CFD SIMULATIONS OF POLLUTANT SPATIAL DISTRIBUTION IN A LARGE OFFICE

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• People spend most of their time indoors
• Indoors: many pollution sources (for example: equipment and construction materials)
• Indoor CFD:
  – No best practice guidelines (in contrast to external flows)
  – Very few basic research cases (usually specific problems are examined)
  – Not clear enough which physical and numerical parameters affect the modelling results
  – Confinement of flow increases the possibilities of existence of spots with unsteady flow phenomena
Objectives

- Examine the flow/ dispersion in a large office
- Focus on differences of concentrations among various working positions of employees
- Examine influence of physical/modelling parameters
• The **physical problem**
• The **simulation methodology**
• Present the results of the ‘basic case’
  – Flow/ dispersion
  – Focus on spatial differences of concentrations
• **Additional cases** in order to examine the influence of physical/modelling parameters:
  – Alternative ventilation cases (different vent strength distribution/ geometry/ layout) – determination of best one
  – Alternative modelling cases (existence of desks/people, grid resolution, thermal influence, inlet conditions, CFD methodology (RANS/LES)) – reliability issues discussed
Physical problem

- Large office (22.26m x 7.80m x 2.54m)
  - 9 windows / 4 doors
- Mechanical ventilation
  - 7 inlet / 6 outlet vents
- Inlet change rate:
  3.5 changes per hour

<table>
<thead>
<tr>
<th>Mechanical ventilation hours</th>
<th>Every day, 07:00 - 19:00</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>- 0.050</td>
</tr>
<tr>
<td>2</td>
<td>-0.067</td>
</tr>
<tr>
<td>3</td>
<td>-0.059</td>
</tr>
<tr>
<td>4</td>
<td>0.127</td>
</tr>
<tr>
<td>5</td>
<td>-0.036</td>
</tr>
<tr>
<td>6</td>
<td>0.047</td>
</tr>
<tr>
<td>7</td>
<td>0.075</td>
</tr>
<tr>
<td>8</td>
<td>0.073</td>
</tr>
<tr>
<td>9</td>
<td>0.077</td>
</tr>
<tr>
<td>10</td>
<td>0.044</td>
</tr>
<tr>
<td>11</td>
<td>0.081</td>
</tr>
<tr>
<td>12</td>
<td>-0.048</td>
</tr>
<tr>
<td>13</td>
<td>-0.035</td>
</tr>
</tbody>
</table>

Flow rate per vent (kg/s)

Total in (kg/s) 0.524
Total out (kg/s) 0.295
Pollutant Emission

- Pollutants such as PM, formaldehyde and other VOCs emitted mainly from floor and floor equipment (i.e. furnitures, desks etc)
- Assumption: uniform surface ground source
- Results will be presented non-dimensionalized with the same global average theoretical in-room concentration $C_{av}$ that the office would have in case of full homogeneous commixture
The Simulation methodology

- Inlet/outlet flows \textit{from vents} taken from experimental data
- Outflows \textit{for doors/windows} simulated with COMIS
- 10cm gap around each door/window

\textbf{ADREA-HF}
- Standard $k$-$\varepsilon$ (RANS)
- Basic case grid: 39 x 110 x 14 cells
- $z_0=0.001$m
- 12 ‘sensors’ corresponding to the working occupants’ positions
Basic case: Main results

Flow close to top level

Flow close to floor level

\[ C/C_\text{ref} = 0.5 \ 1 \ 1.5 \ 2 \ 2.5 \ 3 \ 3.5 \]
Basic case: $C/C_{av}$ isosurfaces
Basic case: $W=0$ isosurface
Basic case: Streamtraces
Basic case: Concentrations at $Z = 1.1m$
Basic case: Concentrations at sensors

If employees were:
- 1m closer to walls: 8% higher av. C
- 1m closer to center: 15% lower av. C

$C_{\text{max}}/C_{\text{min}} = 2.85$
All cases examined

Alternative ventilation

1 – BASE
2 – Uniform inflow rate at vents
3 – Wall 2 vents 60cm closer to wall 2
4 – Other inlets/outlets (uniform inlets/ at wall 2 side)
5 – New vents design (inlet from the side walls)
6 – New vents design (inlet from center)
7 – Base case with 12 desks
8 – Base case with 12 desks and 12 “people”
9 – Fine grid (79 x 223 x 28 cells)
10 – Given T at inlets – energy equation also
11 – Given k at inlets
12 – Preliminary LES

Alternative modelling
All cases: Concentrations at $Z = 1.1m$

1– BASE (average: 1.18/ Max/min: 2.85)

2– Uniform inflow rate at vents (1.18/2.34)

3– Wall 2 vents closer to wall (1.05/2.51)

4– Other inlets/outlets (0.95/2.89)

5– New vents (side inlets) (0.42/2.33)

6– New vents (center inlets) (1.14/1.36)

7– Base case with 12 desks (1.01/3.68)

8– Base with desks & people (0.99/3.91)

9– Fine grid (1.16/2.88)

10– Given T at inlets (1.18/3.20)

11– Given k at inlets (1.14/2.25)

