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TEMPERATURE AND VELOCITY MEASUREMENTS ON A DIFFUSER FOR DISPLACEMENT VENTILATION WITH WHOLE FIELD METHODS

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ABSTRACT

In this study the instantaneous temperatures and velocities close to a diffuser for displacement ventilation have been recorded by using whole-field measuring techniques. The air temperatures were measured indirectly by the use of a low thermal mass screen in conjunction with infrared thermography. The measuring screen was mounted parallel to the airflow, acting as a target screen. By using the thermal images the size of the near zone was also calculated. To determine air movements a whole field method called particle streak velocimetry (PSV) was used. Images of tracks created by small, low-density particles, suspended in the air, were analysed using computerised image processing to obtain the velocities. The experiment took place in a climate chamber in which the wall and air temperatures were controlled. The diffuser was located in the centre of one of the walls. The tests were conducted for a supply flow of 15 l/s and a temperature difference between the inlet air and the room air of 4 $^{\circ}C$ and of 6 $^{\circ}C$. This paper deals with the results obtained from the two whole-field measurement methods. The results show that the two whole-field measurement methods can be good tools for visualising and measuring air velocities and temperatures in rooms. These techniques could be used in the work of improving the indoor climate.

KEYWORDS

Indoor climate, Whole field measurement methods, Air velocity, Air temperature, Digital infrared camera, Temperatures, Diffuser, Displacement ventilation, Infrared thermography, 2D Particle Streak Velocimetry (PSV), Digital pictures, Particle tracking.

INTRODUCTION

Low velocity diffusers, in displacement ventilation systems, supply air directly into the zone of occupation, making the near-zone of the diffuser very critical for comfort assessment. This type of air supply terminal may give rise to a supply Archimedes number, Ar(0), greater than unity. Therefore one can expect buoyancy to strongly influence the flow, leading to the formation of a gravity current with high air velocities close to the diffuser. It is therefore of great importance to determine the size of this zone, in order to be able to achieve acceptable indoor environment. It is rather difficult to investigate the near-zone of a low velocity diffuser in real situations.

Conventional methods for measuring both air velocities and temperatures are based on single point techniques using sensors. With these techniques the measurements are performed only at the spot where the sensor is placed. These conventional methods for measuring within the near-zone do not give adequate information. In this paper, two whole-field measurement methods were used to register accurate information from the whole near-zone instantaneously.

"Particle streak velocimetry" (PSV), or alternatively, particle tracking, is a whole-field method that is used for recording two- or three-dimensional air velocities. This is achieved with the use of images of tracks created by small, low-density particles suspended in the air. In this case the particles are injected into the supply duct. With the help of computerised image processing two-dimensional velocities can be obtained. This method is explained in more detail in Linden et al (1998).

New, high definition, digital infrared cameras have provided opportunities to develop a method for measuring temperatures within a large area. With this method the air temperature is measured indirectly by using infrared thermography and a measuring screen. The method is very useful for air temperature measurements as well as airflow pattern visualisation. For more detailed information about this measurement method see Cehlin et al (2000). The length of the near-zone could be determined with the use of the resulting thermal images.

The two above methods have been developed at the Centre for Built Environment in Gävle. The work presented here is part of a wider research program with the aim of "Making the indoor climate visible at the design stage". It includes whole-field measurement techniques for temperature (infrared thermography), concentration (absorption tomography), velocity (particle streak velocimetry) and computational fluid dynamics.

EXPERIMENTAL METHODS

Velocity and temperature measurements

The experiments took place in a climate chamber with displacement ventilation. The walls and the floor were painted black. The diffuser, with a height of 0.6 m and a free area of 0.03 m^2, was located at the centre of one of the walls. A number of thermocouples were installed in the room together with one in the diffuser. Tests were conducted for a supply airflow of 15 cm/s and temperature differences between the inlet air and the room air temperature at 4 $°C$ and 6 $°C$. The instantaneous velocities and temperatures close to the diffuser were measured using the whole-field methods.

In this experiment some modifications have been made to the original procedures of the particle streak velocimetry method. These changes are explained below.

