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LABORATORY TEST PROCEDURES TO EVALUE THERMAL AND FLUIDODYNAMIC PERFORMANCES OF THE CLIMATISED ROOM

P. Principi, G. Borrelli, C. Di Perna, E. Ruffini

Dipartimento di Energetica - Università degli Studi di Ancona
via Brecce Bianche – I - 60100 Ancona, Italia
Tel: +39712204773 Fax: +39712804239
e-mail: p.principi@popcsi.unian.it

Synopsis

In this paper the experimental results of the measurements obtained after the completion of a test room realised in the laboratories of the Dipartimento di Energetica dell'Università di Ancona and the development of the monitoring system are reported. The same authors have already discuss in others works the preliminary studies about these themes and in which it is possible to read the first data of the effectuated studies about climatization phenomena.
The implementation of the equipment has taken to have a system for the simulation of different environmental conditions, both indoor and outdoor of the building. The laboratory tests can be utilized to obtain the experimental values of parameters which the researchers could use to validate the theoretical results obtained by computational fluid dynamics techniques. The aim of this work is to show the potential resources of the test room through a series of experimental tests based on different configurations. In this paper the experimental results of the measurements obtained testing four different configurations of air diffusion inside a simulated office room are reported. The overall aim of the work is to visualize the air velocity and temperature distributions in different sections of the climatised volume to understand if the thermal comfort condition of the occupants is established.

1. Introduction

The correct diffusion of the air in the room is one of the main conditions to obtain thermal comfort. In fact the supply air must be delivered at the right temperature, humidity and flow rate, so that when it is mixed with internal air, the final condition in the room 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 gain and provide uniform air motion and temperature within the volume. 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 to have thermal and air velocity diagrams. 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 positions are located.

2. Laboratory devices

The controlled room realized in the laboratories of the D.E.A. (Figure 1), is a parallelepiped measuring 4.37 m x 3.39 m and 2.7 m high and consists of a frame of iron profiles.

The test room has been panelled with plasterboard and polystyrene of five centimetres thick. To be designed with the concept of high flexibility, all the sides of the room present the removable panels high 0.40 m on the top and on the bottom, to install the grilles 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 and flexible pipes of plastic material and other equipments described as follow. An individual module 42 BJ, products by Carrier, supplies the air conditioning of the inlet air and it controls all thermal comfort parameters. 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. In the controlled room the thermo fluid dynamic parameters have been measured with an automated apparatus (Figure 2) [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 themselves 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 and 2.6 m long the other one. 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 measurements of thermo fluid dynamic parameters are recorded by HP 34970A data logger with 20 channels. At the end the recorded data have been elaborated with a commercial software (Tecplot), that permits to visualize the obtained results with graphics [4], [5].

