The thermal comfort impact on occupants’ working productivity loss in offices

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1. Introduction

• Influence of thermal comfort on humans’ health and productivity
• Research in the real conditions of two offices at the Faculty of Mechanical Engineering

Figure 1. Drawings of the office 1 (left) and office 2 (right)
2. Literature review

• The most important conclusions derived from relevant papers, researches and standards:

1) The allowed, higher, environmental parameters are still too high for offices in the summer period

2) The desired temperature is usually lower for 0.5°C from neutral temperature

3) In offices there is a little influence of floor and ceiling temperatures on local thermal comfort

4) There is a significant cultural impact on the feeling comfortable in indoors

5) The influence of thermal discomfort on working productivity in offices is on average about 10%
3. Fangers’ thermal heat-balance model

- PMV and PPD indices

\[ PPD = 100 - 95e^{-0.03353 \cdot PMV^4 - 0.2179 \cdot PMV^2} \]

<table>
<thead>
<tr>
<th>Scale</th>
<th>Subjective feeling of thermal comfort level</th>
</tr>
</thead>
<tbody>
<tr>
<td>+3</td>
<td>Hot</td>
</tr>
<tr>
<td>+2</td>
<td>Warm</td>
</tr>
<tr>
<td>+1</td>
<td>Slightly warm</td>
</tr>
<tr>
<td>0</td>
<td>Neutral</td>
</tr>
<tr>
<td>-1</td>
<td>Slightly cool</td>
</tr>
<tr>
<td>-2</td>
<td>Cool</td>
</tr>
<tr>
<td>-3</td>
<td>Cold</td>
</tr>
</tbody>
</table>

Table 1. Scale of thermal comfort
4. Description of the offices and climate conditions

- Position of the offices in relation to other premises
- Systems of heating and cooling in offices - HVAC
- Characteristics of interior surfaces of walls
- Measurements of the temperature and relative humidity of the external air were performed for the entire research period

Figure 2. Diagram of changing the average value of temperature and relative humidity of the outside air for the relevant period per day
5. Experimental measurements

1) The first scenario, so-called "Winter" scenario: 05.03. - 16.03. - radiator valves with thermostatic heads set to "5"

2) The second scenario, so-called "Transient" scenario: 19.03. - 30.03. - radiator valves with thermostatic heads adjusted to "3"

3) The third scenario, so-called "Summer" scenario: 28.05. - 01.06. - in the office 1 split system set to a temperature of 27 °C and the first fan speed

Figure 3. Position of measuring points in offices 1 (left) and 2 (right)
6. Statistical survey

• Collecting data by questionnaires
• The goal of collecting answers
• Surveyed areas:
  1) General information about the user of an office
  2) General thermal comfort
  3) Local thermal comfort
  4) Indoor air quality
  5) Light comfort
  6) Sound comfort
7. Results of survey – general thermal comfort

Figure 4. Summarized answers of the thermal comfort – male (left) and female (right) person in office 1
8. Results of survey – general thermal comfort

Figure 5. Summarized answers of the thermal comfort – male (left) and female (right) person in office 2
9. Results of survey – general thermal comfort

Figure 6. Influence of thermal comfort on the productivity of persons in the office 1
10. Results of survey – general thermal comfort

![Bar chart showing the results of a survey on general thermal comfort, with data categorized by percentage ranges and gender.]

<table>
<thead>
<tr>
<th>Percentage Range</th>
<th>Male Person</th>
<th>Female Person</th>
</tr>
</thead>
<tbody>
<tr>
<td>1% - 10%</td>
<td>5</td>
<td>11</td>
</tr>
<tr>
<td>11% - 20%</td>
<td>10</td>
<td>8</td>
</tr>
<tr>
<td>21% - 30%</td>
<td>5</td>
<td>1</td>
</tr>
<tr>
<td>31% - 40%</td>
<td>2</td>
<td>0</td>
</tr>
<tr>
<td>41% - 50%</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>51% - 60%</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>61% - 70%</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>71% - 80%</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>81% - 90%</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>91% - 100%</td>
<td>0</td>
<td>0</td>
</tr>
</tbody>
</table>

**Figure 7. Influence of thermal comfort on the productivity of persons in the office**
11. Results of survey – indoor air quality

Figure 8. Evaluation of the air quality of both persons in the office 1
12. Results of survey – indoor air quality

Figure 9. Evaluation of the air quality of both persons in the office 2
13. Numerical simulations

- Phoenix FLAIR software
- Computational fluid dynamics - CFD
- Determination of air temperature, radiant temperature, CO$_2$ concentration, PMV, PPD and PLOS indices

Figure 10. Models of office 1 (left) and office 2 (right) in Phoenix FLAIR software
14. Numerical simulations - results

Figure 11. PLOS index for office 1 (left) and office 2 (right) - 05. march
15. Numerical simulations - results

Figure 12. PMV index for office 1 (left) and office 2 (right) - 05. march
16. Numerical simulations - results

Figure 13. PPD index for office 1 (left) and office 2 (right) - 05. march
17. Numerical simulations - results

Figure 14. Temperature field for office 1 (left) and office 2 (right) - 05. march
18. Conclusion

- Comparison of the obtained results of the statistical and numerical part of the research

<table>
<thead>
<tr>
<th>Date</th>
<th>Survey</th>
<th>CFD simulation</th>
<th>Survey</th>
<th>CFD simulation</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Office 1</td>
<td></td>
<td>Office 2</td>
<td></td>
</tr>
<tr>
<td></td>
<td>M</td>
<td>W</td>
<td>Average PMV</td>
<td>M</td>
</tr>
<tr>
<td>05.03.</td>
<td>1</td>
<td>0</td>
<td>0.6</td>
<td>-1</td>
</tr>
<tr>
<td>08.03.</td>
<td>1</td>
<td>0</td>
<td>0.5</td>
<td>0</td>
</tr>
<tr>
<td>28.03.</td>
<td>2</td>
<td>0</td>
<td>0.7</td>
<td>1</td>
</tr>
<tr>
<td>30.05.</td>
<td>1</td>
<td>0</td>
<td>0.9</td>
<td>2</td>
</tr>
</tbody>
</table>

Table 2. Values of PMV index obtained from questionnaires and CFD simulations

- Experimental measurements of CO2 concentration – 1000 ppm
- Impact of office orientation
- Influence of a personal factor
Thank you for your attention!