CFD SIMULATIONS OF POLLUTANT SPATIAL DISTRIBUTION IN A LARGE OFFICE

Nektarios Koutsourakis[1,2], <u>John G. Bartzis[1]</u>, George C. Efthimiou[2], Ioannis Sakellaris[1]

[1] University of Western Macedonia, Greece

[2] NCSR "Demokritos", Greece

Motivation

- 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*

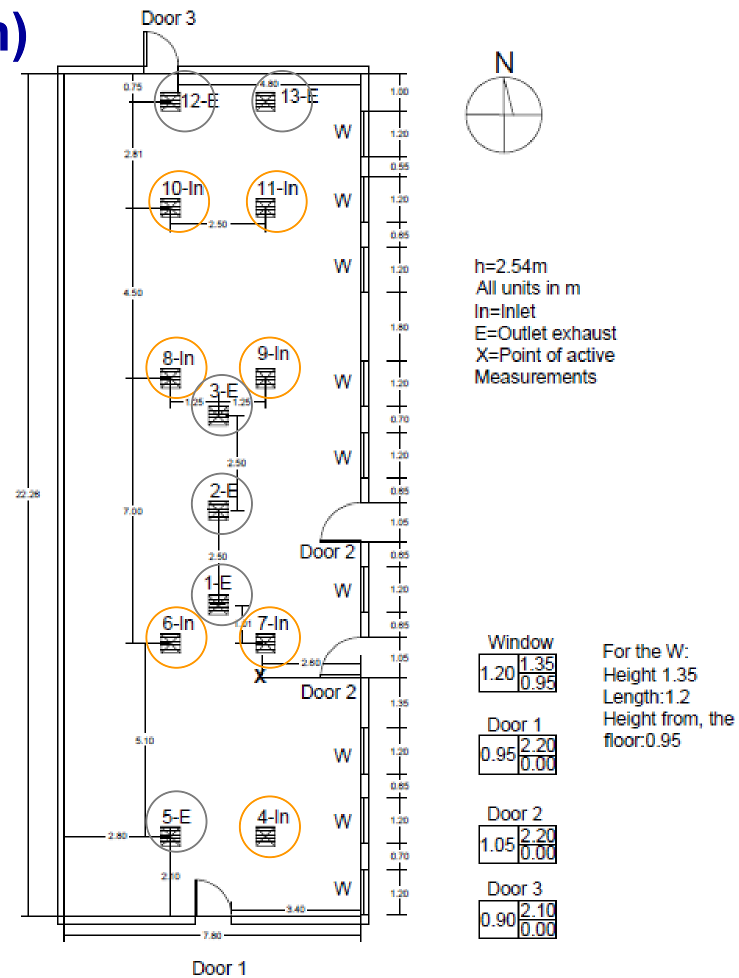
Presentation layout

- 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**

Mechanical ventilation hours	Every day, 07:00 - 19:00	
Flow rate per vent (kg/s)	1	- 0.050
	2	-0.067
	3	-0.059
	4	0.127
	5	-0.036
	6	0.047
	7	0.075
	8	0.073
	9	0.077
	10	0.044
	11	0.081
	12	-0.048
	13	-0.035
Total in (kg/s)	0.524	
Total out (kg/s)	0.295	

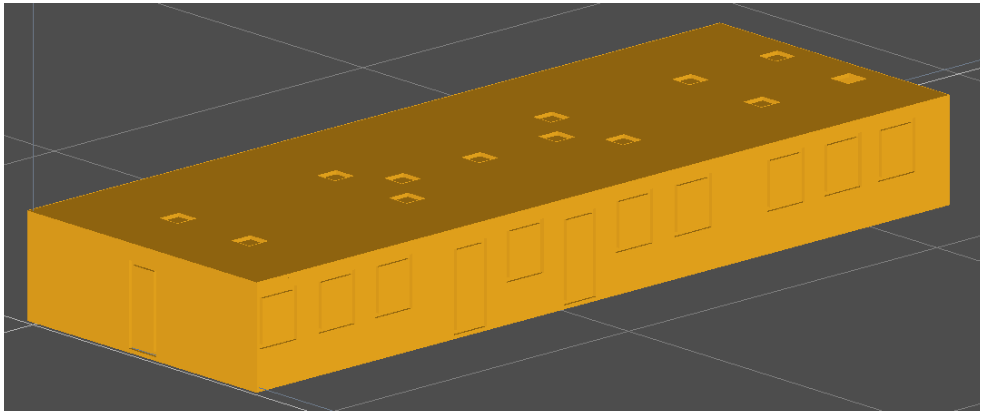


Pollutant Emission

- **Pollutants such as PM, formaldehyde and other VOCs emitted <u>mainly from floor and floor equipment</u> (i.e. furnitures, desks etc)**
- **Assumption : <u>uniform</u> <u>surface</u> 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

