Influence of obstacle and surface emissivity on night-time cooling using mixing and displacement ventilation

- Experimental investigation -

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Night-time ventilation:
Influence of obstacle and surface emissivity

Cooled floor area in EU-15 countries

Source: EECCAC, 2003
Passive and low-energy cooling

Reduction of heat gains
- Glazing ratio
- Solar shading
- Efficient office equipment
- Daylight utilisation

Natural heat sinks
- Night-time ventilation
- Earth-to-air heat exchanger
- Ground water

Solar cooling
...
**Scope of the investigation:**

Evaluate the potential of night cooling by night time ventilation

Measurement of the convective energy exchange and convective heat transfer coefficient

Effect of redistribution of energy between the surfaces due to radiation

Experiments conducted:
- Changing the floor emissivity
- Adding obstacles
Night-time ventilation: 
Influence of obstacle and surface emissivity

Experimental set-up
Night-time ventilation:
Influence of obstacle and surface emissivity

- Test room at Aalborg University (DK):

  Used by N. Artmann for his PhD entitled “Passive cooling of buildings by night-time ventilation”

  Internal dimensions
  2.64 m x 3.17 m (8.4 m²)
  Height: 2.93 m

  Volume
  24.52 m³
Night-time ventilation: Influence of obstacle and surface emissivity

Material properties ($\lambda$, $\varphi$, $\varepsilon$, $C_p$) have been measured at EMPA.
• **Air distribution principles:**

Capacity of the system: air change rate going from 2.3 to 13.5 ACH

Mixing Ventilation

Displacement Ventilation
**Experiments:**
- Homogeneous room temperature at the beginning of experiments
- Ventilation with cold air for 12 hours
Night-time ventilation:
Influence of obstacle and surface emissivity

- Temperature logged every 10 seconds

- Parameters varied
  - Air distribution principle (mixing & displacement)
  - Air change rate, ACR
  - Initial temperature difference, $\Delta T_0$

  Room layout (adding a table)
  Floor emissivity (adding a aluminium foil)
Night-time ventilation:
Influence of obstacle and surface emissivity

- **Conduction:**

  Ceiling
  - Measured internal and external surface temperatures

  Walls and floor
  - Measured internal surface temperatures and external heat flux

Calculation
- Boundary conditions to a transient 1-dimensional finite difference model
- Temperature gradient for each time step
- Conductive heat flux (moving average of 2.5 min)
Night-time ventilation:
Influence of obstacle and surface emissivity

- **Radiation:**
  22 sections at the ceiling
  3 sections at walls and floor

\[
\dot{q}_{rad, i} = \sum_{j} \frac{\sigma \cdot \varepsilon_i \cdot \varepsilon_j \cdot F_{i,j}}{1-(1-\varepsilon_i)(1-\varepsilon_j) \cdot F_{i,j} \cdot F_{j,i}} \left( T_i^4 - T_j^4 \right)
\]

- **Convection:**
  Conservation of energy at the surface

\[
\dot{q}_{conv, i} = \dot{q}_{cond, i} - \dot{q}_{rad, i}
\]
Night-time ventilation:  
Influence of obstacle and surface emissivity

- **Total heat discharged from the room:**

  Total convection at all surfaces
  \[ \dot{Q}_{\text{conv, tot}} = \sum_i A_i \cdot \dot{q}_{\text{conv, i}} \]

  Ventilative heat flow
  \[ \dot{Q}_{\text{vent, tot}} = \dot{V} \cdot \rho \cdot c_p \cdot (T_{\text{out}} - T_{\text{in}}) \]

- **Uncertainty estimated:**

  \[ Q_{\text{conv, tot}} : \pm 16\% \]
  \[ Q_{\text{vent, tot}} : \pm 12\% \]

  Thermocouples (± 0.086 K), position, material properties, thickness...
Influence of floor emissivity
Night-time ventilation:
Influence of obstacle and surface emissivity

- **Set-up:**

  - Initial flooring: EPS
  - Aluminum-foil floor cover ($\varepsilon = 0.03$)
Night-time ventilation:
Influence of obstacle and surface emissivity

- **Displacement ventilation:**

<table>
<thead>
<tr>
<th>No</th>
<th>Type of flooring</th>
<th>ACR (ACH)</th>
<th>$\Delta T_0$ (K)</th>
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9 new experiments
Mean convective heat flux from the room:

![Graph showing the convective heat flux from the room with different ventilation rates and heat transfer coefficients.]

