practical application of a new method for the assessment of comfort, health and productivity in offices

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development and assessment of a new method to evaluate IEQ (measured and perceived) in offices and its effects on occupants’ health, comfort and performance, in intervention studies in real buildings.

modern office building = “efficient machine”

- high insulated envelope
- airtight windows
- energy efficient services and appliances
- mechanical ventilation with heat recover
- indoor environmental control
- ...

low energy consumption to climatize and ventilate buildings
development and assessment of a new method to evaluate IEQ (measured and perceived) in offices and its effects on occupants’ health, comfort and performance, in intervention studies in real buildings.

people spend 90% of their time in enclosed spaces, 30-40% in offices.

Indoor Environment Quality (IEQ) affects occupants’ comfort, symptoms and performance.

building efficiency = low energy consumption + high IEQ
practical application of a new method for the assessment of comfort, health and productivity

overview

method reference models and development

assessment
- case-study
- experiment design
- tools

results
- sample
- standard conditions
- experimental conditions
- thermal environment
- IAQ
- SBS symptoms
- performance

conclusions + recommendations
- method’s advantages and limits
- implementation
measurements of environmental parameters (thermal parameters, IAQ, CO₂, lighting) and completion by occupants of on-line questionnaires and performance tasks

Remote Performance Measurement

- procedure to administer questionnaires and performance task over internet
- developed by the International Centre for Indoor Environment and Energy (ICIEE) in Denmark and tested in buildings in Denmark and Italy
- set of standard performance tasks (used in simulated offices) and two different questionnaires, used to characterize occupants’ perceptions and symptoms
  a. background questionnaire focuses on occupants’ general perception of the indoor environment (e.g. during the previous three months)
  b. instant questionnaire focuses on conditions “right now” used to assess the effects of an experimental intervention that modifies environmental conditions in the working space
**Method**

Reference models and development

### Reference Models

   - IEQ in offices and its effects on occupants’ performance (ICIEE, DTU Lyngby)
2. *ASHRAE (1986-98)*

### Procedure

- On-line questionnaire and performance tasks
- Use in simulated offices during laboratory experiments
- Simultaneous measurements of physical parameters and subjective responses
- Manual distribution of questionnaires
- On field experiments

### Tools

- General questionnaire:
  - Demographic survey
  - Subjective responses
  - Muscleskeleton conditions
  - SBS symptoms
  - Performance tests
- General and instant questionnaire:
  - Demographic survey
  - Subjective responses
- Mobile microclimatic station
- Permanent and mobile microclimatic station
  - Background and instant questionnaires
  - Performance tests

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**IMPLEMENTATION**

- On field experiments + simultaneous measurements of physical parameters and subjective responses
- Permanent and mobile microclimatic station + background and instant questionnaires

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05 PAOLA M. LEARDINI, JØRN TOFTUM  practical application of a new method for the assessment of comfort, health and productivity
assessment

- case-study
- experiment design
- tools

Permasteelisa Headquarters
S. Giacomo di Veglia, Vittorio Veneto (TV, Italy)
2003

typology: new building (2003), 3 stories
layout: single offices + open spaces

case-control
intervention study: 2 weeks set up + 5 weeks monitoring

practical application of a new method for the assessment of comfort, health and productivity
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 façade: NE and SW, double skin facade, ventilated from outside by means of micro fans (Interactive Wall®); NW and SE, lightweight concrete, plastered and painted white

interiors: floors covered with a wall-to-wall carpet of synthetic material; false ceiling made of plasterboard

Permasteelisa Headquarters
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2003

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assessment

- case-study
- experiment design
- tools

HVAC: neutral, dry air supplied by displacement ventilation + radiant ceiling providing heating and cooling

- radiant panels: plastic pipes embedded in the plasterboard, leading a constant flow of chilled/hot water
- displacement ventilation: 12 displacement wall-diffusers (0.25 m/s) along the central corridors; 5 air units for every floor of each building (A, B)
assessment