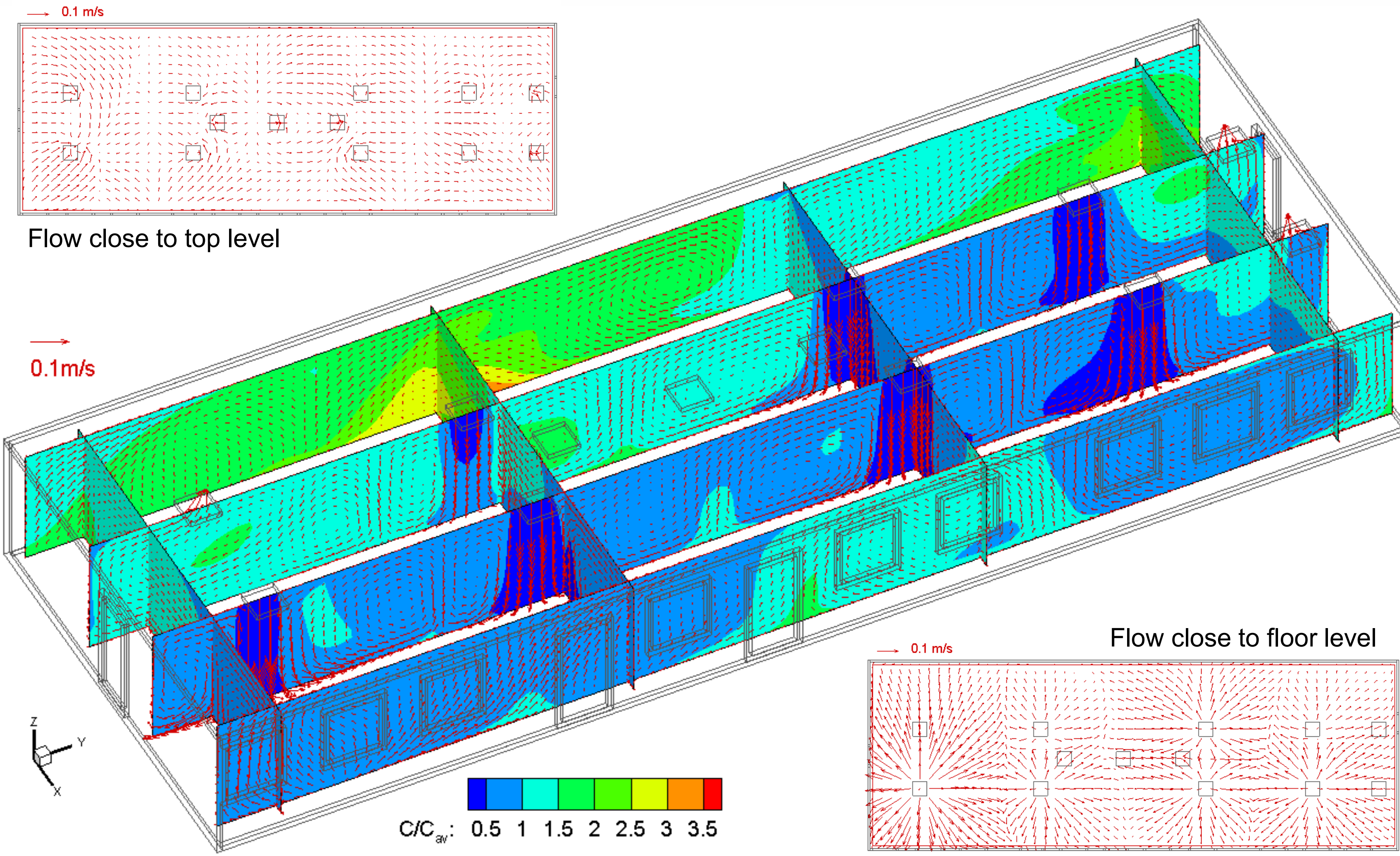
- Inlet/outlet flows *from vents* taken from experimental data
- Outflows *for doors/windows* simulated with COMIS
- 10cm gap around each door/window



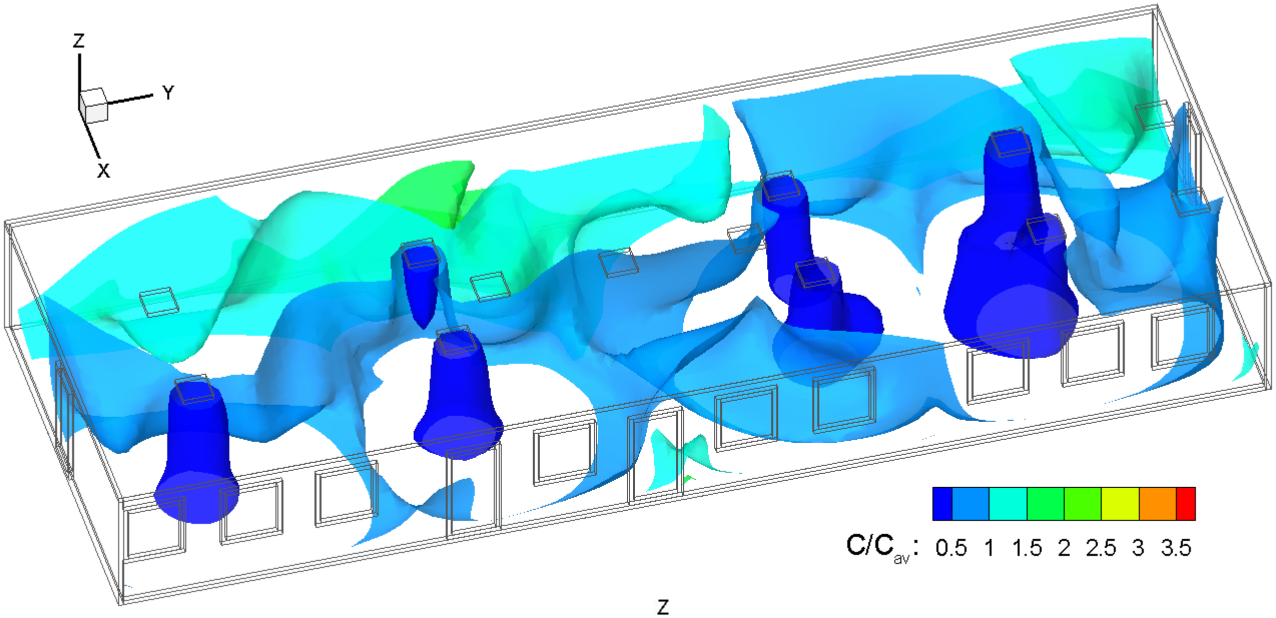
ADREA-HF

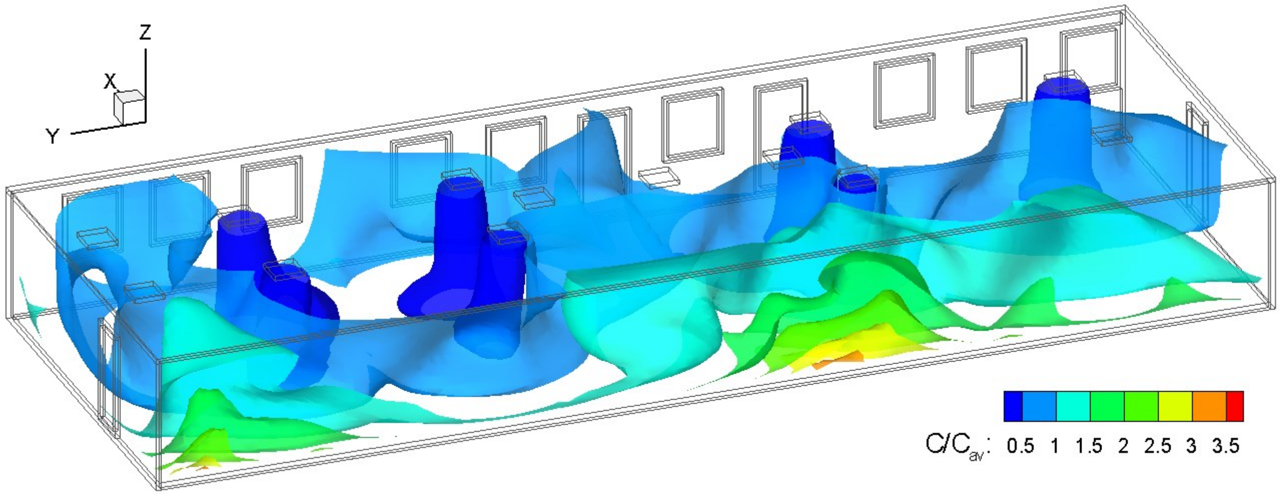
- Standard *k-ε* (RANS)
- Basic case grid: 39 x 110 x 14 cells
- z_0=0.001m
- 12 'sensors' corresponding to the working occupants' positions

