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Determination of flow direction by a globe-sensor containing thermal anemometers

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Synopsis

Conventionally used thermal anemometers are able to measure velocity, but cannot determine direction. In the present study, a new kind of thermal anemometer is presented which consists of a 38mm-diameter sphere with 12 NTC resistances on its surface. Each of them is a single Constant Temperature Anemometer which takes measurements of the local heat transfer on the surface depending on the position on the ball. The calibration of this sensor is taken in 325 different directions for 6 velocities by an automatic calibration system which provides curves of the heat transfer depending on the air flow angle.

The simultaneous measurements of the 12 Constant Temperature Anemometers are compared with the data of the calibration and so the value and the angle of the air flow are determined. This sensor allows the measurement of air velocities over a range of 0.05m/s to 6m/s and of the flow angle over the entire room angle of 360^{o}. So it is possible to obtain information on the value as well as the direction of the air velocity. This new measurement method makes a contribution to a better description of indoor air flow. Using this sensor, it is also possible to check the results of computer programs simulating indoor air flow.

1. Introduction

Air temperature, air velocity and air humidity as well as the temperature of the inner room surface have an influence on the human thermal comfort. A comfortable room air conditioning especially requires low air velocities in the occupied zone to prevent complaints about draughts from the occupants. So measurements of air velocity are important for judging indoor air flow and thermal comfort.

2. Measurement technique of indoor air velocity

For measurements of air velocity a Pitot or Prandtl tube is often applied whose principle is based on the kinetic energy of the flow as a determinant of their velocity. This is practicable for higher velocities, but the measurement of indoor air velocity requires a measuring technique able to record strongly fluctuating velocities smaller than 0.3 m/s. Commonly a thermal anemometer is suited for the measurement of fluctuating gas velocities because of its short response time and its sensitivity to low velocities. A thermal anemometer consists of a heated sensor, often a NTC resistance, whose rate of heat loss is dependent on air velocity. The advantage of a thermal anemometer compared with methods based on kinetic energy is shown in Fig. 2.1 in which the heat transfer and the kinetic energy are plotted against the air velocity. It is evident that for low velocities the signal of the heat transfer is to be preferred.

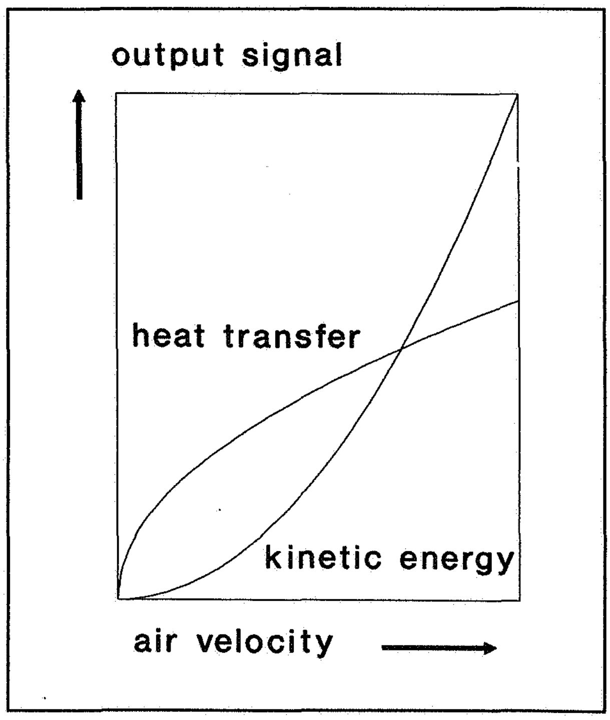

FIG. 2.1: Comparison of the measuring principle of a Prandtl tube and a thermal anemometer

For the present investigation, a Constant Temperature Anemometer is employed. For the description of air velocity, knowledge of the amount and the temporal deviation as well as the direction is essential. To obtain information about the direction of air velocity, smoke is normally used. But this inexact method allows only a qualitative judgement of the direction.