12– Preliminary LES (0.87/2.23)
## Alternative ventilation cases

<table>
<thead>
<tr>
<th>Case</th>
<th>C/C_{av} at the 12 sensors:</th>
<th>Av.</th>
<th>min</th>
<th>max</th>
<th>max/min</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 – BASE</td>
<td></td>
<td>1.18</td>
<td>0.69</td>
<td>1.97</td>
<td>2.85</td>
</tr>
<tr>
<td>2 – Uniform inflow rate at vents</td>
<td></td>
<td>1.18</td>
<td>0.76</td>
<td>1.78</td>
<td>2.34</td>
</tr>
<tr>
<td>3 – Wall 2 vents 60cm closer to wall 2</td>
<td></td>
<td>1.05</td>
<td>0.69</td>
<td>1.74</td>
<td>2.51</td>
</tr>
<tr>
<td>4 – Other inlets/outlets (uniform inlets/ at wall 2 side)</td>
<td></td>
<td>0.95</td>
<td>0.53</td>
<td>1.53</td>
<td>2.89</td>
</tr>
<tr>
<td>5 – New vents design (inlet from the side walls)</td>
<td></td>
<td>0.42</td>
<td>0.29</td>
<td>0.67</td>
<td>2.33</td>
</tr>
<tr>
<td>6 – New vents design (inlet from center)</td>
<td></td>
<td>1.14</td>
<td>0.94</td>
<td>1.28</td>
<td>1.36</td>
</tr>
</tbody>
</table>

![Graph showing C/C_{av} for different cases](chart.png)
Alternative ventilation: comments

- CFD very valuable tool for alternative scenarios
- More uniform ventilation increases uniformity at C
- Spotting problematic areas drives the thoughts for improvements
- Small improvement, of the order of 10-20 % can be achieved with small interventions
- A complete redesign of the ventilation system in this case results in 3 times lower C at working positions (best case from those examined)
Alternative modelling cases

<table>
<thead>
<tr>
<th>Case</th>
<th>C/C_{av} at the 12 sensors:</th>
<th>Av</th>
<th>min</th>
<th>max</th>
<th>max/min</th>
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<tr>
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<td></td>
<td>1.18</td>
<td>0.69</td>
<td>1.97</td>
<td>2.85</td>
</tr>
<tr>
<td>7 – Base case with 12 desks</td>
<td></td>
<td>1.01</td>
<td>0.43</td>
<td>1.58</td>
<td>3.68</td>
</tr>
<tr>
<td>8 – Base case with 12 desks and 12 “people”</td>
<td></td>
<td>0.99</td>
<td>0.42</td>
<td>1.64</td>
<td>3.91</td>
</tr>
<tr>
<td>9 – Fine grid</td>
<td></td>
<td>1.16</td>
<td>0.65</td>
<td>1.88</td>
<td>2.88</td>
</tr>
<tr>
<td>10 – Given T at inlets – energy equation also</td>
<td></td>
<td>1.18</td>
<td>0.62</td>
<td>1.99</td>
<td>3.20</td>
</tr>
<tr>
<td>11 – Given k at inlets</td>
<td></td>
<td>1.14</td>
<td>0.70</td>
<td>1.57</td>
<td>2.25</td>
</tr>
<tr>
<td>12 – Preliminary LES</td>
<td></td>
<td>0.87</td>
<td>0.57</td>
<td>1.26</td>
<td>1.36</td>
</tr>
</tbody>
</table>

The graph below illustrates the distribution of C/C_{av} across the 12 sensors for each case.
General flow features are retained…
…but differences are also present
  – especially at sensor 2 (and 3), but also 6 (and 7)
More geometrical details \(\rightarrow\) lower uniformity at C
Temperature/inlet conditions more critical than grid
Preliminary LES has in general lower av. C in room
Differences seem to relate more to the position than to the choice of the modelling parameters
  – Next slides, focus on:
    sensor 7 (lower C if desks are considered)
    sensors 2, 3 (higher differences among runs)
Alternative modelling: Focus on sensor 7 values

- Sensor 7 presents lower concentrations (about 40%) when desks are incorporated in the model
  - The desk that corresponds to sensor 7 is just below the vent number 11; thus the fresh air spreads above the desk and keeps the C values of sensor 7 very low
Alternative modelling: Focus on sensors 2 and 3

Differences among runs, esp. for sensor 2

- Unsteady flow – close to (unsteady) vortex center
- Sensor 2: clean air transferred from elsewhere
From LES case 12:
U distributions at sensors 2, 3

- Actually, flow at area of sensor 2 (& 3) is unsteady
- From LES, U probability density functions from sensors 2 and 3 are the less Gaussian
Conclusions

- Exposure at large offices presents high heterogeneity
  - In this case: max/ min is 4, if in-room geometry is considered
- CFD is a very valuable tool
  - Analyze the flow, determine best working positions
  - Propose alternative ventilation and even new designs
- Influential physical/simulation parameters:
  - Geometry/layout/strength of vents
  - In-room detailed geometry
  - Thermal effects
  - RANS vs. LES
- Unsteadiness of flow causes CFD reliability issues
- LES should be further examined
- There is a need for a validation database
Acknowledgements

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Ευχαριστώ
Thank you