CFD as a Tool for Thermal Comfort Assessment

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OUTLINE

- Introduction - Aim
- Governing equations & numerical solution
- Room ventilation test cases:

  - Cooling ventilation

  - Heating ventilation

  - Results: air velocity and temperature distributions, ventilation efficiency, evaluation of thermal comfort indices
- Conclusions - future research

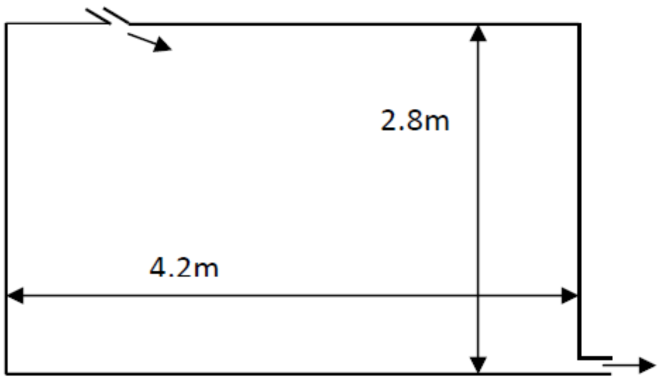
AIM - MOTIVATION

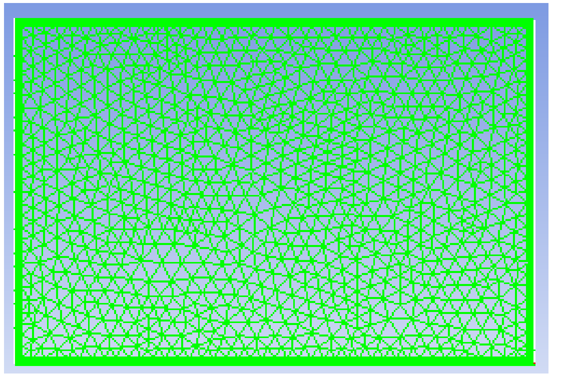
- Ventilation and air-conditioning systems aim to thermal comfort and indoor air quality (IAQ).
- This greatly depends on the local air velocity and temperature distributions in the space.
- Tedious local measurements or numerical CFD simulations are required.
- Practical criteria for local and average air velocity and temperature distributions in order to achieve thermal comfort are available in the literature, even in textbooks.
- Research on thermal comfort greatly rely on experiments and statistics.
- Main difficulty: to consider all the parameters affecting thermal comfort (environmental, personal, subjective), qualitatively and quantitatively (derivation of appropriate indices).
- AIM: To demonstrate CFD application in
  - the assessment of ventilation strategies
  - the numerical prediction of thermal comfort

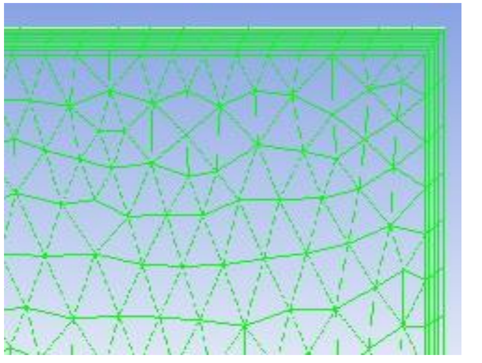
GOVERNING EQUATIONS

- Incompressible, steady, 2D, Reynolds-averaged Navier-Stokes equations (continuity, momentum, thermal energy).
- Gravity terms & buoyancy effects (Boussinesq model).
- Finite Volume method, SIMPLE pressure correction scheme .
- Second order spatial accuracy for the convective terms of the mean flow equations.
- Standard k-ε two-equation eddy-viscosity turbulence model.
- 2D triangular, quadrangular or hybrid grids.
- Boundary conditions: no slip for velocity at walls, Dirichlet for temperature, except a heat flux was prescribed.
- Wall functions model for velocity and temperature, enhanced wall treatment version (that automatically switches to a two-layer low Reynolds approach and resolves the boundary layer up to the wall wherever a small value of y^+ is met).