3. New sensor

Now a new kind of thermal anemometer has been developed which consists in a 38mm diameter sphere with 12 NTC resistances on its surface. Each of them is a single Constant Temperature Anemometer which takes measurements of the local heat transfer on the surface depending on its position on the ball.

3.1. Principle of measurement (Local heat transfer on a sphere)

If a heated sphere is exposed in a flow, the rate of heat loss is strongly dependent on the air flow angle as well as on the air velocity.

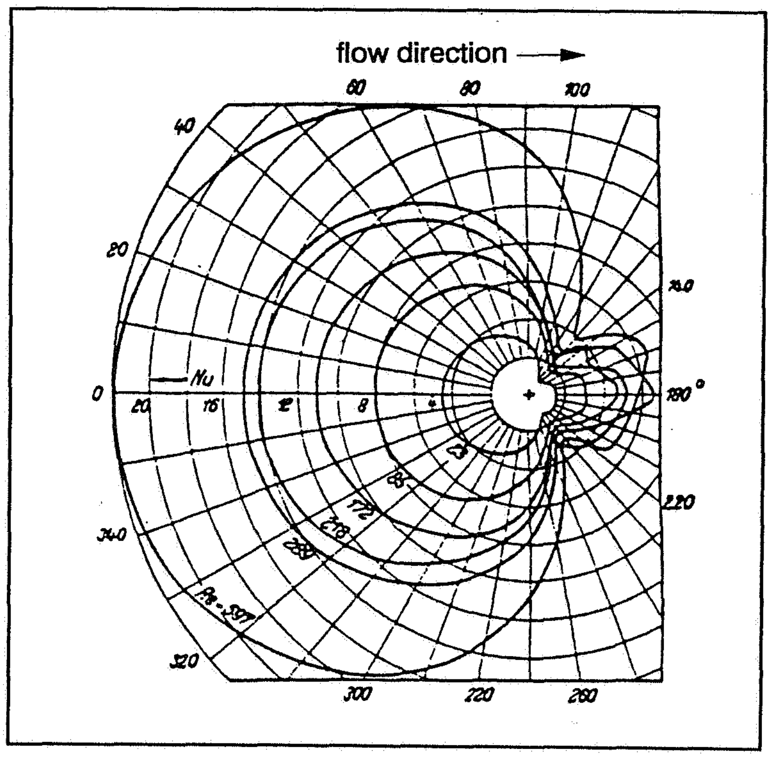

FIG. 3.1: Local heat transfer numbers for Re = 20 - 600 /2/

The heat transfer in an unstable incompressible convection flow over an axisymmetric body (sphere) has been studied by Gröber, Erk and Grigull /2/. For the presentation in Fig. 3.1 polar coordinates are used. The local heat transfer on a sphere (Nusselt number) is presented as a function of the angle between the stagnation point and the point of measurement. The local heat transfer rates are maximum at an angle of 0^o to 80^o from the stagnation point and they decrease progressively with a continuing increase in the angular position of the stagnation point because of the separation of the boundary layer from the ball. On the rear surface of the sphere, the dead water region, the Nusselt number increases again due to the highly turbulent state of flow. It becomes apparent that the difference between the Nusselt number of streamed and non streamed regions is sufficient to determine the flow direction by measurements of the local heat transfer at several points on the surface.

3.2 Construction of the sensor

The measuring device shown in Fig. 3.2 consists of a 38mm diameter sphere with 12 NTCs attached to the cover. Their electrical connections to the electronic equipment pass through a grip fixed to the ball.