Figure 1

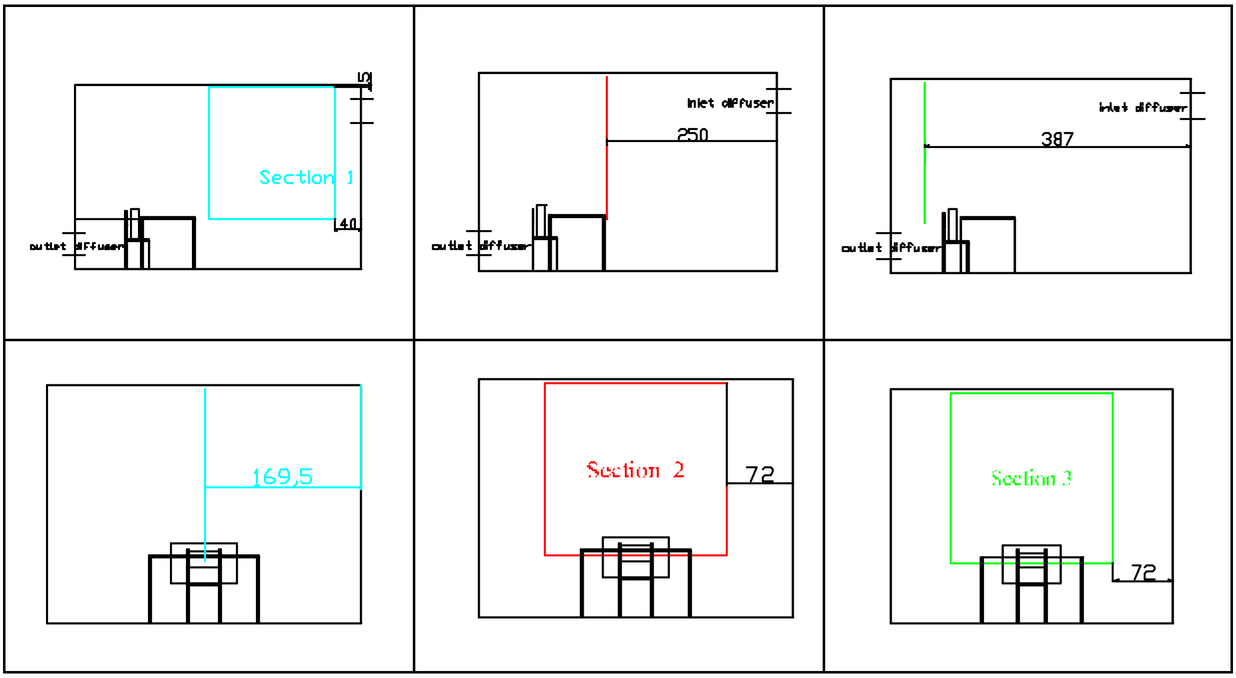
Figure 2

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 on the sides, ceiling and the floor, to value the air velocity and temperature distributions.
In this work four 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 Ti = 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 air diffusion a series of the measurements on three sections of the controlled room have been realized (Figure 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;
- in the end the third section is located on the vertical plane and it is parallel to the inlet diffuser 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 four types of diffusers:



Section 1 **Section 2** **Section 3**

Figure 3

Configuration 1

In the first configuration (Figure 4) has been utilised a traditional inlet diffuser, in aluminium with double row of adjustable blades, 14 vertical and 8 horizontal (Figure 5). 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 middle of the room short side.

The return air grill is located on the bottom of the opposite side.

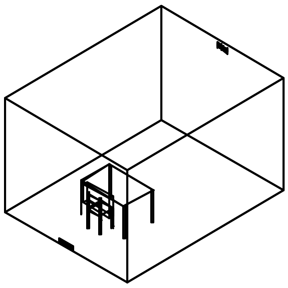
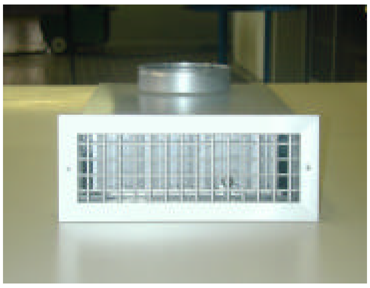


Figure 4



x

Figure 5

Configuration 2

In the second configuration (Figure 6) has been utilised an innovative linear inlet diffuser with one horizontal way blow (Figure 7). 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 is positioned at the foot of the other short side of the room.

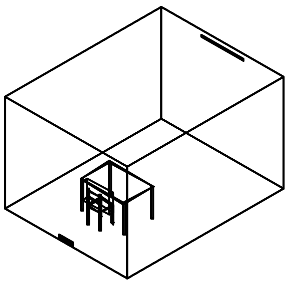


Figure 6

Figure 7

Configuration 3

In the third configuration (Figure 8) in the test room a round ceiling diffuser, shown Figure 9, has been installed. This diffuser consists of a frame equipped with a series of four fixed blades. Its diameter is 15 cm and its effective section is 0.014 m^2.

This diffuser represents a good solution for air diffusion in air conditioning, ventilation and forced air heating systems. Their application is the most reliable and satisfactory in rooms with standard height and in high ceiling applications. It is fixed at a distance of 0.70 cm from the wall of the short side of the room.

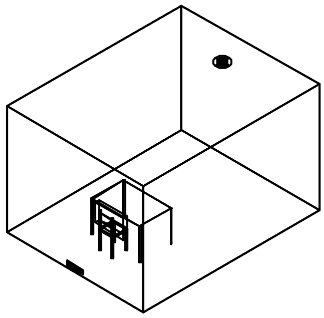


Figure 8

Figure 9

Configuration 4

In the fourth configuration (Figure 10) a linear diffuser has been installed in the floor. Its is constituted by an aluminium plenum and a frame, composed by adjustable blades, 49 vertical and 1 horizontal (Figure 11). Its dimensions are 100 x 4 cm, with efficient section of 0.024 m^2. It is located at a distance of 15 cm from the vertical wall. Such diffusers provide a good distribution of the air in the room, generating induction the air.