To be able to visualise and measure the air motion, particles are introduced into the inlet air. These particles must have a density low enough to follow the air and at the same time be big enough to be observed. In these measurements a new kind of particle has been used. The material consists of cellulose that emits fibres (particles) when it vibrates. A purpose made injector has been used to inject the particles. The injector was a loudspeaker where the cellulose material was placed on the membrane. Duo to the membrane vibrations the fibres were released into the air. This injector was placed inside the ventilation duct 3.5 m upstream of the diffuser.

A light sheet is used to observe the particle movements in the region of interest. The light sheet which has a thickness of about 4 cm to 5 cm is produced by a portable halogen lamp and a cylindrical lens.

Photographs were taken to register the particle movements close to the diffuser. In this work a standard SLR (single lens reflex) camera and black and white film have been used. An asymmetric "chopper" rotating at a known speed was placed in front of the camera. This made it possible to find the particles that have been inside the light sheet during the whole exposure and to identify their directions of movement.

While the camera-shutter is open, the air and therefore the particles, move a short distance. A few times while the camera-shutter is open the chopper will block the camera lens and no light falls on the film. On the photograph this results in streaks with three different lengths, shown in Figure 1. The length of these streaks depends on the chopper rotation speed and the particle velocities.

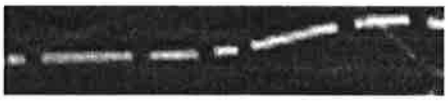

Figure 1: A streak made by a particle.

The photographs were digitised and then analysed in an image-processing program. The first step in analysing the images was to locate the streaks. Secondly, the co-ordinates of the end-points were measured. Only the streaks with the right proportions between the different sub-streaks, were chosen. The co-ordinates were measured in pixels in a two-dimensional system. Within the flow-field there was a system of three reference points with known co-ordinates. This co-ordinate system made it possible to convert the image co-ordinates to co-ordinates in the room.

By using the particle displacement ($\Delta x, \Delta y$) and the time-period Δt, the velocities were then be evaluated. With this method the velocities were registered at the points in the room where the individual particles were at the photographed moment.

The temperatures have been measured with the whole-field method explained in Cehlin et al (2000).

Near zone measurements

The horizontal distance, x_d, from the centre of a semicircular diffuser, with radius R and height H, to the point where the air drops down on the floor, is defined in a non-dimensional term, $x_d^* = x_d/H$. According to the theory we have

$$x_d^* \propto \sqrt{\left(\frac{R}{H}\right)^2 + 2\frac{R}{H}\frac{1}{Ar(0)^{1/2}}} \quad (1)$$

See Etheridge and Sandberg (1996) page 384 for information about the derivation of Equation 1.

The purpose of the experiments described in this section was to study how accurate the dimensionless distance, x_d^*, from a low velocity diffuser can be measured by infrared thermography compared to the theory. The type of camera used was an AGEMA 570 with a resolution of 320x240 pixels, sensitive to long-wave radiation (7.5 μm to 13 μm). A paper screen was used as measuring screen throughout all of the experiments. Two light emitting diodes were placed out as position-markers. One was placed on the floor next to the diffuser-inlet and the other one was placed at a horizontal distance of 800mm from the diffuser. Experiments were carried out for 5 different supply air conditions with a semicircular diffuser of height 600mm and free area $0.0075 m^2$. x_d was redefined under the experiment because it was very hard to estimate the point where the air dropped down on the floor from the infrared camera measurements. Instead, x_d was defined for these experiments as the distance from the diffuser to the point where the airflow pattern seemed to change direction to a purely horizontal flow, as indicated in Figure 2.

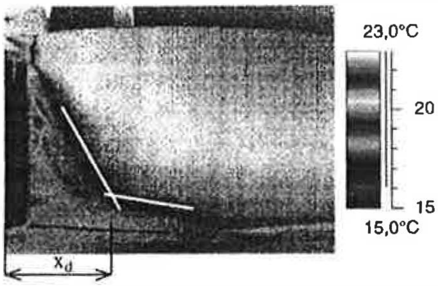

Figure 2. Thermal image, showing the distance, x_d, from the diffuser to the point where the airflow pattern seems to change direction to purely horizontal flow. U_{in} = 0.13 m/s, T_{in}=17.0 °C and Ar(0) = 3.86.