Basic case: Main results

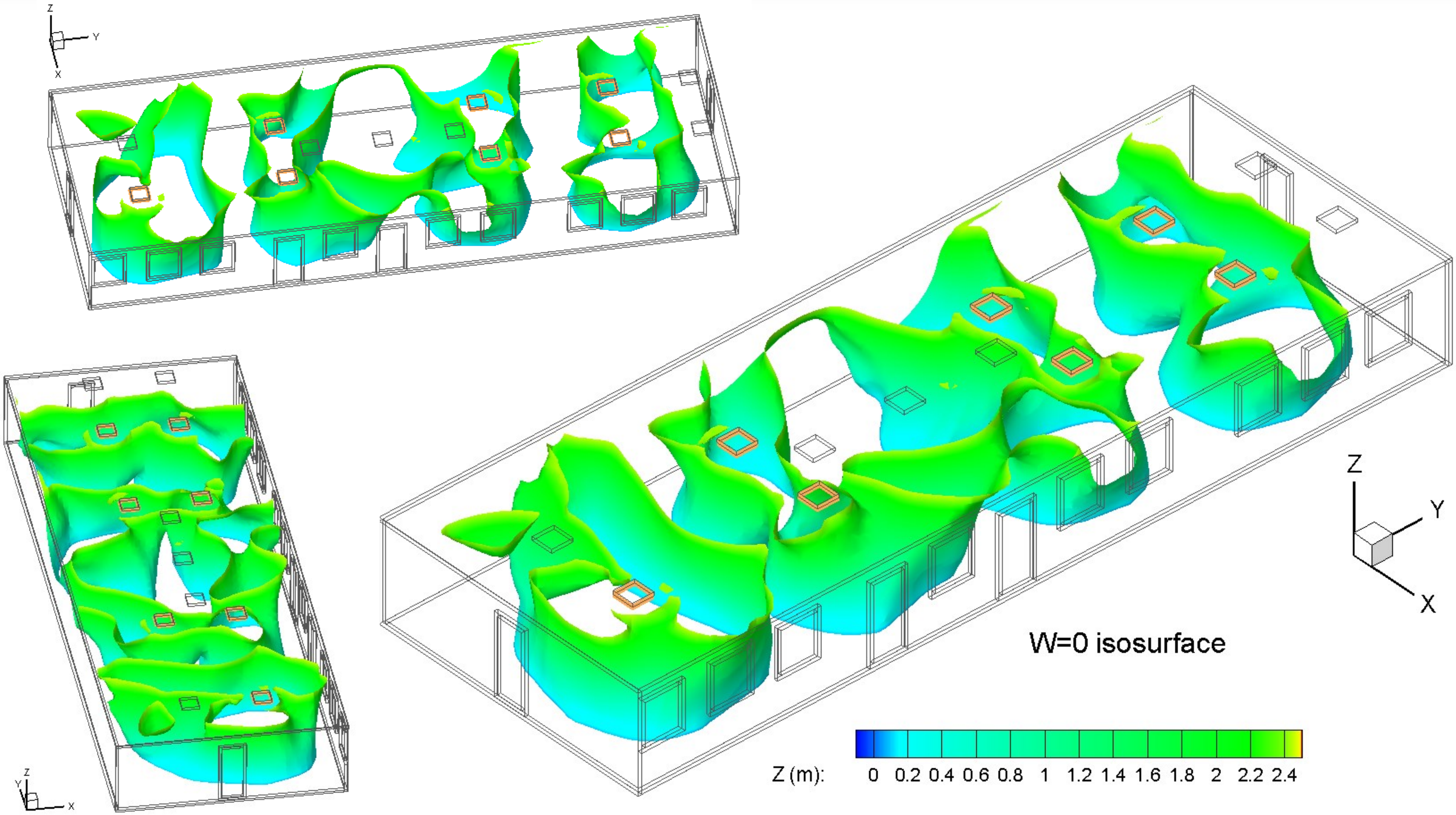


Basic case: C/C_{av} isosurfaces

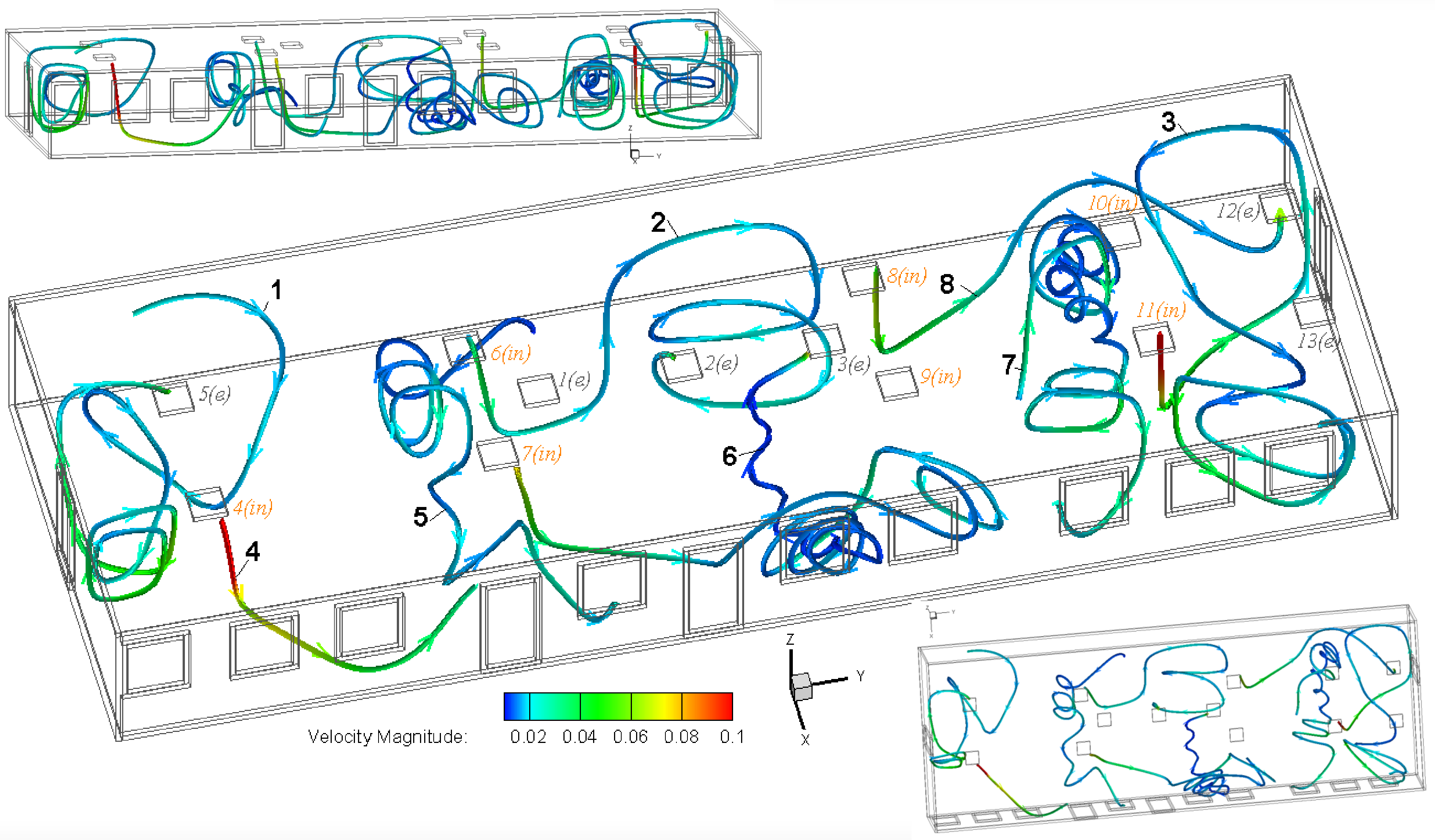




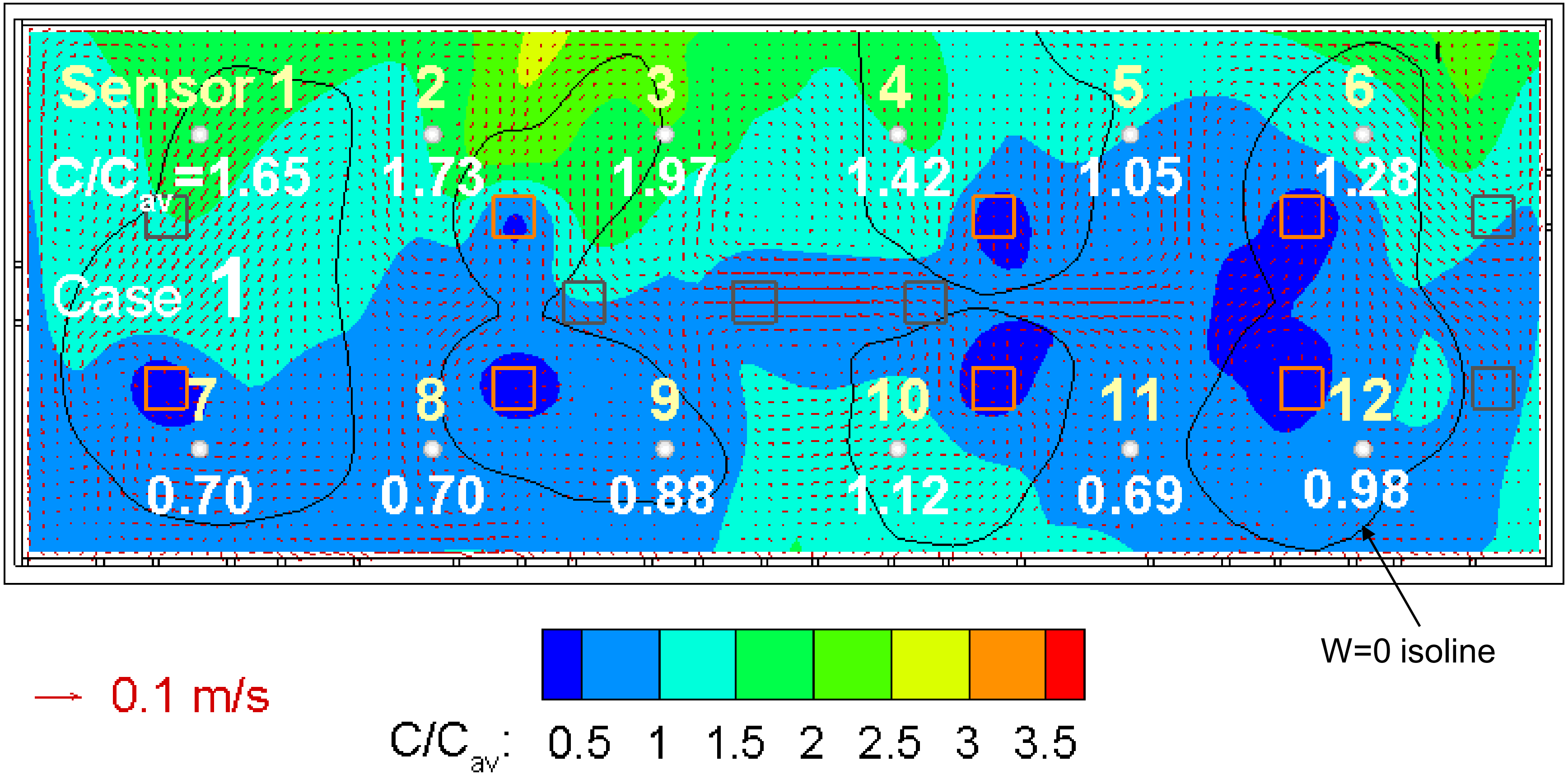