COOLING VENTILATION CASE





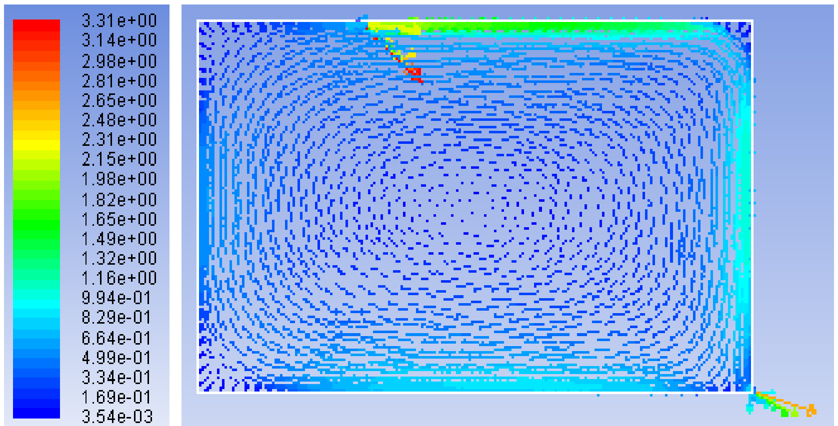


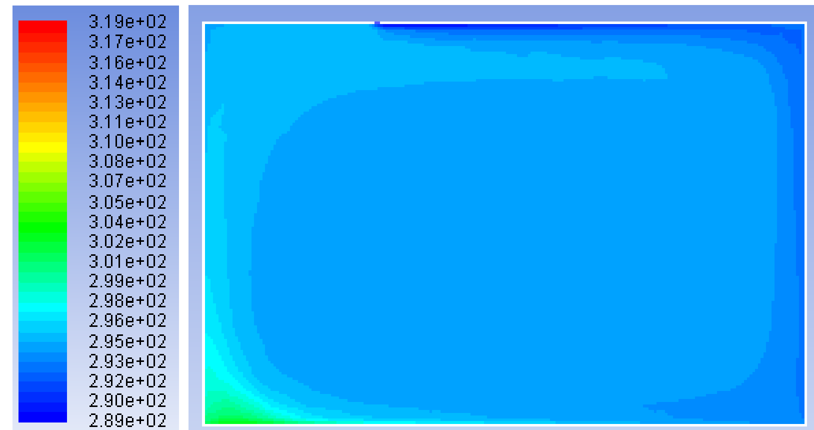
- 3D test room “designed for evaluating the performance of ceiling diffusers” (Awbi, 1989).
- Square floor 4.2m x 4.2m and 2.8 m height.
- Heat load was produced by electrically heated tapes over the floor.
- Experimental vertical distributions of mean velocity and temperature in the occupied zone.
- 2D simulations can be used in the symmetry plane of the room longitudinally.
- Grid of mixed trianglular and quadranglular elements (8614 elements/5154 nodes).

Conditions for the Cooling Ventilation Case

Case	[l/s/m]	ΔT_o[°C]	q_{floor}[W/m]	T_S [°C]	$T_R=T_{wall}$[°C]
A	30	-8.4	86.8	12.1	20.5
B	48	-7.2	99.2	13.3	20.5
C	60	-5.5	94.8	15.0	20.5

RESULTS (1/4)

