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On the use of hot-sphere anemometers in a highly transient flow in a double-skin façade

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ABSTRACT

Hot-sphere anemometers are widely used for measurement of air velocity in the occupied zone. In this paper, the ability of hot-sphere anemometers to measure transient flow in a double-skin façade is investigated. When hot-spheres are used in a double-skin façade, the conditions are very different from the measurement of air velocity in the occupied zone. The velocity is higher and the flow is more transient, the anemometer is subjected to high loads of direct solar radiation and wide temperature ranges and, finally, the direction of the flow is important.

The flow in the double-skin façade is highly transient and therefore, the dynamic properties of the hot-sphere anemometer must be investigated. An experimental setup to measure the dynamic property using a jet-wind tunnel and a device for moving the anemometer is described. The experimental setup allows examination of the standard deviation measured by the anemometer.

Temperature compensation is the working principle of anemometers. The ability to compensate for different temperatures when exposed to solar radiation is investigated in a controlled environment using a powerful lamp as a radiant heat source.

In the double-skin façade, both upward and downward flow will occur and therefore, it is important to determine the direction of the flow. A simple method using two hot-sphere anemometers separated by a small plate is discussed.

INTRODUCTION

Application of the hot-sphere anemometer is defined by its ability to measure the air speed in the range of the low velocities typically found within buildings. Therefore, the measurements of the air speed in an occupied zone became the widest hot sphere application area.. As a rule, the air speed in the occupied zone varies by 0-0.2 m/s and frequently, this is the velocity range for application of hot spheres. However, the hot-sphere capability is much higher, as measuring of air velocity in the range of 0-5 m/s is allowed.

Regarding the air flow in the naturally ventilated Double-skin façade (DSF) cavity the following aspects are defined to distinguish the DSF operation and thus the air motion in the cavity space. Naturally driven air flow in the DSF cavity is highly transient due to highly fluctuating wind character and, as a result, the variation of the air flow magnitude in the DSF cavity is huge. Moreover, the velocity profile in the DSF cavity varies depending on the flow regime, defined by the ambient temperature, glazing temperature (solar radiation absorbed by glazing), etc. Solar radiation is the necessary parameter for the DSF performance and thus in most of the cases, equipment installed in the DSF cavity is exposed to the high solar fluxes.

The phenomenon of the naturally driven air flow in the double-façade cavity is regarded as one of the most difficult elements in prediction of the DSF performance. Scientists express the need for the empirical investigations of a double-skin façade with the superior attention to the air-flow motion in the DSF cavity.

Due to the fluctuations, the instant values of the air velocity in the DSF can vary by 0-5 m/s. As a consequence, the detailed measurements of the air flow in the cavity require equipment able to perform measurements of the velocity at a highly varying velocity magnitude. A lot of equipment is necessary for the measurements of the velocity profile in the cavity and at the same time it is essential to have small-size equipment to minimize the disturbances of the flow pattern in the cavity. Moreover, the equipment must be able to respond adequately to the fluctuations and also to cope with the high solar loads. Finally, the ability of equipment to distinguish the flow direction (upwards/downwards) is a great advantage.

The described conditions in the DSF cavity are very different from the conditions in an occupied zone, but still, according to the tests described in this paper, the hot-sphere anemometers are an excellent choice for the measurements in the DSF cavity. It is demonstrated how the hot-sphere anemometer responds to fluctuations and exposure to the high solar fluxes, and how the hot-sphere anemometers can be used to distinguish the flow direction in the DSF cavity. Results of these tests were applied to measurements in the outdoor DSF test facility ’The Cube’, at Aalborg University [1].

TESTING THE DYNAMIC PROPERTIES OF THE HOT-SPHERE ANEMOMETERS

In the DSF, the airflow is highly transient, especially when the DSF is naturally ventilated. When using hot-sphere anemometers in a double façade cavity it is vital that the anemometer is able to measure the air velocity, responding adequately to the flow dynamics.

To ensure this, a test method following the requirements in [2] aimed at measuring the mean velocity and turbulence intensity in the occupied zone in connection with thermal comfort is applied. The key parameters in the requirements are

- Instantaneous velocity range — 0,05 - 1,0 m/s
- Temperature range — 18 - 35°C
- Upper response frequency — 1 Hz
- Direction sensitivity — Omni directional
- Measuring period — ≥ 180 s
- Sampling rate — ≥ 5 s^{-1}

The principle of the test method is to place the anemometer in the laminar air flow generated by a jet-wind tunnel and then oscillate the sensor back and forth in the air flow by means of a crank movement, hereby overlaying the laminar flow with an almost pure sine wave. The principle is shown in Figure 1, and in Figure 2, a picture of the setup is shown.

