Laboratory Experimental Method to Measure Thermal Fluid Dynamic Parameters Characterizing the Climatised Office Room

P. Principi, C. Di Perna and E. Ruffini

Dipartimento di Energetica, Universitàdegli Studi di Ancona, via Brecce Bianche, 60100 Ancona, Italia

Abstract - *In this paper the experimental results of the measurements obtained testing two different configurations of air diffusion inside a simulated office room are reported. The overall aim of the work is to visualise the air velocity and temperature distributions in different sections of the climatised volume to understand if the right thermal comfort condition of the occupants are established.*

To reach the goal the research group of the Dipartimento di Energetica dell'Università di Ancona (D.E.A.), has designed and realised a series of laboratory devices and monitoring systems to test several air conditioning components and air diffusion configurations.

In this way is possible to verify the right position of inlet and outlet diffusers, the flow rate and inlet air temperature to establish an uniform distribution of the air velocity. For this purpose vertical grills, round ceiling diffusers and floor linear diffusers are installedon the sides of a controlled room, where walls, floor and ceiling are modular to have whatever positions for the inlet and outlet diffusers.

To record in steady state the values of the temperature and the air velocity on different vertical planes cutting the climatised volume an automated apparatus, designed and built with the component derived from the robotic technologies, has been utilised.

The device consist of two guides, the first vertical and the other horizontal, on which moves a trolley, transporting the probes at the prefixed coordinates on the vertical plane. Driving the apparatus by a dedicate software, it is possible to reproduce in the air the mesh of numerical methods and measure the values of the environmental parameters at the nodes. The results of the tests are thermal and air velocity maps, which visualize the temperature and velocity gradient on the measured plane.

In this work the results of the tests, carried out utilising two different type of vertical diffusers, are presented.

Keywords: Air conditioning systems - Diffuser - Air velocity and temperature gradients - Thermal comfort - Test room - Automated apparatus - Monitoring.

1. INTRODUCTION

The correct diffusion of the air in the rooms is one of the main components to obtain the thermal comfort conditions. In fact the supply air must be delivered at the right temperature and humidity in the right flow rate, so that when it is mixed with internal air, the resultant room air condition meets design specification, in according to theoretical comfort condition. It is possible to say that an air conditioning system is only as good as it air distribution. In this way it is very important to distribute the air into the space, in order to balance the heat gane and provide uniform air motion and temperature within space. The most important component of an air distribution system is the terminal distribution equipment, as grilles, diffusers and so on. Their position on the sides of the room is important for the distribution strategy. In this item it is possible collocate the natural ventilation research program of the Ancona University started in spring of 1998.

It began with the intent to study the thermal fluid dynamic phenomena inside the natural ventilated and climatised buildings [1, 2]. The experimental section of the research was carried out monitoring an innovative building and realizing laboratory tests utilizing a controlled room and an original automated apparatus. These studies regard a more empty research to value the energetic behaviour of the building, considering also the possibility to involve all the questions about the building and air conditioning system. The research is developed in situ with the measurements of all the parameters affecting the thermal comfort, characterizing the indoor and the outdoor environments, while laboratory studies were carried out to set up the original equipment designed to measure the thermal fluid dynamic field on vertical or horizontal cut sections of a controlled volume.

Actually the research consists in studies about the modality of air diffusion in office rooms with small dimensions. It is developed on laboratory tests inside a controlled room, where different diffusers, in different position are located.

2. TEST ROOM

The controlled room has been designed with the concept of the minimum building cost and an high flexibility to have the more varied configurations of diffusion and retaking airflow and then to study the distributions of airflow in the controlled volume. The test room has been realized in the laboratories of the D.E.A. (Fig. 1).

Fig. 1

Fig. 2

It is a parallelepiped measuring 4.37 m x 3.39 m and 2.7 m high and consists of a frame of iron profiles with a section 100 x 100 mm. The test room has been panelled with plasterboard and polystyrene of five centimetres thick. They have been fixed to the frame and completely closed on the edges of attack of the same structure.

All the sides of the room present the removable panels high 0.40 m on the top and on the bottom, to install the grids and to have different configurations and positions of air diffusion.

The ceiling is composed by 0.60 x 0.60 m fibre panels and the floor is a floating system fixed on supports 0.4 m high above the laboratory floor. Both the ceiling and floating floor panels are removable to install horizontal diffusers to inject air from the top and/or the bottom of the room.