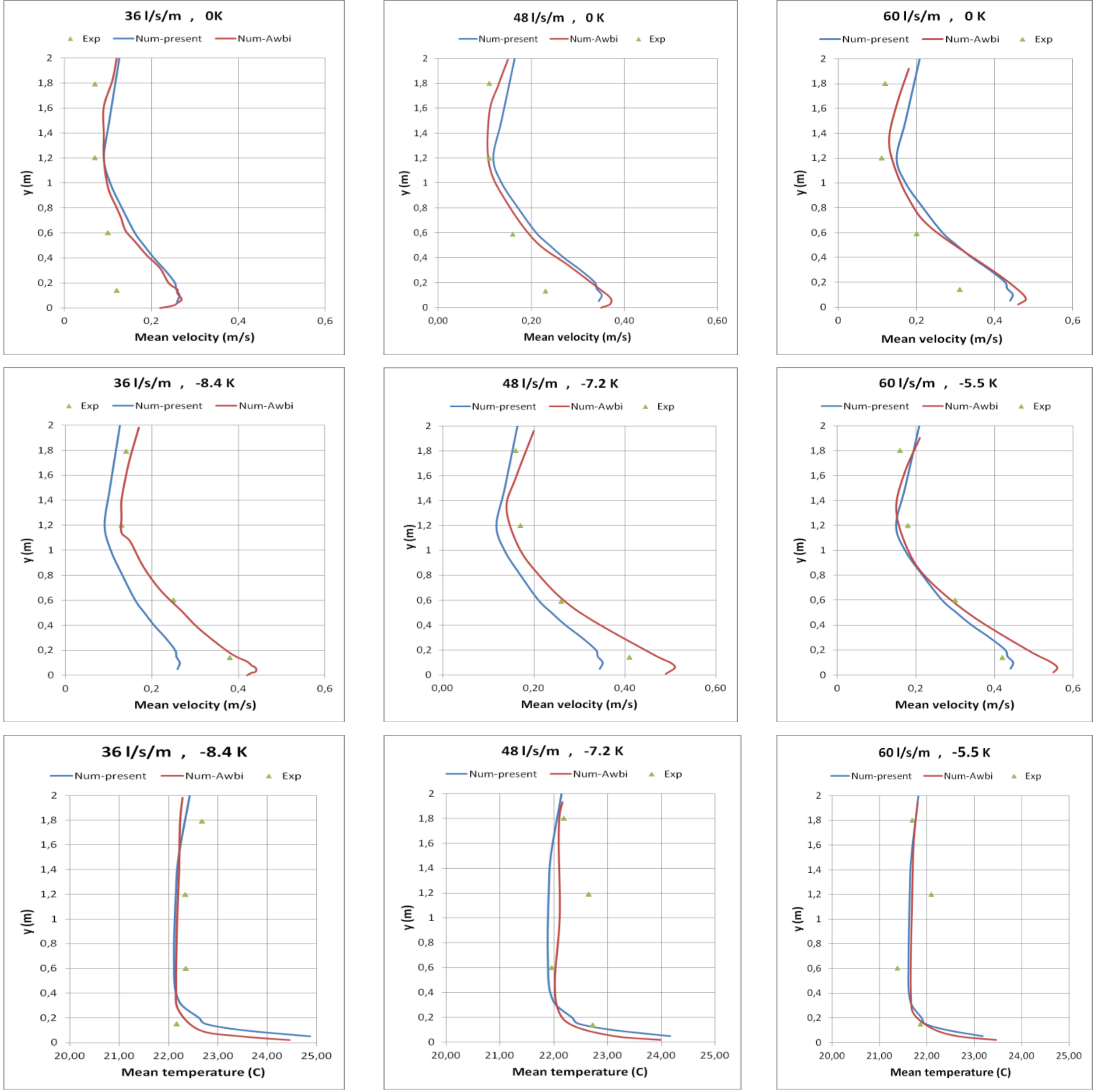




Non-isothermal problem C

- Extended recirculation zone at the central region of the occupied zone consisting of very small velocity values.
- At steady state: supply air moves perimetrically.
- A part leaves the room from the outlet slot at a rate equal to the mass inflow.
- The rest recirculates in the room.
- While passing above the floor, it removes the heating load.
- Uniform distribution of temperature in the occupied zone.

RESULTS (2/4)


