Effect of Jet Disturbance on Convective Flow from a Heat Source

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Effect of Jet Disturbance on Convective Flow from a Heat Source

Aim of the study
Modelling of the effects of jet disturbance on convective flow (=plume) characteristics

Hypothesis
The air flow rate of the plume will be increased by disturbances
A part of a project

Convective Flows from Heat Sources

1. Effects of disturbances on a plume
   - Jet
   - Floor current
   - Moving plate (simulating a person)
2. Effect of heat location on plumes (INRS, FIOH)
3. Real plumes
   - Kitchen cookers
   - Data and overhead projector
The content of the paper and presentation

Effect of Jet Disturbance on Convective Flow from a Heat Source

1. Convective flows in room air conditioning design
2. “Engineer” modelling of plumes
3. Measurement methods
4. Measurement results and modelling
   - undisturbed cases
   - disturbed cases
5. Conclusions
Convective flows and room air conditioning design

“DGB Industrial ventilation 2001”
ROOM AIR CONDITIONING STRATEGY
The idea and the target of stratification in a space

PISTON   STRATIFICATION   ZONING   MIXING

SU = SUPPLY   EX = EXHAUST   T = TEMPERATURE   C = CONCENTRATION   x = ABS. HUMIDITY
Convective flows and room air conditioning design

When the stratification and zoning strategies are applied, the plumes are the key flow elements for:

- dimensioning the supply air flow rate
- designing the air distribution method

in order to achieve a high heat and contaminant removal efficiency
Convective flows and room air conditioning design

Also when a local exhaust method is applied, the plumes are the key flow elements for:

- dimensioning the air flow rate
- designing and dimensioning the hood
Convective flows from heat sources

The air flow rate and the shape of the convective flow are dependant especially on the
- dimensions
- shape
- convective heat power

of the heat source, but also on the
- disturbances around the plume?
"Engineer modelling" Plume equations

Air flow rate (not for linear source)

\[ q = A_q P_c^{1/3} (z - z_{virt})^{5/3} \]

In modelling can be varied
the dimension \( Z_{virt} \) (free convection, different shapes of the heat source)
or
the factor \( A_q \) (partly forced convection, disturbances).

Momentum flow rate

\[ M = A_M P_c^{2/3} (z - z_{virt})^{4/3} \]
Heat source

**Cylinder**

<table>
<thead>
<tr>
<th>Measurement cases</th>
<th>Convection (W)</th>
<th>Radiation (W)</th>
<th>Total (W)</th>
</tr>
</thead>
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<td></td>
<td>300</td>
<td>600</td>
<td>900</td>
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<td>50</td>
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<td>150</td>
</tr>
</tbody>
</table>
Measurements at FIOH Turku

- thermal insulated test room 10m x 4m x 6m
- undisturbed conditions require very even supply air distribution
- nozzle ducts were used
- Kaijo ultrasonic probes
Visualization of plumes

Photo and video documentation

Fast temperature measurements with Dantecin omnidirectional probes

-> excel animation

Smoke

Helium filled soap bubbles
12 measurement cases

- 4 different electric power (heat power)
- 3 height levels of measurement plane
- area 2,1 m x 1,7 m
- 1 vertical measurement plane
- grid 100 mm x 100 mm
- velocity, temperature, 1 min average
- measurement time with 2 probes was 15-20 h / case
Undisturbed plume

Measurement and analysis

- background velocity with Gaussian fit
- air flow rate \( q = \sum (A_i v_i) \)
- momentum flow rate
\[
M = \sum (\rho_i A_i v_i^2)
\]
- average radius / diameter -> virtual origin
\[
r = q \sqrt{\frac{\rho}{\pi M}}
\]
- coefficients of the plume equations
\[
q = A_q P_c^{1/3} (z - z_{virt})^{5/3}
\]
\[
M = A_M P_c^{2/3} (z - z_{virt})^{4/3}
\]
Undisturbed plume