- case-study
- experiment design
- tools

1. physical parameters measurements:
   - mobile microclimatic station: measurements in 14 work places (10 bld A + 4 bld B)
   - 2 permanent microclimatic stations (1 bld A + 1 bld B)
   - HVAC system performance
   - CO₂ concentration (5 bld A + 5 bld B)

2. work environment assessment
   - background questionnaire: filled in once
   - instant questionnaire: filled in weekly

3. work performance assessment (weekly)
   - addition test
   - text typing test
   - short term memory test

Permasteelisa Headquarters
S. Giacomo di Veglia, Vittorio Veneto (TV, Italy)
2003

case-control intervention study

interventions on the HVAC system in order to obtain different and specific indoor climatic conditions

3 experimental conditions
2 standard condition (OT=23°C)
assessment

- case-study
- experiment design
- tools

physical parameters
measurements

mobile
microclimatic station

14 work stations
(10 bld A + 4 bld B)

cadence
weekly (Thursday)
interval
10.00 am - 1.00 pm
time x work station:
10 min (response time)
+ 3 min (measure)
position
3 heights
(+0.10, +0.60 e +1.1 m)

air temperature
mean radiant temperature
plan radiant temperature
radiant asymmetry
absolute humidity
dew point
air velocity
subjective work environment assessment

background questionnaire

32 questions (previous 3 months) on individuals, their health and their assessment of their own work environment

background characteristics (1-10)
health characteristics (11-15)
SBS symptoms frequency (16)
work area satisfaction (17-21)
personal control (22-25)
personal comfort (26-27)
environmental sensitivity (28-32)

cadence
one session (week preceding measurements)
access
on-line
compilation time
10 min

HEALTH CHARACTERISTICS
(16) During the LAST THREE MONTHS have you had any (one or more) of the following symptoms? (Please, answer every question even if you have not had any symptoms)

<table>
<thead>
<tr>
<th>Symptom</th>
<th>No, never</th>
<th>Yes, sometimes</th>
<th>Yes often (every week)</th>
<th>Yes, daily</th>
</tr>
</thead>
<tbody>
<tr>
<td>a. Fatigue</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

If "YES", do you believe that it is due to the environmental conditions at your workplace?

<table>
<thead>
<tr>
<th>Condition at workplace</th>
<th>No, never</th>
<th>Yes, sometimes</th>
<th>Yes often (every week)</th>
<th>Yes, daily</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

PAOLA M. LEARDINI, JØRN TOFTUM practical application of a new method for the assessment of comfort, health and productivity
**Personal Comfort**

1. Please rate your overall thermal sensation
   (Tick the scale below at the location that best represents how you feel at this moment)

   - Hot
   - Warm
   - Slightly warm
   - Neutral
   - Slightly cool
   - Cool
   - Cold

2. Please state how you would prefer to be now:
   - Warmer
   - No change
   - Cooler

3. How do you assess the thermal environment in your office?
   - Acceptable
   - Unacceptable

If "Yes" please mark with (+) for warm and (-) for cold

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**Subjective Work Environment Assessment**

- **Case-study**
- **Experiment Design**
- **Tools**

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**Instant Questionnaire**

27 questions (condition "right now")
- personal comfort (1-10)
- visual comfort (10-19)
- IAQ (20-21)
- acoustic comfort (22)
- metabolic rate (23-24)
- clothing resistance (25)
- SBS symptoms intensity (26-27)
- self assessment (27)

on individuals, their comfort (thermal, lighting, acoustic), their health and their assessment of their own work environment

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**Practical Application of a New Method for the Assessment of Comfort, Health and Productivity**