36 l/s/m , 0K
Exp
Num-present
Num-Awbi
y (m)
Mean velocity (m/s)
48 l/s/m , 0 K
Num-present
Num-Awbi
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y (m)
Mean velocity (m/s)
60 l/s/m , 0 K
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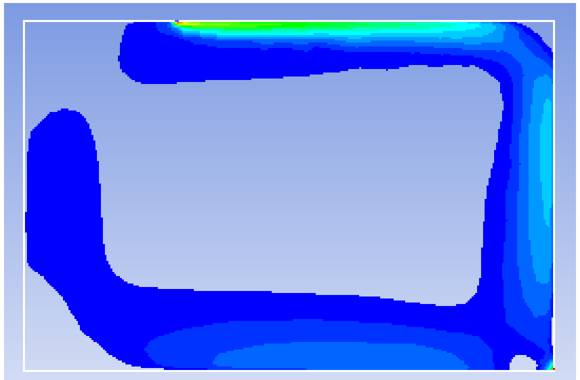
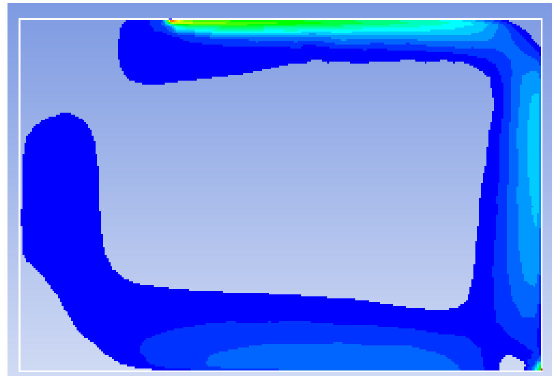
Mean temperature (C)

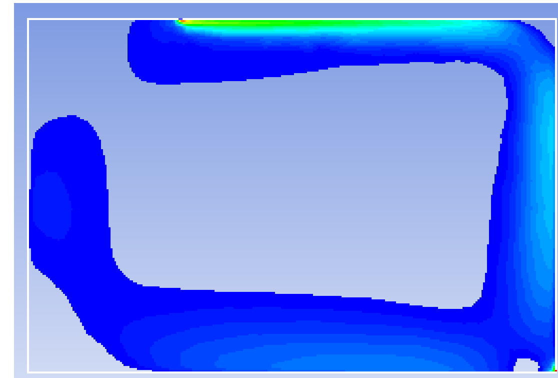
RESULTS (3/4)