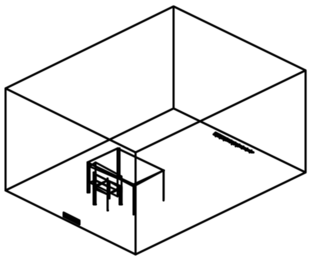


Figure 10

Figure 11

5. Experimental results

In both cases the thermal fluid dynamic parameters, temperature and air velocity, have been measured in the three considered sections. On the trolley of the automated apparatus a 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 the controlled room, in particular they have been located on the inlet and outlet diffusers, on the thermal radiator surface, on the external ceiling surface and on the 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 to 22.6 °C, demonstrating the different air mixing phenomena inside the room.

Configuration 1

The Figures 12 – 17 show the air velocity and temperature distributions in the sections 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° on the axis of the plum flow. The diagrams show the characteristic jet flow in the room. The jet flow 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 doesn't realise a good air mixing inside the occupied volume, also if the Coanda effect is verified and the supply air is cooled. In this case the airflow 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 while the temperature is 18.1 °C. The diagrams give a good representation of thermal fluid dynamic conditions in the test room, but if the researcher wants a more precision of the values, it is possible to increase the numbers of nodes charactering the mesh.

Configuration 2
In the Figures 18 - 23 the diagrams obtained by measurements realised on the cut sections of the room are reported. 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 longitudinal 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 phenomenon guarantees air temperature and air velocity uniform 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.

Configuration 3
As the diagram of the Figure 24 shows, only 5 cm below the diffuser the air has a temperature of 21.5 °C, demonstrating an induction phenomenon, being the outlet air temperature 15.3 °C. In the same zone the air velocity reaches 0.11 m/s (Figure 25), that is a low value for a distance of 10 cm from the outlet section. This condition determines a cooler air fall (21.7 °C) inside of the air mass at 22.4 °C. Going in the direction of the outlet diffuser, it is possible to see a vertical stratification of the air with a higher temperature in correspondence of the outlet air direction. In fact this thermal condition is verified on the diagram of the air velocity, that demonstrates a stopped air in a velocity range between 0.00 and 0.07 m/s in the asurface, unless the diffusion zone, where the air velocity reaches the value of 0.11 m/s. The induction effect is very low and the low air velocity doesn't prevent from using the Coanda effect on the ceiling. The diagrams, concerning the other two vertical sections, show the same thermal fluid dynamic conditions (Figures 26 – 29). In fact 2 m below the diffuser, the temperature gradient is 0.6 °C, while at the left and right of the darker zone of the diagram have 1 °C more than the ceiling.

Configuration 4
In this case an horizontal floor diffuser is used. At the left of the diagram in the Figure 30 is possible to see the vertical plum jet that reaches the ceiling and for Coanda effect generates a by pass of the central volume of the room, flowing under the ceiling and reaching on the opposite site the return diffuser. This condition is more evident on the air velocity diagram (Figure 31), where in the left upper corner the airflow turns with the 0.2 m/s velocity. In both the temperature and air velocity diagrams respectively the air vertical temperature stratification and an homogeneous air velocity field, in a range of very low values as 0.01 – 0.06 m/s, are shown. In the Figure 32, referring to the section 2 at right on the top, in coincidence with the centre, there is the lower value of temperature characterizing the plum jet in the horizontal direction.