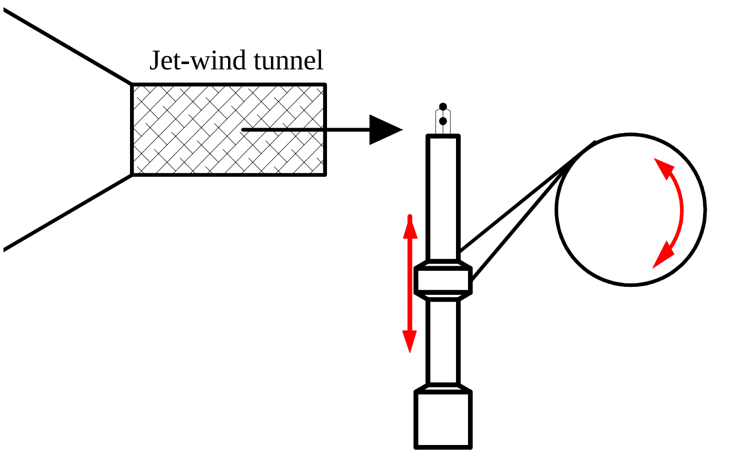

Figure 1. Principle of dynamic test of hot-sphere anemometer.

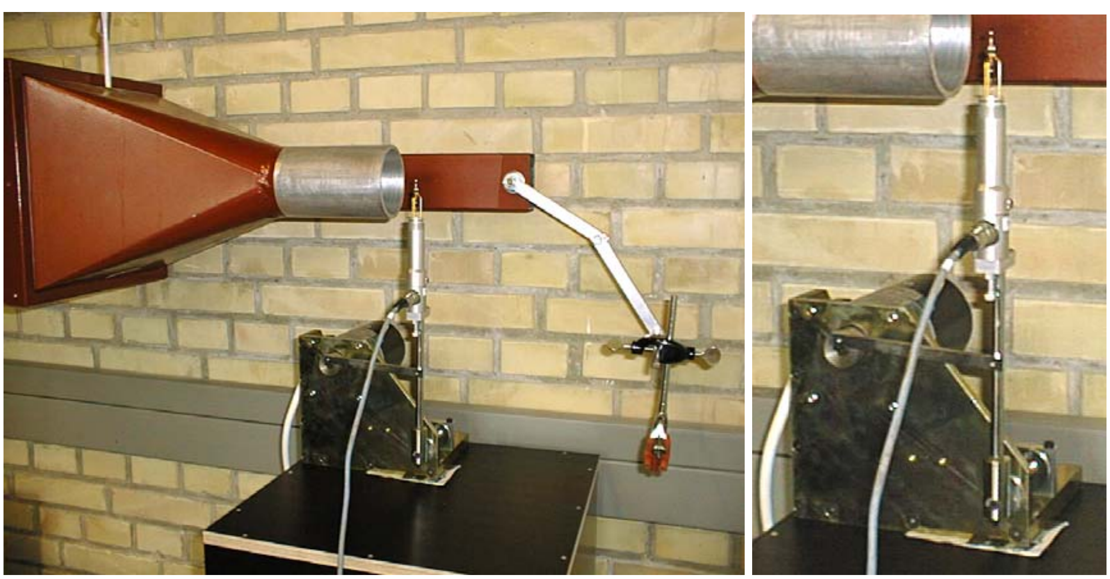

Figure 2. Picture of the experimental setup. When measuring, the anemometer is shielded from the surroundings by a Perspex tube (not shown in the picture).

There are three decisive conditions that must be fulfilled for testing the dynamic response of the anemometer.

1. The air flow from the jet-wind tunnel must be laminar. If the air flow is not entirely laminar, an unknown amount of turbulence intensity and consequently, an unknown standard deviation is added to the sine wave. Therefore, first, it must be ensured, that the flow from the jet-wind tunnel is indeed laminar.

2. The fixing of the anemometer and the generation of the sine wave must be without wobble and vibrations of any kind. The motor must have sufficient torque at all numbers of revolutions so that the angular velocity is kept as constant as possible.

3. The downstream speed of the anemometer must be lower than the one of the jet-wind tunnel. This ensures that the sensor is not subjected to the turbulence created by its own movement.