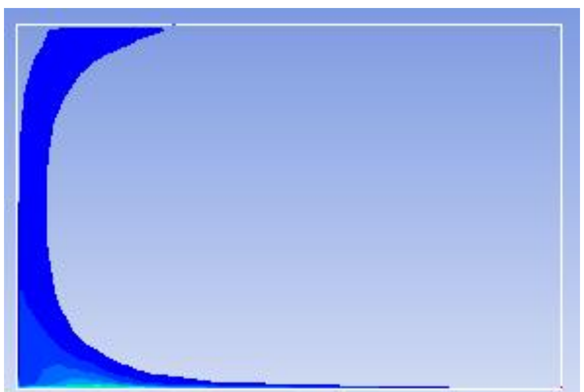
V > 0.15 m/s



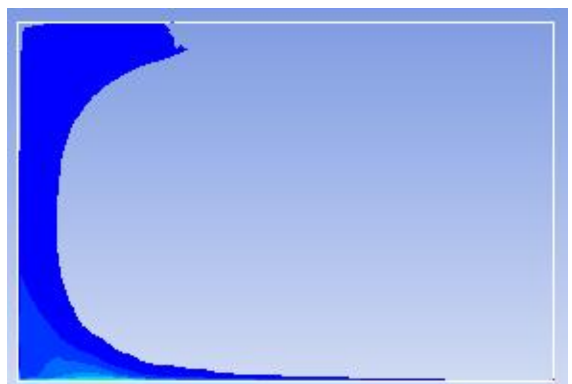
V > 0.20 m/s



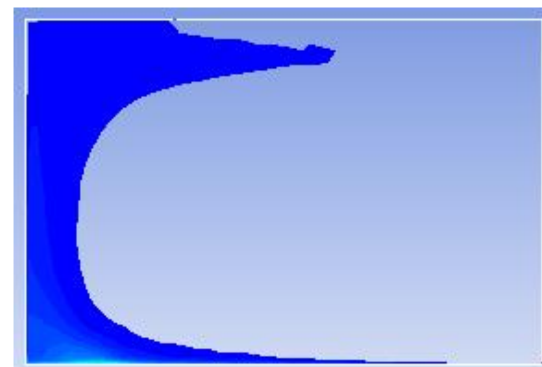
V > 0.25 m/s



T > 24 ^{o}C



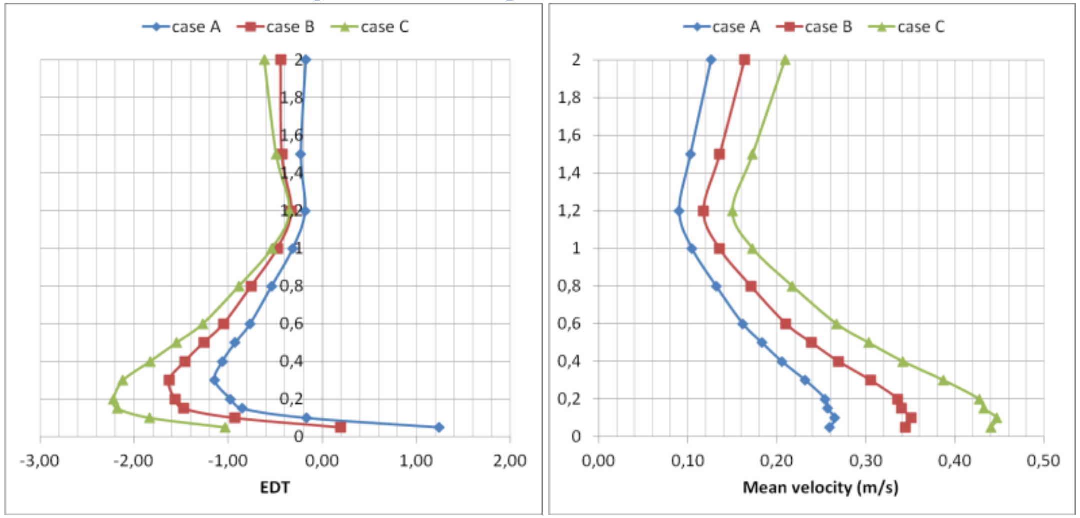
T > 23 ^{o}C



T > 22 ^{o}C

Velocity (V) and Temperature (T) greater than indicative threshold values are shown (V threshold values are representative of what people can tolerate from a thermal comfort point of view).

RESULTS (4/4)



Ventilation efficiency

$E=(T_R-T_S)/(T_m-T_S)$ 100% = **78.5%**

Effective Draught Temperature

$EDT=(T-T_m)-7.65(U-0.152)$

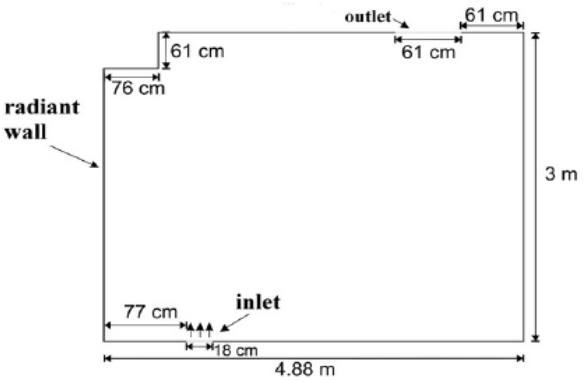
(T °C, U m/s, EDT °C) (Jones, 1989)

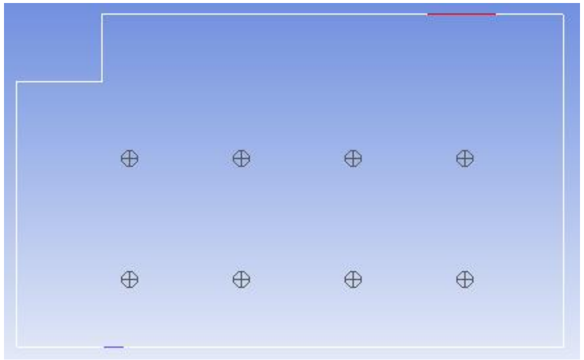
- Indicative air distribution index: relates air velocity with EDT in the occupied space.
- Air distribution performance of a ventilation system is expressed by the percentage of positions in the occupied zone that :

