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NATURAL CONVECTION IN ROOMS

French National Coordinated Research Program "A.R.C Convection Naturelle dans l'Habitat"

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SUMMARY

The studies described in the present paper have been developed by the teams involved in the French National Research Programm " ARC Convection Naturelle dans l'Habitat" coordinated by CNRS-PIRSEM (Interdisciplinary Research Programm on Energy and Materials , National Scientific Reseach Center) and suported by AFME (French Agency for Energy Management). After a short description of the experimental facilities of each laboratory, we give some significant results on high Rayleigh number natural convection in rooms. The various studies are carried out either in real scale test cells representative of real rooms , or in scale models. Present studies are mainly oriented to physical analysis of the various regimes found in the cavities, unstabilities development, influence of radiation heat transfer on natural convection flows and heat transfer.

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1 - INTRODUCTION

The main objective of "ARC Convection Naturelle dans l'Habitat" is to improve our knowledge on natural convection flow patterns and heat transfers in thermally driven cavities at high Rayleigh numbers, representative of convective phenomena found in a room.

In a first phase of this program, the contribution of each team has been to design, realize and test various experimental facilities, real scale cavities, scale models, in laboratory or in situ. The common goal was, in a complementary approach, to realize a first typology of thermal configurations found in a room, to define and to value the characteristic parameters.

In parallel with this experimental approach, different level of numerical analysis have been made and compared with the experimental results.

In the present paper, we describe the experimental facilities, we give a short presentation of the main results obtained, and we present the perspectives of current projects.

2 - EXPERIMENTAL FACILITIES

The experimental facilities are made of both real scale test cells and scale models, each one with specific goals defined in the general frame of the project.

2.1 - In Situ Test Cell , LMTB INSA de Toulouse

Figure 1 presents a longitudinal view of the in situ experimental set up developped by INSA de Toulouse [1,2]. The initial goal of this experiment was to study the effects of real climatic conditions on natural convection in a room heated by transmission through a wall in contact with a green house.

The initial goal has been redefined and the cell has been modified various times since 1986 [1]. The main objective of the modifications realized is to lead to a better control of thermal boundary conditions. Heat exchangers have been added to two opposite vertical surfaces in order to improve the quality of boundary conditions.

A "thermo-anemometer" has been developed, calibrated and is used [3] on this experiment to measure the velocity field along the walls at various height. Furthermore the thermal field is defined by the surface temperature measured along the six walls of the cavity and air temperature measurements made along the walls and in the core of the room.

The results obtained [3] are dealing with the influence of boundary conditions on flow patterns and an evaluation of convective heat fluxes by two methods using either direct measurements of the thermal gradient at the wall or an integral method.

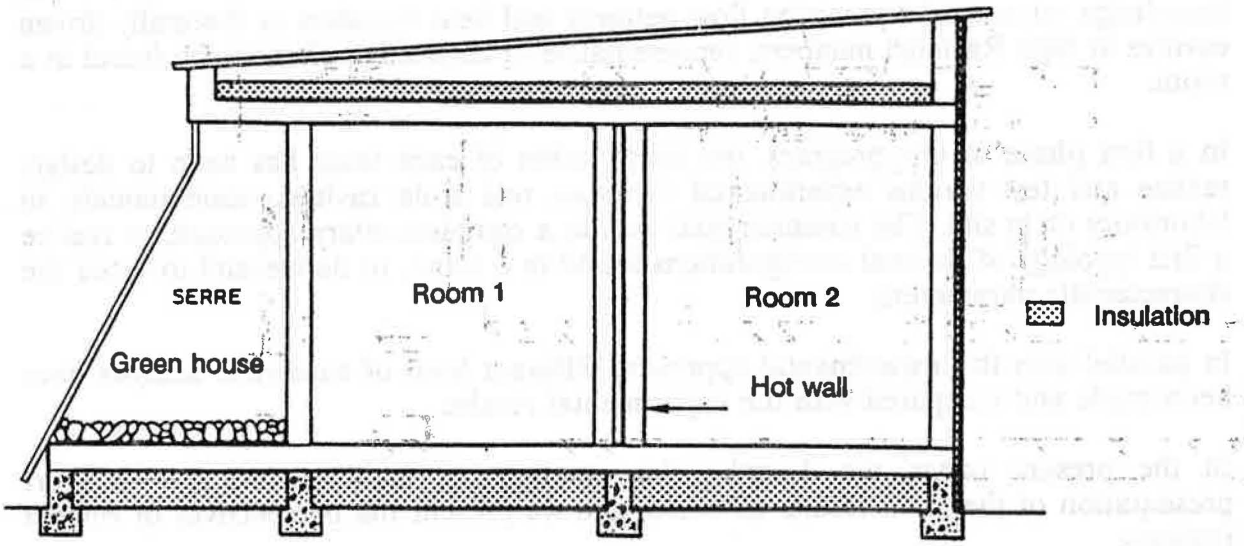


Figure 1: In Situ Test Cell in INSA Toulouse.

2.2 - MINIBAT Test Cell, CETHIL INSA de Lyon

Figure 2 presents a longitudinal view of our experimental set up called MINIBAT [4,5]. The main part of this experimental set up is a real scale room (3.1m x 3.1 m x 2.5m) built in a thermally controlled environment. Five of its walls are thermally guarded, the sixth one, the façade, is a 10mm thick glazing submitted on its external side to artificial outdoor climatic conditions generated by a climate simulator. This device is made of a thermal housing where the air temperature varies from -10°C to 30°C, and of a solar simulator built of 12x1100W CSI lamps. This simulator provides solar lightings compatible with those found in a natural environment.

The ceiling is made of a 2.5cm thick plywood coated by a 5.5cm thick mineral wool. The internal surface of the ceiling received the same gypsum board layer as for the vertical walls of the cell. A resistive electrical film has been located between the plywood and the gypsum-board to realize a uniform heating of the ceiling.