Basic case: W=0 isosurface



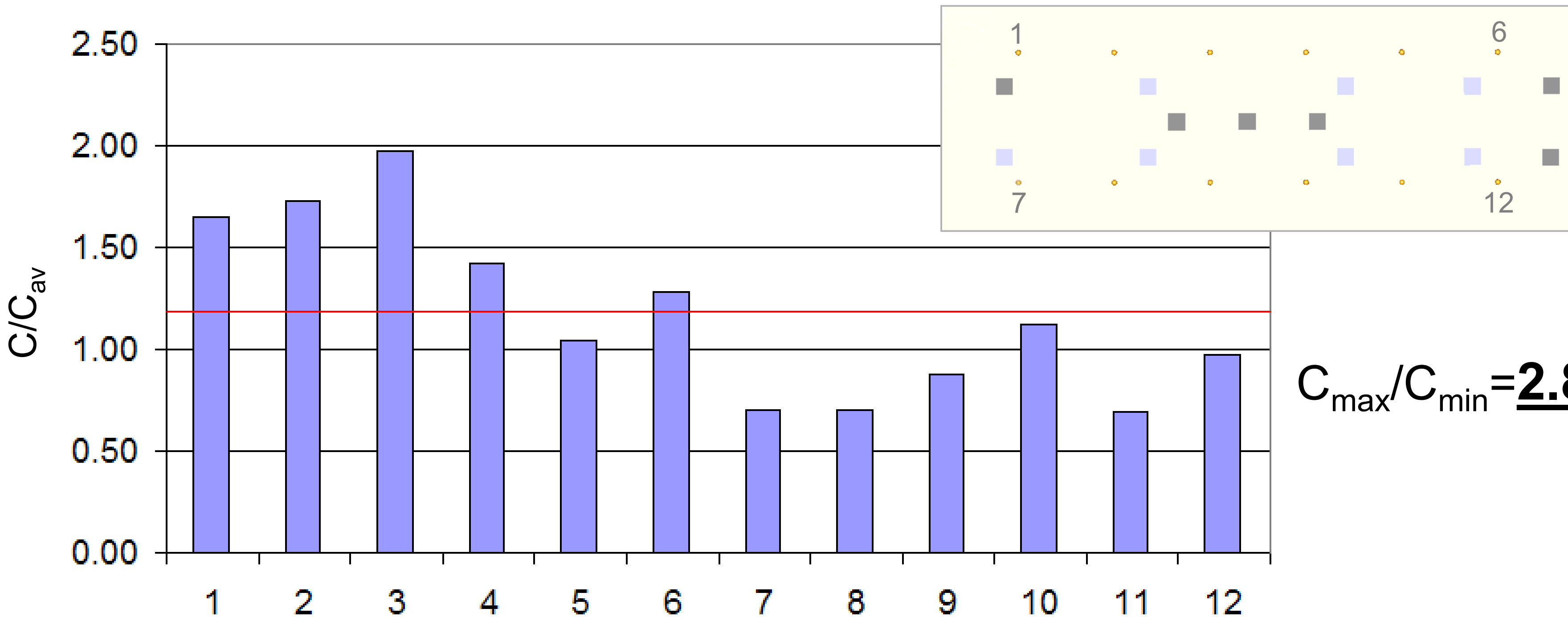
Basic case: Streamtraces



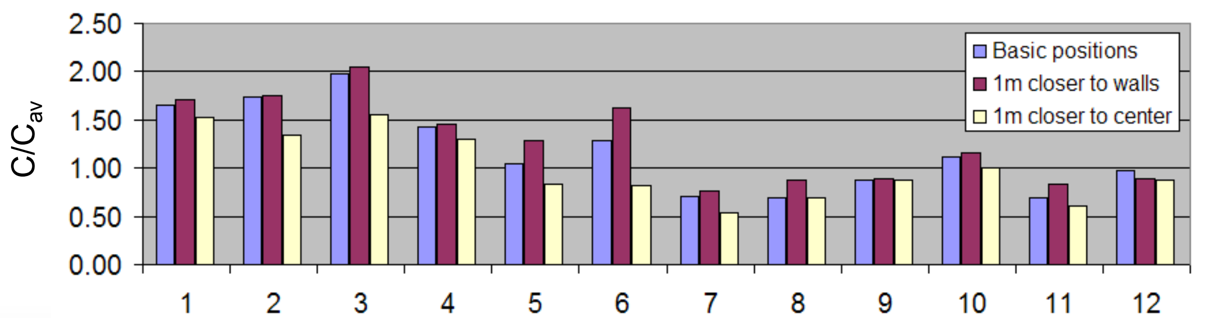
Basic case: Concentrations at Z = 1.1m



