Performance of Wall Confluent Jets Ventilation System in School Environment compared with Displacement Ventilation

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HÖGSKOLAN I GÄVLE

School ventilation: **challenging from thermal comfort and air quality considerations**

- In schools, the number of students per square metre of floor area has increased during the last decade.
- Increase in heat load has caused indoor climate problems in schools .
- Ventilation systems that have been designed for other applications may not perform well in school buildings.

Supply Methods

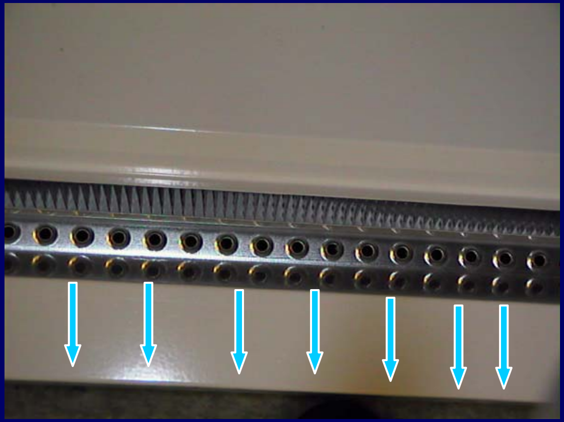
- **The method of supplying conditioned air to a room or a zone in a building has a direct impact on:**

  - ✓**The air quality in the zone**
  - ✓**The thermal comfort in the zone**
  - ✓**The energy consumption of the HVAC system**
  - ✓**The facility management schedules**

Definition

- In ventilation, a confluent jet is formed, when circular jets issuing from different apertures in the same plane flow in parallel directions, and at a certain distance downstream they coalesce and move as a single jet .
- Two type of configurations:
  (a) Ceiling level
  (b) floor level (blowing to the wall)

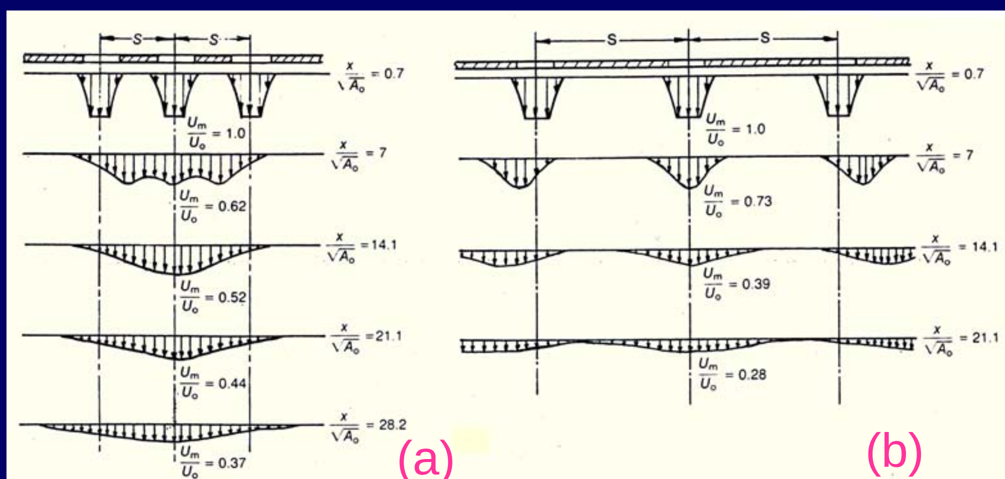
(a)

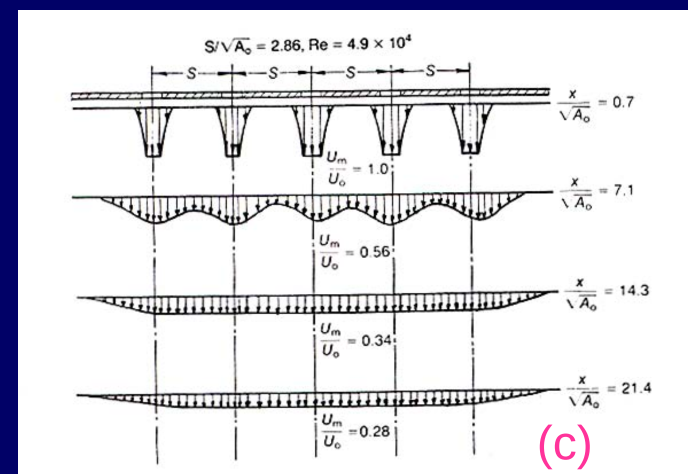


(b)

Spacing: Confluent Jets

- **The distance from the outlets at which the jets merge depends on the distance between and the area of the outlets.**





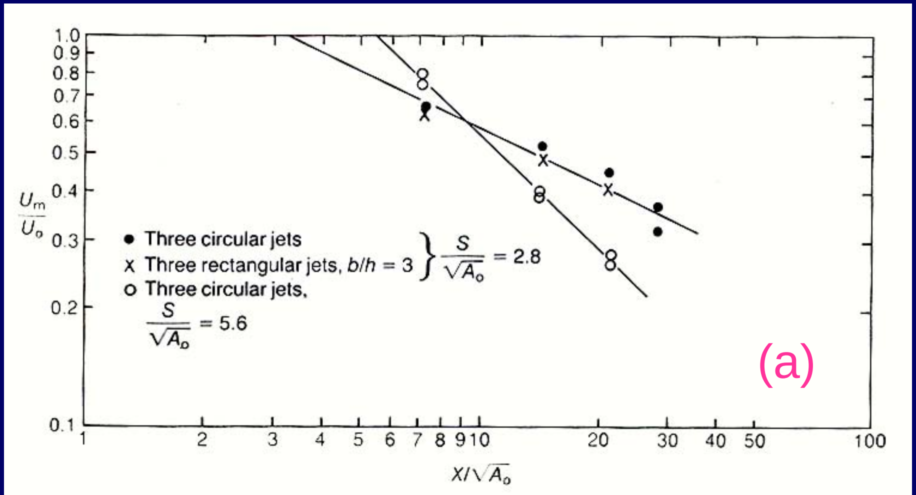
Velocity profiles for confluent circular jets. (a) Closely-spaced $S/\sqrt{A_o} = 2.8,\ \mathrm{Re}=8\times10^4$