All the thermal and radiative properties of the materials used have been measured in our laboratory. In order to get the complete thermal field along the surfaces and inside the volume of the cell, 360 sensors are actually used, most of them are devoted to air or surface temperature measurements. All these sensors have been calibrated in our laboratory, they are connected to a data acquisition system controlled by a PC which assumes the acquisition and a first local treatment of the data.

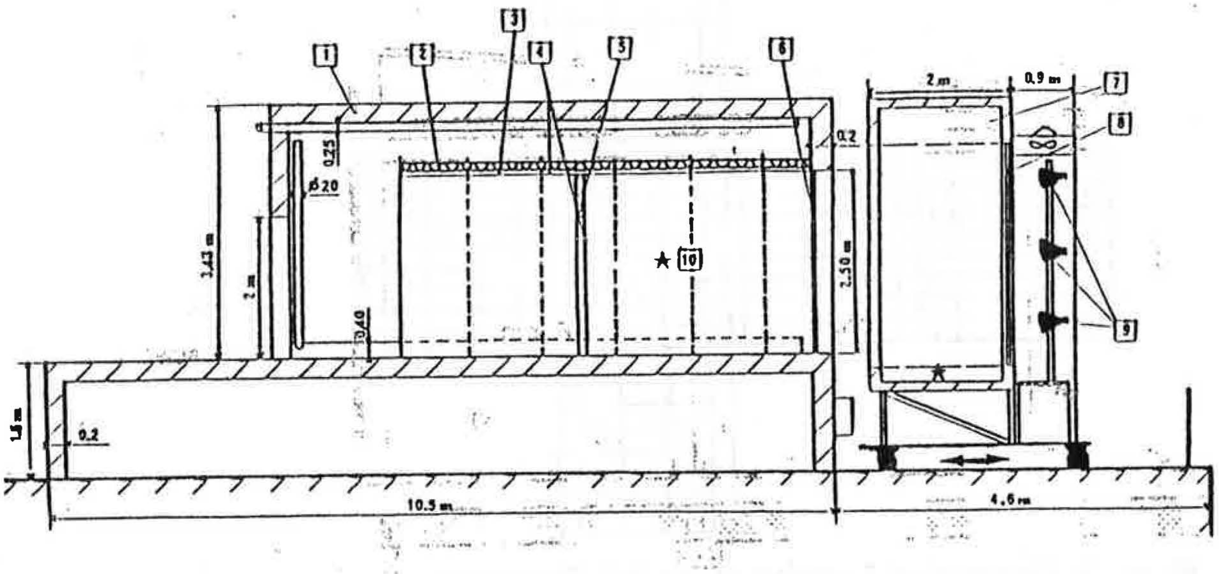


Figure 2: Longitudinal Section of MINIBAT. (1) External envelop (cellular concrete e=.2m), (2) Fibreglass (e=.05m), (3) Plywood (e=.025m), (4) Gypsum-board (e=.01m), (5) Fibreboard (e=.05m), (6) Glazing (e=.01m), (7) Mobile Climatic Housing, (8) Double Glazing, (9) Solar Simulator, (10) Test Cell.

In the frame of ARC project, MINIBAT has been used to get an experimental data base of surface temperatures resulting from coupled heat transfer in a room submitted to various thermal boundary conditions. This data base has been used in a first step to reproduce realistic boundary conditions on the LET's fluxmetric cell, and later on as input for numerical simulations [6].

2.3 - Fluxmetric Test Cell, LET Poitiers.

The geometrical characteristics of this test cell are exactly the same as MINIBAT's dimensions. This cell has been specially built to measure heat fluxes along the walls [7-]. It is build of fluxmetric walls made of 250 fluxmeters. A special care has been given to the regulation system which enables us to control the 250 surface temperatures imposed to the cell and resulting from theoretical boundary conditions or real measurements made on MINIBAT or any other room.

Figure 3 gives a description of the 250 flux meters, Fig 4 gives a general view of the cavity.

At first, the internal coating was a high emissivity one (ϵ = .85) representing usual surfaces in buildings. In 1986, in order to improve the precision of the convection heat fluxes evaluation , this coating has been modified and the walls received a reflective coating (ϵ =.07).

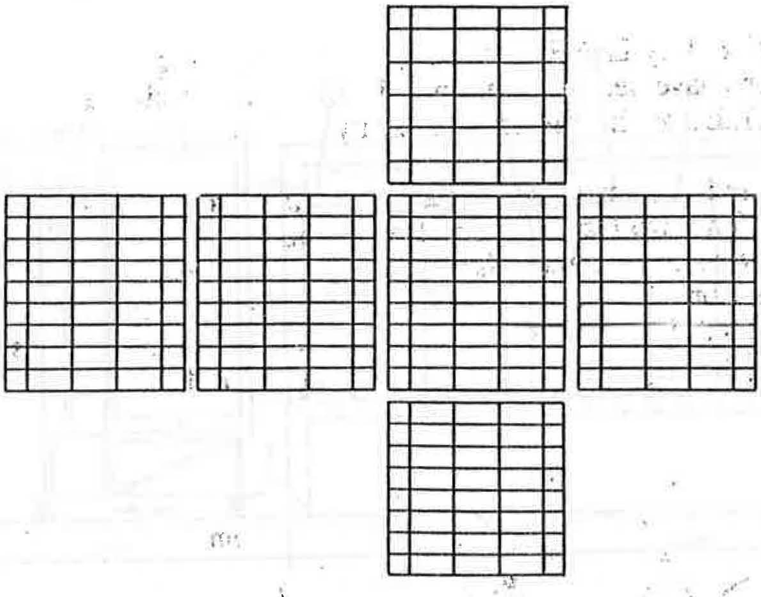


Figure 3: Geometrical Location of the 250 Fluxmeters.