- **Method**
  - Assessment
  - Case-study
  - Experiment Design
  - Tools

---

**Cadence**

- weekly (5 monitoring weeks)
- access
- on-line
- compilation time
- 10 min
work performance assessment

performance tasks

3 tasks simulating office work, to assess the performance using few, comparable parameters such as speed and accuracy

cadence weekly (5 monitoring weeks)
access on-line
compilation time 20 min

1. addition test
2. text typing test
3. short term memory test

<table>
<thead>
<tr>
<th>speed</th>
<th>No.Completed [additions/min]</th>
</tr>
</thead>
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<td>access</td>
<td>ActiveTimeOnPage</td>
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<tr>
<td>accuracy</td>
<td>errors [errors/total]</td>
</tr>
<tr>
<td>index</td>
<td>Correct [corrects/min]</td>
</tr>
</tbody>
</table>
Assessment

- Case-study
- Experiment design
- Tools

Performance tasks

- 3 tasks simulating office work, to assess the performance using few, comparable parameters such as speed and accuracy

- Cadence weekly (5 monitoring weeks)
- Access on-line
- Compilation time
- 20 min

1. Addition test
2. Text typing test
3. Short term memory test

<table>
<thead>
<tr>
<th>speed</th>
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</thead>
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</tr>
<tr>
<td>index</td>
<td>[ \frac{\text{LD}}{\text{pttp}} ] [errors/(chars/min)]</td>
</tr>
</tbody>
</table>
assessment

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work performance assessment

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cadence
weekly (5 monitoring weeks)
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20 min

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<table>
<thead>
<tr>
<th>speed</th>
<th>[\sum dt]</th>
<th>[total time]</th>
</tr>
</thead>
<tbody>
<tr>
<td>accuracy</td>
<td>[\frac{\text{errors}}{\sum \text{Trial}}]</td>
<td>[errors/total]</td>
</tr>
<tr>
<td>index</td>
<td>[\frac{\text{correct}}{\sum dt}]</td>
<td>[corrects/min]</td>
</tr>
</tbody>
</table>
results

- sample
  - standard conditions
  - experimental conditions
  - thermal environment
  - IAQ
  - SBS symptoms
  - performance

building A (case office)
- 55 individuals
- 80% technicians
- Italian native speakers
- avg 29 years old

building B (control office)
- 28 individuals
- 80% technicians
- Italian native speakers
- avg 28 years old

<table>
<thead>
<tr>
<th>building</th>
<th>gender</th>
<th>Bld A</th>
<th>Bld B</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>#</td>
<td>Avg age</td>
<td>#</td>
</tr>
<tr>
<td>female</td>
<td>10</td>
<td>28</td>
<td>3</td>
</tr>
<tr>
<td>male</td>
<td>45</td>
<td>30</td>
<td>25</td>
</tr>
<tr>
<td>tot</td>
<td>55</td>
<td>29</td>
<td>28</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>job</th>
<th>% tot</th>
<th>#</th>
<th>% tot</th>
<th>#</th>
</tr>
</thead>
<tbody>
<tr>
<td>administrative</td>
<td>1.82%</td>
<td>1</td>
<td>3.57%</td>
<td>1</td>
</tr>
<tr>
<td>management</td>
<td>7.27%</td>
<td>4</td>
<td>10.71%</td>
<td>3</td>
</tr>
<tr>
<td>technical</td>
<td>80.00%</td>
<td>44</td>
<td>82.14%</td>
<td>23</td>
</tr>
<tr>
<td>marketing</td>
<td>3.64%</td>
<td>2</td>
<td></td>
<td></td>
</tr>
<tr>
<td>develop. &amp; research</td>
<td>5.45%</td>
<td>3</td>
<td>3.57%</td>
<td>1</td>
</tr>
<tr>
<td>secretary</td>
<td>1.82%</td>
<td>1</td>
<td></td>
<td></td>
</tr>
<tr>
<td>tot</td>
<td>100.00%</td>
<td>55</td>
<td>100.00%</td>
<td>28</td>
</tr>
</tbody>
</table>