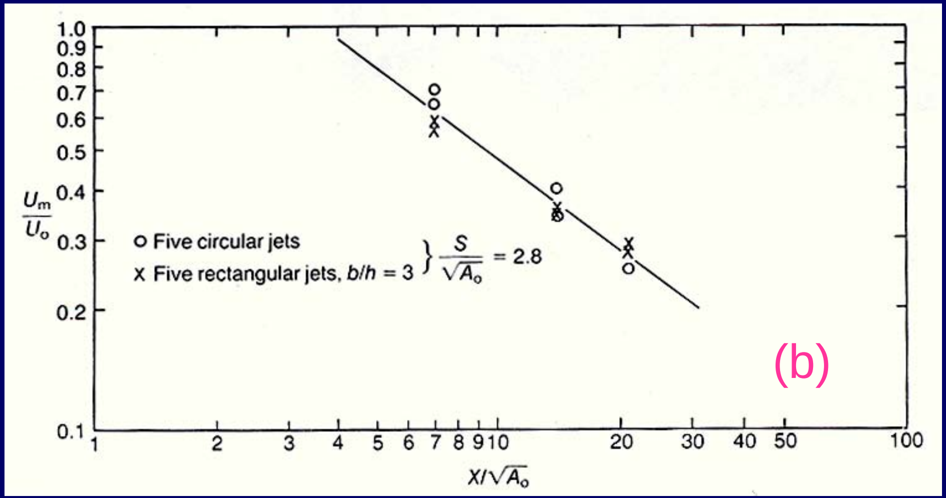
(b) widely-spaced $S/\sqrt{A_o} = 5.6,\ \mathrm{Re}=5.8\times10^4$ Awbi (2003)

(c) Velocity profiles for five confluent circular jets $S/\sqrt{A_o} = 2.86,\ \mathrm{Re}=4.9\times10^4$.

Definition: Confluent Jets /Con…

Awbi (2003)





(a) Velocity decay for three confluent jets (circular & rectangular openings).

(b) Velocity decay for five confluent jets (circular & rectangular openings).

MECHANICAL VENTILATION

Mixing Air Distribution

A mixing ventilation system aims to dilute the indoor pollutants by mixing fresh air with room air. Usually, an air jet is supplied at high level to achieve the mixing and provide acceptable velocities at low level.

Ventilation efficiency < 50% (if one choose 50% as perfect mixing!!!).

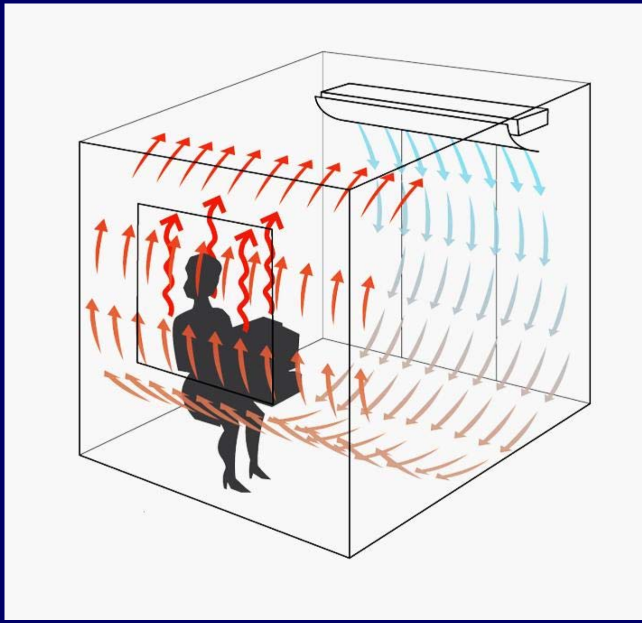
Displacement Ventilation

Here, air is usually supplied directly into the occupied zone at low velocity and heat and indoor pollutants are displaced upwards due to the plumes rising above heat sources in the room. The ventilation efficiency is usually >>50%.

Wall DV units are only suitable for small cooling loads (<40W/m^2) and for higher loads chilled ceiling panels or chilled beams are used to supplement the cooling.