The experimental conditions are described below:

Average air velocity from the jet-wind tunnel $\bar{v} = 0.12\, m/s$

Standard deviation $s_v = 0.05\, m/s$

As a result, the turbulence intensity is calculated as follows:

$$T_u = \frac{s_v}{\bar{v}} = \frac{0.05}{0.12} \cdot 100\% = 42\% \quad (1)$$

$$v_{\sin,\max} = \sqrt{2} \cdot s_v = \sqrt{2} \cdot 0.05\, m/s \cong 0.07\, m/s \quad (2)$$

Accordingly, the turbulence intensity is in the range of 40-60% (typically found within buildings) and the air velocity in relation to the sensor varies between:
Minimum 0.12-0.07= 0.05 m/s
Maximum 0.12+0.07= 0.19 m/s

Considering the range of the speed of the sensor movements and the air speed, one can conclude that the anemometer is tested in the low-velocity range, which is considered as being the most difficult for anemometer response to the flow dynamics. Moreover, according to [3], this, is the air velocity range that is important for assessment of comfort in the occupied zone.

Figure 3 shows an example of the anemometer response to the dynamic test. The figure includes the results of the raw data at the acquisition frequency of 10 Hz. The dynamic test includes 4 different conditions, which are determined by the frequency of the anemometer movements.

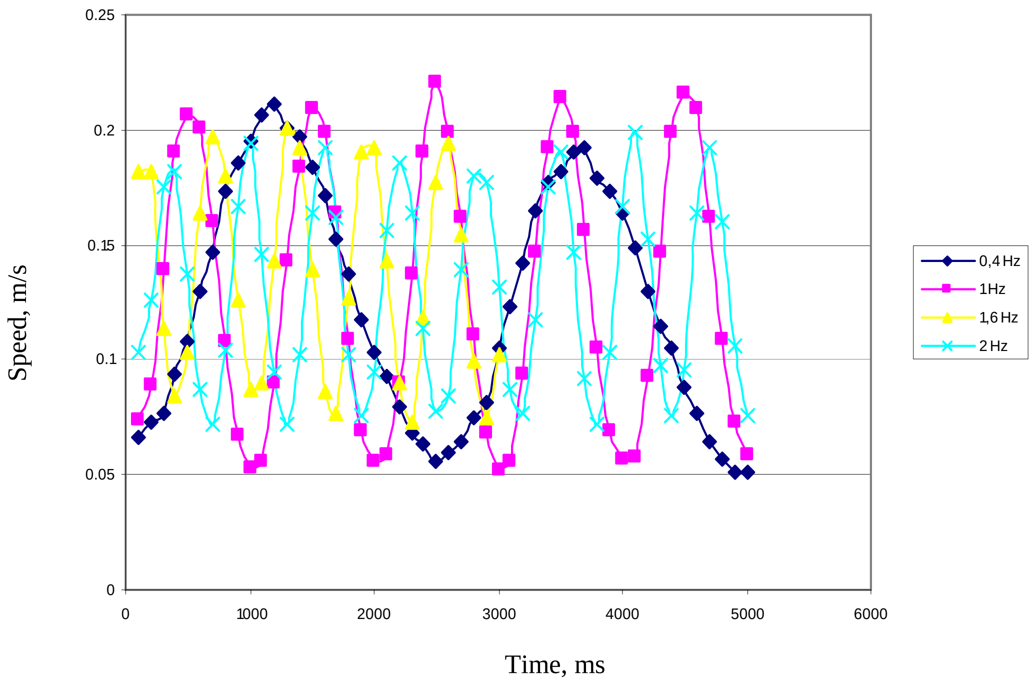

Figure 3. Dynamic response of the Dantec hot-sphere anemometer measured at 4 different frequencies of deviation.

Figure 3 shows that the anemometers respond very well to fluctuations up to 1Hz, but the amplitude of measured velocities becomes smaller at the frequencies of 1.6 and 2Hz. Particularly, problems can be noticed when the low velocities are to be measured (0.05 m/s), this is explained by the time constant of the sensor having the largest influence on the readings at the minimal velocities.

TESTING OF THE HOT-SPHERE PERFORMANCE WHEN EXPOSED TO DIRECT SOLAR RADIATION

Temperature compensation is the working principle of the hot-sphere anemometer. It is designed with two spheres: the heated and unheated one. The unheated, so-called ‘cold’ sphere measures the temperature of the flow, while the heated ‘hot’ sphere measures convection at the surface of the heated sensor. The air speed is determined as a result of compensation between readings from the ‘cold’ and ‘hot’ sphere. Accordingly, an accurate measurement of the air temperature with the ‘cold’ sphere is crucial for the acceptable temperature compensation and thus for the reliable measurement of the air speed.

