TEST INSTALLATION TO DEVELOP A NEW MODEL CONCEPT TO MODEL AND CONTROL THE ENERGY AND MASS TRANSFER IN A THREE DIMENSIONAL IMPERFECTLY MIXED SPACE.

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1. PROBLEM

In the existing literature about the modelling of the response of the micro climate to variations of the control inputs (ventilating rate and heat supply), different quantitative models have been proposed. An important disadvantage of these models is that they have too restrictive constraints to be useful for control purposes:
- In these models the perfect mixing of the room air is supposed [2,3,27].
- The ventilating rate is considered to be constant level or is considered to be a linear function of the room temperature [1,10]. For control purposes however, the air flow rate is the most important non linear control input regarding the micro climate at different positions in the room.
- In the proposed models, only the relatively slow variation in temperature is considered and in most cases the option of constant steady state is chosen [5,6,21].

It is shown that the simulation technique gives an excellent opportunity to get deeper understanding in the dynamic behaviour of physical processes [illegible]. Indeed, the knowledge of the physical processes within a system is the essential link to achieve better control. In this purpose, many research has been done to study the dynamic behaviour of air flow pattern within a ventilated space. In most cases the main problem is to generate stable air flow patterns and to simulate physically the dynamic behaviour in a repeatable way and this because of practical considerations.
A powerful tool to get deeper understanding in the dynamic behaviour is the visualisation of the air flow pattern and control volumes of temperature and moisture (as defined by Berckmans [4]). The problem here is the gathering of quantitative data. In literature research has been described about the quantification of air flow patterns and the distribution of mass and energy in a ventilated space. Often the flow visualisation is used to get a general, qualitative overview of the flow field.

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Today many models of air flow patterns and room air distribution are developed using the powerful supercomputing techniques [18], while the proposed models only are to be validated with the use of statistical techniques on flow visualisation data.

It is shown that quantitative data (measurements and visualisation of flow patterns) are needed to develop and validate useful algorithms to model the dynamic response of physical micro-environmental factors in an imperfectly mixed fluid.

2. OBJECTIVES

By combining the power of on-line modelling algorithms or mathematical identification procedures, with a model, part based on physical laws, the project is focused on the modelling of the physical process of energy and mass transport in a non-perfectly mixed bio-space. The first objective of this paper is to describe the experimental installation and this for several reasons:

- Since a lot of measurements have been realised yet and more will be realised and published, it is important to give a good description of the installation.
- The description of the test installation gives the opportunity for other research teams to propose other experiments.
- The test installation gives the opportunity to visualise fluid flows and distribution of mass and energy in a quantitative way.
- The installation gives the opportunity to test and validate different control algorithms and proposed models.

The second objective is to describe shortly the developed method:
- to visualise the air flow pattern
- to quantify the (dynamic behaviour of) the three dimensional air flow pattern
- to visualise the control volumes (as defined by Berckmans [4]) of inside temperature and humidity.

3. METHOD

In following sections different aspects of this test installation will be explained.

3.1 THE TESTCHAMBER

The purpose for which the testchamber was built, is to generate stable air flow patterns and to measure the transient behaviour from one air flow pattern to

another. To guarantee stable airflow patterns different parameters must considered. In literature [8] the following parameters that influence the air velo(and temperature are proposed:

- the geometry of the room
- the geometry, size and position of the air inlet
- the geometry, size and position of the air outlet
- the position of the heat production unit
- the surface temperature of the walls
- the temperature difference between the inside air and the fresh air entering room
- the velocity of the incoming air
- the turbulence of the inside air

These items will be described in the following sections.

