Numerical investigation of airflow in an open geometry

Boris BRANGEON[1], Alain BASTIDE[1], Patrice JOUBERT[2].

Corresponding email : boris.brangeon@univ-reunion.fr

INTRODUCTION

This paper presents a numerical investigation of airflow in an open geometry. The case under consideration is a room with two opposite and decentred openings which create a strong potential for ventilation. This study is the first step in a global work (wall to fluid heat transfer, flow zones definition, turbulence model test and selection, radiative heat transfer, etc. . .), but here only natural convection is considered. This room model proceeds from a benchmark exercise “ADNBATI” [1] (http ://adnbati.limsi.fr) coordinated by the ”Centre National de la Recherche Française -CNRS-“.

BUILDING CHARACTERISTICS

The building characteristics dimensions are the followings : H = 2.50 m height and W = 6.50 m width . The opening ratio H_1/H_2 equals 0.5. Ra is the Rayleigh number based on the cavity height H. A temperature difference between the inside walls and the outside air is fixed, resulting in a characteristic Rayleigh number ranging from 10^5 to 1.49 10^8.

Height low East opening H_1 [m]	0, 60
Height low West opening H_2 [m]	0, 30
Height wall East H_3 [m]	1, 70
Height wall West H_4 [m]	2, 15

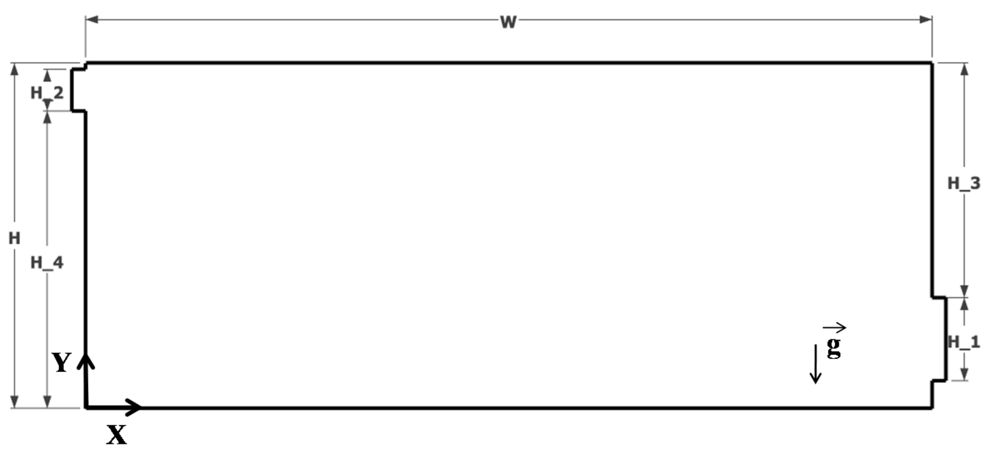


FIGURE 1: Geometry characteristic parameters.

NUMERICAL APPROACH

The usual dimensionless Boussinesq 2D Navier-Stokes equations were used. The numerical code has been developed thanks to the environment OpenFOAM [2]. The time derivatives in the momentum and in the energy equations are performed by a second-order backward differentiation. The convection terms are approximate using a second-order Adams-Bashford extrapolation method. The diffusion terms are implicitly treated.

BOUNDARY CONDITIONS

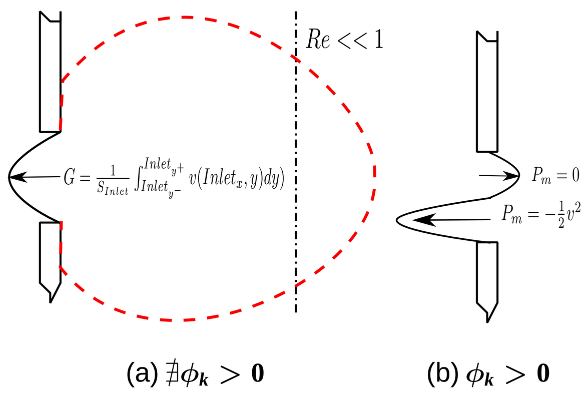
Wall boundary conditions and opening boundary conditions :