Average convective heat transfer coefficient:

\[ h' = \frac{q_{conv,\,tot}}{T_{surface} - T_{inlet}} \]
Mean convective heat flux from specific surfaces:

From ceiling

From floor

Night-time ventilation:
Influence of obstacle and surface emissivity
Surface temperature at the floor:

The dimensionless temperature is defined by:

\[ \theta = \frac{T - T_{\text{inlet}}}{\Delta T_0} \]

3.1 ACH

6.7 ACH
Temperature efficiency:

Feasible parameter for modelling night-time ventilation performance.

\[
\eta = \frac{T_{\text{outlet}} - T_{\text{inlet}}}{T_{\text{surface}} - T_{\text{inlet}}}
\]
- **Mixing ventilation:**

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Ratio of convection to total heat flow for the ceiling

![Graph showing the ratio of convection to total heat flow for the ceiling with different ventilation rates.](image)
Night-time ventilation: Influence of obstacle and surface emissivity

Temperature efficiency

![Graph showing temperature efficiency vs. air change rate for two different floor types: Mixing, floor in EPS and Mixing, floor with foil.](image-url)
Night-time ventilation:
Influence of obstacle and surface emissivity

Mean Convective Heat Flux

- Mixing, floor with foil
- Mixing, floor in EPS

- $13 \, \text{h}^{-1}$: $h' = 1.36 \, \text{W/m}^2\text{K}$
- $13 \, \text{h}^{-1}$: $h' = 1.24 \, \text{W/m}^2\text{K}$
- $6.7 \, \text{h}^{-1}$: $h' = 0.72 \, \text{W/m}^2\text{K}$
- $6.7 \, \text{h}^{-1}$: $h' = 0.67 \, \text{W/m}^2\text{K}$
- $3.3 \, \text{h}^{-1}$: $h' = 0.40 \, \text{W/m}^2\text{K}$
- $3.3 \, \text{h}^{-1}$: $h' = 0.34 \, \text{W/m}^2\text{K}$
Night-time ventilation:
Influence of obstacle and surface emissivity

Influence of an internal obstacle
Night-time ventilation:
Influence of obstacle and surface emissivity

New set up with the internal obstacle:
test room with the table

Axonometric view of the test room with the table
Night-time ventilation: Influence of obstacle and surface emissivity

Overview of experiment with the table and displacement ventilation: Air Change Rate & $\Delta T$

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7 new experiments
Night-time ventilation:
Influence of obstacle and surface emissivity

Results: Mean convective heat flux in the test chamber in function of temperature difference

![Graph showing mean convective heat flux in function of temperature difference.]

- Displacement with the table
- Displacement without the table

- 12.0 & 12.7 ACH: $h = 1.36 \text{ W/m}^2\text{K}$
- 6.2 ACH: $h = 1.01 \text{ W/m}^2\text{K}$
- 3.1 ACH: $h = 0.58 \text{ W/m}^2\text{K}$
Night-time ventilation:
Influence of obstacle and surface emissivity

Results: Mean convective heat flux at the ceiling of the test chamber in function of temperature difference
Night-time ventilation: Influence of obstacle and surface emissivity

Results: Temperature efficiency in function of air change rate
Conclusions:
Influence of the floor emissivity (Aluminium foil)

- Total convective heat transfer similar in both cases. Similar temperature efficiency.
- But some differences are visible in the case of displacement ventilation:
  - Surface temperature of the floor decreasing
  - Reorganisation of the convective heat transfer at the floor and at the ceiling
- In practice there is no influence of the extremely low emissivity of the floor cover on the efficiency of the night-time ventilation
Conclusions:
Set-up with table & displacement ventilation
vs set-up without table and displacement ventilation

- Based on obtained results it can be concluded that insertion of the table does not have significant influence on the heat distribution in the room

- Heat transfer due to convection and ratio of convective heat transfer to total heat transfer in the room remains the same for both set-ups and for various ACRs

- There can be observed insignificant changes in temperature efficiency
Thank you for your attention
Night-time ventilation: Influence of obstacle and surface emissivity

Results: Ratio of convective to total heat flow in function of Archimedes number

![Graph showing the ratio of convective to total heat flow as a function of Archimedes number. The graph includes data for different ventilation rates: 13 h⁻¹, 6.7 h⁻¹, 4.3 h⁻¹, and 3.3 h⁻¹. The x-axis represents the Archimedes number, and the y-axis represents the ratio.]