Configuration 1

Section 1

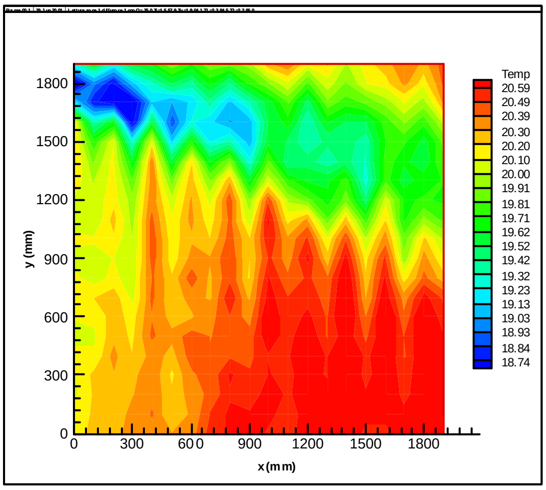


Figure 12

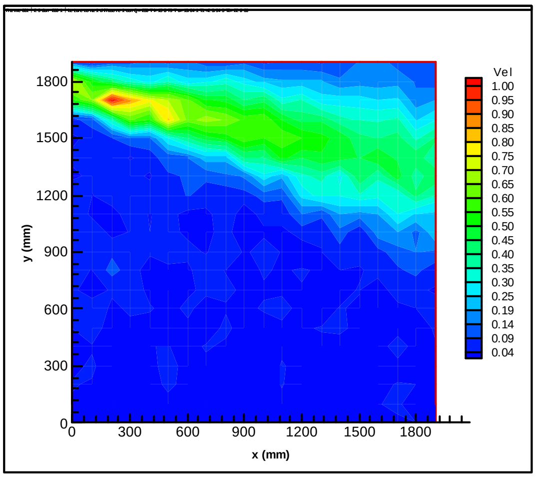


Figure 13

Section 2

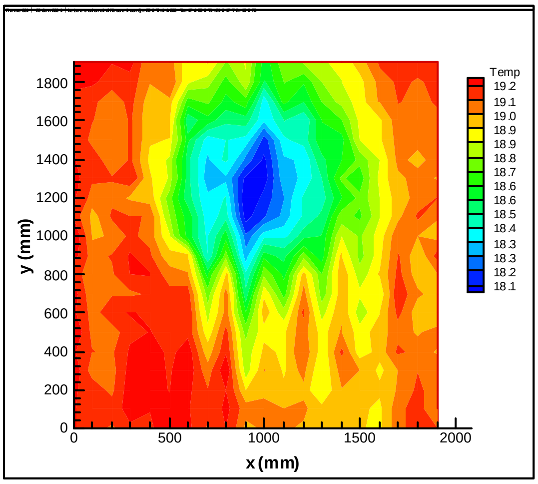


Figure 14

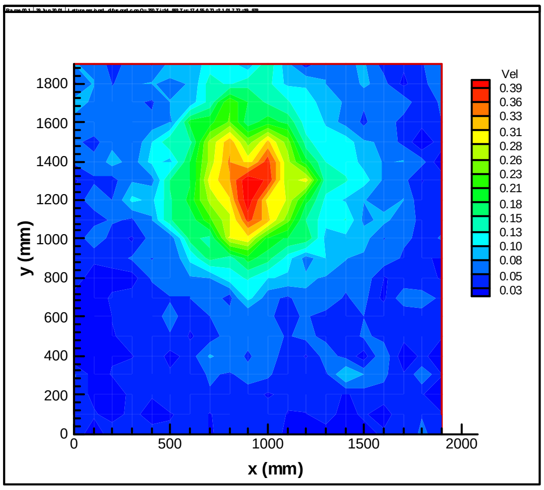


Figure 15

Section 3

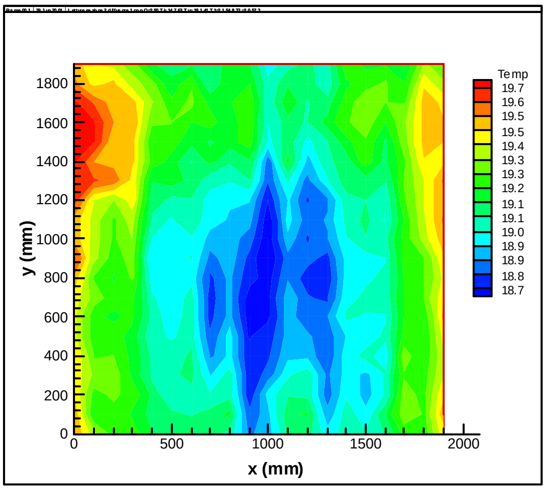


Figure 16

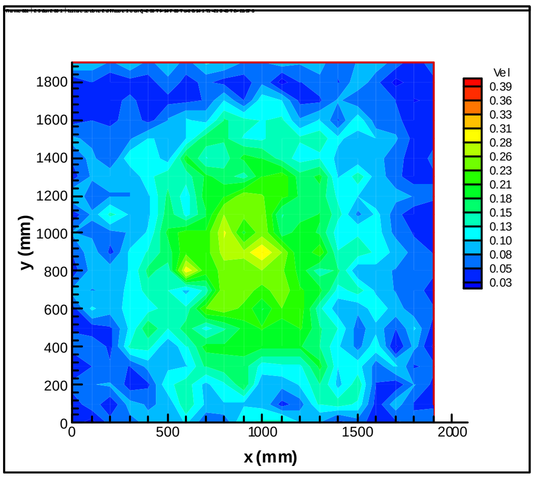


Figure 17

Configuration 2

Section 1

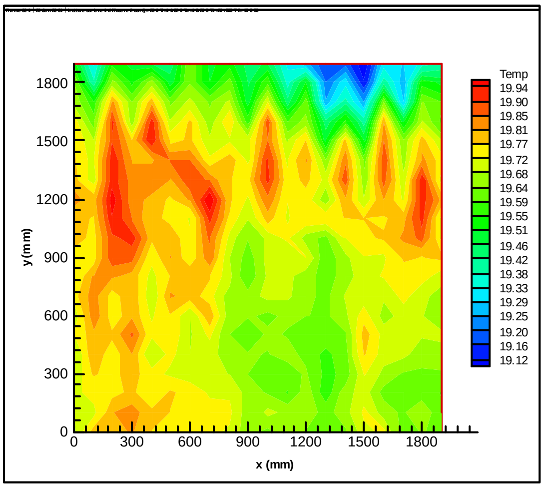


Figure 18

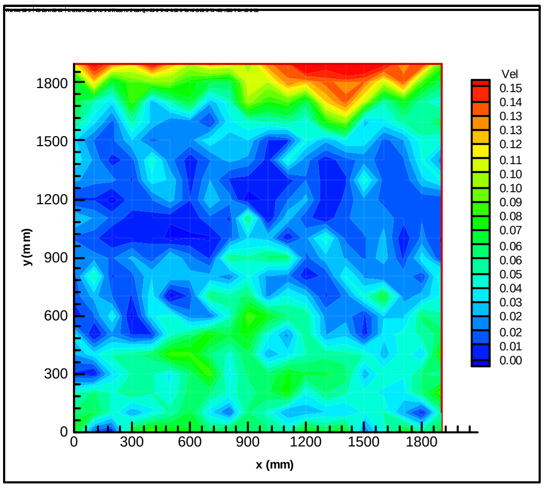


Figure 19

Section 2

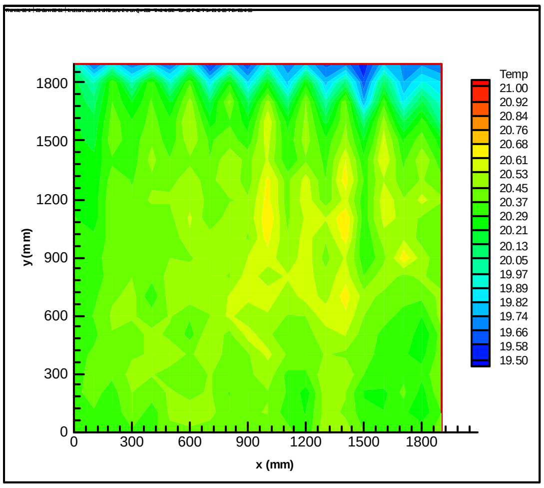


Figure 20