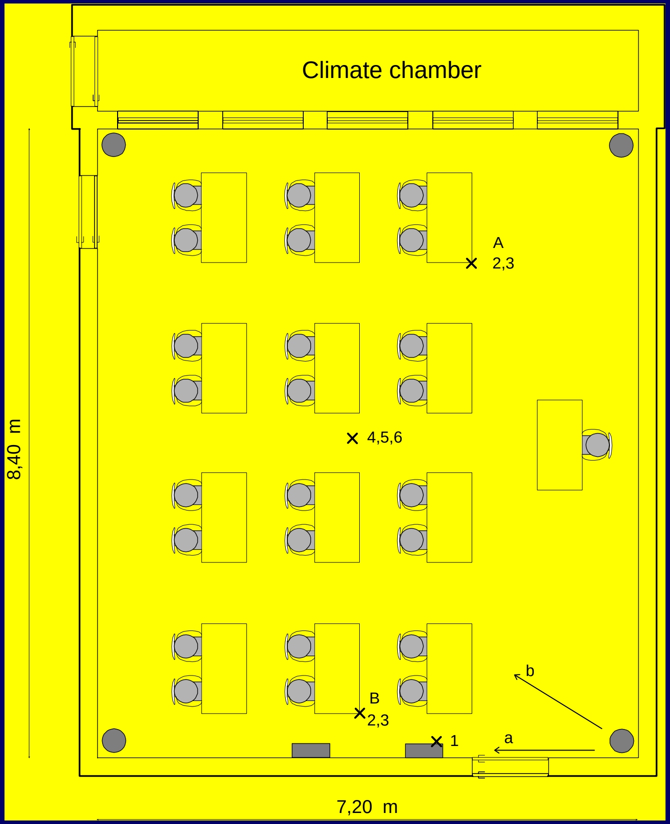
Confluent Jets Ventilation

- Here a jet of air is supplied downward on to the floor with quite a high momentum (i.e. resembling mixing ventilation) but the velocity decays very rapidly away from the point of impact on the floor. This method is suitable for cooling and heating.
- The ventilation efficiency is usually >>50% .
- Confluent jets units are suitable for high cooling loads (>40W/m^2 ; 60W/m^2 was tested in Reading climate chamber).



BMG Lab. Gävle, Sweden

a Teacher & 24 Students



Heat Loads

Classroom Loads used in the CFD simulations

(8.4∗7.2∗3 m)

Load	Surface Area [m^2]	Cooling Load	Heating Load
Window gain (loss) 25 person simulators Light (9 lamps)	7.9 1.69 each 0.87 each	776 2375 525	(-517) 2375 525
Total (W)		3676	2383
Total (W/m^2)		63	41

B.C.: Inlet velocity and wall temperatures were obtained from measurements

We need parameters to compare systems

Fangers Definitioner (ISO 7730; 1994)

- Percentage of dissatisfied with the indoor air quality:

$$PD = 395 \cdot \exp\left(-1.83\dot{v}^{0.25}\right)$$

- Percentage of dissatisfied with the thermal environment:

$$PPD = 100 - \exp - \left\{0.03353\left(PMV\right)^4 + 0.2179\left(PMV\right)^2\right\}$$

Definitions & ADI (Air Quality Index), Ventilation Parameter

Ventilations Efficiency for Heat Removal:

$$\varepsilon_t = \frac{T_o - T_i}{\overline{T} - T_i}$$

Ventilations Effectiveness for Contaminant Removal:

$$\varepsilon_c = \frac{C_o - C_i}{\overline{C} - C_i}$$

Thermal comfort Number:

$$N_t = \frac{\varepsilon_t}{PPD}$$

Air Quality Number:

$$N_c = \frac{\varepsilon_c}{PD}$$

Ventilations Parameter (VP)
or
Air Distribution Index (ADI)

