Indoor environment and productivity in office environment

summary of the key contents of REHVA Guidebook no 6

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Federation of European Heating and Air-conditioning Associations (REHVA) = Professional organization with 28 member countries representing more than 100 000 HVAC experts in Europe
Procedure to include indoor environment in calculations is needed

• for engineering analysis to compare alternative technical systems
• to convince the employers to invest on better indoor environment
• to motivate building owners to invest on better indoor environment and
• to justify higher rents of high quality leased buildings
Economic calculations in design and operations stage should include:

- **Investment cost**: euros per occupant/employee
- **Operation cost**: including energy
- **Productivity and health benefits/decrements**
From improved building performance to benefits

Building design and operation

Indoor air quality

Human responses

Benefits

Value of the benefits
Economic benefits as a driving force for better IEQ

Owner occupied building

Investment

Better IEQ

Better productivity
   Improved performance
   Less sick leave
   Less complaints

Economic benefits
Simplified definition of productivity

\[
\text{Productivity} = \frac{\text{Output}}{\text{Input}}
\]
Productivity, building investment and cost

Productivity =

\[
\frac{\text{Work performance}}{\text{Investment and operational cost}}
\]
Factors affecting productivity

*(Clements-Croome 2000)*

**Social Environment**
- Relationships between people

**Organisation**
- Leadership
- Organisational structure

**Productivity**
- Work, career
- Home/work relationship
- Commitment to work

**Personal Characteristics**
- Indoor Environment

**Environment**
IAQ-factors with quantitative effect on productivity

• Ventilation and sick leave
• Ventilation and work performance
• Temperature and performance
• Perceived indoor air quality and task performance
• SBS-symptoms and performance
Ventilation rates affect

- Concentration of pollutants from indoor sources and outdoor sources
- Pollutants from air handling system itself
- Humidity etc.
- Perceived air quality
- Sick building syndrome symptoms
- Dryness etc.

What about objectively measured sick leave and performance?
Ventilation rates and sick leave
Relative risk for short term sick leave was 1.53 with lower estimated ventilation rate of 12 L/s compared with ventilation rate of 24 L/s.
Short term sick leave or illness inflicted by infectious diseases vs. ventilation rate (ach)
(Adapted to Wells-Riley-model)

- Drinka (1996), illness in nursing home
- Brundage (1988), illness in barracks, all years
- Particle concentration model
- Brundage (1988), illness in barracks, 1983 data
- Milton (2000), sick leave in offices

Relative sick leave days vs. Ventilation Rate (1/h)
Ventilation rates and performance
Meta analysis of studies on ventilation rate and performance

- six studies in office environment
- two studies in laboratory
- one in school
- some with multiple ventilation rates
Example of results from a laboratory study
(Wargocki et al. 2000)

Increase of ventilation rates 3, 10, 30 L/s per person improved performance of office tasks in simulated office environment.
Increase of performance (%) per in increase in ventilation rate of 10 L/s-person
Relative performance vs. ventilation rate in L/s-person in relation to 6.5 L/s-person

![Graph showing relative performance vs. ventilation rate](image)
With balancing of air ventilation rates to better IAQ and energy efficiency

An office building in Helsinki

Ventilation rate $l/s$, person

Minimum ventilation rate $10\ l/s$, person

Good ventilation rate $20\ l/s$, person

Room number

(Tuomainen ym. 2003)
Performance and perceived air quality (PAQ)

- Perceived air quality has been used close to hundred years as a criteria of air quality and ventilation rates – also in many standards
- PAQ is affected by pollutants, adaptation, ventilation and other environmental parameters (°C, RH)
- PAQ is used also as an indicator of air quality for performance
Performance in text-typing vs. perceived air quality in percentage of dissatisfied (PD%) - IAQ can be improved either by removal sources or by increasing ventilation rates.
Temperature and performance
Effects of Temperature

• **High temperature**
  – causes discomfort
  – increases heart attacks and mortality

• **Low temperature**
  – causes discomfort
  – decreases the dexterity of fingers

• **High temperature in the winter**
  – increases SBS-symptoms
  – deteriorated perceived indoor air quality
  – increases the complaint on dry air

What about performance?
Meta analysis of studies on temperature and performance in office work

(Seppänen, Fisk, Lei 2005)

• 24 studies with objectively measured performance and temperature – 148 data points

• All included studies were controlled for
  – work environment (ventilation, humidity, work load etc.)
  – clothing
  – personal factors
Change in performance in % per 1 °C increase in temperature

Seppanen et al. 2005
Relative performance vs. temperature compared to the maximum 95% confidence range 20-24 °C
APPLICATION OF THE PROCEDURE IN ENGINEERING ANALYSIS
Example 1
Feasibility of night-time ventilative cooling