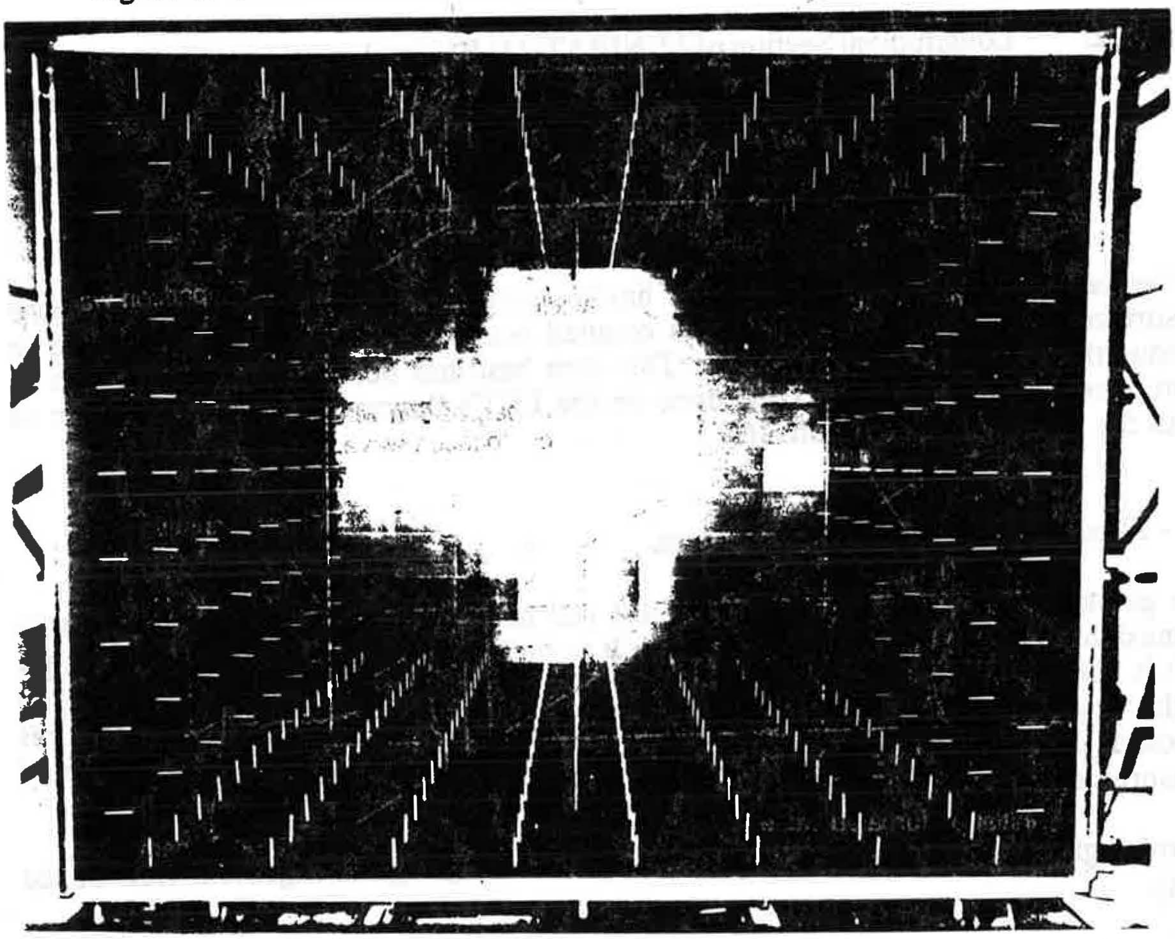


Figure: Internal View of LET 's Fluxmetric Test Cell.

2.4 - 1/4 Scale model, LESETH Paul Sabatier University, Toulouse

The scale model realized by LESETH in Toulouse is .65m high, .81m wide and .56m deep, these dimensions have been defined in order to check the similarity with real scale experiments using R12B1 as fluid inside the cavity [8].

Four walls are regulated in temperature by a thermostat, two oposite vertical walls, the floor and the ceiling. The two last walls are transparent, in order to let the laser beam cross the cavity. The whole experiment is located in an air conditionned room to avoid any temperature variation in time. 140 thermocouples are used to control the thermal boundary conditions, real time holographic interferometry is used to access the thermal field in the cavity. Figure 5 gives the principle of this method.