occupants' gender and job

<table>
<thead>
<tr>
<th>building</th>
<th>Allergy</th>
<th>Eczema</th>
<th>Vision</th>
<th>Smoker</th>
<th>Cigarettes</th>
<th>Fitness</th>
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<tr>
<td></td>
<td>good</td>
<td>average</td>
<td>bad</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Bld A</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>no</td>
<td>83.64%</td>
<td>92.73%</td>
<td>61.82%</td>
<td>76.36%</td>
<td>44.12%</td>
<td>50.00%</td>
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<tr>
<td>yes</td>
<td>16.36%</td>
<td>7.27%</td>
<td>38.18%</td>
<td>23.64%</td>
<td>33.33%</td>
<td>61.90%</td>
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<tr>
<td>tot</td>
<td></td>
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<td></td>
<td></td>
<td>40.00%</td>
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<tr>
<td>Bld B</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>no</td>
<td>78.57%</td>
<td>92.86%</td>
<td>50.00%</td>
<td>75.00%</td>
<td>47.62%</td>
<td>47.62%</td>
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<tr>
<td>yes</td>
<td>21.43%</td>
<td>7.14%</td>
<td>50.00%</td>
<td>25.00%</td>
<td>14.29%</td>
<td>85.71%</td>
</tr>
<tr>
<td>tot</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>39.29%</td>
</tr>
</tbody>
</table>

health conditions
results

- work area: acceptable for 68% of occupants
- work conditions: satisfactory for 33% of occupants
- thermal environment, personal control: absent for 65% of occupants - 87% unsatisfied

background questionnaire

subjective work environment assessment

practical application of a new method for the assessment of comfort, health and productivity
results

- sample
- standard conditions
- experimental conditions
  - thermal environment
  - IAQ
  - SBS symptoms
  - performance

physical parameters measurements

- low control of experimental conditions
- low variability between experimental conditions
- temperature and air flow rates according to standards

<table>
<thead>
<tr>
<th>Date</th>
<th>Week</th>
<th>Condition</th>
<th>Out. door T° (°C)</th>
<th>sky air inlet</th>
<th>Building A Air T° (°C)</th>
<th>Airflow rate (m³/h)</th>
<th>Airflow per person (m³/h)</th>
<th>Air T° (°C)</th>
<th>Cell Surf. T° (°C)</th>
<th>TMR</th>
<th>Op. T° (°C)</th>
<th>CO₂ open sp. (ppm)</th>
<th>CO₂ exh. air (ppm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1/7</td>
<td>1</td>
<td>standard</td>
<td>25.4</td>
<td>21.7</td>
<td>24.3</td>
<td>52</td>
<td>4294</td>
<td>78</td>
<td>23.8</td>
<td>19.2</td>
<td>22.3</td>
<td>23.1</td>
<td>434</td>
</tr>
<tr>
<td>9/7</td>
<td>2</td>
<td>cool air 20% panels on</td>
<td>25.9</td>
<td>22.1</td>
<td>26.2</td>
<td>48</td>
<td>4294</td>
<td>84</td>
<td>24.6</td>
<td>21.3</td>
<td>23.4</td>
<td>24.0</td>
<td>266</td>
</tr>
<tr>
<td>15/7</td>
<td>3</td>
<td>neutral air panels on</td>
<td>22.9</td>
<td>23.8</td>
<td>24.7</td>
<td>47</td>
<td>4294</td>
<td>88</td>
<td>23.5</td>
<td>18.8</td>
<td>21.8</td>
<td>22.6</td>
<td>380</td>
</tr>
<tr>
<td>22/7</td>
<td>4</td>
<td>neutral air panels on</td>
<td>29.6</td>
<td>25.5</td>
<td>26.8</td>
<td>44</td>
<td>2735</td>
<td>59</td>
<td>25.5</td>
<td>21.0</td>
<td>23.9</td>
<td>24.7</td>
<td>476</td>
</tr>
<tr>
<td>29/7</td>
<td>5</td>
<td>standard</td>
<td>23.1</td>
<td>19.5</td>
<td>24.6</td>
<td>31</td>
<td>4294</td>
<td>130</td>
<td>23.3</td>
<td>19.4</td>
<td>22.0</td>
<td>22.6</td>
<td>311</td>
</tr>
</tbody>
</table>