Cool night time outdoor air is used to cool down the building during night

Fans use energy but day-time indoor temperature is reduced and work performance improved
Effect of night time ventilative cooling on room temperatures

Kolokotroni et al. 2001

Temperature, °C

00:00  06:00  12:00  18:00  00:00

Room air - no night time v.
Room surfaces - no night time v.
Outdoor air
Room air – with night time v.
Room surfaces – with night time v.
Data used in the analysis

Extra operation time of fans 10 h/night

- Power use 2.5 kW per m$^3$/s
- Cost of electricity 0.5 – 0.20 c/kWh
- Value of the work 25 €/h
- Effect of temperature on performance at office work
Effect on temperatures and lost work time

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<td><strong>Less lost work time, min per day</strong></td>
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<td>17.2</td>
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Cost effectiveness of night-time ventilative cooling

(4 ach, 8 h/night, 2.5 kW/m³s⁻¹)

<table>
<thead>
<tr>
<th>Cost of electricity</th>
<th>Use of electricity during night (8 h)</th>
<th>Additional cost of electricity</th>
<th>Increase in productivity, € 23.4-6.2 =17.2 min/d, 25 €/h</th>
<th>Benefit to cost ratio</th>
</tr>
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<tbody>
<tr>
<td>c/kWh</td>
<td>kWh/d</td>
<td>$/d</td>
<td></td>
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<tr>
<td>5</td>
<td>1.84</td>
<td>0.09</td>
<td>7.15</td>
<td>79</td>
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<td>10</td>
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<td>0.18</td>
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<td>40</td>
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<td>15</td>
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<td>0.28</td>
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<td>20</td>
<td>1.84</td>
<td>0.37</td>
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(REHVA Guidebook no 6, 2006)
Example 2

Cost effectiveness of air conditioning, extended operation time of ventilation, and increased supply air flow rate
Simulated case study

• **Building description**
  – concrete construction
  – private office of 15 m²
  – 2 m² window facing south
  – venetian blinds between the glazing

• **Basic case**
  – ventilation 2 L/sm²
  – no air conditioning
  – operation 10 h per day

• **Improved cases compared with IDA/ICE simulation program**
  – central cooling 20 W/m²
  – operation time 24 h per day
  – supply air flow rate 4 L/sm²
Costs and benefits of air conditioning and extended operation time

- Basic case: 2 L/sm², 10 h/d
- 20 W/m², 10 h/d
- 2 L/sm², 24 h/d
- 4 L/sm², 24 h/d
- 4 L/sm², 24 h/d, 20 W/m²
Example 3

Economizer System Evaluation = use more outdoor air and less return air when feasible
Economizer Systems
Modulate Outdoor Air (OA) Supply

Purpose
• reduce HVAC energy
• maintain minimum vent. rate

Method
• use outdoor air for cooling when less expensive than mechanical cooling

Usage in the USA
• common in large HVAC
• considered too expensive for small HVAC
Energy & Ventilation Rate Modeling

- 2000 m² office building in Washington, DC, VAV HVAC, with and w/o economizer
  - Used DOE 2 energy simulation model
  - Hourly ventilation rates for year
  - Energy use for year

Economic analyses

- energy cost savings from DOE-2 model
- apply absence - vent. rate model
- value of absence based on salary & benefits
Results
Estimated Annual Benefits of Economizer

<table>
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<tr>
<th>Minimum Vent Rate</th>
<th>Sick Leave Savings</th>
<th>Energy Cost Savings</th>
</tr>
</thead>
<tbody>
<tr>
<td>10 L/s per person</td>
<td>€0.9 - €1.1</td>
<td>€180 - €220</td>
</tr>
<tr>
<td>20 L/s per person</td>
<td>€0.4 - €0.5</td>
<td>€83 - €97</td>
</tr>
</tbody>
</table>

Estimated savings from reduced illness-related absence is 3 - 8 times energy cost savings.
Economic benefits as driving force
Leased building

- Higher market value of building
- Higher user satisfaction
- Building owner
- Investment
- Better IAQ
- Better productivity
- Less sick leave
- Less complaints
- Benefits to employer
- Higher rent
- Higher user satisfaction
- Higher market value of building

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Conclusion

• Value of productivity and health improvements should be included in the life cycle calculations
• These costs are significant, and in same order of magnitude or higher than the energy cost of buildings
• Most IAQ improvements are very cost effective when productivity and health benefits are included
• Qualitative data is not adequate between IAQ and human responses – more quantitative data is needed
Thank you for your attention

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