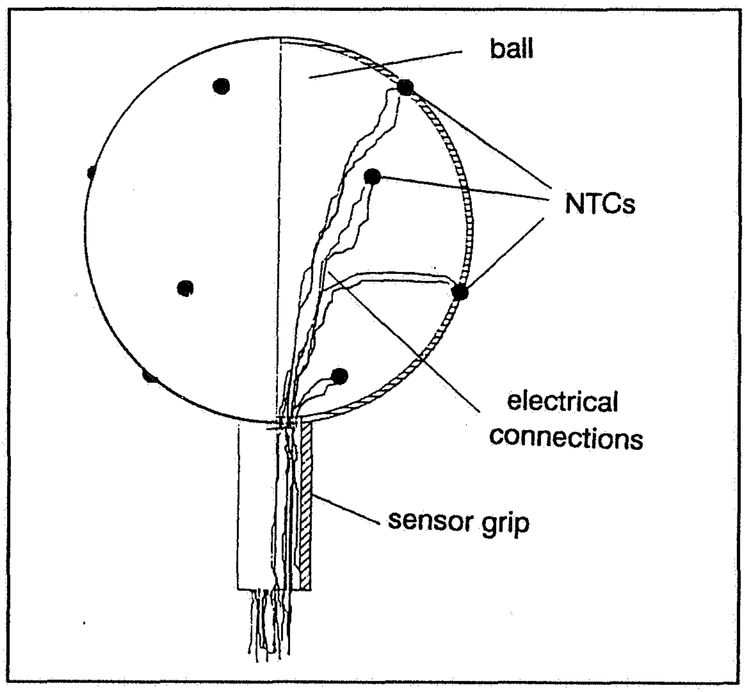

FIG. 3.2: Construction of the sensor

To limit the great influence of thermal buoyancy force especially at low velocities, the heat-up of the whole sphere is avoided. On the surface of the sensor 12 NTC-resistances are arranged at the edges of a regular polyhedron; the chosen geometry is a dodecahedron. In Fig. 3.3 the polar coordinates and the geometry are illustrated.

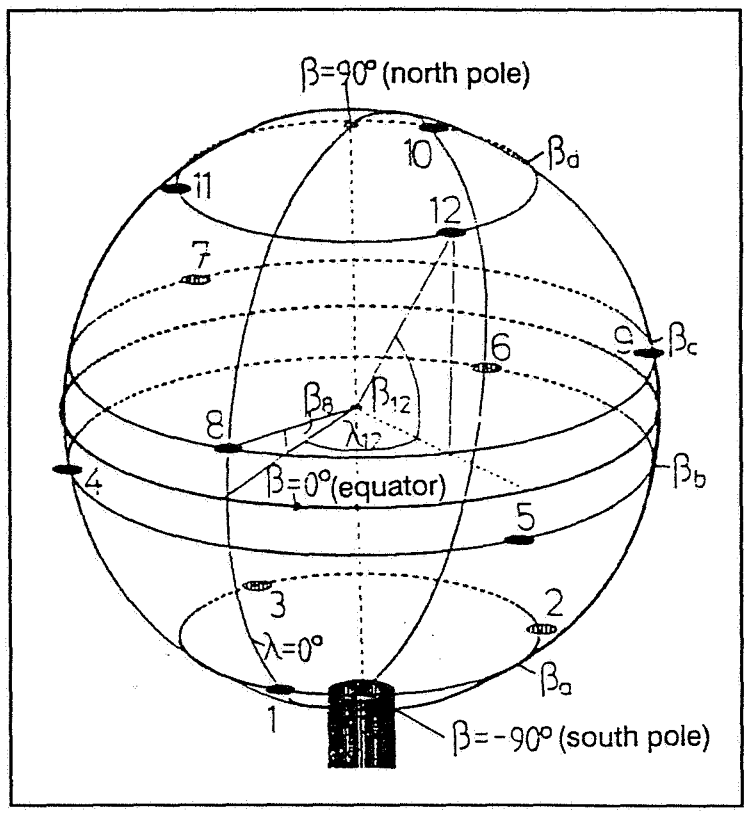

FIG. 3.3: Sensor with 12 measuring points and spatial polar coordinates

4. Calibration

In order to calculate the approach velocity and the initial direction of flow, it is necessary to know the Nusselt number over the whole surface of the sphere as a function of the air flow angle. But the theoretically precise mathematical formulation of the heat transfer problem is exceedingly difficult, so that a calibration has to be carried out.