Basic case: Concentrations at sensors



C_{max}/C_{min}=**2.85**



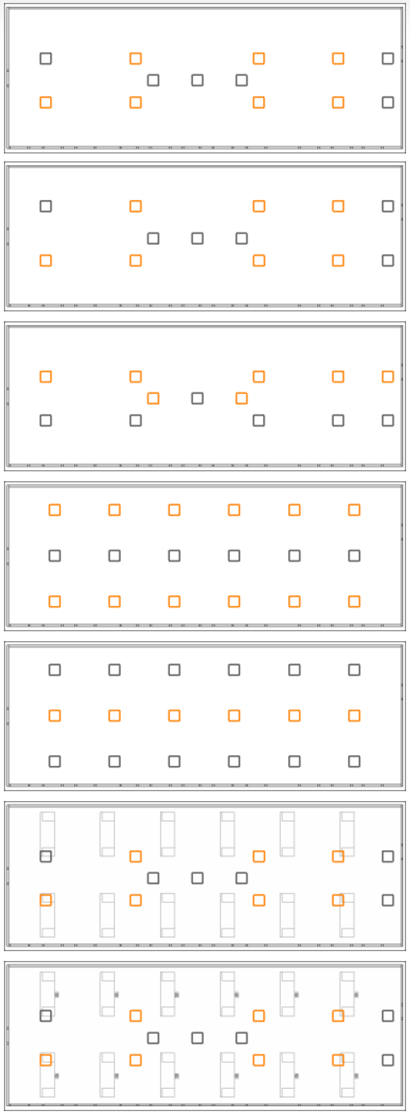
If employees were:
- 1m closer to walls:
  8% higher av. C
- 1m closer to center:
  15% lower av. C