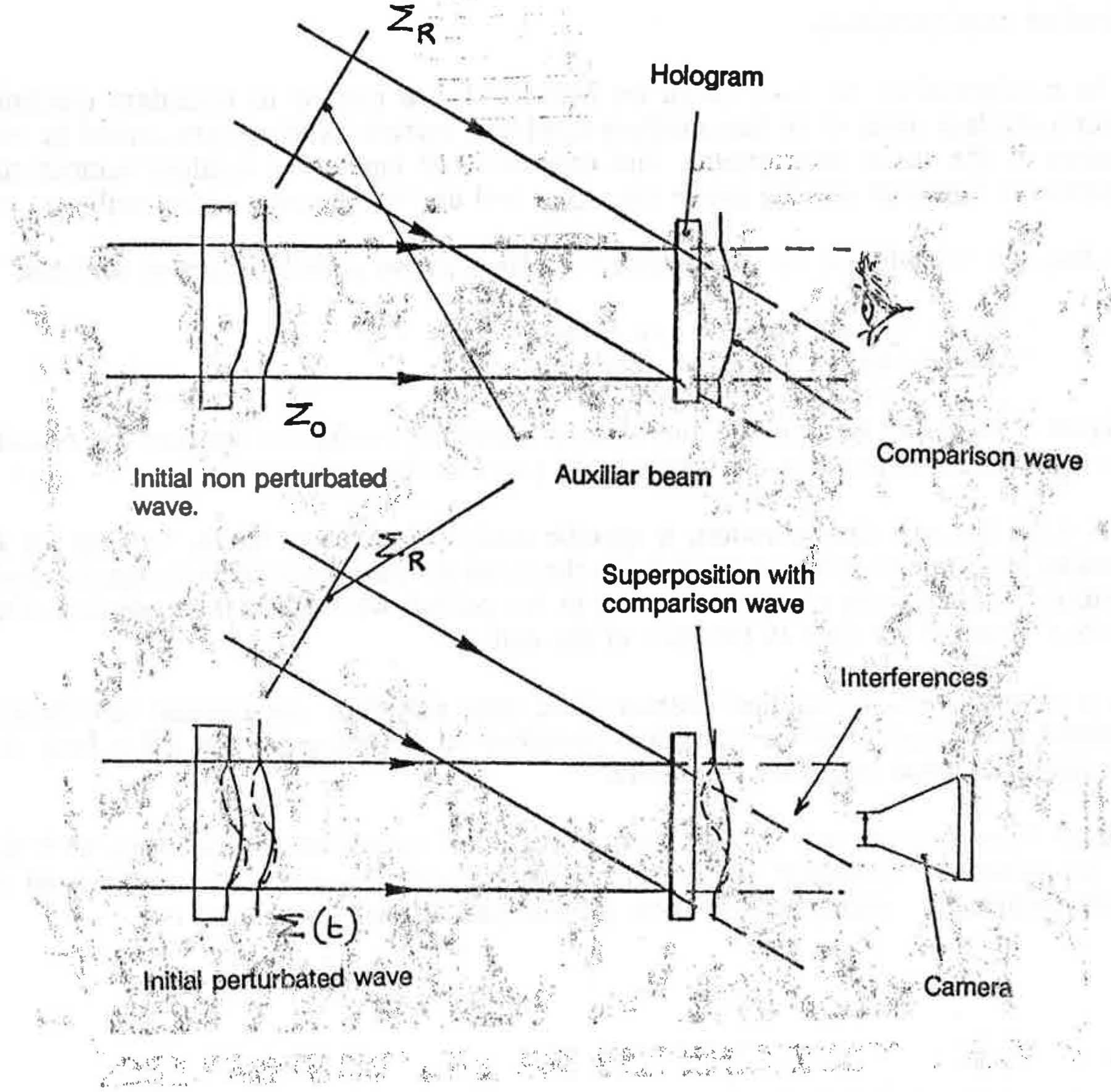


Figure 5: Real Time Holographic Interferometry (LESETH, Paul Sabatier University Toulouse).

3 - SIGNIFICANT RESULTS

It is a difficult task to define in few lines the more significant results of this ARC project. A first balance has been made in 1986 [1]. We will give here only few examples of the more general results.

3.1 - Global characterization of the flow patterns and thermal field in a room.

The aim of the first step of the ARC project was the definition of different thermal configurations representing characteristic behaviours of a room. Each team has contributed to this first part by its own experiments, but MINIBAT with its controlled environment was more specifically devoted to this task.

Studied configurations.

The configurations we considered on MINIBAT are related to boundary conditions found inside a room of an intermediary level of a current building surrounded by other rooms at the same temperature. The only selected inputs are outdoor temperature, shortwave lightings arriving inside the room and uniform heating of the ceiling.

In fact the behavior of the cell results from the relative activity of active surfaces:

* Horizontal walls (ceiling or floor)
* Vertical walls (facade or rear wall)

Figure 6 shows an example of four different thermal configurations and the resulting thermal field measured in the vertical mid plane of the cavity.

For each thermal configuration, a specific analysis has been made, looking for the leading phenomena and trying to identify characteristic parameters. For instance, varying outdoor temperatures or injected power in the ceiling, we studied the evolution of the vertical thermal gradient in the core of the cell.

In a second step, we studied characteristic time scales of the thermal stratification process in a room after a mechanical perturbation (swithing on and off a fan), or a change in thermal boundary conditions.

Figure 7 gives an example of the results obtained, it represents the evolution with time of temperatures measured at different heights along the central vertical axis of the cavity, when the existing stratification is destroyed by switching on a fan.