$$ADI = \sqrt{N_t \times N_c}$$

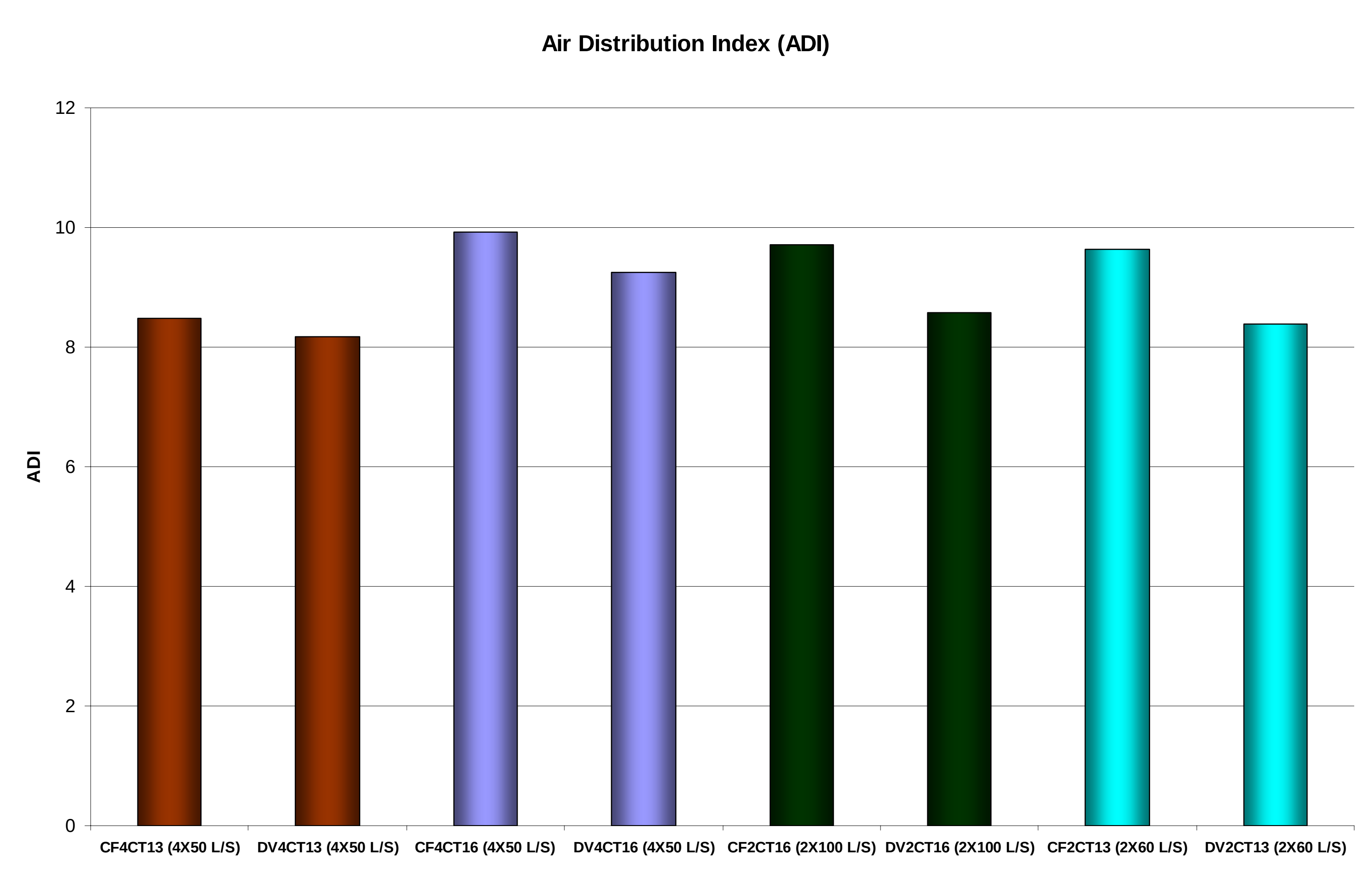
Measurements in Classroom BMG, Gävle

Case	No. of Terminals x flow rate [l/s]	Position (See FIG.)	Local Air Exchange Index $\frac{\tau_n}{\tau_p}$					Air Exchange Effectiveness $\frac{\tau_n}{2\langle\bar{\tau}\rangle}\times 100$	
			Point no. 2	Point no. 3	Point no. 4	Point no. 5	Point no. 6	EXP.	CFD
DV4C_A50	4 x 50	A+middle	1.28	0.68	1.19	0.95	0.79	43	48
CF4C_A50	4 x 50	A+middle	1.195	1.155	1.32	1.35	1.145	56	54
CF4C_B50	4 x 50	B+middle	1.48	1.28	1.10	1.19	1.06	73	54
CF4C_B3	4 x 32	B+middle	1.755	1.61	1.43	1.36	1.26	50	52
CF2_B60	2 x 60	B+middle	1.75	1.52	1.58	1.43	1.22	51	50
CF2C_B100	2 x 100	B+middle	1.20	1.1	1.11	1.12	1.01	51	52

DV = Displacement system   *CF= Confluent Jets System*

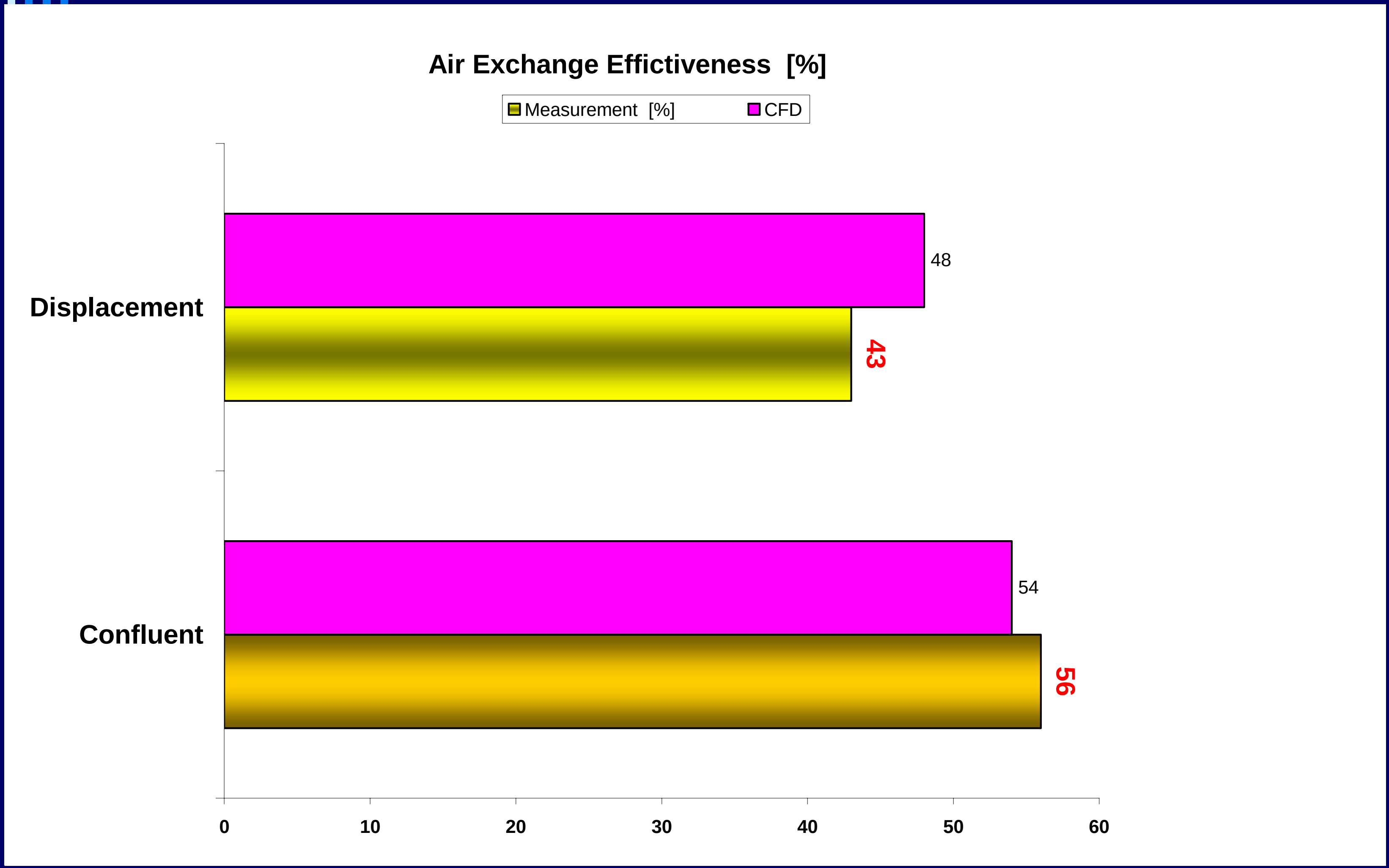
COMFORT AND AIR QUALITY					Vortex version	Case	No of device Times flow rate (l/s)
VENTILATION EFFECTIVENESS [%]	VENTILATION EFFICIENCY [%]	COMFORT NUMBER FOR AIR QUALITY [-]	COMFORT NUMBER FOR THERMAL SENSATION [-]	AIR DISTRIBUTION INDEX (ADI)) [-]			
102.3	105.1	5.622	12.74	8.464	Vortex3Cκ-ε	CF4CT13	4 x 50
98.46	99.50	5.411	12.37	8.180	Vortex3Cκ-ε	DV4CT13	4 x 50
107.8	125.1	5.922	16.65	9.931	Vortex3Cκ-ε	CF4CT16	4 x 50
113.6	129.8	6.245	16.75	10.23	V4D-RNG	CF4CT16	4 x 50
98.43	113.5	5.409	15.83	9.253	Vortex3Cκ-ε	DV4CT16	4 x 50
101.6	115.0	5.583	15.69	9.359	V4D-RNG	DV4CT16	4 x 50
111.8	98.06	6.144	12.19	8.654	Vortex3Cκ-ε	CF2CT13	2 x 100
94.82	91.92	5.211	11.66	7.795	Vortex3Cκ-ε	DV2CT13	2 x 100
108.3	114.0	5.954	15.81	9.702	Vortex3Cκ-ε	CF2CT16	2 x 100
92.07	145.2	5.060	14.53	8.574	Vortex3Cκ-ε	DV2CT16	2 x 100
119.5	121.5	6.570	16.10	10.28	V4D-RNG	CF2CT16	2 x 100
113.5	163.8	4.506	19.66	9.412	Vortex3Cκ-ε	CF4T13 30Lit	4 x 30
117.5	165.4	4.466	20.79	9.636	Vortex3Cκ-ε	CF2T13 60Lit	2 x 60
98.83	128.8	3.756	18.69	8.379	Vortex3Cκ-ε	DV2T13 60Lit	2 x 60