The calibration of the sensor for the determination of flow direction also requires in addition to the variation in the air velocity, a change in the angle of attack. The air flow angle is the one between the measuring point of the local Nusselt-number and the equator (see Fig. 4.1).

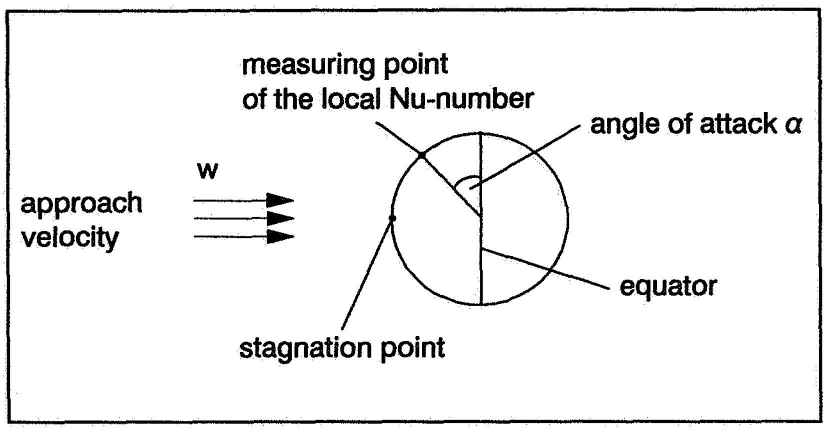

FIG. 4.1: Angle of attack

4.1 Calibration plant

The test apparatus shown in Fig. 4.2 consisted of the sensor mounted in a wooden wheel, subdivided into several chambers equipped with material. The wheel is fixed on the wall and is driven by a stepping motor, controlled by the frequency generator of a computer; this is guaranteeing a constant revolution velocity. The wheel is able to generate different air velocities from 0.05 to 6m/s. It is assumed that after a certain time the enclosed air volume in the wheel is moving with the same velocity as the wheel. The anemometer is attached to a supporting system.

This calibration technique permits in contrast to a tube flow, measurements of low velocities with low turbulence (laminar flow). Furthermore calibrations are taken in a tube flow because of the different heat transfer mechanisms in laminar and turbulent flow.