	Wall
u	u = 0, $\forall$ wall
θ	θ = 1, $\forall$ wall

	Outlet
u	∂_n u = 0, $\forall\ \phi$
θ	$\begin{cases} \partial_n\theta = 0, \ si\ \phi > 0 \\ \theta = 0, \ si\ \phi < 0 \end{cases}$
P_m	$P_m = 0, \forall\ \phi$

Height low East opening boundary conditions :

We here propose the use of a Bernoulli boundary condition to the opening (cf. figure 2.a). If $\phi_k > 0$ exist then a mixed boundary condition were used (cf. figure 2.b).



(a) $\nexists \phi_k > 0$ (b) $\phi_k > 0$

FIGURE 2: Inlet boundary conditions.

	Inlet
u	$\begin{cases} \partial_n u = 0, \ \forall\phi \\ u_t = 0, \ si\ \phi < 0 \end{cases}$
θ	$\begin{cases} \partial_n\theta = 0, \ si\ \phi > 0 \\ \theta = 0, \ si\ \phi < 0 \end{cases}$
P_m	$\begin{cases} P_m = -\frac{G^2}{2}, \ si\ \nexists\phi_k > 0 \\ P_m = 0, \ si\ \phi_k > 0 \text{ et } P_m = -\frac{1}{2}v^2, \ si\ \phi_k < 0 \end{cases}$