The test room is fed from an aeraulic circuit constituted by rigid or flexible pipes of plastic material and some equipments are described below.

An individual module 42 BJ, products by Carrier, supplies the air conditioning of the inlet air and it controls all thermal comfort parameters. The module consists of a high efficiency filter, an electric resistance, a finned tube coils for cooling and heating, a centrifugal fan with variable quantity of flow. It is connected with an air chiller condensing unit (Carrier model 30RA), having a cooling power of 5.15 kW and equipped by all the hydraulic components for the operating.

The aeraulic circuit is completed by a Venturi nozzle dimensioned in according to the national standard UNI 10023 for a full scale flow rate of 300 m^3/h. At the end of the inlet and outlet air ducts are located two plenum realized with sheet metal to distribute uniformly the airflow on the grill section.

3. AUTOMATED APPARATUS

In the controlled room the thermo fluid dynamic parameters have been measured with anautomated apparatus (Fig. 2). The technology of the automated apparatus is based on the robotic components of the industry [3].

It is composed by two mechanical perpendicular guides on which run, driven by motors, two towed trolleys which carry the probes and that can stop himself at the prefixed coordinates on the vertical plane. The equipment reproduces in the air the theoretical grids of numerical models and measures the values of thermodynamic parameters at the nodes.

The maximum dimension of the measured area is defined by the length of the two guides. The horizontal guide is 2.3 m long, the other one is 2.6 m long. The fixed velocity of the trolleys has been defined by the mechanical characteristics of electric motors.

The mechanical and electric components are controlled by a series of electromagnetic relays that check the rotation, the switching on and the switching off of the motors. A National Instruments system card moves the electromagnetic relays with a management software controlled by a portable computer. This software has been realized with Visual Basic language and allows the manipulation of the numerical mesh matrix of points to optimise the probes movement.

The electronic equipment is connected to the mechanical device by cables with high impedance and screened as appropriate. Besides the electromagnetic interference problems are verified during the set up of the automated apparatus. They have been solved by particular common added masses, screened cables and appropriate filters sensitive to the outgoing and ingoing signals as well as the feeders (motors and potentiometers).

The measurements of thermo fluid dynamic parameters are recorded by HP 34970A data logger with 20 channels. At least the recorded data have been elaborated with a commercial software (Tecplot), that permits to visualize the obtained results with graphics [4, 5].

The system is designed to compare the numerical data obtained with the thermodynamic calculation codes with experimental results and for this reason an interfacial software has been developed.

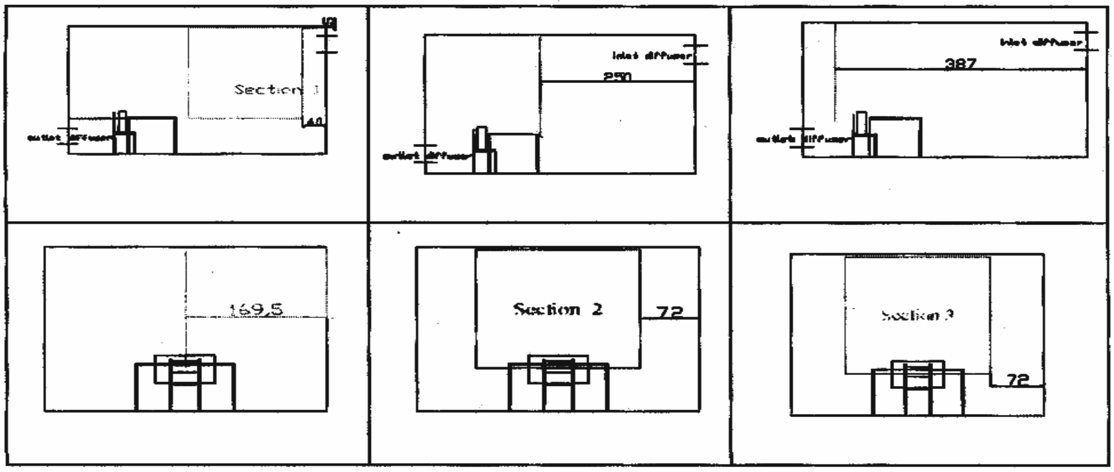
4. EXPERIMENTAL TESTS

The overall aim of the research program is to establish the main strategies to distribute the air in the office room when it is occupied. For this purpose a series of tests in the controlled room are realised, utilizing different diffusers, both inlet and outlet, installed in the several positions, to value the air velocity and temperature distributions. In this work only two representative samples are presented, but many data have been recorded from other configurations and in future several tests will be carried out. In the experimental tests has been established that the inlet air temperature airflow is $T_i = 15$ °C and flow rate is $V = 250$ m^3/h.