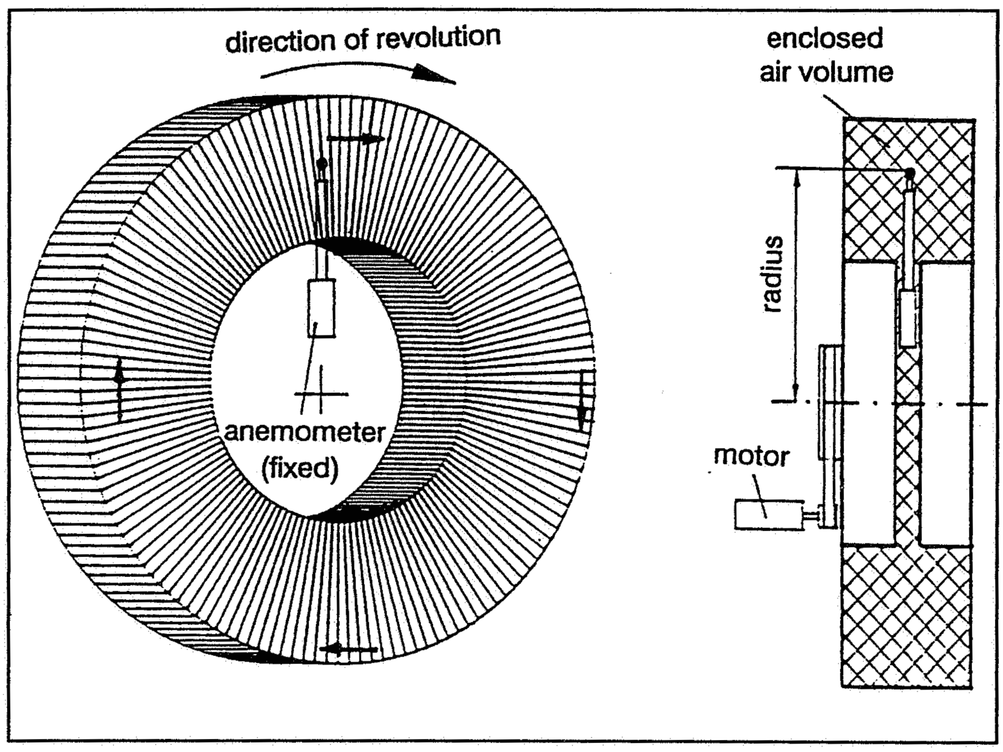

FIG. 4.2: Calibration wheel

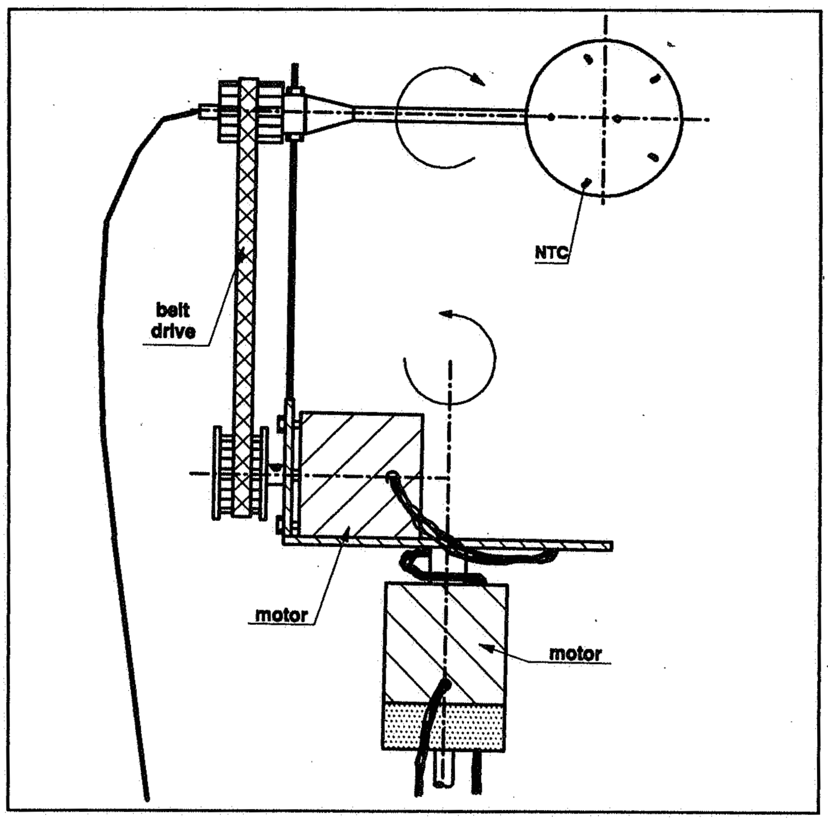

FIG. 4.3: Motion device for the sensor

The motion of the sensor over the whole room angle is carried out by two stepping motors, one for the vertical and one for the horizontal axis, as shown in Fig. 4.3.

4.2 Experimental procedure and results

To permit an exact calibration an investigation of the heat transfer rates of the 12 NTCs depending on the air flow angle and the air velocity is required. The initial conditions such as air pressure and air temperature should be the same as exist in the experimental situation. The impact of air temperature is secondary, because in the field of indoor air flow the air temperature varies only over a small range. The calibration of the sensor is taken for 325 different directions for 6 velocities over a velocity range of 0.08m/s to 5.21m/s by an automatic calibration system which also controls the stepping motors of the motion device and of the wheel. The average of the 10 measurements of air velocity and the polar coordinates are stored.

