smoking**

<table>
<thead>
<tr>
<th>Standard</th>
<th>Class</th>
<th>20% smoker</th>
<th>40% smoker</th>
<th>100% smoker</th>
</tr>
</thead>
<tbody>
<tr>
<td>CR1752</td>
<td>A</td>
<td>8</td>
<td>12</td>
<td>12</td>
</tr>
<tr>
<td></td>
<td>B</td>
<td>7</td>
<td>10</td>
<td>11</td>
</tr>
<tr>
<td></td>
<td>C</td>
<td>6</td>
<td>10</td>
<td>11</td>
</tr>
</tbody>
</table>
Possible Revised Ventilation Rate Procedure (from 62R)

People Component

<table>
<thead>
<tr>
<th>Design</th>
<th>Outdoor Air Ventilation Rate</th>
<th>Minimum l/s/Person</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Number of People</td>
</tr>
</tbody>
</table>

Building Component

<table>
<thead>
<tr>
<th>Design</th>
<th>Ventilation per Smoker</th>
<th>Minimum l/s/m²</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Number of Smokers</td>
<td>Building Area</td>
</tr>
</tbody>
</table>

DVR = RpPd + RsSd + RhAb

Minimum l/s/Person

Number of People

Minimum l/s/m²

Building Area

Analytical procedure

The required ventilation rate is calculated as:

\[ Q = \frac{G}{(C_i - C_o) E_v} \text{l/s} \]

where

- \( G \) = Total emission rate \( \text{mg/s} \)
- \( C_i \) = Concentration limit \( \text{mg/l} \)
- \( C_o \) = Concentration in outside air \( \text{mg/l} \)
- \( E_v \) = Ventilation effectiveness

DESIGN VENTILATION RATES

<table>
<thead>
<tr>
<th>Standard</th>
<th>Category</th>
<th>Required ventilation rate in office l/s Person</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>No smoker</td>
<td>20% smoker</td>
</tr>
<tr>
<td>CRI 1752</td>
<td>A</td>
<td>0.20</td>
</tr>
<tr>
<td></td>
<td>B</td>
<td>0.15</td>
</tr>
<tr>
<td></td>
<td>C</td>
<td>0.10</td>
</tr>
<tr>
<td>CR 2094</td>
<td>A</td>
<td>0.20</td>
</tr>
<tr>
<td></td>
<td>B</td>
<td>0.15</td>
</tr>
<tr>
<td></td>
<td>C</td>
<td>0.10</td>
</tr>
</tbody>
</table>

DESIGN VENTILATION RATES

<table>
<thead>
<tr>
<th>Standard</th>
<th>Class</th>
<th>Required ventilation l/s Person</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>No smoker</td>
<td>20% smoker</td>
</tr>
<tr>
<td>A</td>
<td>10</td>
<td>20</td>
</tr>
<tr>
<td>B</td>
<td>7</td>
<td>14</td>
</tr>
<tr>
<td>C</td>
<td>6</td>
<td>12</td>
</tr>
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<td>5</td>
<td>10</td>
</tr>
<tr>
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</table>

DESIGN VENTILATION RATES

<table>
<thead>
<tr>
<th>Standards</th>
<th>Room</th>
<th>Occupancy</th>
<th>Only People</th>
<th>STANDARD calculation</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Person</td>
<td>% of</td>
<td>%</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>A</td>
<td>B</td>
<td>C</td>
</tr>
<tr>
<td>CRI 1752</td>
<td>0.5</td>
<td>0.7</td>
<td>0.4</td>
<td>2.0</td>
</tr>
<tr>
<td>DEC 9094</td>
<td>Single office</td>
<td>1.0</td>
<td>0.7</td>
<td>0.4</td>
</tr>
<tr>
<td>ASHRAE 52</td>
<td>0.56</td>
<td>0.7</td>
<td>1.1</td>
<td></td>
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<tr>
<td>ASHRAE 62-89</td>
<td>Office</td>
<td>0.56</td>
<td>0.7</td>
<td>1.1</td>
</tr>
<tr>
<td>NKB-61 (91)</td>
<td></td>
<td>1.05</td>
<td>0.5</td>
<td></td>
</tr>
<tr>
<td>CIBSE-Guide A (new 93)</td>
<td>0.8</td>
<td></td>
<td></td>
<td></td>
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### DESIGN VENTILATION RATES