3.1.1 The geometry of the room

One of the most important parameters to influence the air flow pattern, is the ro geometry. In literature specific scientific research was done on the effect of room geometry to the air flow pattern. Different researchers [2,3,15,16,17,22] use rectangular balk with a length-heigth fraction larger then one. They motiva there choice explicitly or implicitly by referring to real life- and production spa whom mostly have an rectangular section. Despite the fact that the lenght-hei fraction is not explicitly included in the Archimedes number [22,23], there is so influence on the airflow pattern. This influence was demonstrated by using the epsilon model [20]. Nielsen concluded that an increase of the length-heigth fracti decreased the Archimedes number by 20 % only. In literature [26,27] the influe of the length-heigth fraction was shown on the Coanda-effect. It was demonstra that the Coanda-effect disappears when the length of the room decrea Considering these conclusions, the following room geometry was taken (figure 1):
- the length-heigth fraction must be greater then one, i.e L= 3 m and H= 2 m.
- the width B= 1.5 m

3.1.2 The geometry and position of the air inlet

The position and the geometry of the air inlet are of most importance generatir stable air flow pattern. Consequently different aspects of the air inlet must be ta into account such as:
- the geometric form
- the dimensions
- the position

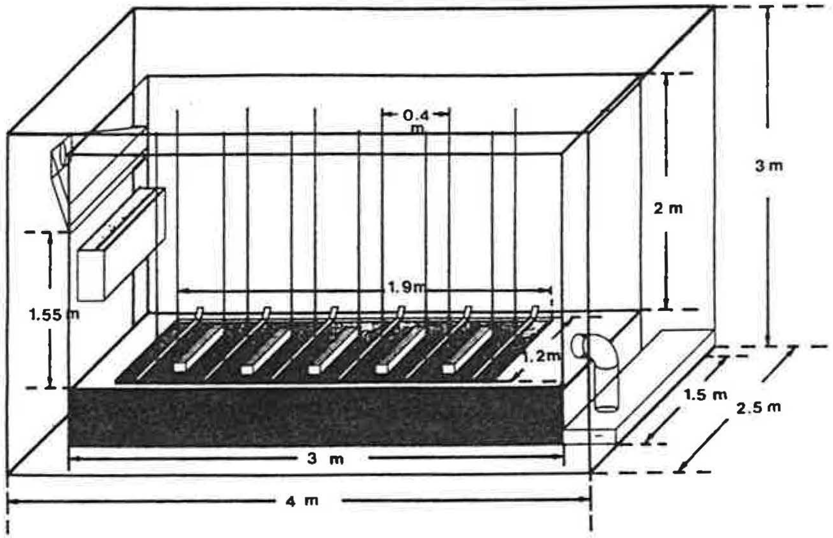

Figure 1: Dimensions of the test installation

3.1.2.1 The geometric shape of the air inlet

Most researchers consider a rectangular air inlet (slot inlet) to be the most appropriate form.

3.1.2.2 The dimensions of the air inlet and the inlet velocity of the incoming air

The dimensions of the supply opening are dictated by the desired maximum air velocity. The influence of the Coanda-effect and the effect of buoyancy are function of the inlet velocity. In literature [22] a velocity of 5 m/s is proposed to achieve a stable, horizontal air flow pattern. The value of 3 m/s is suggested as an under limit [13]. With a given maximum air flow rate in our testchamber of 320 m^3/h, it was decided to take 0.02 m^2 as size of the supply opening. Based on recommendations in literature [16,17,22,25] the horizontal dimensions (width) of the supply opening of 1 m is taken (figure 1).

3.1.2.3 The position of the air inlet

The position of the air inlet above the floor, is an important parameter in realisin stable air flow pattern. In literature [15] it is mentioned that the height above t ground is function of the air inlet velocity and function of the angle of the ceiling relation to the vertical wall. Different rules are mentioned to define the height the air inlet. Leonard and Mc Quitty [16], determined that the air flow pattern v attach to the ceiling when the air supply opening is installed on a distance below t ceiling of four times the width of the supply opening. They concluded that influence was found of the Coanda effect when the air inlet opening was position 0.6 m below the ceiling. Their main conclusion was that more research had to done "to determine the distance of the orifice below the ceiling beyond which j will not attach...". Based on the experimental testchamber of Leonard and Mc Qui [16] the air supply opening is installed on 1.55 m above the ground (figure 1).