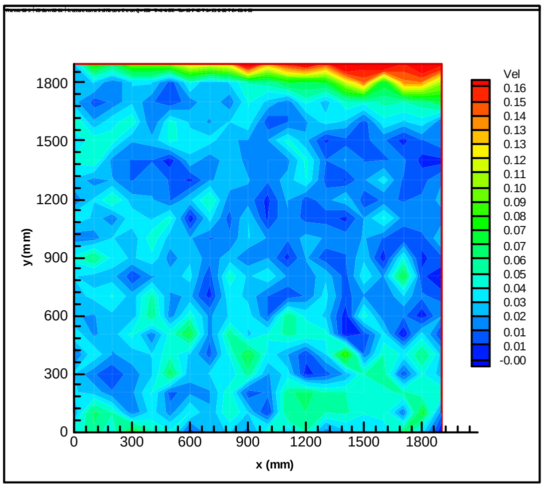


Figure 21

Section 3

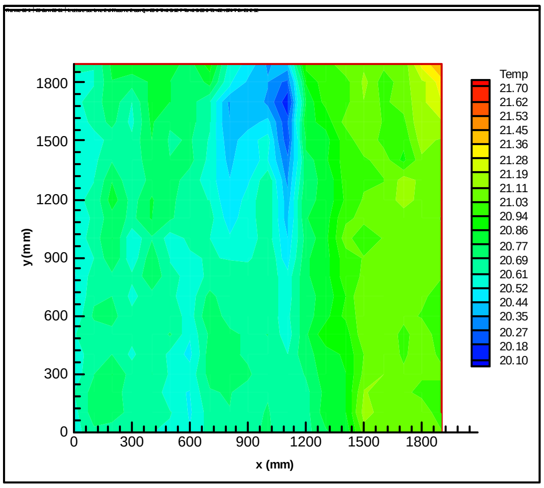


Figure 22

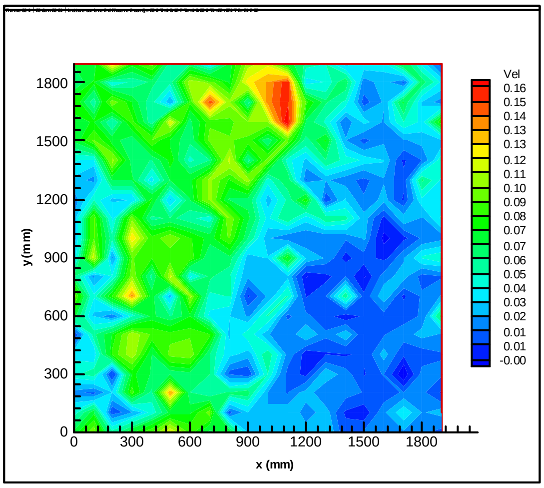


Figure 23

Configuration 3

Section 1

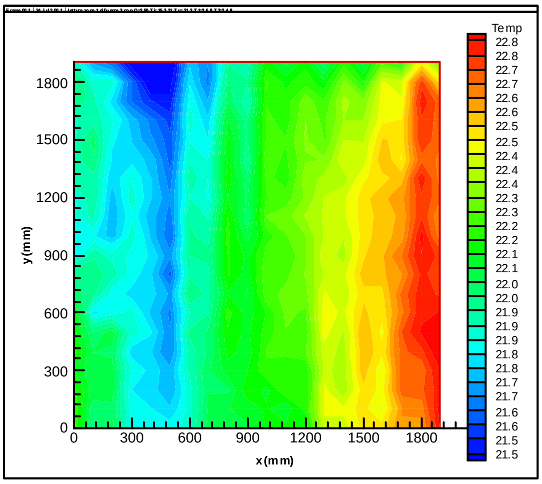


Figure 24

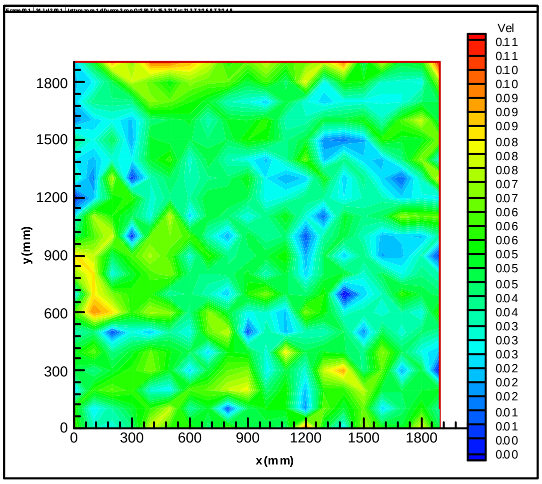


Figure 25

Section 2

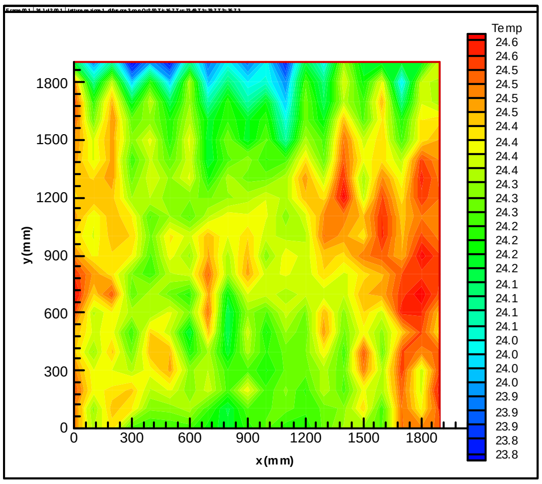


Figure 26

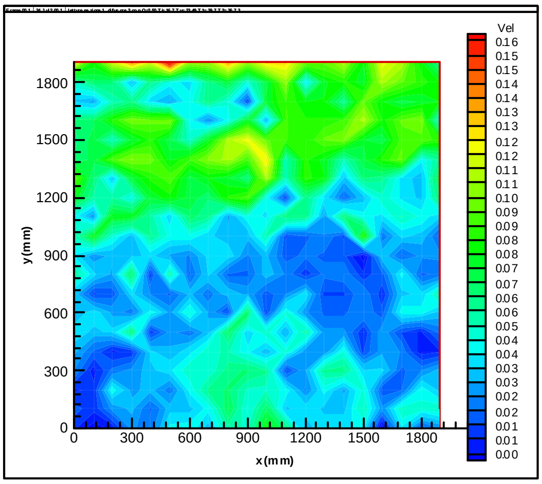


Figure 27

Section 3

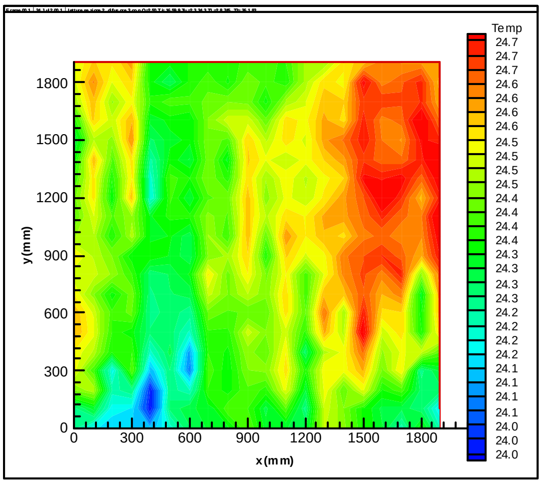


Figure 28

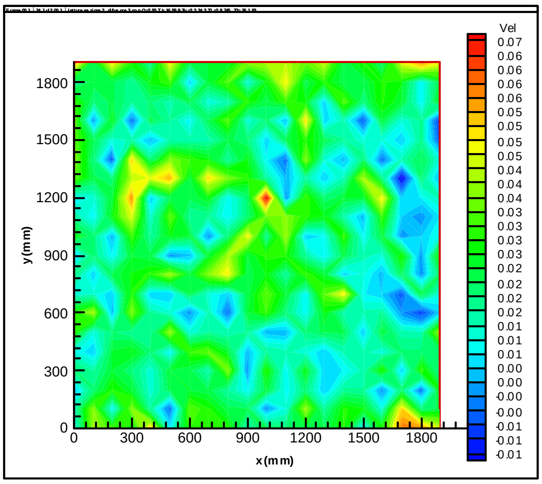


Figure 29

Configuration 4

Section 1