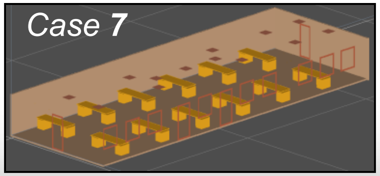
All cases examined

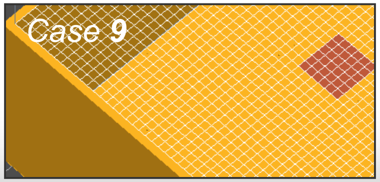
Alternative ventilation

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**

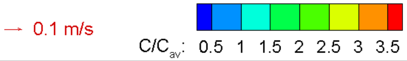
Alternative modelling

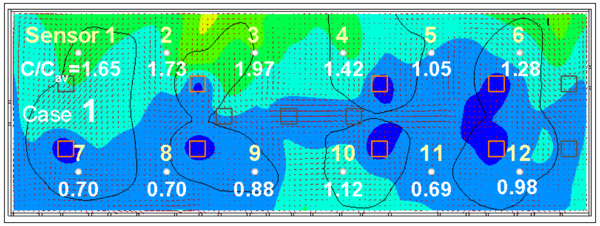




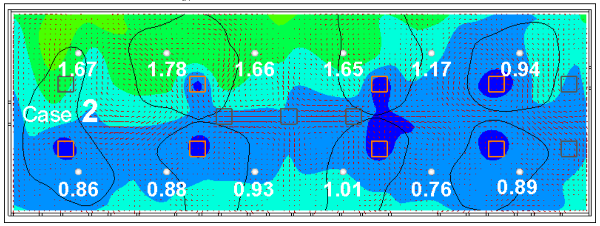


All cases: Concentrations at Z = 1.1m

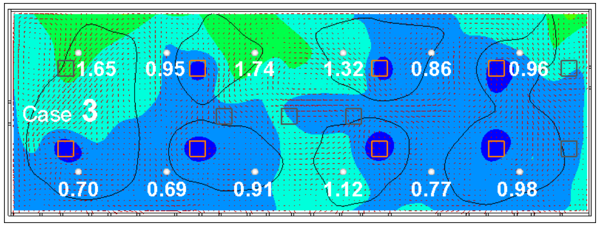




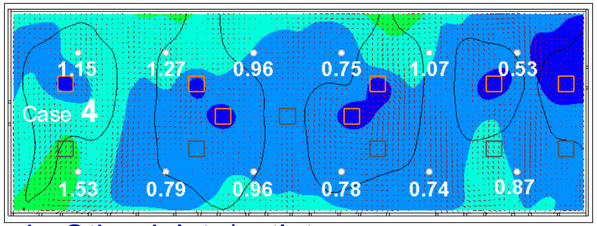
1– BASE (average: 1.18/ Max/min: 2.85)



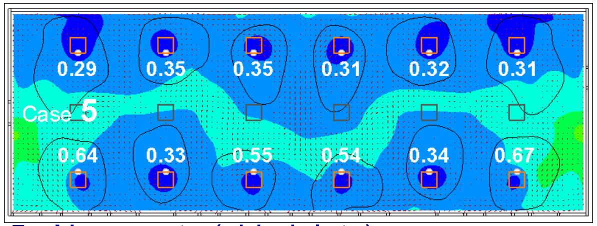
2– Uniform inflow rate at vents (1.18/2.34)



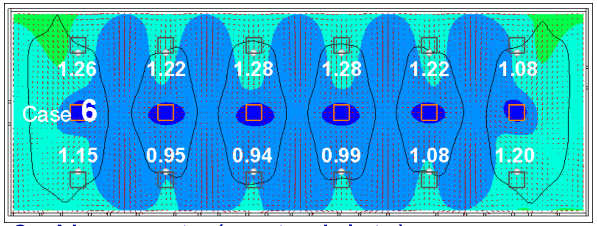
3– Wall 2 vents closer to wall (1.05/2.51)



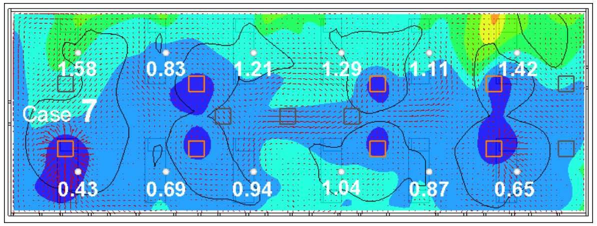
4– Other inlets/outlets (0.95/2.89)



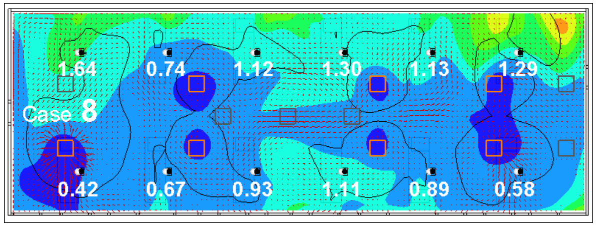
5– New vents (side inlets) (0.42/2.33)



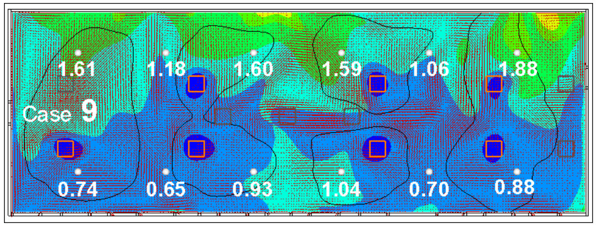
6– New vents (center inlets) (1.14/1.36)



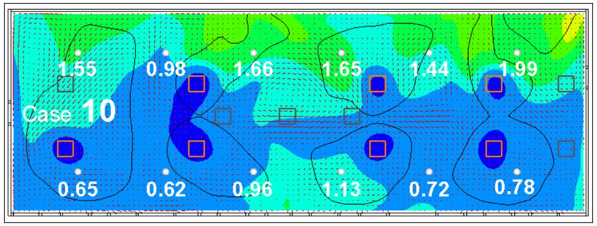
7– Base case with 12 desks (1.01/3.68)



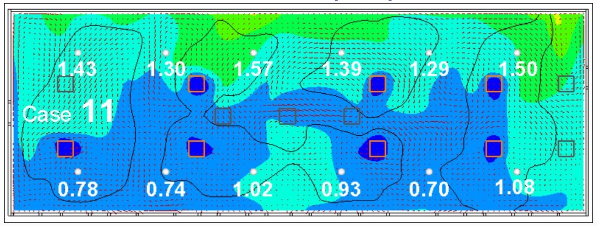
8– Base with desks & people (0.99/3.91)



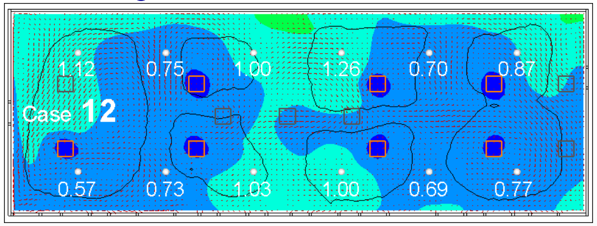
9– Fine grid (1.16/2.88)



10– Given T at inlets (1.18/3.20)