3.1.3 Position of the external heat production

In literature many research is described regarding the position of the heat supp unit [26] and the influence on the separation point of the air flow pattern. It concluded that a main influence can be seen on the generated air flow pattern wh installing the heating element on the same wall as the air supply opening: the a flow pattern sticks much better to the ceiling when the heat production is turned o This effect could not be seen when positioning the external heat production on th wall facing the air supply opening. Consequently a heating element (2500 Watt) h been installed under the air inlet. (figure 2)

3.1.4 The surface temperature of the walls

To minimize the disturbing influence of the walls on the air flow pattern as cause by the surface temperature of the walls, a second building envelope is bui surrounding the primary testchamber. The temperature in the interspace betwee the two test chambers is controlled in order to reduce the conduction of heat troug the walls of the internal test chamber.

3.1.5 The temperature difference between the inside air and the incoming air

The temperature of the incoming air is calculated from the corrected Archimede number to generate a stable air flow pattern. The temperature of the incoming air i controlled by a cooling installation. In this way, it is tried to generate stable air flo patterns when using different inlet temperatures. Indeed, the cooling installation dimensioned to ensure a range of inlet temperatures to be used.

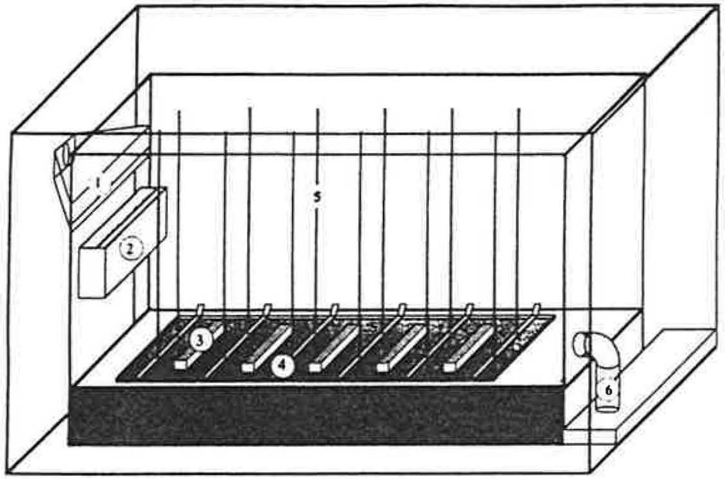

Figure 2: Representation of the different parts in the test installation

1. Air Inlet (slot inlet). 2. External heat production. 3. Internal heat production. 4. Internal moisture production. 5. Support of the temperature and humidity sensors. 6. Air outlet

3.1.6 The turbulence of the inside air

Turbulence caused by moving persons or animals and chinks are not taken into account in this study. The test installation is free of any moving object and of chinks that can cause turbulences.

3.2 MEASUREMENT OF THE DIFFERENT IN- AND OUTPUT VARIABLES

The input variables as measured in the testchamber are (figure 3):
- air flow rate
- temperature of the incoming air
- relative humidity of the incoming air
- heat supply
- internal heat production
- internal moisture production
- pressure difference between the testchamber and the envelope

The considered output variables are:
- temperature and relative humidity of the room air
- the quantified air flow pattern
- the three-dimensional distribution of the temperature and humidity