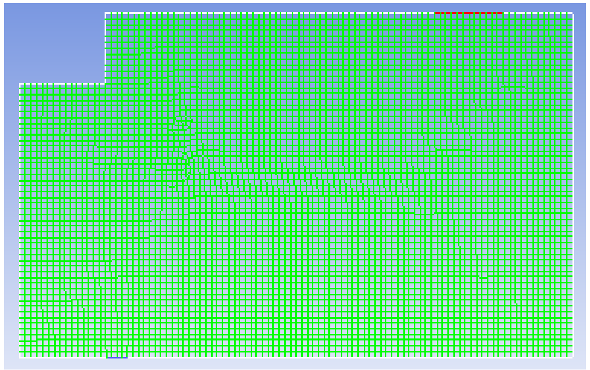
  -1.7°C < EDT < 1.1°C and, at the same location, V< 0.35m/s

  (80% is regarded as satisfactory)
- Instead of local EDT and V, vertical distribution of mean EDT and V values were computed herein on planes above the floor.
- Satisfaction of air distribution index for cases A and B: **100%**
- Satisfaction of air distribution index for case C: **69%** (it involves smaller temperatures in combination with greater velocities that can potentially inhibit thermal comfort).

HEATING VENTILATION CASE

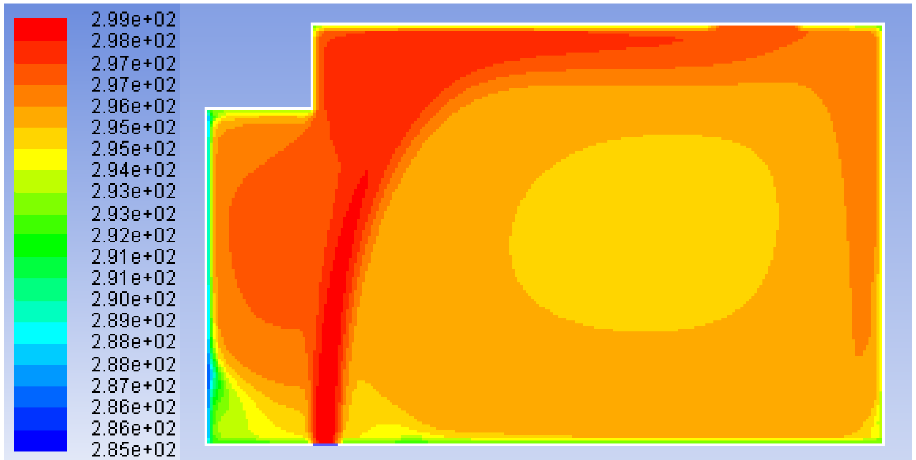


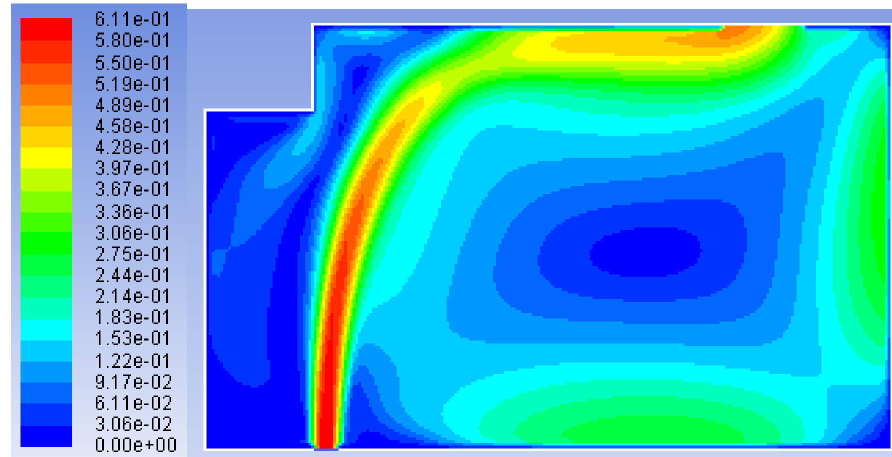




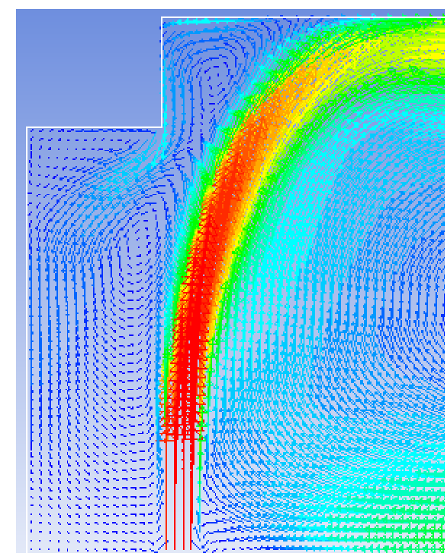
- Ventilation of a 3D room for heating purposes (orthogonal floor 3.66mx4.88m and 3m height) (Chafi and Halle, 2011).
- The room exhibits heat loss due to its radiant left wall maintained at a temperature of 12^{o}C, while the rest of the walls are at a temperature of about 20^{o}C.
- Air is supplied from a 18mm width continuous slot diffuser, located to its floor, while a second slot on the ceiling serves as an outlet.
- Experimental velocity and temperature measurements at eight points in the occupied zone, at heights 0.6m and 1.7m, at distances 1, 2, 3 and 4m from the left wall.
- 2D simulations were used in the symmetry plane of the room longitudinally.
- Unstructured grid consisting of quadrangular elements (5684 elements/5842 nodes).
- Inlet velocity: 1.6m/s. Temperatures: 25.8^{o}C at inlet, 12^{o}C at left wall, 20^{o}C at ceiling and right wall, 19^{o}C at floor and convective flow at the outflow.

RESULTS (1/2)





- Uniform temperature distribution in the occupied zone is achieved.
- An extended recirculation zone evolves that allows for very small velocities at the central region of the occupied zone.
- In steady state, the supply air moves perimetrically.
- A part of it leaves the room from outlet slot at a rate equal to the mass inflow, while the rest recirculates in the room.