CF = Confluent Jets DV= Displacement T16 – T13 = Supply temp 16℃ and 13℃ respectively


Air Distribution Index (ADI)
ADI
12
10
8
6
4
2
0
CF4CT13 (4X50 L/S)
DV4CT13 (4X50 L/S)
CF4CT16 (4X50 L/S)
DV4CT16 (4X50 L/S)
CF2CT16 (2X100 L/S)
DV2CT16 (2X100 L/S)
CF2CT13 (2X60 L/S)
DV2CT13 (2X60 L/S)

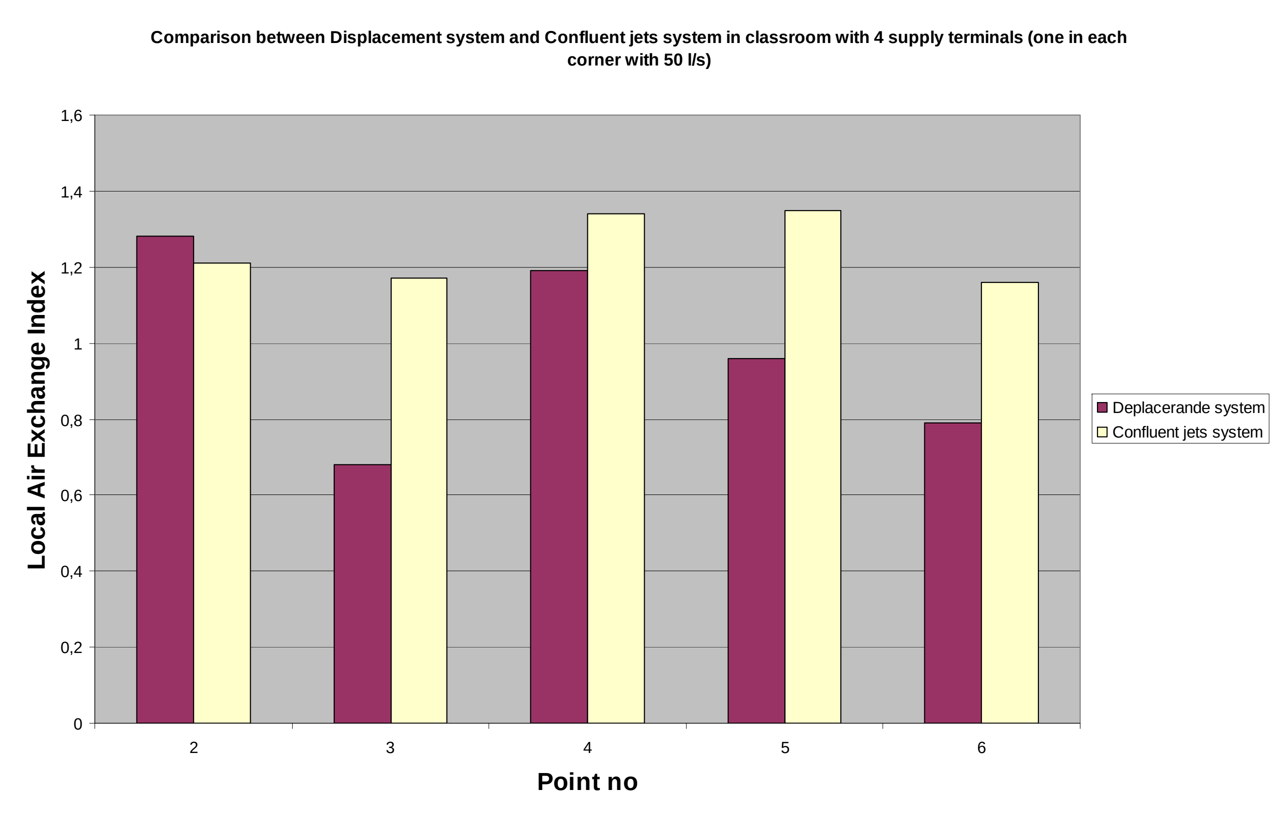
Measured and calculated velocities [m/s] and Temperatures [℃] for Confluent Jets Supply terminal, Case CF4CT16, Four device placed at the corners and the flow rate of 50 l/s for each device Distance from the wall is 3 cm.