A work station, constituted by one desk and one chair, have been introduced, to simulate the same conditions which are present in a real office room. For each configuration of diffusion a series of the measurements on three sections of the controlled room have been realized (Fig. 3) :

- the first section is located on the vertical plane and it is perpendicular to the inlet diffuser, at the distance of 0.40 m from the vertical wall and 5 cm from the ceiling;
- the second section is located on the vertical plane and it is parallel to the inlet diffuser a distance of 2.50 m from it, in front of the work station;
- at least the third section is located on the vertical plane and it is parallel to the inlet diffuser is at a distance of 3.87 cm from it, behind the work station.

A second series of tests have been realised, simulating the heat load due to the human body metabolism, too. For this reason, in the controlled room has been introduced a thermal radiator with a thermal power of 100 W. The cases explained below see both vertical diffusers fixed on the short side of the room in front of the seated person.



Section 1 Section 2 Section 3

Fig. 3

Configuration 1

In the first configuration has been utilised a traditional inlet diffuser, in aluminium with double row of adjustable blades, 14 vertical and 8 horizontal (Fig. 4). The dimensions of the diffuser are 30 x 10 cm, with an effective section of 0.018 m^2. The diffuser has been positioned at 10 cm from the ceiling, in the short side of the room. The return air grill is located on the bottom of the opposite side (Fig. 5).

Configuration 2

In the second configuration has been utilised an innovative linear inlet diffuser with one horizontal way blow (Fig. 6). It is equipped with a plenum to guarantee the maintenance of the fixed air velocity value. Being the best operating of the diffuser based on the Coanda effect, it is fixed at 0.14 m from the ceiling on the short side of the test room. Its dimensions are 120 x 5 cm and it presents an effective section of 0.036 m^2. The return air grill diffuser, at the foot of the other short side of the room, is positioned.

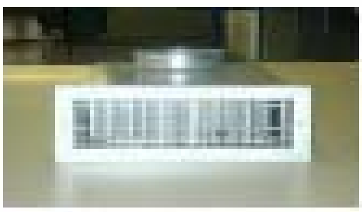


Fig. 4

Fig. 5

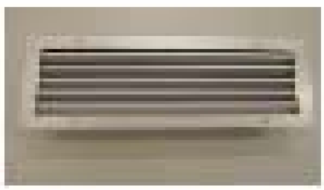


Fig. 6

5. EXPERIMENTAL RESULTS

In both cases the thermo fluid dynamic parameters, temperature and air velocity, have been measured in the three considered sections. On the trolley of the automated apparatus an hot wire anemometer and a thermocouple, type T, copper and constantan, have been positioned. The automated apparatus has been set up to reproduce, in a vertical plane, a regular mesh with 400 points of measurement. Besides some thermocouples have been located to verify the air temperature values inside and outside of the controlled room, in particular they have been located on the inlet and outlet diffusers, on the thermal radiator surface, on the external ceiling and on the vertical wall at a distance of 0.40 m from it. During the tests the inlet temperature has been measured in a range of 0.3 °C between 14.8 °C and 15.1 °C, while the outlet temperature, for different diffusers has been measured in a range of 4.5 °C from 18.1 °C demonstrating the different air mixing phenomena inside the room.

Configuration 1

The figures 7-12 show the air velocity and temperature distribution in the section 1, 2 and 3 of the test room, utilizing a supply aluminium grilles with double row of blades. The tests are carried out with vertical and horizontal blades tilted 0° ont the axis of the plum flow. The diagrams show the caracteristic jet flow in the room : it presents a range of air velocity between 1.0 m/s, measured on the section of the supply device and 0.35 m/s, at 1,6 m from the floor and 2 m from the opposite wall to the diffuser. As literature reports, the vertical double row of blades diffuser.doesnt realise a good air miwing inside the occupied volume, also if the Canada effect is verified and the supply air outside cooled. In this case the ariflow around the work station is stopped with a velocity less than 0.01 m/s and values of temperature near 19 °C. High 1.8 m from the floor the air velocity reaches the value of 0.4 m/s and the temperature is 18.1 °C. The diagrams give a good representation of thermal fluid dynamic conditions in the test room, bu tif the researcher wants more precision on the values, it is possible to increase the numbers of nodes charactering the mesh.