RESULTS : $Ra = 10^5$, 10^6, 10^7 and 1.49 10^8

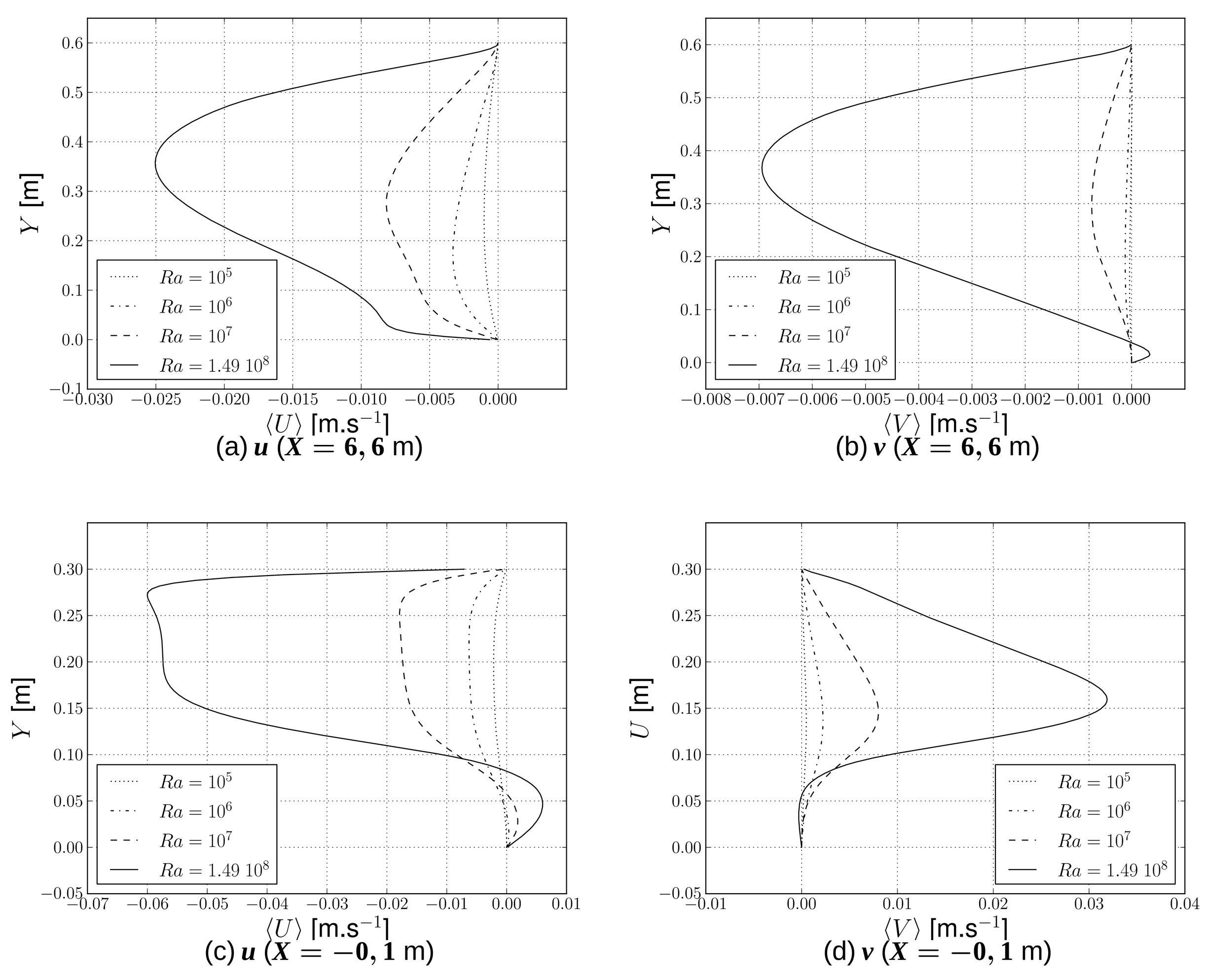


FIGURE 3: Average horizontal (left) and vertical (right) velocity profiles at inlet : 3(a)-3(b) and outlet : 3(c)-3(d).