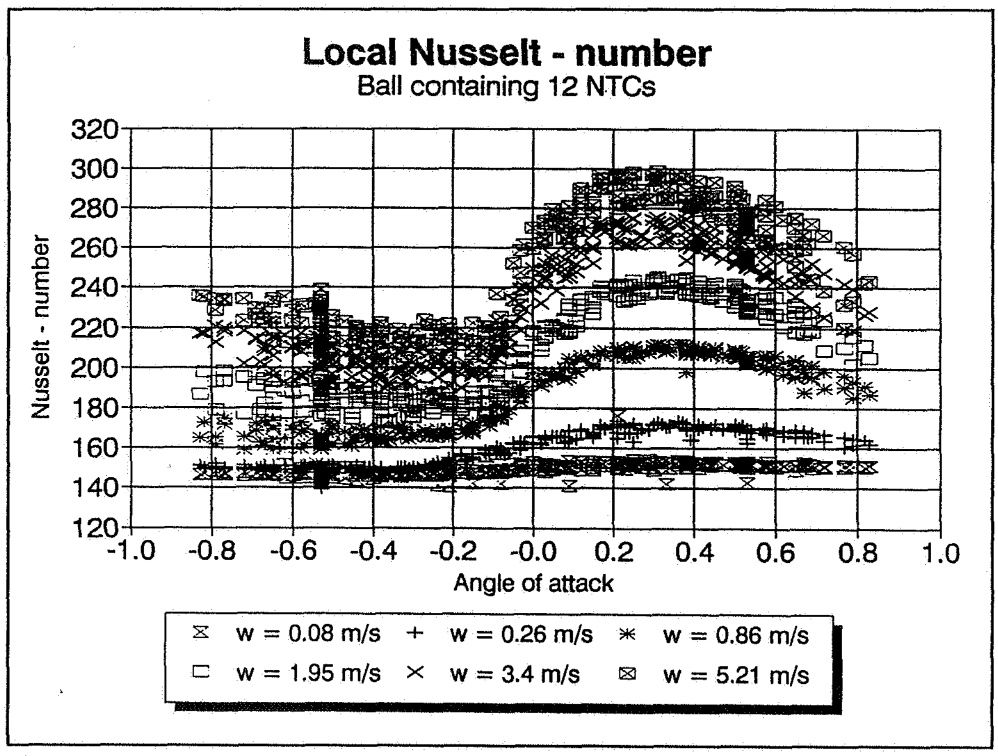

FIG. 4.4: Calibration results of the local Nusselt number for different air velocities (ball containing 12 NTCs)

Based on theoretical knowledge of the heat transfer mechanism, various equations are derived to determine the relation between the Nusselt number and air flow angle. The results obtained from the calibration as well as the curves investigated by using a numerically solved compensation theorem are represented in Fig. 4.4.

It was necessary to subdivide the data into two ranges, below and up to sin alpha = -0.2, in order to give a better agreement between the equation values and the measurements. For velocities above 0.2m/s, the difference in the Nusselt number between the luv and the lee hemisphere is so distinct that the determination of the air flow angle is guaranteed.

For lower velocities, the decay of the Nusselt number in the region of flow separation is insufficient, so that the value of 0.2m/s is taken as the limit of measurement.

5. Measurements

For the determination of the air flow direction, the sensor is placed in an air flow and the simultaneously taken measurements of the 12 Constant Temperature Anemometers are compared with the data of the calibration. Thus the value and the angle of the air flow velocity are determined.

Fig. 5.1 shows shows an illustration of this procedure: First the calibration is taken for different air velocities and air flow angles and the curves of the Nusselt number as a function of the flow angle are investigated. Then measurements in an unknown air flow are taken.