CONDITION 3: thermal neutrality + standard air flow rate
CONDITION 4: max operative temperature + reduced air flow rate
CONDITION 5: low operative temperature + max air flow rate

PAOLA M. LEARDINI, JØRN TOFTUM practical application of a new method for the assessment of comfort, health and productivity
results

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physical parameters measurements

comfort

PMV/PPD

- thermal conditions in the working area related to external climate
- climate zones: core cooler than perimeter
- comfort provided in 5 conditions:
  - summer indoor air temperature <26°C (UNI 10339-95)
  - -0.5<PMV>+0.5 and PPD<10% (ISO 7730-94)

air temperature: average value in different indoor climate zones (core and perimeter)

comparison between indoor temperatures: air temperature, mean radiant temperature and operative temperature

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physical parameters measurements

comfort
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- climate zones: core cooler than perimeter
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  - summer indoor air temperature <26°C (UNI 10339-95)
  - 0.5<PMV<0.5 and PPD<10% (ISO 7730-94)

---

PMV calc. bld. A

- Facade W
- core
- Facade E
- average

weeks
1 2 3 4 5

PAOLA M. LEARDINI, JØRN TOFTUM   practical application of a new method for the assessment of comfort, health and productivity
results

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physical parameters measurements

local discomfort

- vertical temperature difference $< 2^\circ\text{C}$
  PD $< 2\%$ (ISO 7730-2005)
- radiant asymmetry $< 5^\circ\text{C}$
  PD $< 1\%$ (ISO 7730-2005)
- air speed $< 0.1 \text{ m/s}$
  DR $< 15\%$

![Graphs showing air speed and draught risk (DR): average values in different indoor climate zones](image)
**results**

- sample
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---

**instant questionnaire**

**subjective assessment (ISO 10551-95)**

**thermal sensation**

- difference between thermal sensation and PMV (0.5 clo, 1.2 met)
- PMV calculation: real clothing thermal resistance (clo) and metabolic activity
- thermal neutrality: correlation thermal sensation/operative temperature

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**correlation thermal sensation/operative temperature**

thermal sensation and PMV in 5 experimental conditions

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instant questionnaire
subjective assessment (ISO 10551-95)
thermal preference and acceptability

thermal sensation expressed by participants consistent with the changes in indoor climate, the acceptance and the preferences regarding the thermal environment

thermal neutrality (OT=22.6°C)
slightly warm (OT=24.7°C)

<table>
<thead>
<tr>
<th>thermal environment</th>
<th>operative temperature 22.6°C</th>
<th>condition 3</th>
</tr>
</thead>
<tbody>
<tr>
<td>thermal neutrality</td>
<td>100.00%</td>
<td>Acceptable</td>
</tr>
<tr>
<td>slightly warm</td>
<td>18.75%</td>
<td>Unacceptable</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>thermal environment</th>
<th>operative temperature 24.7°C</th>
<th>condition 4</th>
</tr>
</thead>
<tbody>
<tr>
<td>thermal neutrality</td>
<td>50.00%</td>
<td>Unacceptable</td>
</tr>
<tr>
<td>slightly warm</td>
<td>18.75%</td>
<td>Acceptable</td>
</tr>
</tbody>
</table>
results

- sample
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- thermal environment

IAQ
- SBS symptoms
- performance

instant questionnaire

subjective assessment

Perceived Air Quality (PAQ):

- PAQ affected by air flow rate, air temperature and humidity

Visual Analogue Scale

- 20% di insoddisfatti

Not disturbing  Slightly disturbing  Moderately disturbing  Very disturbing

- 20.65% tobacco A
- 34.44% humans A
- 41.56% chemicals A
results

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NO significant differences among experimental conditions were demonstrated in terms of SBS symptoms (higher general feeling of malaise expressed by the participants of group A).