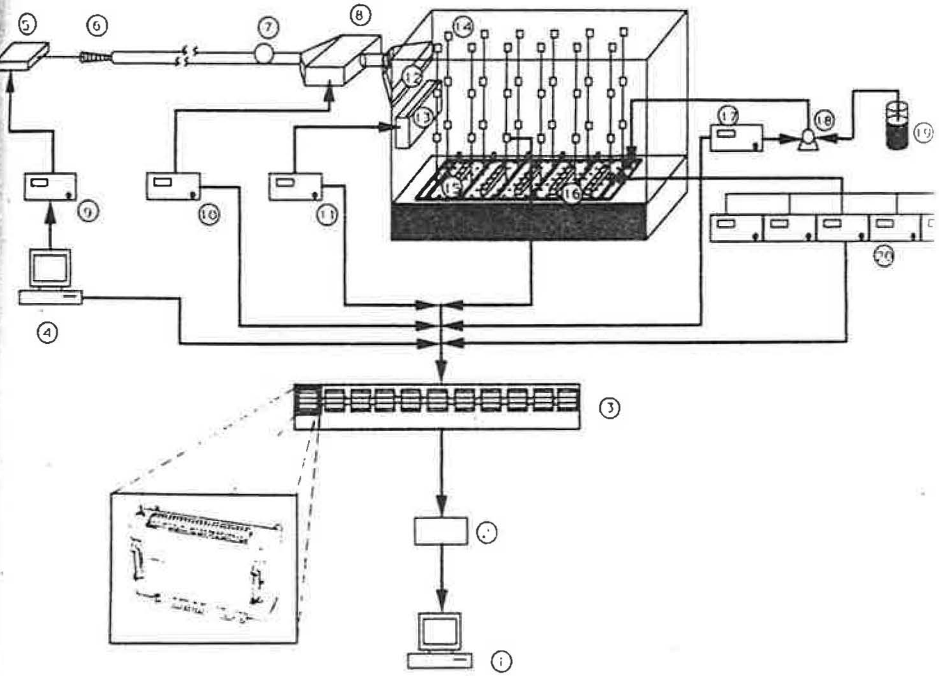

Figure 3: Schedule of the test installation

1. Minicomputer (monitor, floppy disc, to store and visualise the measured data). 2. Parallel-inte for digital and analog signals. 3. Scan- and measurement unit. 4. Minicomputer (to control measure the produced air flow rate). 5. Stepmotor to control the position of the cone, usc diaphragm. 6. Cone, used as diaphragm, to produce the desired air flow rate. 7. Centrifugal fa generate a ventilating rate. 8. Cooling installation to control the inlet temperature. 9. Differ pressure transducer to measure pressure difference between the testchamber and the envelop Control- and measurement unit of the cooling installation. 11. Control- and measurement unit o heating element. 12. Air inlet (slot inlet). 13. Heating element. 14. Three dimensional gri temperature and humidity sensors. 15. Aluminium semi conductor heatsinks to provide internal production. 16. Undeep water reservoir with a streamer containing hot water to generate the int moisture production. 17. Unit to control and measure the amount of water supplied to the un water reservoir. 18. Water pump. 19. Water supply resrevoir. 20. Power supplies for internal production.

3.2.1 Measurement of the air flow rate

To measure the air flow rate a sharped orifice is used. By measuring the pressure drop over this orifice, the air flow rate is calculated. The orifice was constructed and built accordingly to the international standards DIN 1952 and NBN 688 [9,19]. To produce the desired air flow rate, a cone is used as a diaphragm. This cone can be positioned by steering a stepmotor (figure 3). In the control system the measured air flow rate is calculated using the air temperature, the relative humidity of the air and the atmospheric static pressure. The system of air flow rate production and measurement has an accuracy of 6 m^3/h.

3.2.2 Internal heat production

The amount of heat supplied to the room can be varied between 100 and 600 watt [24]. It has been tried to reduce the dimensions of the heating elements in an effort to minimize the obstructions for the air flow. Conventional solutions to simulate the internal heat production, therefore were not appropriate. To determine the temperature of the heating surface, one must consider the physiological implications. Randall [21,22,23] simulated living occupants by using butylsacs filled up with warm water. The surface temperature of his "animals" varied between 28.5 and 39.5 degrees Celsius. Based on in literature [13,16] a surface temperature of the heating surfaces of 30.5 degrees Celsius was to be taken. To provide this surface temperature and a maximum surface-volume ratio, it was decided to built aluminium semiconductor heatsinks. On these heatsinks low voltage power resistors were installed to dissipate the desired heat. By measuring the supplied power to these resistors a global measurement of the internal heat production became possible. The measurement and production of the internal heat production has an accuracy of 1 Watt.