<table>
<thead>
<tr>
<th>Standards</th>
<th>Room Occupancy</th>
<th>Only People</th>
<th>STANDARD-calculation</th>
<th>30 % Smokers</th>
</tr>
</thead>
<tbody>
<tr>
<td>Class</td>
<td>Person/m²</td>
<td>l/s m²</td>
<td>l/s m²</td>
<td>l/s m²</td>
</tr>
<tr>
<td>prENV 1752</td>
<td>5.0</td>
<td>3.5</td>
<td>2.0</td>
<td>6.0</td>
</tr>
<tr>
<td>DIN 1946</td>
<td>0.5</td>
<td>4.2</td>
<td>2.4</td>
<td>1.0</td>
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<tr>
<td>ASHRAE 62 (rev.96)</td>
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<td>5.0</td>
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<tr>
<td>NKB-61 (91)</td>
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<td>10.0</td>
<td></td>
<td></td>
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<tr>
<td>CIBSE-Guide A (rev.93)</td>
<td>4.0</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>SUMMARY</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

- General agreement on standards for thermal comfort (ASHRAE, ISO, CEN)
- Need for more knowledge on Indoor Air Quality and Ventilation
- Sources like people, activity, building, HVAC-systems and outdoor air must be taken into account.
- Influence of sources like people and smoking is available
- More information is needed on sources like buildings and HVAC systems.
- Relation between contaminant concentration and health effect is needed

### Minimum requirements

- Operative temperature range for mainly sedentary people
  - Winter: 20 - 24 °C
  - Summer: 23 - 26 °C
- Heating systems should be dimensioned for 20 °C
- Cooling system should be dimensioned for 26 °C
- Ventilation systems should be dimensioned for 10 l/s/person
- Personal and individual room control is important

### Background

- Poor data on direct effects of air pollution on human performance in offices

Three independent studies were carried out at the International Centre for Indoor Environment and Energy in 1998 and 1999 studies were carried out at the International Centre for Indoor Environment and Energy in 1998 and 1999

### SUMMARY

Pollution source control and ventilation improve health, comfort and productivity

(www.ie.dtu.dk)
Diagnostic tests in schools

Mean Peformance index

Air-conditioning has had a well documented positive effect on productivity and economic growth in warm climates

Source: Myhrvold et al. (1996)

Large field studies show substantial rates of dissatisfaction in practice

(Mendell, 1993; Fisk et al., 1993; Bluyssen et al., 1994; Sundell, 1994; Sekhar et al., 2000; Bischhof 2000)

Sick Building Syndrome:

- irritation of eyes and nose
- headache
- fatigue

In typical office buildings

- 20-40% of occupants with SBS symptoms
- 20-40% of occupants finding the IAQ unacceptable even though existing ventilation standards are met.

Indoor Pollution Sources
Five independent studies have shown a significant impact of indoor air quality on office productivity.

High indoor air quality:

- reduce indoor pollution sources
- increase the ventilation rate

Methods: interventions

- Source present
  - 10 L/s/person
- Source absent
  - 3 L/s/person (0.6 h⁻¹)
  - 10 L/s/person (2 h⁻¹)
  - 30 L/s/person (6.0 h⁻¹)

Outdoor air rates:

Pollution sources:

Samples of a 20-year-old used carpet having size equal to the office floor area
Experimental set-up

Subjects & procedure

- 30 healthy females
- 20-31 years old
- performed simulated office work during 4.4 hours: occupation of the office:
  - text typing
  - arithmetical calculations
  - creative thinking

Methods: exposure office

- 90 female subjects
- 18-33 years old
- students
- not atopic

Methods: measurements

• Air quality: immediate rating of acceptability of air quality upon entering to the office

Methods: measurements

• SPS symptoms: marking visual analogue scales during exposure

Methods: measurements

• Performance: performing simulated office work during exposure

Methods: measurements

ACCEPTABILITY SCALE

- Clearly acceptable
- Just acceptable
- Just not acceptable
- Clearly not acceptable
Methods: performance

Subjects performed simulated office work:
- Text typing
- Proof-reading
- Arithmetical calculations
- Tests of knowledge and recall
- Tests of creativity

Results: air quality

Results: SBS symptoms

Results: performance

Source control works and pays!