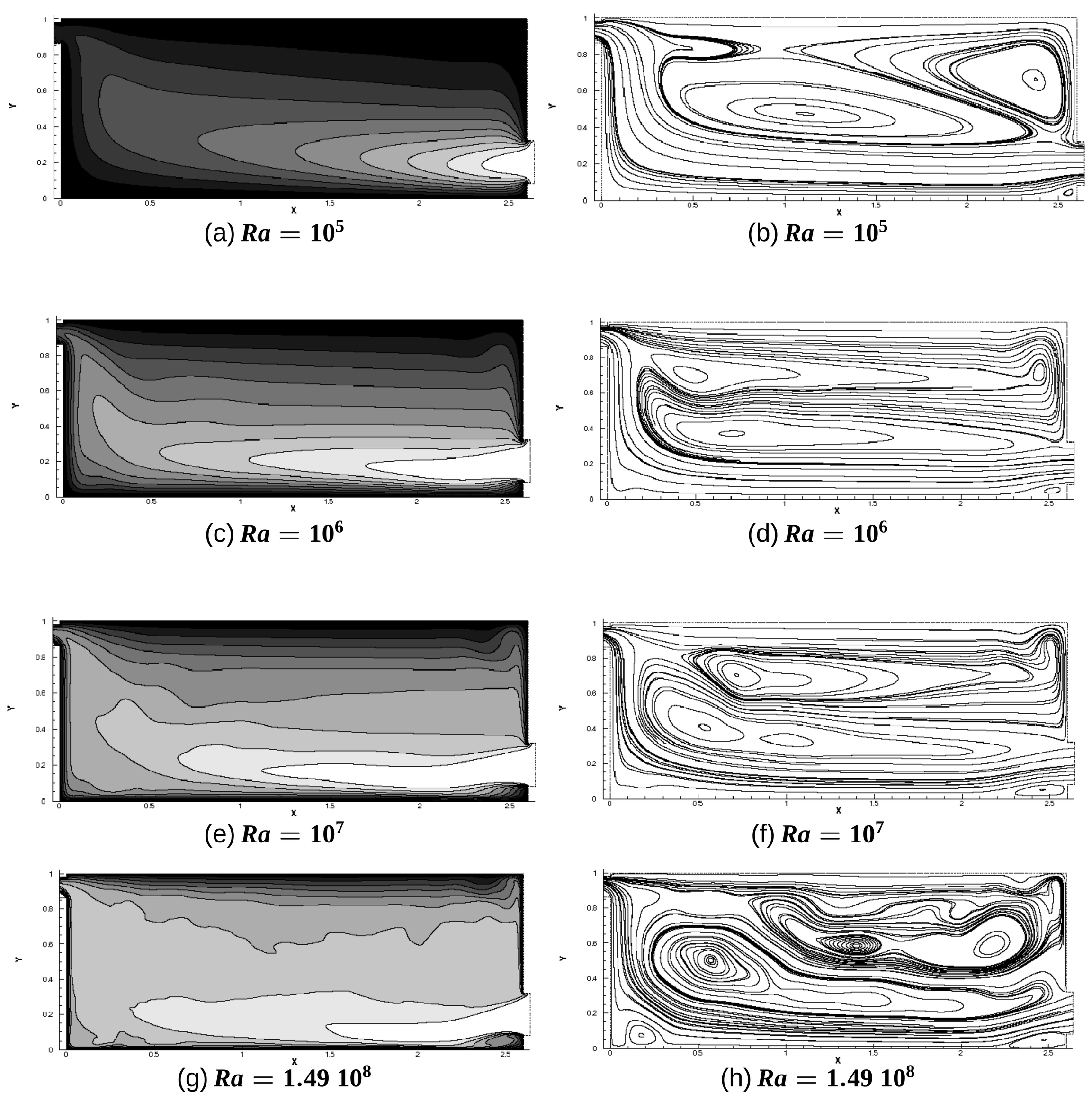


FIGURE 4: Average solutions. Left : Average temperature field. Right : streamlines of average flow. $Ra = 10^5, 10^6, 10^7$ and 1.49 10^8.

Wall heat transfer and mass flow rate :

Wall Average Nusselt number Nu_i (cf. table 1.a) :

- Nu_F Floor,
- Nu_R Roof,
- Nu_O Western wall,
- Nu_E Eastern wall.

Characteristic parameters for night cooling (cf. table 1.b) :

a)

Ra #	10^5	10^6	10^7	1.49 10^8
Nu_F	3.60	8.01	17.95	41.27
Nu_R	0.80	1.49	2.97	7.44
Nu_O	1.58	7.21	17.41	43.38
Nu_E	3.41	7.49	17.60	40.11

b)

Ra #	10^5	10^6	10^7	1.49 10^8
G [-]	0.0230	0.0209	0.0180	0.014
Q_v [m^3.h^{-1}]	1.47	4.230	11.43	35.50
τ [vol.h^{-1}]	0.01	0.26	0.71	2.17
θ_m [-]	0.85	0.70	0.55	0.405
P [W]	2.96e-5	6.85e-4	1.55e-2	0.488

TABLE 1: Average Nusselt number (a) and summary of average flow results (b).

CONCLUSION

A direct numerical simulation of the natural airflow in an open cavity has been presented and discussed. We choose a room model which will be used as a basis for other simulations in order to expand our knowledge in regards to night cooling. The validation of the choice concerning the boundary condition on the inlet pressure has been realized on the basis of a comparison with the numerical data of the benchmark for $Ra = 5.10^5$ [3] The first results that we are presenting in the benchmark configuration here ADNBATI [1] will be confronted in a near future to other team's results especially concerning the values of the numbers of Nusselt and the obtained mass flow rate. The future perspectives would be, for example, to establish the evolution of the number of Rayleigh (Nu = αRa^{γ}.) In order to realize a more realistic situation, Ra = 10^9-10^{10}, it would be indispensable to take turbulent models so as to obtain a time step compatible with parametrical simulations. A numerical approach of the flows through the large eddy simulation will be used for the superior numbers of Rayleigh to be found in the building.

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[1]PIMENT, Université de la Réunion, Tampon, France,
[2]LEPTIAB, Université de La Rochelle, La Rochelle, France.