3.2.3 Internal moisture production

The production of moisture in the testchamber was conceived by indirect heating of water. A streamer with hot water, with a diameter of the tubes of 4 mm, built in a specific form to provide maximal heat dissipation to the surrounding water, is placed in an undeep water-reservoir (0.03 * 1.80 * 1.40 m). Using this system it becomes possible to evaporate a large quantity of water in an homogeneous way by covering a large surface. The control of the water flow to be evaporated is done by measuring the level in the water reservoir. The water supplied to the reservoir, to maintain the desired level, is weighted. In this way the quantity of evaporated water during the experiment can be measured. Controlling the amount of evaporated water can be

done by controlling the inlet temperature of the hot water or by regulating the flow rate of the water in the streamer (figure 3).
The flow rate of the water can be installed at different levels, varying from 0.3 l/h to 1.3 l/h. The maximum inlet temperature of the water in the streamer is 55 degrees Celsius. When this temperature is used to evaporate water in the reservoir, the amount of water evaporated is 0.5 l/h.

3.2.4 Measurement of the temperature of the inside air

A previous survey about the appropriate sensors to measure the temperature resulted in the choice of thermocouples. These sensors did meet the following characteristics:

- low response time
- good linearity
- high mechanical strength
- long life time
- minimal dimensions to reduce air flow pattern obstructions

Taking into account these specifications, a thermocouple type EJ-P (Constantan-Chromel) was selected. The accuracy is ± 0.1 degrees Celsius. The time constant is less then 1 second.

3.2.5 Measurement of the relative humidity of the inside air

The specifications postulated regarding the choice of the humidity sensors were:

- measurement accuracy of 5 %
- low response time (time constant less then one second)
- good repeatability and stability
- minimal dimensions
- simple calibration

Following these conditions, relative humidity sensors (Transmicor 131) based on a change of electrical capacity, were chosen. The sensors were calibrated using a calibration installation shown in figure 4. To install different levels of humidity several salt solutions were used. By solving salt in water the vapour pressure reduces [14]. The salt solutions were conserved in airtight PVC-containers. The different transducers were installed above the salt solution in the PVC-container and the resulting current was measured. In this way, calibration curves were determined given the relation between humidity and output current or output voltage. Using this calibration method, it could be deduced that the R2 of the linear function that exist between the output voltage and the measured humidity was 0.99 as an average and that the sensors have a statistical accuracy of ± 2.25 % Relative Humidity. The calibration curve for each individual sensor is used in the datalogger.

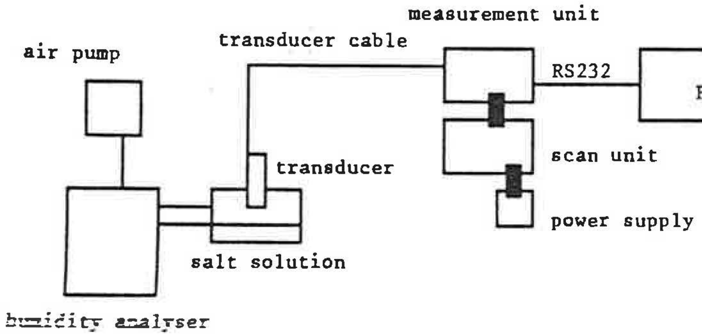

Figure 4: Calibration installation used to calibrate to humidity sensors

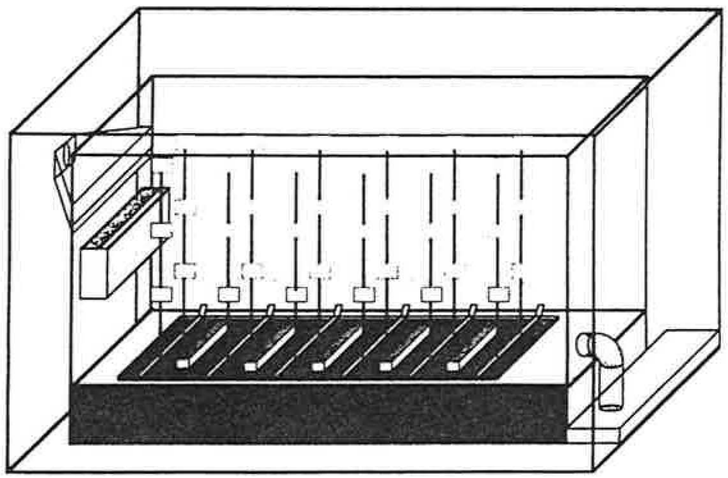

Figure 5: Representation of the sensor positions

3.2.6 Supports of the sensors

The total number of sensors in the testchamber is 144, positioned i dimensional grid of 72 measuring points. Each measuring point is provi temperature sensor and a relative humidity sensor since the model uses and mass equation. Sensors are installed in four equidistant planes reference plane, using 18 Inox aerials, divided in three rows of 6 aerials. system is self supporting which means that any connection to the wa testchamber is avoided (figure 5).