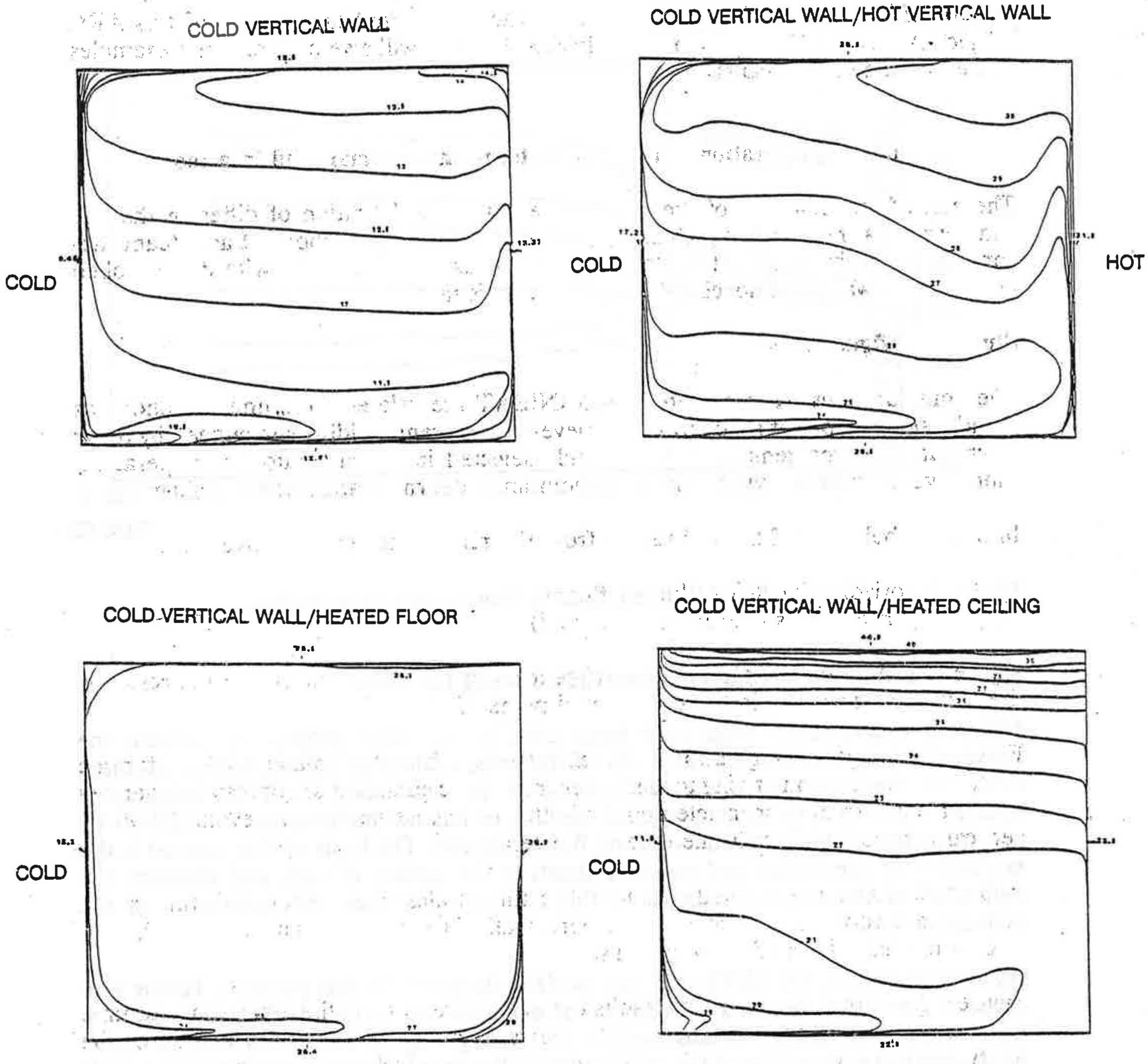


Figure 6: Characteristic Isotherm Lines Measured in the Vertical Mid Plane of MINIBAT in Four Different Boundary Conditions.

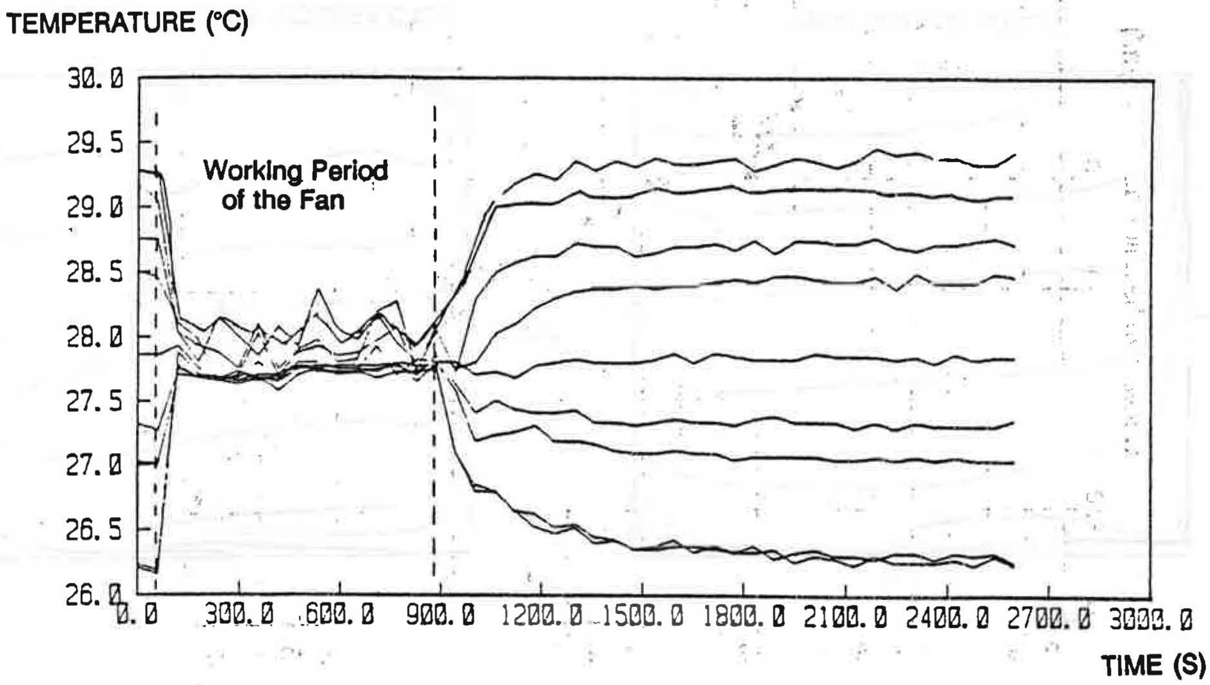


Figure 7: Stratification Establishment after a Mechanical Perturbation.

3.2 - Determination of convective heat fluxes along the walls.

Different experimental ways have been used in the ARC project to evaluate the convective heat fluxes along the walls of the cells, evaluation of the thermal gradient close to the wall by direct measurements in real scale cavities, holographic interferometry in scale model, integral method, or balance method used on MINIBAT and more specifically in Poitiers on the fluxmetric cell. The basis of this method is the evaluation of conductive and radiative fluxes at the surface of each wall element, the definition of the thermal balance of this element, and then the calculation of the convective flux.

As we said before, the LET's cell was specially designed for this purpose. Taking into account theoretical boundary conditions or experimental surface temperature profiles measured on MINIBAT, various empirical formula giving the convective heat flux have been obtained as functions of the temperature difference between the wall element itself and an average wall temperature representing the thermal state of the cavity.