Height above floor (m)		Distance from supply (m), along the directions shown by the arrows in Fig. 3											
		0.5		1.0		1.5		2.0		2.5		3.0	
		Temp (ºC)	Vel. (ms^{-1})	Temp (ºC)	Vel. (ms^{-1})	Tem p (ºC)	Vel. (ms^{-1})	Temp (ºC)	Vel. (ms^{-1})	Temp (ºC)	Vel. (ms^{-1})	Temp (ºC)	Vel. (ms^{-1})
0.10	Exp.	19.5	0.65	19.9	0.55	20.3	0.48	20.5	0.47	20.6	0.43	21.0	0.33
	κ-ε RNG	19.2 19.0	0.6 0.56	20.1 19.7	0.40 0.57	20.2 20.6	0.35 0.51	21.2 21.1	0.32 0.39	21.3 21.3	0.30 0.32	21.7 21.6	0.29 0.34
0.25	Exp.	19.7	0.59	20.2	0.59	20.5	0.46	20.6	0.41	21.0	0.32	21.2	0.24
	κ-ε RNG	19.8 19.6	0.31 0.45	21.6 21.4	0.36 0.51	21.9 21.9	0.29 0.42	22.1 22.0	0.21 0.39	22.1 22.0	0.20 0.30	22.1 22.0	0.10 0.20
0.40	Exp.	19.8	0.88	20.3	0.64	20.8	0.43	21.0	0.36	21.2	0.29	21.4	0.21
	κ-ε RNG	22.5 22.3	0.35 0.70	21.9 21.6	0.31 0.52	22.0 21.7	0.25 0.39	22.1 21.8	0.18 0.30	22.2 22.0	0.18 0.20	22.3 22.1	0.08 0.18
0.60	Exp.	20.3	0.66	20.6	0.59	21.0	0.40	21.2	0.29	21.4	0.25	21.6	0.19
	κ-ε RNG	22.6 22.6	0.30 0.58	22.5 22.4	0.21 0.55	22.4 22.2	0.25 0.36	22.3 22.3	0.10 0.30	22.5 22.3	0.06 0.20	22.5 22.3	0.08 0.15
0.80	Exp.	20.6	0.54	21.0	0.52	21.3	0.32	21.5	0.26	21.7	0.22	21.9	0.15
	κ-ε RNG	22.7 22.7	0.11 0.46	22.8 22.6	0.15 0.41	22.8 22.5	0.10 0.28	22.8 22.6	0.08 0.23	22.7 22.5	0.03 0.19	22.7 22.5	0.03 0.09