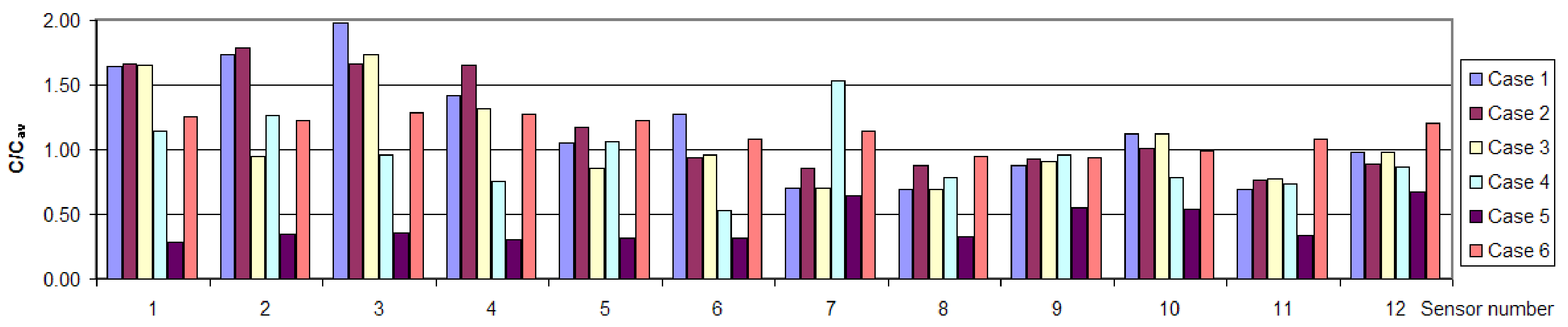
11– Given k at inlets (1.14/2.25)



12– Preliminary LES (0.87/2.23)

Alternative ventilation cases

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

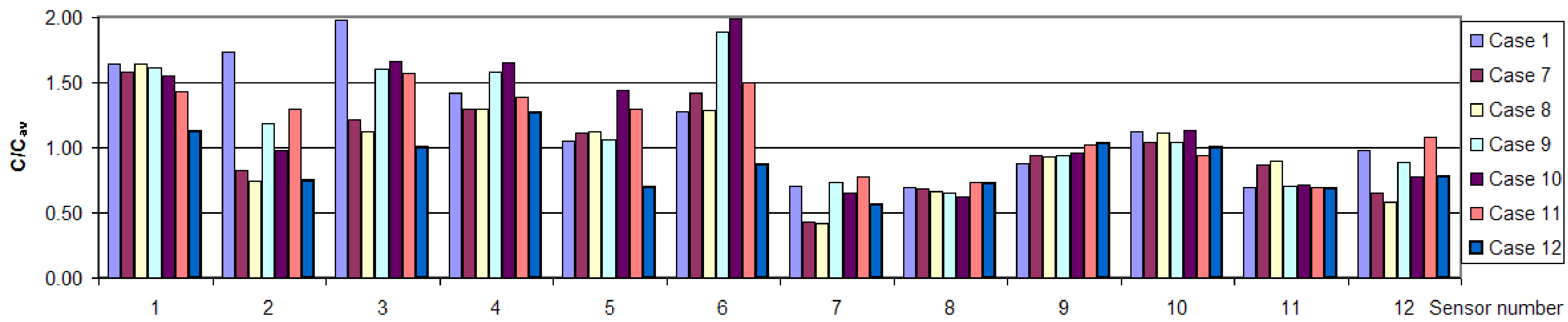


Alternative ventilation: comments

- 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)

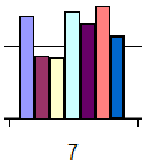
Alternative modelling cases

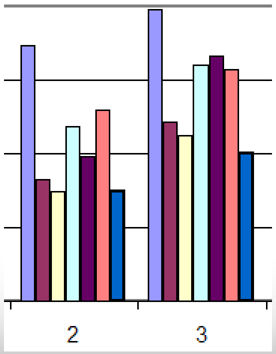
Case | C/C_{av} at the 12 sensors:	Av.	min	max	max/min
1 – BASE	**1.18**	0.69	1.97	**2.85**
7 – Base case with 12 desks	**1.01**	0.43	1.58	**3.68**
8 – Base case with 12 desks and 12 "people"	**0.99**	0.42	1.64	**3.91**
9 – Fine grid	**1.16**	0.65	1.88	**2.88**
10 – Given T at inlets – energy equation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



Alternative modelling: comments

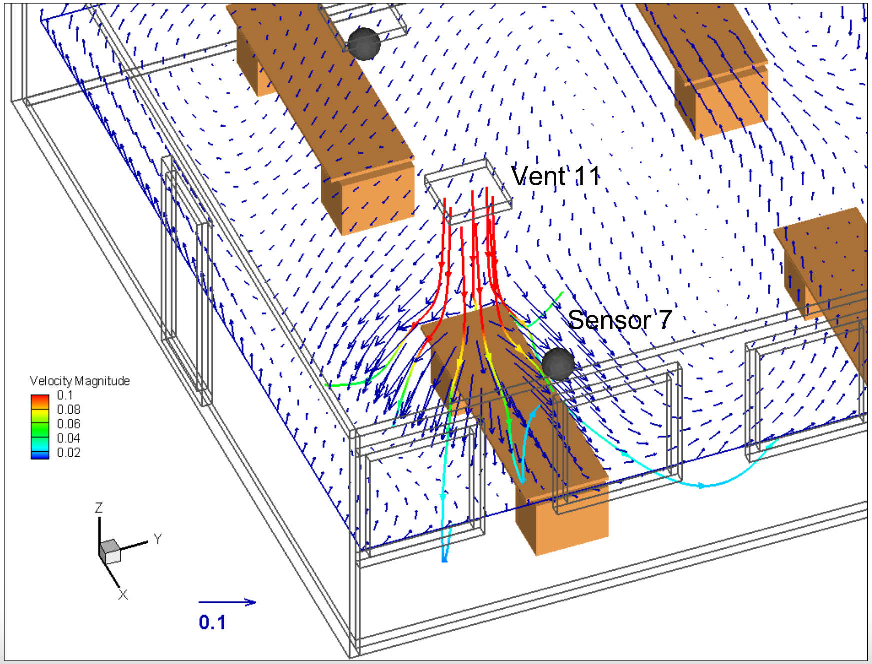
- **General flow features are retained…**
- **…but differences are also present**
  - **especially at sensor 2 (and 3), but also 6 (and 7)**
- **More geometrical details → lower uniformity at C**
- **Temperature/ inlet conditions more critical than grid**
- ***Preliminary* LES has in general lower av. 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)