- SBS symptoms affected by:
  - building and furniture materials
  - IAQ, air flow rate
  - air temperature and humidity

instant questionnaire

subjective assessment

SBS + self-estimated performance

CONDITION 4

operative temperature 24.7°C + reduced air flow rate

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practical application of a new method for the assessment of comfort, health and productivity
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performance tasks

addition test (without calculator)

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>[\sum \text{ActiveTimeOnPage}]</td>
<td></td>
<td></td>
<td>[\sum \text{ActiveTimeOnPage}]</td>
<td></td>
</tr>
</tbody>
</table>

effect of indoor temperature

CONDITION 2+4
worse environmental conditions
= lower performance

CONDITION 3+5
better environmental conditions
= higher performance

\[\Delta T_a = -2.2^\circ C\]

speed = +3%
accuracy = -5%

\(\Delta T_a = -2.2^\circ C\)

speed = +3%
accuracy = -5%
results

- sample
- standard conditions
- experimental conditions
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- IAQ
- SBS symptoms

performance

performance tasks
short term memory test

speed

accuracy (% of error)

index

\[ \sum dt \] [total time]

\[ \sum \text{errors} \]/[errors/total]

\[ \sum \text{correct} \]/[corrects/min]

\[ \sum dt \] [corrects/min]

effect of indoor temperature relation to thermal sensation learning effect

\[ \text{CONDITION 3} \]
thermal neutrality

\[ \text{CONDITION 4} \]
slightly warm

max accuracy = 0.13% errors
min accuracy = 0.58% errors

practical application of a new method for the assessment of comfort, health and productivity
conclusion

- method’s advantages and limits
- implementation

- development, and first field application, of a new method to assess indoor environmental quality in office buildings, and its effects on occupants

- quantity and quality of the data collected and results found indicate the substantial effectiveness of the proposed method

- innovative aspects: on-line implementation and the simultaneous collecting of instrumental and subjective information

- research outcomes are unavoidably connected with the specific case-study: demonstration of the methodology rather than final documentation of IEQ effects on performance in practice

- confirmation of the effects of environmental conditions on occupants’ comfort, emerging from earlier laboratory studies

- effectiveness of questionnaires in collecting detailed information on personal judgment and of occupants’ perception of many different environmental factors

- field application of the method highlighted some inconsistencies and problems: suggestions for future application of the method are given…
recommendations

- method’s advantages and limits
- implementation

conclusions+recommendations

OBJECTIVES

preliminary site exploration

problems identification

background questionnaire

EXPERIMENT DESIGN

procedure

experimental intervention

tools

DATA COLLECTION

measure grid

measurements

transducer

internet

instant questionnaire

sample

DATA ANALYSIS

performance tasks

improvement

PAOLA M. LEARDINI, JØRN TOFTUM: practical application of a new method for the assessment of comfort, health and productivity
thank you
conclusion

method’s advantages and limits

implementation

advantages

- easy field application
- on-line access: flexibility
- simultaneous access for an unlimited number of subjects
- cheap (time and costs) procedure to collect and analyse data
- easy implementation and customization of tools
- effectiveness of questionnaires in collecting detailed information on personal judgment and of occupants’ perception of many different environmental factors
- simultaneous availability of (comparable) information on different environmental factors
- easy and repeatable performance tests

limits

- field application: less control than in simulated office environments (more difficult to obtain and maintain the desired experimental conditions)
- on-line access: excessive compilation time and number of repetitions
- limited opportunity of assisting and instructing occupants
- lack of performance tests’ sensitivity to environmental factors
- lack of exposure to environmental factors before the compilations