Investigation of ceiling fans for improving summer thermal comfort

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Content

- The background
- Characterisation of a ceiling fan
- Test cell results
- Simulations
- User surveys
- Outlook
passive cooling by night ventilation is not sufficient to avoid temperature increase outside the comfort range
Misbalance between thermal charging and discharging

Monitoring results for a 3 storey office building with night ventilation in DE

- Ambient temperature
- Average 1st floor
- Average 2nd floor
- Average 3rd floor

<table>
<thead>
<tr>
<th>Date</th>
<th>Temperature (°C)</th>
</tr>
</thead>
<tbody>
<tr>
<td>21.07.</td>
<td>10</td>
</tr>
<tr>
<td>23.07.</td>
<td>15</td>
</tr>
<tr>
<td>25.07.</td>
<td>20</td>
</tr>
<tr>
<td>27.07.</td>
<td>25</td>
</tr>
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<td>29.07.</td>
<td>30</td>
</tr>
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<td>31.07.</td>
<td>35</td>
</tr>
<tr>
<td>02.08.</td>
<td>20</td>
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Findings

- **Passive Cooling by night ventilation** was found to be insufficient under high thermal stress due to **insufficient heat retraction** by free or forced ventilation. Air change rates are practically limited (size of openings, fire safety, electricity demand, …) and temperature differences are mostly small. Convective heat transfer is limited due to stable air temperature stratification.

- Melted phase change materials - **PCM** - as part of gypsum boards, plasters or suspended ceilings in light weight constructions were often **not re solidified during night** due to insufficient heat retraction. The storage capacity for the next day remains limited.

Outlook

- The predicted **climate change** increases the summer thermal stress and the cooling loads in the Mid European Buildings commercial building sector. Concepts for peak situations are needed for new but also for existing buildings.
The Concept - Cooling and improved discharging by air movement

- Ceiling fans are low speed, quiet devices with typical diameters of 100 to 150 cm with individual, remote speed control from the work space. Typical are AC motors but energy efficient DC motors are available today.

- The air temperature stratification in the room is reduced or fully exhausted during fan operation.

- At typical low speed, downdraft operation air movement near to the body is increased without additional thermal loads (e.g. by opening windows at high temperatures).

- Instead of increasing air change rates in the night ventilation mode of a building, automatic ceiling fan operation may improve the discharging of thermal mass or constructions containing PCM.
Day - Comfort

Air movement increases the heat loss of the human body by convection and evaporation.

Night – Heat Dissipation

Air movement increases the convective heat transfer from the ceiling to the air thereby increasing the efficiency of night ventilation.

\[ h_r = 5, \quad h_c = 0.7 \text{ W/m}^2\text{K (DIN EN ISO 6946)} \]

\[ h_r = 5, \quad h_c = ? \text{ W/m}^2\text{K} \]
The Test Cell - btga box
15 m² experimental test cell at Wuppertal University Campus

automatic window control

exhaust air fan

ceiling fan

axis for air velocity measurements

front

back

middle
Air velocity during daily fan operation

Flow directed downwards, 3 fan settings (high, med, low)

measured air velocity 60 cm (legs) above the floor ranges between 0.4 and 0.8 m/s

measured air velocity 110 cm (head) above the floor ranges between 0.5 and 1.3 m/s
Air velocity and summer thermal comfort
Comfort increase by air movement according to DIN EN ISO 7730

Increasing the air speed in the occupied zone ($V_a$) of a room to 0.5 m/s already raises the acceptable, upper temperature limit under high temperature conditions by 1.7 K.
Measured Power Consumption of a Ceiling Fan
Efficient DC - systems reduce the power consumption by about 50%

Type factory 4 WH
- brushless DC motor
- diameter 135 cm
- remote control
- 6 stages

![Ceiling Fan Image](http://www.deckenventilator.com/deckenventilator-factory-weiss-pjis-883.html?cPath=256)

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**power [W]**

- air flow direction
  - downwards
  - upwards
- night mode
- day mode

**fan power setting**

1 2 3 4 5 6
Air velocity during fan operation at night
Flow directed upwards to the ceiling, 3 fan setting (high, med, low)

Depending on the setting the max. air speed (75 cm from the center) 5 cm below the ceiling was detected to 1.1 to 1.5 m/s
Heat flow density analysis at the ceiling
Flow directed upwards to the ceiling, fan setting high and night ventilation with 3.4 ac/h
Major Findings