3.2.7 Data-acquisition

The data-acquisition is achieved using an intelligent measurement collection unit developed for industrial and scientific data acquisition ap This data acquisition system can measure different variables:

- *DC-voltage*
- *DC-current*
- *Temperature (thermocouples)*
- *Strain Gauges*
- *Digital inputs*

The measurement is carried out by a analog to digital convertor that programmed to provide either 16 or 14 bits of resolution and is sensitive microvolt. Measurement speed can be programmed from 40 readings/sec readings/sec with associated degradation in noise rejection and resolution. channels of the datalog system can be controlled individually and configurat tailor made software (figure 3).

3.3 VISUALISATION OF THE ACQUIRED DATA.

The analysis of the measured data will consist in testing the new model co model the three dimensional energy and mass transfer in a non-perfect fluid. Any physical interpretation of a conceived model demands a deep i the processes that take place in the test installation. In the considere concept the notion of control volume (defined by Berckmans [4]) is importance. At the laboratory of Agricultural Buildings Research software developed to visualise the measured data in three dimensions, to show th volumes of humidity and temperature, and to visualise the dynamic beh these control volumes as well. An output of this computer program is s figure 6.

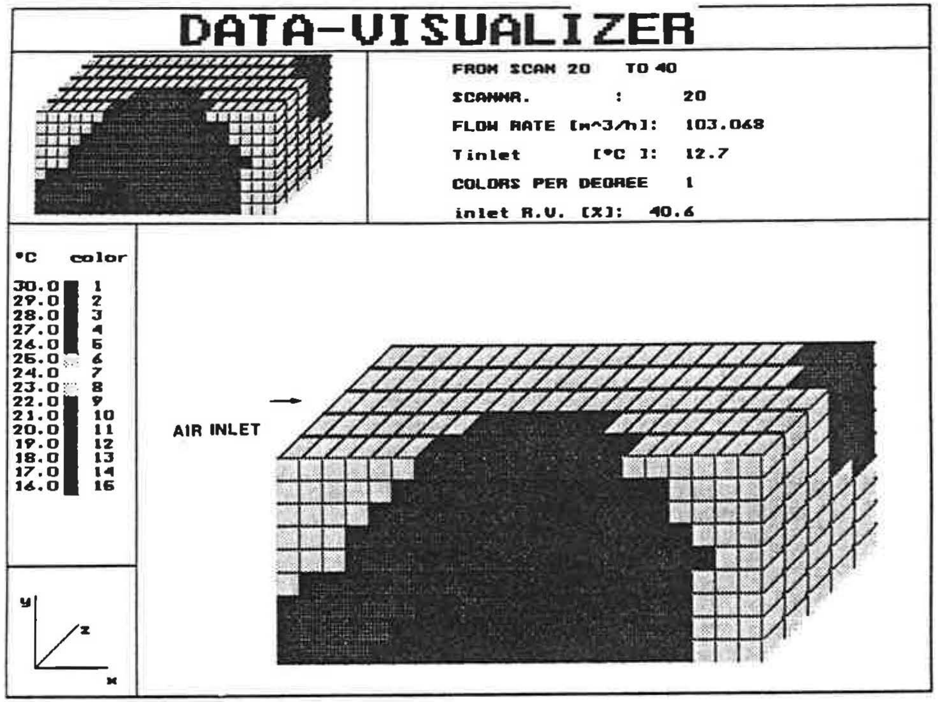

Figure 6: Visualisation of the distribution of the room air temperature

3.4 VISUALISATION OF THE AIR FLOW PATTERN

One of the strengths of the model concept is the capability of modelling the dynamic behaviour of the air flow pattern. Consequently it has been tried to visualise and to quantify the (dynamic behaviour of) air flow patterns. A previous survey about the methods to visualise the air flow pattern, resulted in using the smoke $TiCl_4$. By doing so the air flow pattern can be filmed and the produced images are digitised. Using the digital images of the smoke pattern, it is possible to quantify the generated airflow pattern by calculating the centerline of the visualised air flow patterns. In this way, different air flow patterns can be quantified, can be compared to each other and finally can be checked with the measured data. The developed procedure can be used for steady state air flow patterns and for transient behaviour as well.