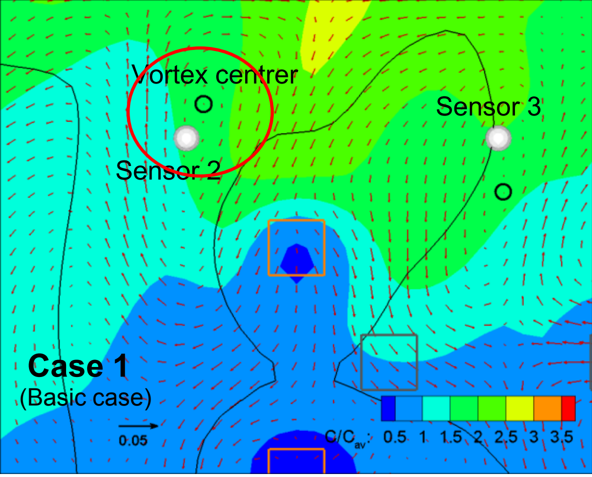




Alternative modelling: Focus on sensor 7 values

- **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**

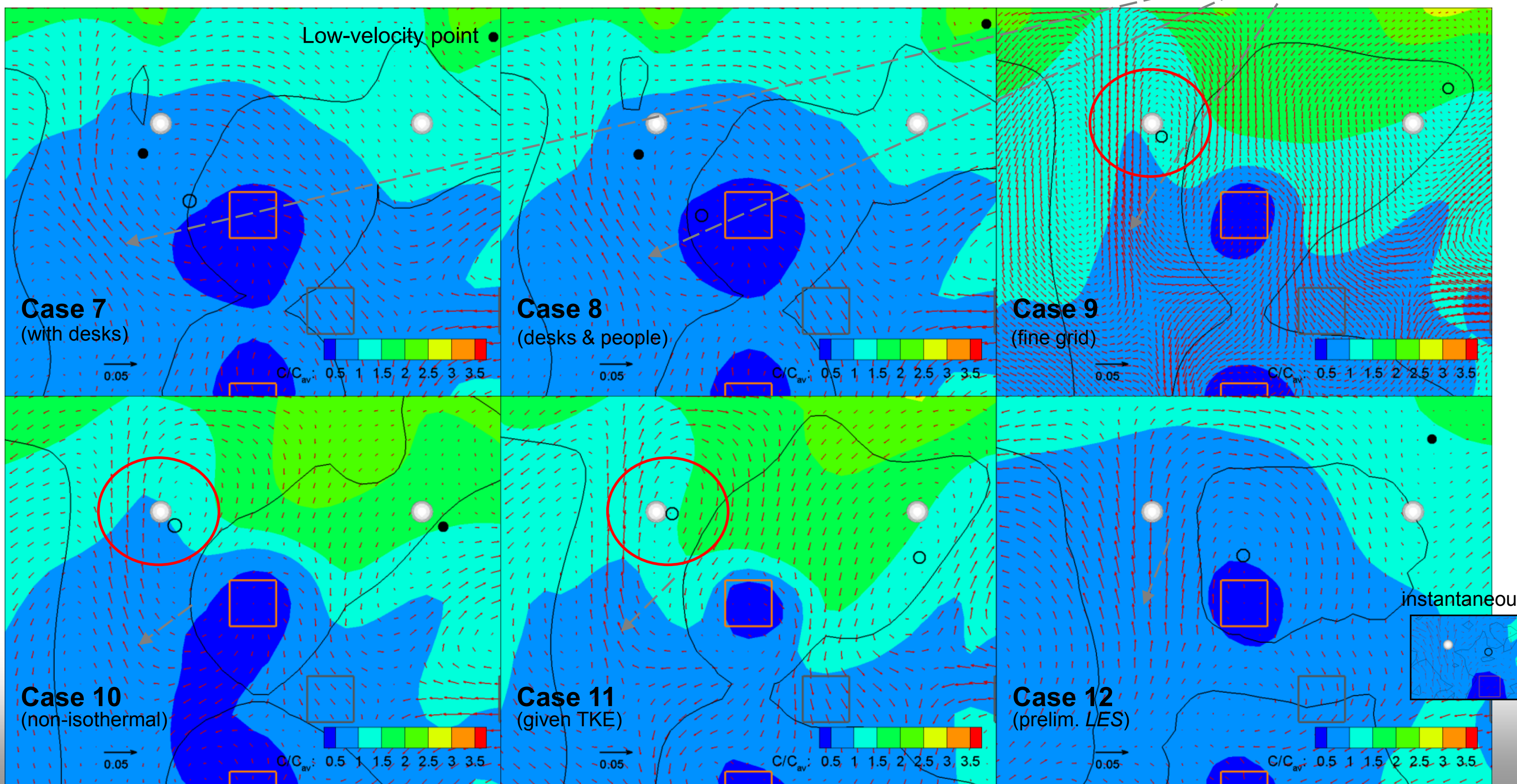




Alternative modelling: Focus on sensors 2 and 3

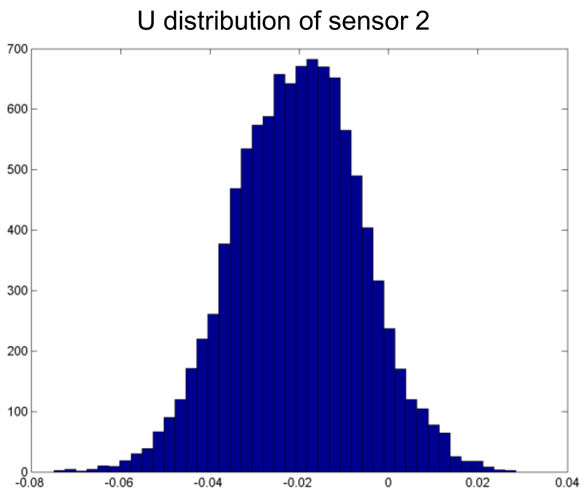
Differences among runs, esp. for sensor 2

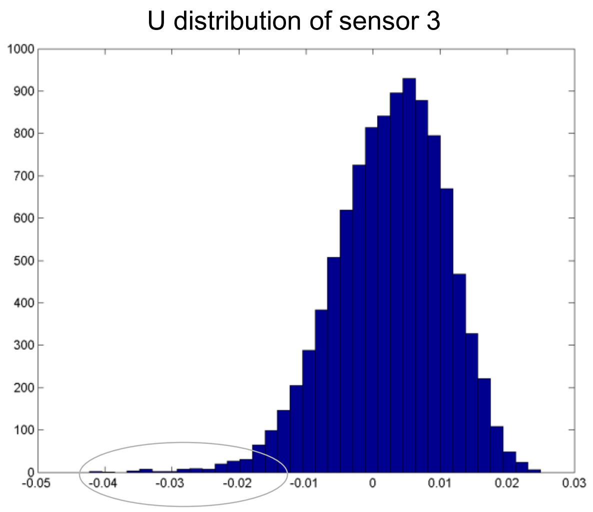
- Unsteady flow – close to (unsteady) vortex center
- Sensor 2: clean air transferred from elsewhere



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

This is a follow-up work of the EU FP7 project

OFFICAIR (On the reduction of health effects from combined exposure to indoor air pollutants in modern office buildings)

Funded under the topic :

ENV.2010.1.2.2-1: Indoor air pollution and health risks of modern office buildings

Ευχαριστώ

Thank you