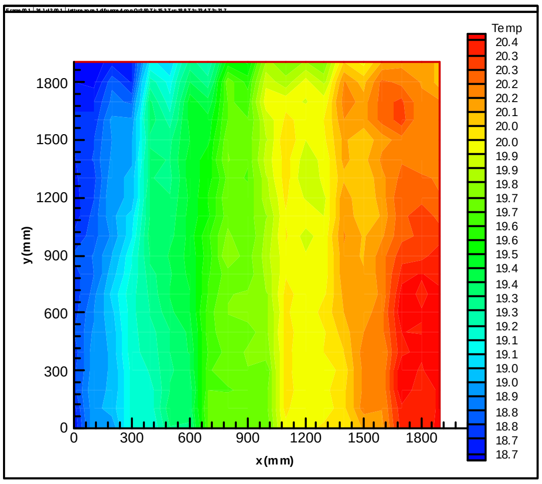


Figure 30

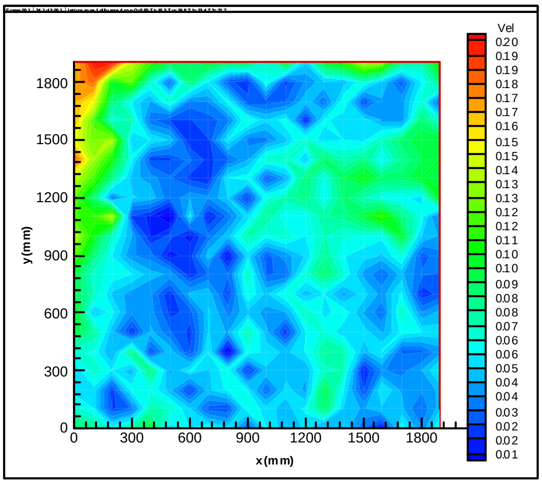


Figure 31

Section 2

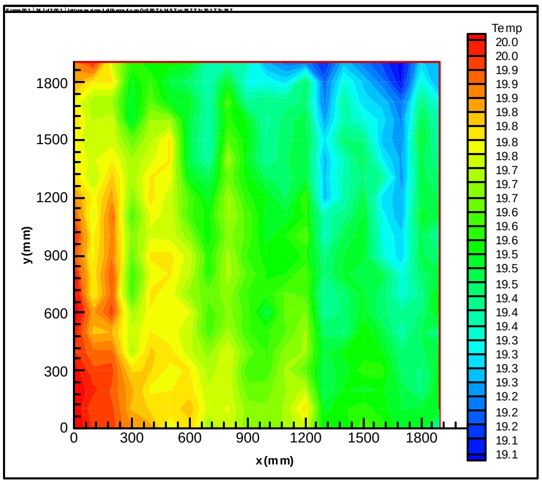


Figure 32

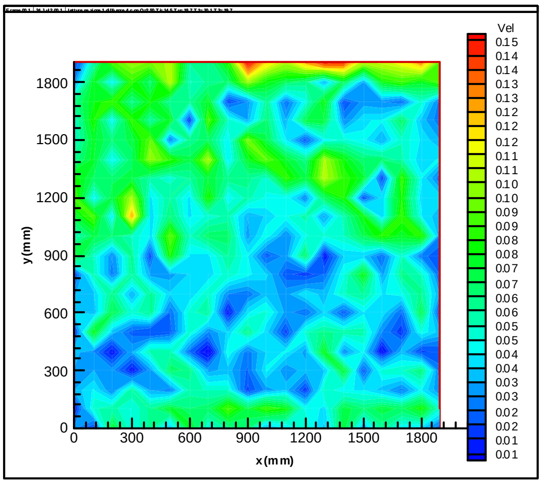


Figure 33

Section 3

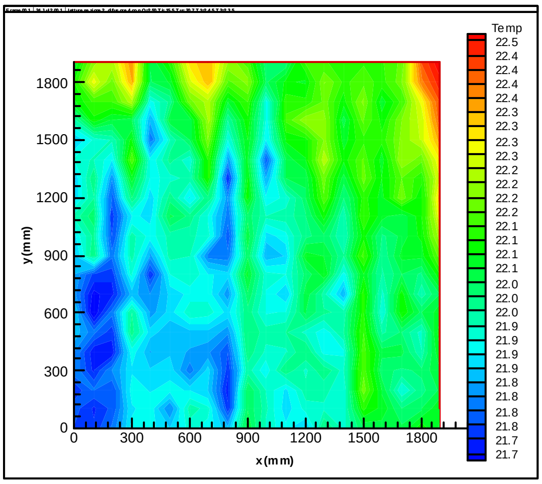


Figure 34

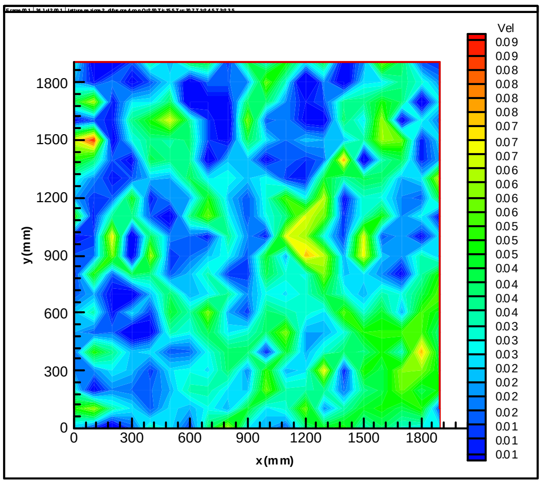


Figure 35

6. Conclusions

The main aim of the work is to present an experimental method to utilise 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 for 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. The 400 nodes mesh utilised to elaborate the diagrams, seems to give a very good detailed distribution of the measured parameter. To have a complete configuration of the airflow inside the room, it should be necessary to amply the measured area. In fact in the present tests are not shown the thermal fluid dynamic conditions around the outlet section and in correspondence of the internal side surface. For this reason, it will be useful to build an apparatus having the horizontal and vertical axis longer than actual profiles of the utilised apparatus. In the next future the control system of the aeraulic and hydraulic circuits will be integrated with sophisticated device to have a more precision on the measured values of the thermal fluid dynamic parameters. The research program of air diffusion, distribution and retaking, concerning the air conditioning system and hybrid ventilated system, will be carried out, utilizing several configurations and changing the air flow-rate and the air temperature values. In fact for each configuration and type of diffusion will be simulated the summer and winter environmental conditions.

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