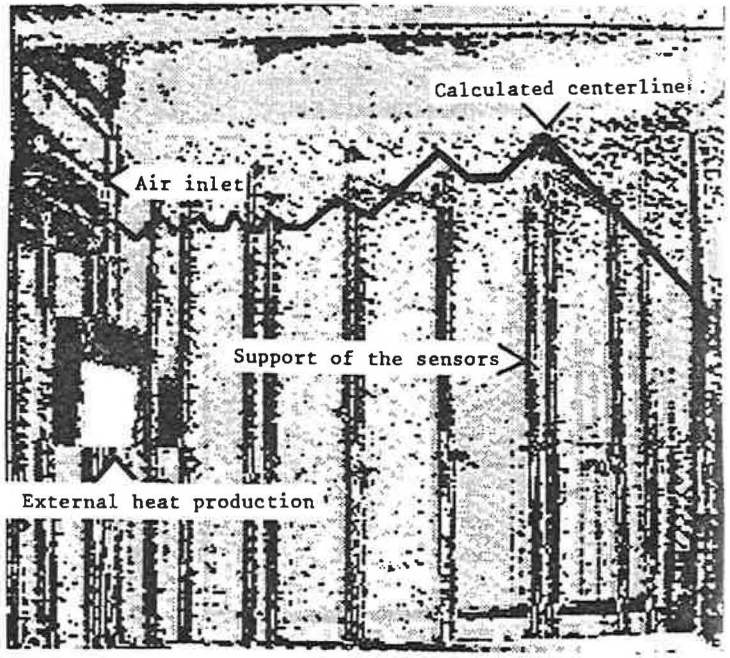

Figure 7: Output of the air flow visualisation program with the calculated cen

4. CONCLUSIONS

A new model concept has been developed to model the energy and mass tra an imperfectly mixed fluid [4]. The model permits to predict the dynamic be of the volumetric concentration of heat flow, mass flow and the fluid flow pa well. Therefore a laboratory test room has been built:

- to visualise the control volumes as defined in the model concept [4]
- to visualise the air flow pattern
- to quantify the three dimensional air flow pattern
- to do measurements on the steady state and the transient behaviour of the temperature, humidity and air flow pattern to validate the models cap predict the air flow pattern.

The measurements, backed up with a quantitative visualisation of the fluid p and distribution of mass and energy in the test chamber, permit to gain understanding in the physical processes behind the dynamic behaviour of a patterns, in relation to the room air distribution.

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EXPERIMENTAL AND NUMERICAL ANALYSIS OF TRANSIENT AIR CHANGES IN BUILDINGS: A CASE STUDY

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SUMMARY

Air change rates calculated from the data obtained using tracer gas techniques ar usually considered as constant in time, therefore their values represent the average i the time measurements interval.

In this paper the measurements performed in two identical detached test houses, usin the decay technique, are described. The two houses, which were built by Italian mai gas company, are very well equipped with instruments in order to acquir meteorological data and inside air temperatures; pressurization tests were als performed in the past.

After a quick glance at the mathematical formulation of the problem using th parameter estimation theory, the concentration measured values are here analysed b considering the air change rates as parameters which change in time.

The computed air change or air flow rates are plotted as time functions and ar compared with the results obtained by assuming the parameter constant in time uncertainties due to measurement errors and to calculation procedures are taken int account.

Finally it is shown how interesting considerations and information, on the validity (the experiment, can be obtained by the analysis of the results.