Figure 8 gives an example of a practical interpretation of these results. Tms represents the average surface temperature of the cavity. Tp is the surface temperature of the vertical wall under consideration. These first set of results have been obtained with an emitting coating (ϵ =.85).

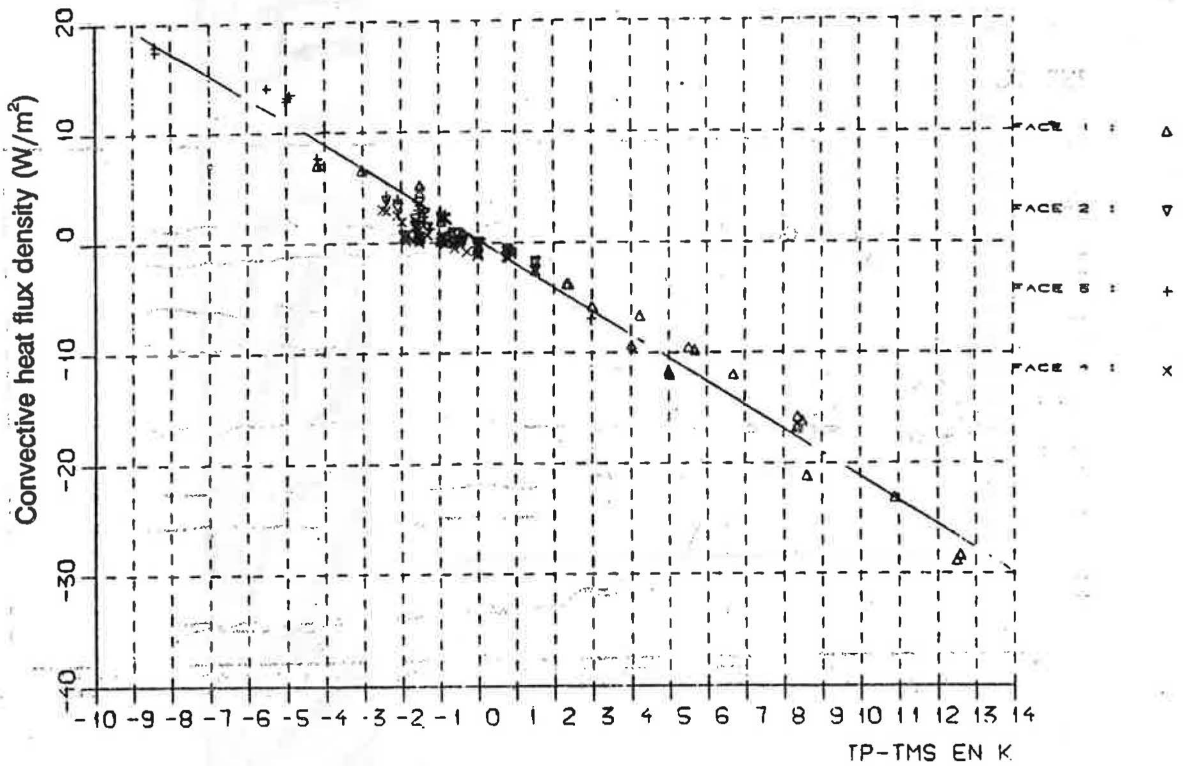


Figure 8: Convective heat flux density along a vertical wall as a function of temperature difference Tp-Tms.

In order to improve the precision of this method by decreasing the influence of radiative heat fluxes, the coating has then be replaced by a reflective one (ϵ =.07) and the same surface temperatures have been used as boundary conditions. Contrary to our expectation the convective heat fluxes varied significantly, and in any way much more than the precision of the method. This problem remains open but a special effort is devoted to the study of coupled heat transfer by natural convection and radiation in a participating fluid. We already demonstrated significant modifications of flow patterns and heat transfer due to the radiative participation of the fluid. However, much work is necessary to conclude for building applications.

3.3 - Boundary Layer Stability Studies:

Using the LESETH's 1/4 scale model, various stability studies have been performed using real time holographic interferometry [9]. Figure 9 gives an example of such studies, significant differences are found in the flow regimes, on one hand the first configuration called C-5F corresponding to a vertical hot wall coupled with five cold walls at the same temperature, on the other hand C-F corresponding to a hot vertical wall opposed to a hot vertical wall, the others being at intermediate temperatures.