RESULTS

Velocity and temperature measurements

By using the PSV method a number of streaks were found and the position, speed and direction for the particles were calculated. The two-dimensional velocity field is presented as an airflow pattern diagram. The lengths of the arrows represent the speed of each particle. The results from the whole-field method using infrared thermography were images with different colours representing different temperatures of the air around the diffuser. Both whole-field methods were combined, as shown in Figures 3a and 3b.

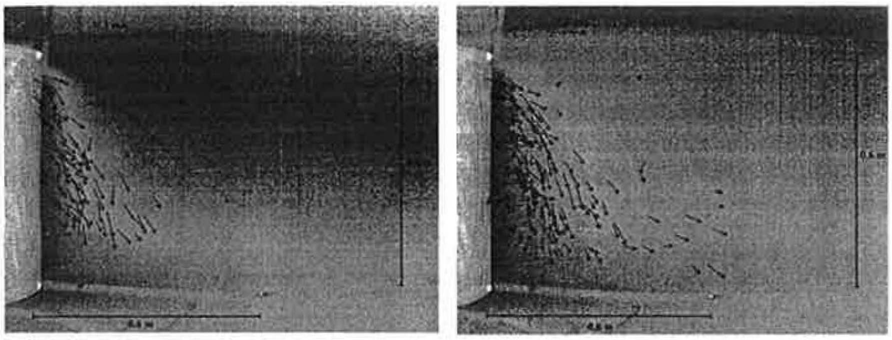

Figure 3: Temperatures and velocities around a diffuser.
3a (left): Supply flowrate =15 l/s, $\Delta T_{in} = 4$ °C and Ar(0) = 0.32.
3b (right): Supply flowrate =15 l/s, $\Delta T_{in} = 6$ °C and Ar(0) = 0.47.

Measurements of the near zone

As can be seen in Figure 4, the results show that the dimensionless horizontal distance, x_d^*, measured by infrared thermography conforms to Equation 1, which is derived from theory. However, x_d^* was slightly less than predicted by the theory. One source of error is probably that the x_d defined in the experiment was not identical to the theoretical parameter. Another source of error is that the flow from the supply diffuser in the theory is assumed to be uniform, which is not the case in reality.

Case	U_{in} (m/s)	T_{in} (°C)	Ar(0)
1	0.09	17.0	12.25
2	0.13	17.0	3.86
3	0.20	16.9	2.10
4	0.27	16.8	0.72
5	0.35	17.0	0.31

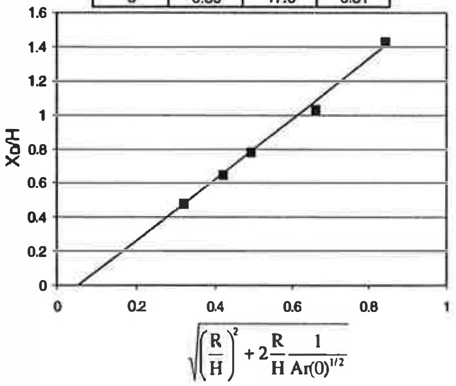

Figure 4. Recorded dimensionless distance for different supply air conditions.

DISCUSSION

"A photograph says more than thousand words" seems to be appropriate at least when looking at the results from the whole-field measurement techniques. Both the different colours representing temperatures and the velocity arrows clearly show the airflow in the near-zone of the diffuser. This kind of visualisation is of great assistance in understanding the indoor airflow. Furthermore, these techniques could be valuable for designing pleasant indoor environment systems.

NOTATIONS

g   Acceleration of gravity [m/s^2]
H   Height of supply device [m]
U_{in} Supply velocity [m/s]
T   Temperature [K]
ΔT_{in} Temperature difference between room air temperature and supply temperature T_{in}
Ar(0) Supply Archimedes number

$$Ar(0) = \frac{g \frac{\Delta T_{in}}{T} H}{U_{in}^2}$$

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