Measurement and analysis

- background temperature with Gaussian fit
- low temperature differences -> inaccuracy
- radiation heat flow rate was determined using 25 measured surface temperatures on the cylinder and calculated view factors to surrounding surfaces
- in the model $P_{\text{conv}} = P_{\text{electr}} - P_{\text{rad}}$
Undisturbed plume

radius / diameter -> virtual origin \( z_{\text{virt}} = -0.16 \) m (under the floor)

\[ r = q \sqrt{\rho / (\pi M)} \]
Undisturbed plume

Plume air flow rate vs. convection heat, fit result -> $A_q = 3.38$

$$q = A_q P_c^{1/3} (z - z_{virt})^{5/3}$$
Undisturbed plume

Measurements and modelling

Air flow rate

$$q = A_q P_c^{1/3} (z - z_{virt})^{5/3}$$

Momentum flow rate

$$M = A_M P_c^{2/3} (z - z_{virt})^{4/3}$$
Disturbed plumes / Jet

Horizontal jet, 40 measurement cases

- $\phi$100 mm duct
- 4 flow velocities 0,25 , 0,5 , 0,75, 1,0 m/s
  -> 0…8 l/s
- distances 1 m (basic) ja 2 m
- 4 jet height levels (basic 2m)
Measurement arrangement of jet disturbance
Disturbed plumes / Jet

Example
Air velocity distribution at a horizontal measurement plane at height 2 m with jet velocities 0 – 1 m/s

0 m/s  0.25 m/s  0.50 m/s  0.75 m/s  1.0 m/s

tendence for spreading
Undisturbed Jet velocity 0 m/s

Jet velocity 0.75 m/s

Disturbed plumes / Jet Convection 200 W

Temperature

Velocity
Disturbed plumes

Radius of plume

-> Virtual origin of undisturbed case $Z_{virt} = -0.16$ m was used in modelling

![Graph showing plume radius with disturbance, all plume power cases, jet distance 1 m and height 2 m]
Relative plume equation coefficient $A_q$ vs. disturbance jet velocity

$$q = A_q P_c^{1/3} (z - z_{virt})^{5/3}$$
Relative plume air flow rate vs. relative disturbance $M_{\text{jet}}/M_{02m}$

$M_{02m}$ is the momentum flow rate at 2 m level in the undisturbed case.
Increase of plume air flow rate vs. relative disturbance
jet distance 1 m and jet height 2 m

Corrected increase of relative air flow rate, jet distance 1 m and height 2 m

\[ y = -0.2813x^2 + 0.8746x \]

\[ R^2 = 0.7544 \]

\[ R^2 = 0.8415 \]

Relative disturbance \( M_{\text{jet}} / M_{0\text{2m}} \)

Increase of relative air flow rate

- 2 m
- 3 m
- 4 m
- polyn

Polyn. (2 m)
Polyn. (3 m)
Polyn. (4 m)
Polyn. (polyn)

Ave
Plume air flow rate and radius vs. relative disturbance $M_{\text{jet}}/M_{02m}$

**Air flow rate, jet distance 1 m**

Corrected relative air flow rate, jet distance 1 m and height 2 m

- $R^2 = 0.8247$
- $R^2 = 0.9247$
- $R^2 = 0.864$

**Air flow rate, jet distance 2 m**

Corrected relative air flow rate, jet distance 2 m and height 2 m

- $R^2 = 0.9062$
- $R^2 = 0.2133$
- $R^2 = 0.9362$

**Radius, jet distance 1 m**

Plume radius, jet distance 1 m and height 2 m

- $R^2 = 0.8247$

**Radius, jet distance 2 m**

Plume radius, jet distance 2 m and height 2 m

- $R^2 = 0.9062$
- $R^2 = 0.2133$
- $R^2 = 0.0424$
Air flow rate at 3 m vs. jet height level

Plume air flow rate at height 3 m, 594 W

Plume air flow rate (l/s)

Jet height (m)

- 0 m/s
- 0.25 m/s
- 0.5 m/s
- 0.75 m/s
- 1 m/s
- 0.75 m/s (2m)
Summary and conclusions

1. Air flow rate was increased by the jet disturbance up to 60%.

2. Correlation between the increase of air flow rate and radius is high.

3. The increase was continued when the disturbance increased until the plume skipped out from the measurement area.

4. The increase of the air flow rate must be paid attention to when the stratification and zoning room air condition strategies are applied.

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Even in laboratory environment the undisturbed flow field is not easy to arrange
Thank You

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