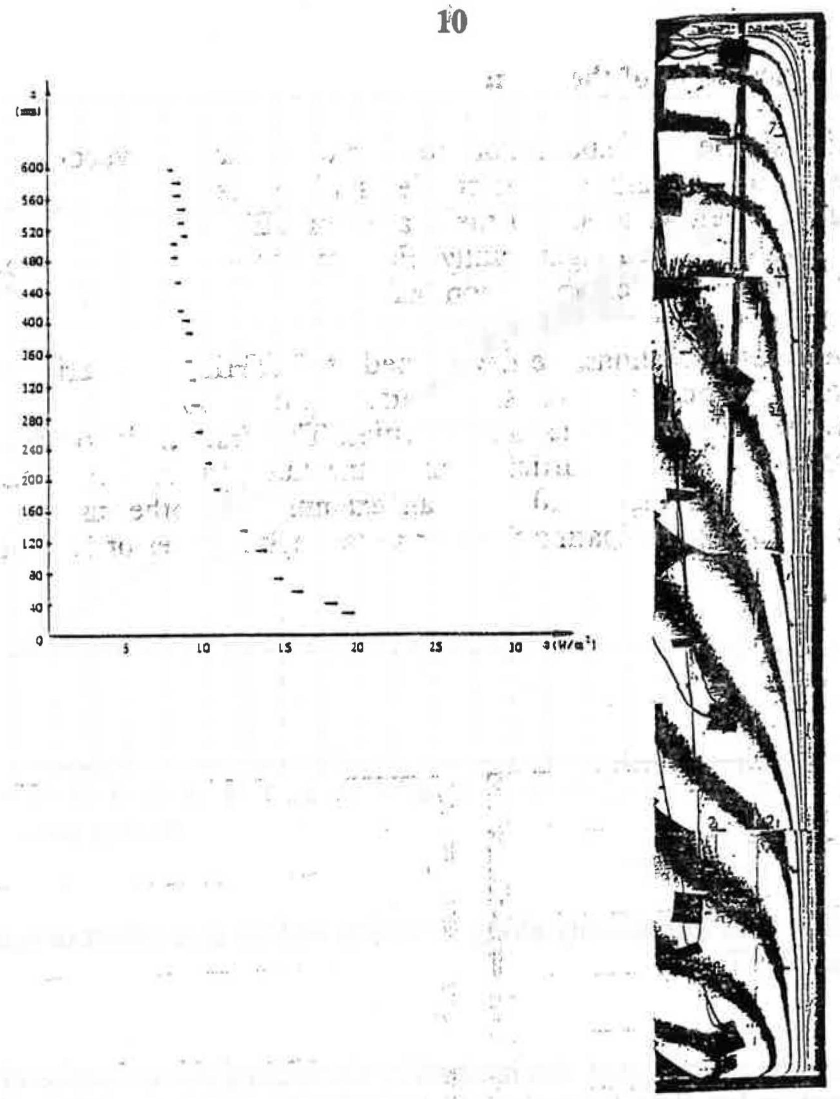


Figure 9: Interferograms and Resulting Heat Flux Densities (laminar case).

C5F appears to be stable all along the vertical hot wall. At the contrary, C-F leads to fluctuations in the boundary layer for the same Rayleigh number. This experiment also enables us to demonstrate the influence of the boundary conditions along the vertical walls, it appears for instance that the critical Rayleigh number increases significantly when the floor temperature decreases slightly.

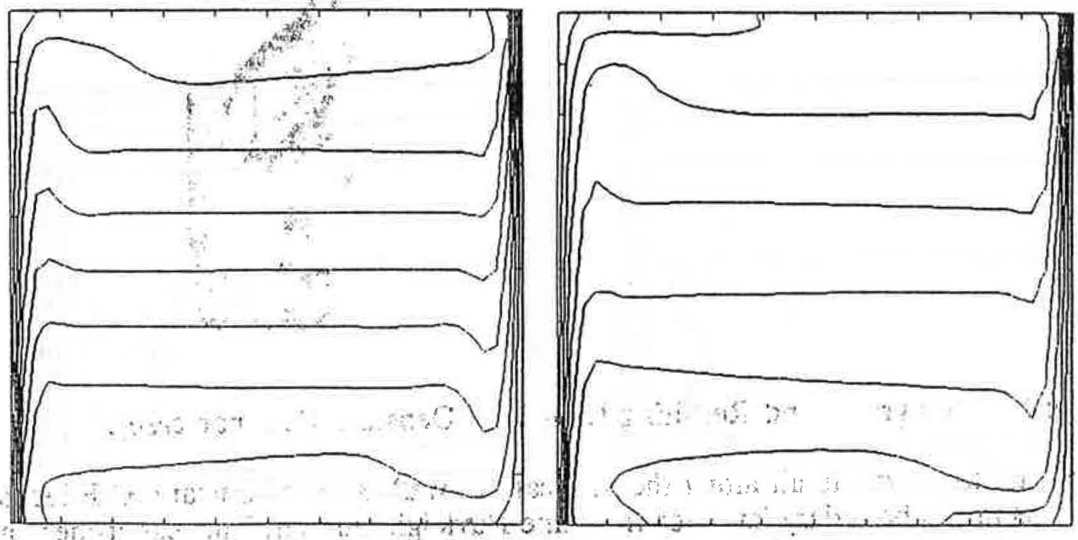
4 - CURRENT STUDIES

This year, new goals have been defined for the ARC project, these objectives are mainly oriented to numerical studies supported by the existing experimental results. Two prioritary actions have been defined, the first one concerns the influence of radiative participation of a fluid on heat transfer and flow paterns within a cavity, the second one is devoted to the developement of adapted numerical models for high Rayleigh numbers natural convection.

4.1 - Radiative participation of the fluid:

The influence of radiative participation of the fluid on natural convection in cavities is always assumed to be neglegibie in our problems. Nevertheless, when as we reported earlier in this paper, when we modified the coating of LET's cell, the convective heat fluxes along the walls changed significantly. Furtheremore, the fluids used in scale models (R12B1) have very thick absorbtion bands.

In order to answer these questions, we developped at CETHIL a numerical analysis of natural convection in participating fluids. In a first step our approach has been limited to gray fluids enclosed in two dimensionnal cavities. The first results obtained show a significant influence of radiative participation of the fluid on flow patterns and heat transfers inside the cavity. Figure 10 gives an example of isotherms obtained in a transparent fluid and in a participating fluid for a Rayleigh number of 10^7 and a Planck number of .05.



Without radiation With radiative participation

Figure 10: Isotherms in a Transparent and in a Participating Fluid.

In a first step, our study has been limited to theoretical gray fluids with isotropic scattering, we studied the influence of thermal and radiative boundary conditions and of the coupling parameter [10,11].

In parallel with this numerical analysis, a new experiment has been designed by LET. The new cavity has the same size than the old fluxmetric one, but the coating can be easily changed. Furtheremore, the convective heat fluxes will be measured by evaluation of thermal gradients in air within the conductive sublayer using a "cold wire" sensor. The same sensor used as hot wire anemometer will enable us to study the dynamical boundary layer.

4.2. - Numerical studies of High Rayleigh number natural convection in cavities.

Two kinds of studies are presently developped by ARC teams. The first one consists of direct simulations of high Rayleigh number natural convection in cavities. The goal of these studies carried out by LRC and LIMSI is a better understanding of transition to turbulence. They used spectral methods to solve Navier Stokes equations, Figure 11 gives an exemple of a direct simulation by Tchebycheff spectral method of an experiment realised on MINIBAT [12].