Configuration 2

In the figures 13-18 the diagrams obtained by measurements realised on the out sections of the room are reporte As it is possible to see this linear diffuser provides a good mixing of room air with supply air outside the occupied zone. This type of diffuser provides a good Coanda effect. The longitubdinal cross section of the test room shows that the plum flow comes in the room at 15 °C near the inlet section with 1.5 m/s air velocity, mixing with the room air near the ceiling. This phenomena guarantees an uniform air temperature and air velocity distributions, and it prevents air draughts in correspondence of the occupied zone. Nevertheless the thermal comfort is not reached, because the inlet air temperature is more than 13 °C, insufficient to establish the mixed air at a 20 °C.

6. CONCLUSION

The main aim of the present work is to present an experimental method to be utilised to compare the experimental measured values with those obtained by numerical codes in simulations or to use the experimental values at the nodes of the theoretical mesh similar to the mesh reproduced by the automated apparatus. For this reason the proposed method may be a valid tools to the researchers which have the possibility to impose the input data and the shape of the mesh to measure the thermal fluid dynamic parameters to characterise the environmental conditions.

REFERENCES

[1] P. Principi, C. Di Perna and E. Ruffini, '*Monitoring of an Efficient Energy Building*', Rebuild 3rd European Conference, Barcellona, Spain, August 1999.

[2] P. Principi, C. Di Perna and E. Ruffini, '*Measurements in Situ of Fluidodynamic Parameters in the Buildings with Natural and Hybrid Ventilation*', Annex 35, Hybvent Forum'99, 3th Expert Meeting, Sydney, Australia, September 1999.

[3] P. Principi, C. Di Perna and E. Ruffni, '*Sistema Automatico di Misura per Analisi Termofluidodinamiche*', 17° Congresso UIT, Ferrara, Italy, July 2000.

[4] P. Principi, C. Di Perna and E. Ruffini, '*Design and Construction of an Automated Apparatus for Measurement of Environmental Parameters*', Annex 35, Hybvent Forum'99, 3th Expert Meeting, Sydney , Australia, September 1999.

[5] P. Principi, C. Di Perna and E. Ruffini, '*Results of an Experimental Investigate of Natural Ventilated Building*', Euro Conference, New and Renewable Technologies for Sustainable Development, Madeira Island, Portugal, June 2000.