- The air jet from the floor actually isolates the cold wall and prevents the heat loss towards it by creating a secondary recirculation zone between the inflow jet and this wall.



RESULTS (2/2)

Point	Velocity (m/s)			Temperature (°C)			EDT
	Present	Num	Exp	Present	Num	Exp	
1	0.29	0.21	0.16	23.9	20.3	20.7	0,04
2	0.14	0.16	0.10	22.6	20.5	19.5	-0,11
3	0.16	0.15	<0.05	22.5	20.3	19.7	-0,36
4	0.14	0. 03	0.02	22.7	20.2	19.6	-0,01
5	0.43	0.16	0.2	24.9	21.4	19.6	-0,03
6	0.12	0.26	0.15	22.4	20.7	21.7	-0,16
7	0.06	0.20	0.08	22.2	20.5	20.9	0,10
8	0.08	0.02	<0.02	22.3	20.5	20.9	0,05

Predicted velocity and temperature values against numerical and experimental results

- The numerical results for the velocity are generally close each other, but seem to overestimate velocity compared to the measured values.
- Greater temperature values have been predicted by (Chafi and Halle, 2011) with respect to the experimental ones. Temperatures by the present results are even greater.
- Based on the mean temperature in the room (T_m=22.8°C), the ventilation effectiveness (for heat replenishment) in this case was found **67%**.
- Effective Draught Temperature (EDT) was calculated for the eight points based on local temperature and velocity values. Satisfaction of air distribution index: **100%**.

CONCLUSIONS–FUTURE RESEARCH

- Two ventilation cases concerning room cooling and heating were numerically simulated by means of CFD.
- Temperature and velocity distribution predictions were satisfactory compared to corresponding experimental and numerical results from the literature.
- The numerical prediction of thermal indices was presented to demonstrate the capability of CFD as a tool to evaluate thermal comfort.
- Future research includes:

  - simulation in 3D spaces

  - natural ventilation flows

  - calculation of other thermal comfort indices (e.g. Fanger).

CFD as a Tool for Thermal Comfort Assessment

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