In a second step, these methods are presently improved to solve non Boussinesq flows and turbulent flows using subgrid models.

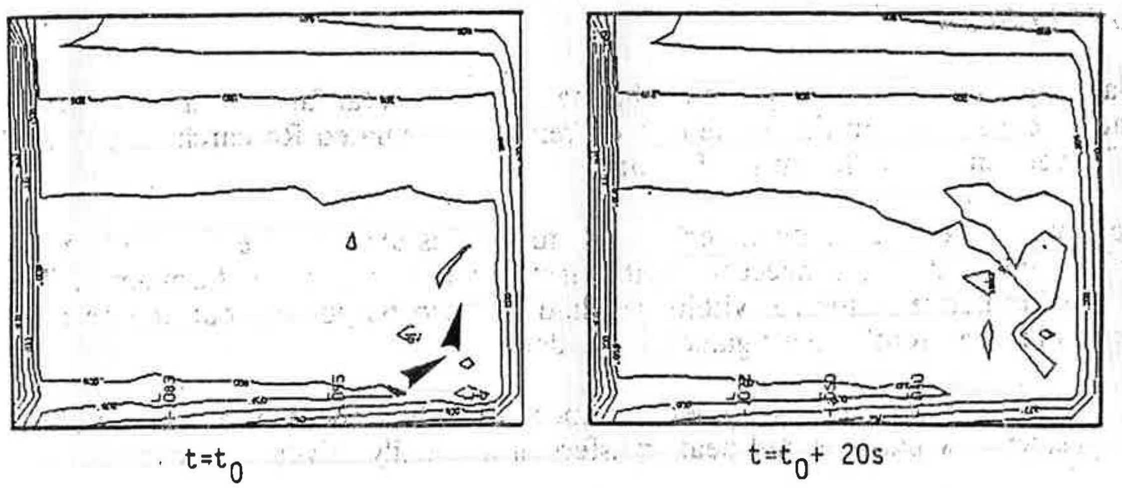


Figure 11: Isotherm lines in the vertical mid plane of MINIBAT obtained by spectral Tchebycheff numerical simulation.(Ra = 6.10^8)

The second kind of numerical study presently realised by CETHIL [14] is devoted to numerical simulation of turbulent flows in cavity by low Reynolds K-ϵ model. Figure 12 shows an example of simulation realised on an experimental test case presented earlier on Figure 6. A global agreement does exist between numerical results and experiments but these models have to be improved in order to predict the flows and heat transfers in real configurations.

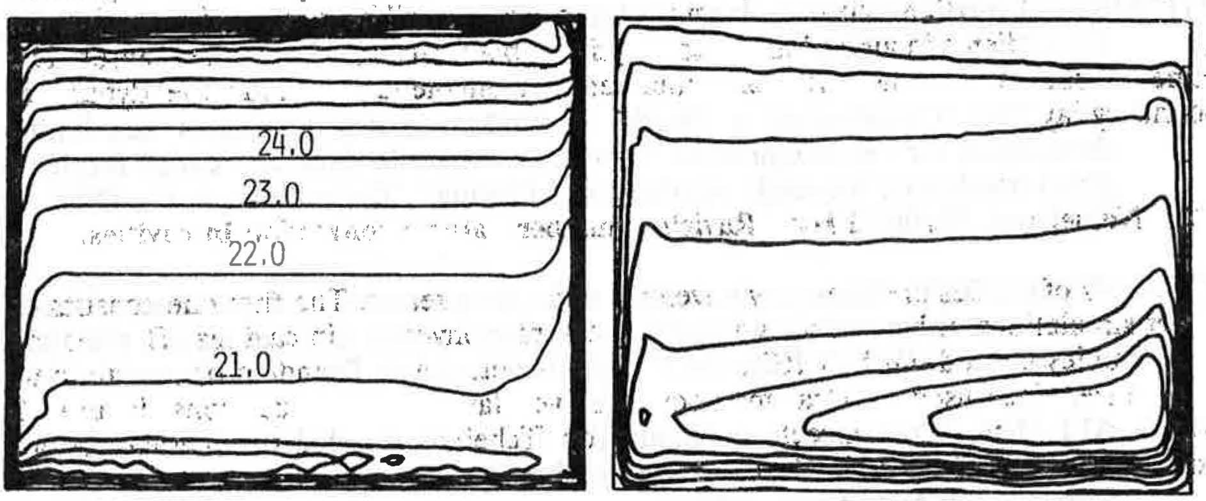


Figure 12: Isotherms and streamlines in the vertical mid plane of MINIBAT obtained by low Reynolds number numerical simulation. (Heating ceiling, Ra= 10^{10})

5 - CONCLUSION

This paper gives a short description of the main experimental facilities and numerical approaches developped in the frame of the French Coordinated Research Programm " ARC Convection Naturelle dans l'Habitat".

This research project based on experimental studies has already given a lot of results conerning flow patterns, convective heat transfer and transition to turbulence. The influence of radiative couplings within the fluid has also be pointed out and an open research field is presently investigated in this domain.

This national program has also generated specific studies about numerical methods able to predict flow patterns and heat transfers in thermally driven cavities.

Much more work is obviously necessary to complete our goals. Nevertheless this coordinated research action has already generated aditionnal related investigations such as mixed convection in rooms or natural convection in partitionned cavities which are now necessary to improve our knowledge of air flow patterns and heat transfers in buildings.

Aknowledgements: *This project is supported by CNRS/PIRSEM " National Scientific Research Center" and AFME " French Agency for Energy Management" within the frame of a National Research Programm on Natural Convection in Buildings, the numerical calculations have been performed on the Cray 2 of CCVR " Vectorial Computer Center for Research Applications".*

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