Configuration1

Section 1

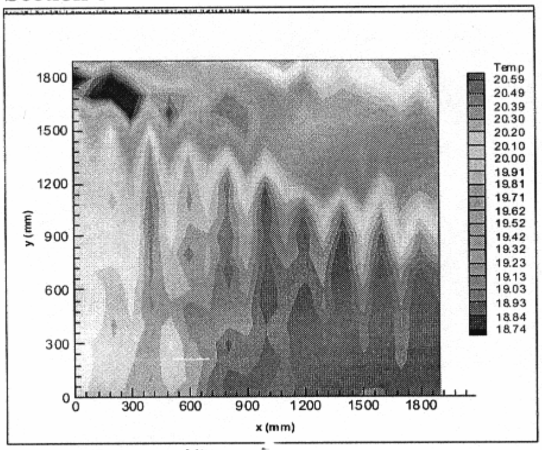


Fig. 7

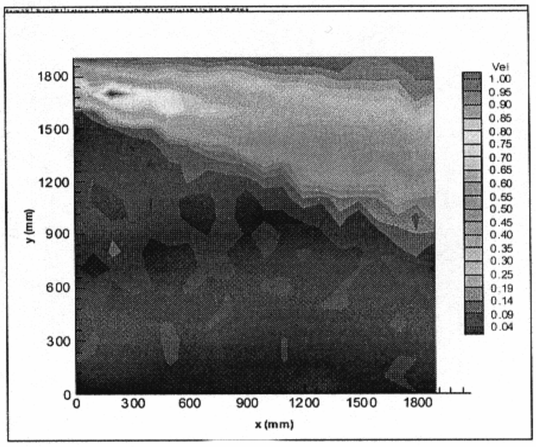


Fig. 8

Section 2

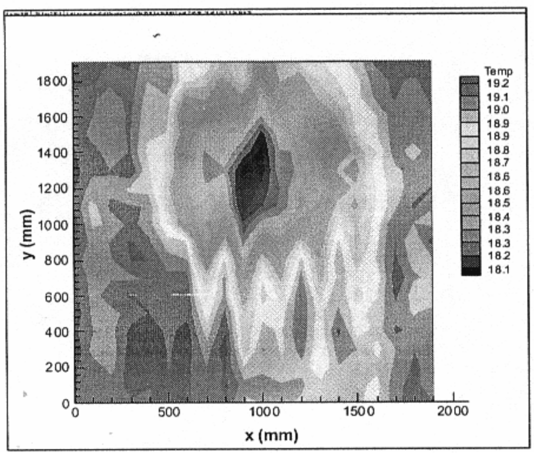


Fig. 9

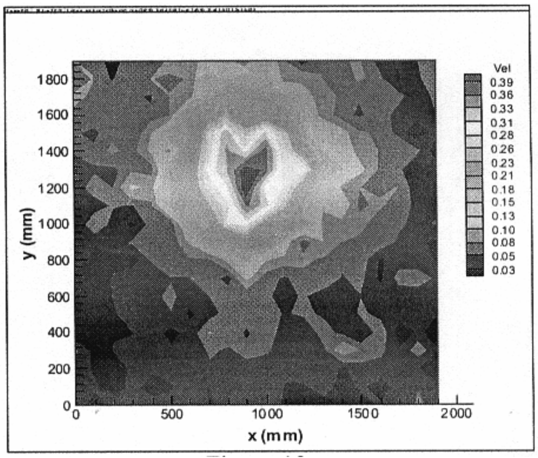


Fig. 10

Section 3

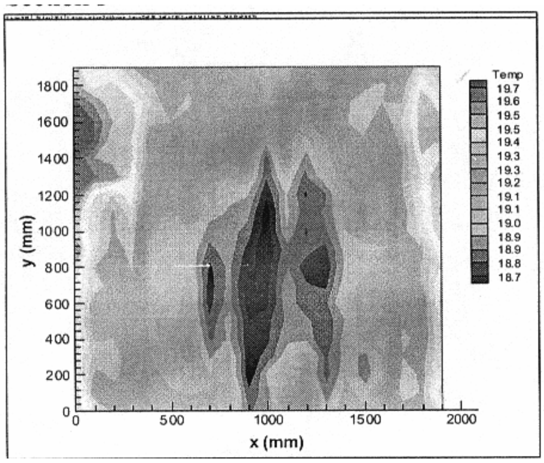


Fig. 11

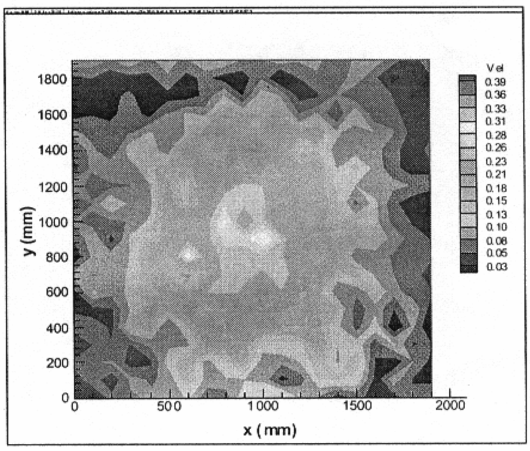


Fig. 12