Pettenkofer (1858):

“If there is a pile of manure in a space, do not try to remove the odor by ventilation. Remove the pile of manure.”
Total productivity

Perceived air quality

\[ R^2 = 0.763; P = 0.010 \]

Ventilation rate (L/s per person)

\[ R^2 = 0.777; P = 0.009 \]

Effects of ventilation on sick absence in offices

\[ (Milton et al., 2000) \]

\[ (P < 0.05) \]

Economics of improving IAQ from mediocre to high:

- Improved productivity \( \sim 5\% \)
- Cost \( -0.5\% \)
- Profit \( 4.5\% \)

Estimated Improvement in performance of office work

- 10% less dissatisfied with air quality = 1.1% increase in performance
- Halving pollution load = 1.6% increase in performance
- Doubling ventilation rate = 1.8% increase in performance

In a life cycle cost analysis of a building a lost annual productivity of 5% becomes completely dominating
Worker salaries vs building energy & maintenance costs

- Salaries/energy costs = 25-100
- Salaries/maintenance costs = 25-100
  

Empirical findings

- Net savings (due to decreased short-term sick leave) following increase of ventilation from 12 to 24 L/s per person are estimated to $400/year/employee ($22.8 billion/year nationally)

  Source: Milton et al. (2000)

Potential annual savings from changes in building factors (U.S. data):

- Infectious diseases - $6-$19 billion;
- Allergies and asthma - $1-$4 billion;
- Acute sick-building (SBS) health problems - $10-$20 billion;
- Direct impact of indoor environment on worker performance (unrelated to health) - $12-$125 billion.

  Total: $30-$170 billion
  German conditions: DEM 21-120 billion

Benefits vs costs of improving IAQ (U.S. data):

- Total benefits - $62.7 billion/year
  (productivity gains=$54.7 billion; health-related savings=$8 billion; acute respiratory diseases=$1.2 billion, building-related illness (e.g. humidifier fever)=0.8 billion; IAQ illnesses including SBS= $6 billion)

- Total costs - $87.9 billion (initial)

  (in 40% of US buildings regarded unhealthy)

  + 4.8 billion/year (maintenance)

  Pay-back time = 1.4 years
  German conditions: similar

Source: Fisk & Rosenfeld (1997)
Source: Dorgan et al. (1998)

Only 0.1 L/s per person or 1% is consumed, 99% is wasted!
Why not serve clean air directly to people?

Personalized Air (PA):
Small amount of clean air supplied directly and gently to a person’s breathing zone

Personalized Air
( PA )

Personalized Ventilation

- Office with ventilation rate 15 l/s per person
  temp = 23°C, RH = 30%
- Typical substantial office pollution load
- 6 workstations equipped with PV
- Individual control of location, direction and airflow rate
  0-15 l/s from PV
Experimental design

Mixing ventilation
23 °C
PV
23 °C
PV
20 °C

Human subjects

- 30 subjects
- groups of 6 subjects
- simulated office work
- 4 hours exposure

Well being

Headache

Ability to think

Dissatisfied

%-Dissatisfied

p < 0.03

p < 0.002
Impact of temperature and humidity on perceived air quality

Conclusions

- Poor air quality affects negatively productivity in offices.
- The present data document the economic benefits of providing indoor air of a higher quality than the minimum prescribed by the present ventilation standards.
Conclusions (contd)

- Measures used to reduce costs of owning and operating buildings can be counter-productive.

- Measures used to improve indoor environmental conditions can be highly cost-effective due to increased productivity and reduced health and comfort complaints.