Air exchange effectiveness: $\frac{\tau_n}{2 \cdot \langle \bar{\tau} \rangle}$

Measurements in BMG classroom, Gävle

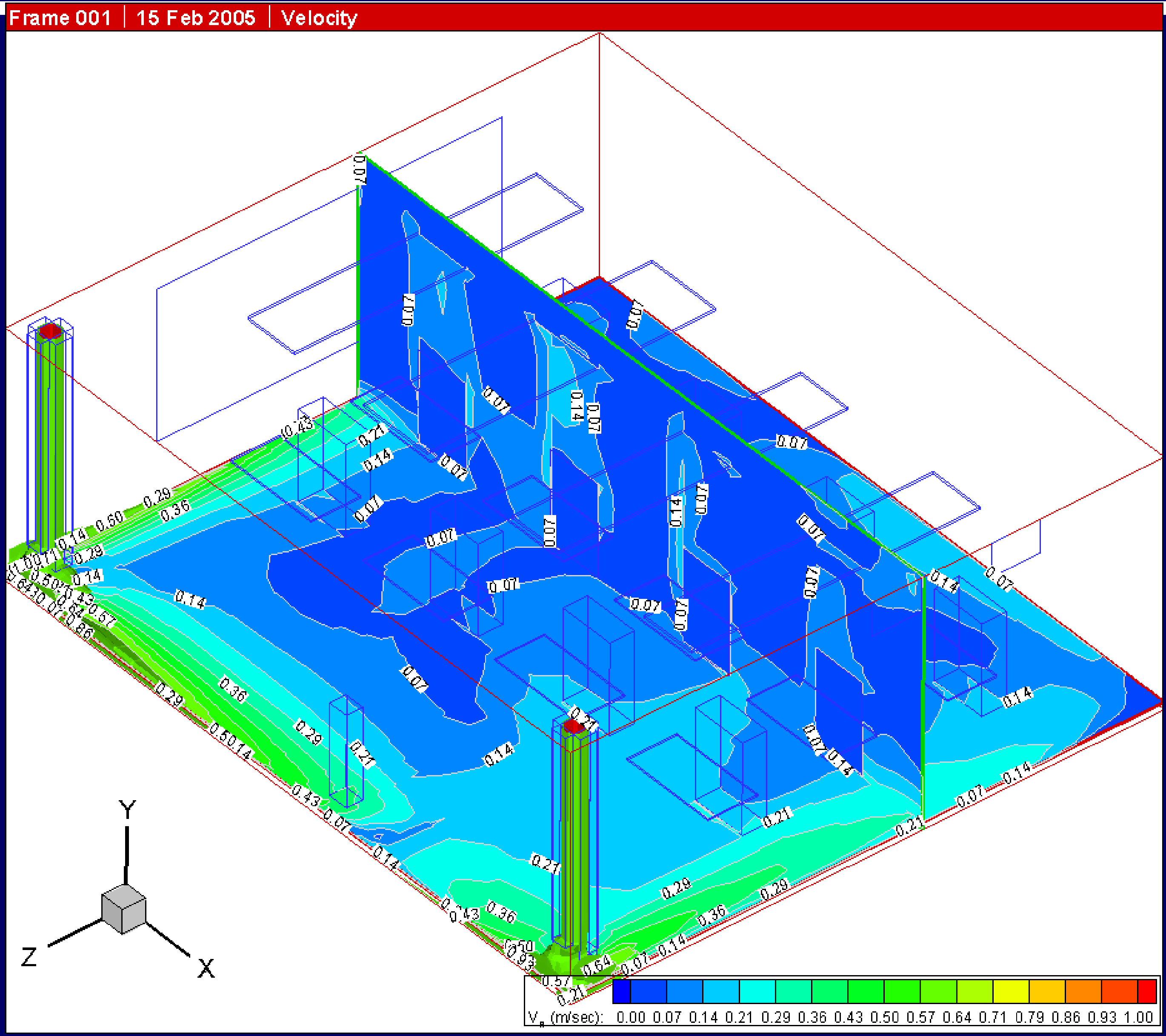


Local Air Exchange >1

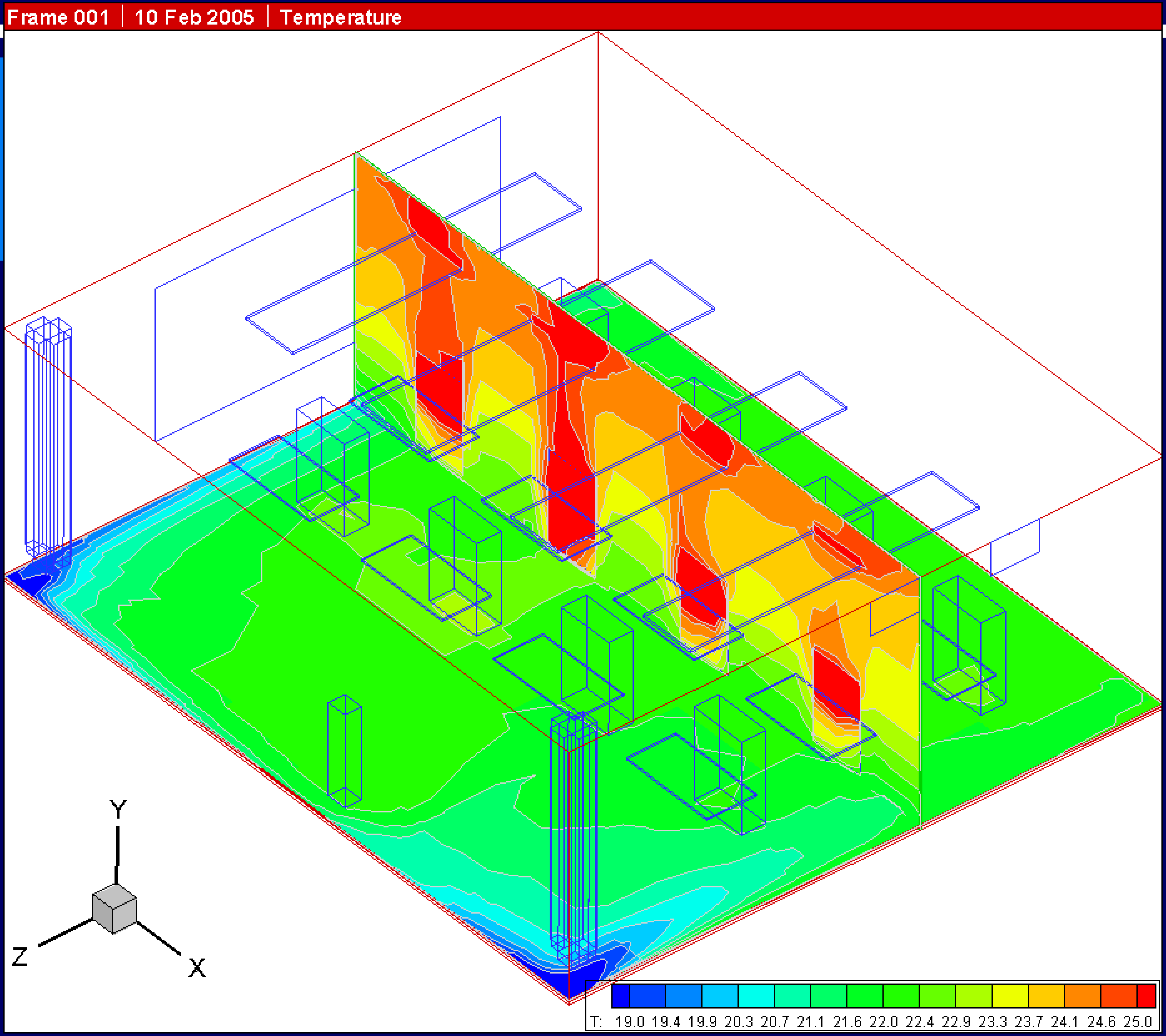
Good Air Exchange

$$\frac{\tau_n}{\tau_p}$$

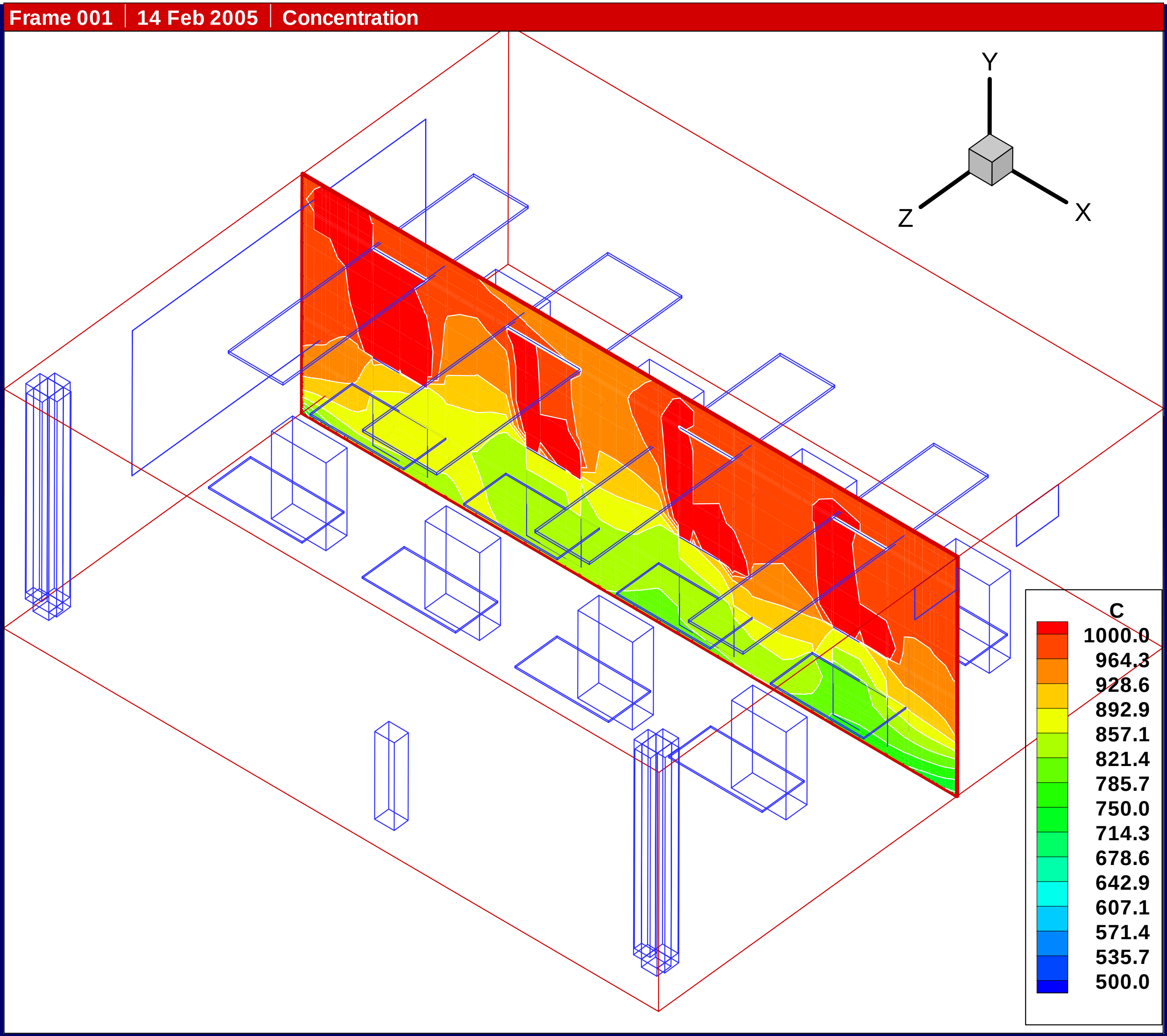
Def.: Local Air Exchange Index=(Nominal time constant)/(Local mean age at the point)



Velocity pattern for Confluent Jets System (Case CF2CT16)



Temperature field for Confluent Jets System (Case CF2CT16)



Concentration for Confluent Jets System (Case CF2CT16)

Conclusions

- The Wall Confluent Jets Ventilation System is a promising system for use in schools.
- The RNG turbulence model (κ-ε model as well) gives promising results for room air flow pattern.
- One should be careful about the errors in measurements particularly resulting from the short air velocity sampling period.
- Wall confluent jets can successfully be used for both heating and cooling – a combined effect of mixing and displacement systems .
- CFD can be used successfully in predicting thermal comfort and air quality for indoor air climate.