Configuration2

Section 1

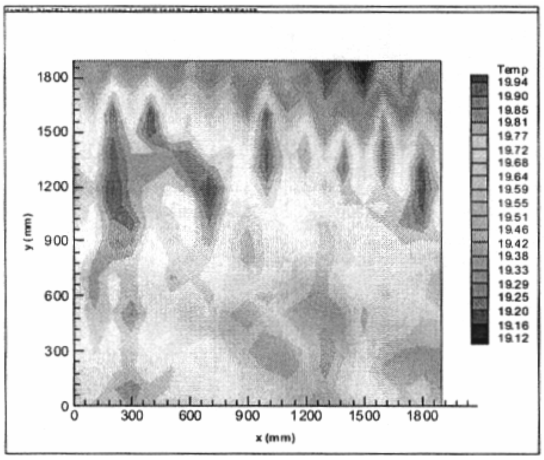


Fig. 13

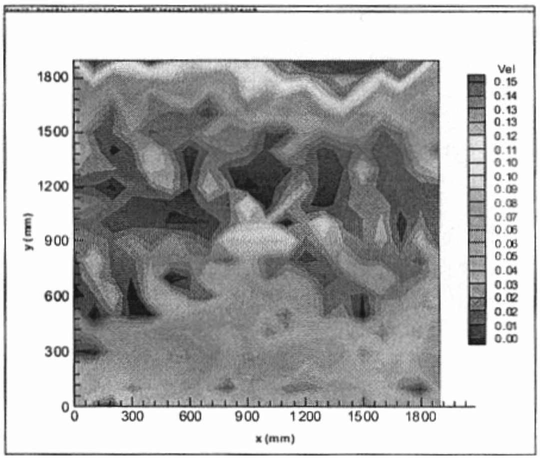


Fig. 14

Section 2

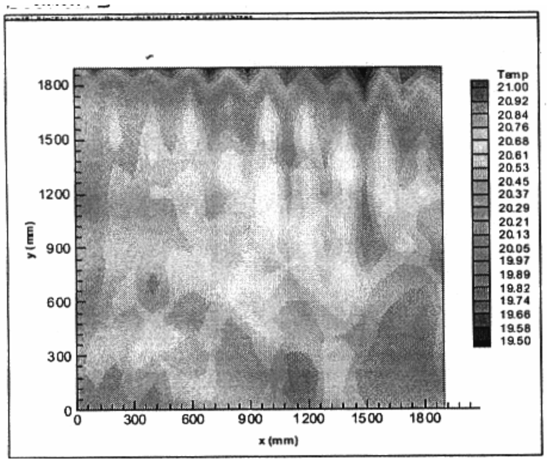


Fig. 15

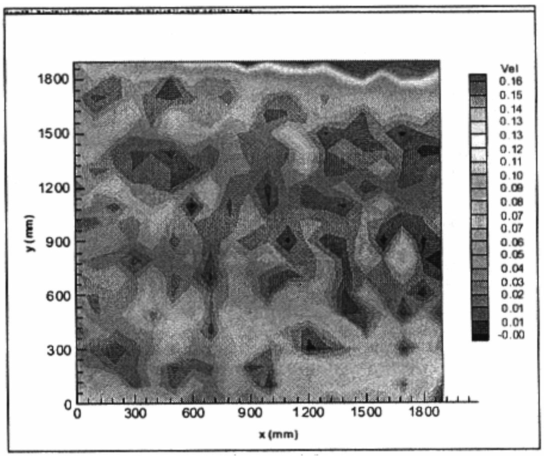


Fig. 16

Section 3

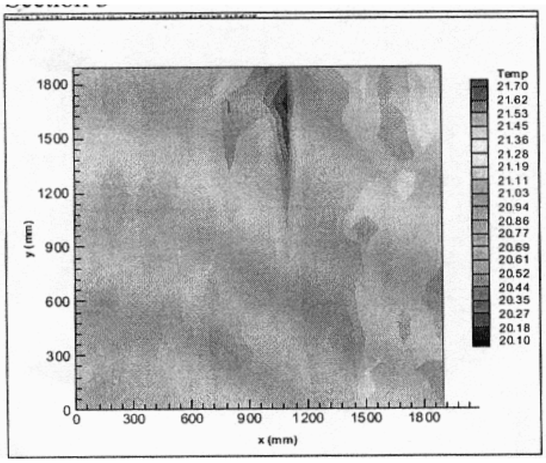


Fig. 17

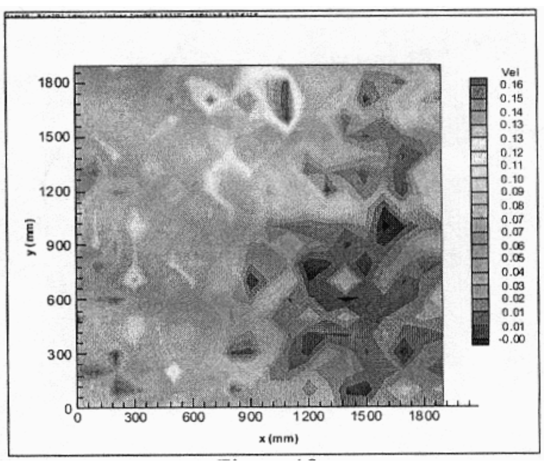


Fig. 18