The aim is to achieve agreement by comparative analysis of the calibration and the measurement values so that the required rotation angle is a determinant for the air flow angle.

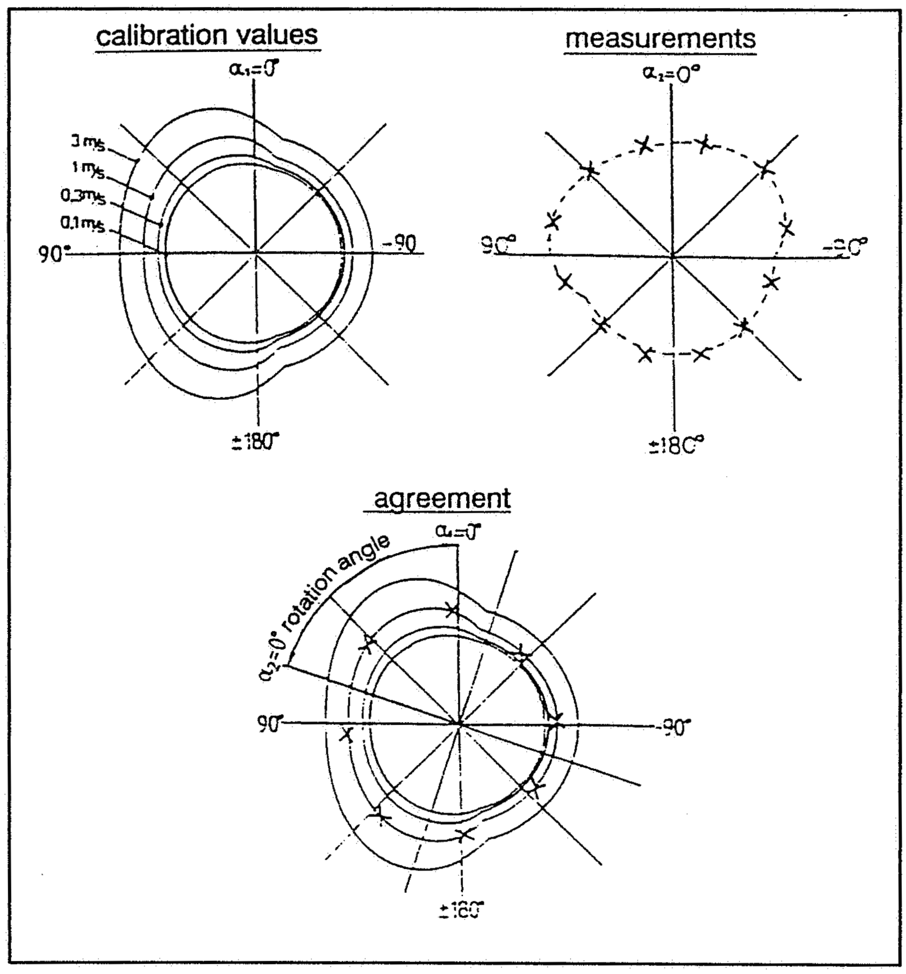

FIG. 5.1: Illustration of the determination of air flow direction

6. Summary

The aim of this investigation was the development of a thermal anemometer able to determine the air velocity over a range of 0.05m/s to 6m/s as well as the air flow angle over the entire room angle of 360^{0}. This sensor was composed of a sphere containing 12 resistances on its surface. The principle of measurement is based on a theoretical treatment and an accurate experimental investigation of the heat transfer mechanisms of a ball.

By calibration, the average Nusselt number for the heat transfer from a sphere was obtained as a function of the air flow angle for different air velocities and air flow angles. In an unknown indoor air flow, the comparative analysis of calibration values and measurements permits the determination of air velocity and flow angle.

This new measurement method makes a contribution to a better description of indoor air flow.

8. References

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