- Large differences in heat transfer (charging and discharging) between front and back of the room resulting from:
  - inlet air temperature and air warming by passing through the room
  - local differences in the thermal stratification
  - differences in radiative heat transfer with the floor, partly hidden by direct solar radiation

- Increase of heat transfer by the effect of the ceiling fan, mainly close to the façade and not directly at the fan position (warm air transferred to the relatively cold front section of the room)

- Much larger effects resulting from a tilted window compared to a supply air valve on the facade
Simulation Results – Trnsys **Single Zone** Modelling

Small visible effect but more detailed modelling required (CFD)

![Graph showing operative temperature over hours of the simulation year](image-url)
### User Survey

<table>
<thead>
<tr>
<th>Wie empfinden Sie im Augenblick die Temperatur an Ihrem Arbeitsplatz?</th>
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</thead>
<tbody>
<tr>
<td>☐ kalt  ☐ kühlig  ☐ etwas kühlig  ☐ neutral  ☐ etwas warm  ☐ warm  ☐ heiß</td>
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</table>

<table>
<thead>
<tr>
<th>Wenn Sie wählen könnten, wie wäre Ihnen im Augenblick die Temperatur lieber?</th>
</tr>
</thead>
<tbody>
<tr>
<td>☐ sehr viel kühlig  ☐ kühlig  ☐ weder noch  ☐ wärmer  ☐ sehr viel wärmer</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Verspüren Sie im Moment eine Luftbewegung?</th>
</tr>
</thead>
<tbody>
<tr>
<td>☐ gar nicht  ☐ sehr schwach  ☐ schwach  ☐ stark  ☐ sehr stark</td>
</tr>
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</table>

<table>
<thead>
<tr>
<th>Wenn Sie wählen könnten, wie wäre Ihnen im Augenblick die Luftbewegung lieber?</th>
</tr>
</thead>
<tbody>
<tr>
<td>☐ viel schwächer  ☐ schwächer  ☐ weder noch  ☐ stärker  ☐ viel stärker</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Wie bewerten Sie die Raumtemperatur in diesem Augenblick?</th>
</tr>
</thead>
<tbody>
<tr>
<td>☐ komfortabel  ☐ gerade noch komfortabel  ☐ gerade nicht mehr komfortabel  ☐ nicht komfortabel</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Wie fühlen Sie sich in Bezug auf die vorhandenen Kontrollmöglichkeiten der Temperatur?</th>
</tr>
</thead>
<tbody>
<tr>
<td>☐ ☐ ☐ ☐ ☐ ☐ ☐ ☐ ☐ ☐ ☐</td>
</tr>
<tr>
<td>völlig fremdbestimmt  völlig selbstbestimmt</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>ALS Sie heute morgen in Ihr Büro kamen, wie empfanden Sie die Raumtemperatur im Vergleich zu der erwarteten Raumtemperatur?</th>
</tr>
</thead>
<tbody>
<tr>
<td>☐ sehr viel kälter  ☐ etwas kälter  ☐ so wie erwartet  ☐ etwas wärmer  ☐ sehr viel wärmer</td>
</tr>
</tbody>
</table>
User Survey – Test Cell Conditions with Occupants

Histogram of difference between perceived and preferred air speeds. A value of 0 signifies that perceived and preferred air speeds coincide. Positive values stand for higher preferred air speeds than the currently perceived ones.
Histogram of air speeds measured during field studies in the summer of 2011 for which occupants reported no preferred change of the air velocity. In 105 of 132 cases changes were not preferred.
Conclusions

- Ceiling fans were found to be a promising option to handle the summer thermal peaks. Main advantages are based on day time usage:
  - local, individual control and immediate effect related to air movement at the work place
  - easy understandable (high user acceptance !)
  - decentralised applications in rooms with thermal comfort problems especially in existing buildings

- Night ventilation efficiency increases but optimization is needed to justify fan power consumption in relation to the thermal effect (COP). Operation with tilted windows is preferred compared to façade integrated supply air valves (flow rate, supply air temperature).

- Single zone modelling was found not to be sufficient to describe and understand the results in full detail. CFD modelling is required.
Outlook

- Advanced experiments with a new double test cell (KIT, Karlsruhe) allow simultaneous tests with and without fan operation, including user surveys.
- Development of system solution for the renovation of typical office configurations with suspended acoustic ceilings.
- Research related to special conditions like hotel rooms where ceiling fans may be favourable due to simplicity and understandable, visible effect.
- ....