The presence of direct solar radiation is an essential and distinctive element in the DSF operation. Consequently, the hot-sphere anemometer is exposed to sun when measuring in the double-façade cavity, the ‘cold’ and ‘hot’ spheres heated by solar radiation and, as a result, the sensor’s ability to compensate for temperature becomes doubtful. The following experiments were performed in order to evaluate the influence of solar radiation on the performance of a hot-sphere anemometer measuring of the upward and downward flow.

The experiments took place in the isothermal conditions in the laboratory. A hot-sphere anemometer was located in the jet-wind tunnel, described in the above sections. The effect of solar radiation was imitated by a strong lamp, producing 800 W/m^2 of radiative heat flux (Figure 4).

Figure 4. Hot-sphere anemometer in the jet-wind tunnel lit by the lamp imitating solar radiation.

First, the air speed was measured at the exit from the jet-wind tunnel without the radiative heat flux. The true mass flow rate was determined from the pressure difference registered by micro manometer at the orifice in the wind tunnel. Afterwards, the same measurement was repeated with the heat flux. All in all, the experiment was conducted for eight different mass flow rates.

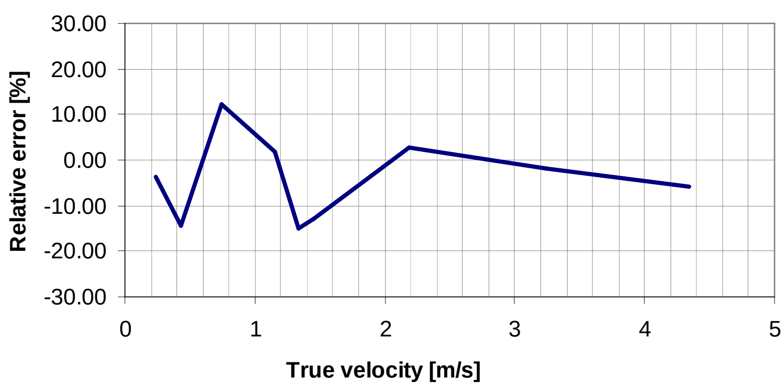

Figure 5. Relative error measured by a hot-sphere anemometer measured when exposed to a strong radiative heat flux.

The relative error is calculated as:

$$E_r = \frac{V_{rhf} - V}{V_t} \cdot 100\% \qquad (3)$$

Where,

E_r - relative error

V_{rhf} - velocity measured with the radiation heat flux

V - velocity measured without the radiation heat flux

V_t - true air velocity in the jet-wind tunnel calculated from orifice

If there is any influence of radiation on the performance of the anemometer then it ought to be strongest in the range of low velocities. According to the Figure 5, there is no consistency in the measured relative error. The magnitude of the error varies a lot, and even in the range of the low velocities it is not possible to identify any regularity. One can conclude that the hot-sphere anemometer does not change the performance when exposed to direct solar radiation. This can be explained by two factors. The first one is the surface of the spheres which has very high reflectance properties and it is possible that the major part of solar radiation approaching the sphere is reflected. Moreover, the ‘cold’ and ‘hot’ spheres must be heated up equally as both of them are equally exposed, and, because the main principle of the hot-sphere anemometer is the temperature compensation, equally heated spheres must not affect the temperature compensation.

According to the above conclusion, the hot-sphere anemometers were used for measurements of the velocity profile in the double-façade cavity in the outdoor test facility ‘The Cube’ at Aalborg University. The air-flow rate in the DSF cavity calculated on the basis of the velocity profiles and the air-flow rate measured by the tracer gas method show good correspondence, as discussed in [4].

TESTING OF HOT SPHERES FOR MEASUREMENTS OF THE FLOW DIRECTION

In the double-skin façade, both upward and downward flow will occur and therefore, it is important to determine the direction of the flow. However the exact angle of flow direction is insignificant. From this point of view, any simple method that does not require advanced equipment could be useful. A simple method to register a flow direction using two hot-sphere anemometers separated by a small plate is tested, as explained below.

It is suggested that two hot-sphere anemometers are placed in the flow field separated by a plate perpendicularly to the main flow, as shown in Figure 6. As a consequence, readings from these two sensors will be different and the flow direction from it is possible to read from the sensors. The sensor measuring the highest velocity denotes the flow direction from the sensor to the plate.

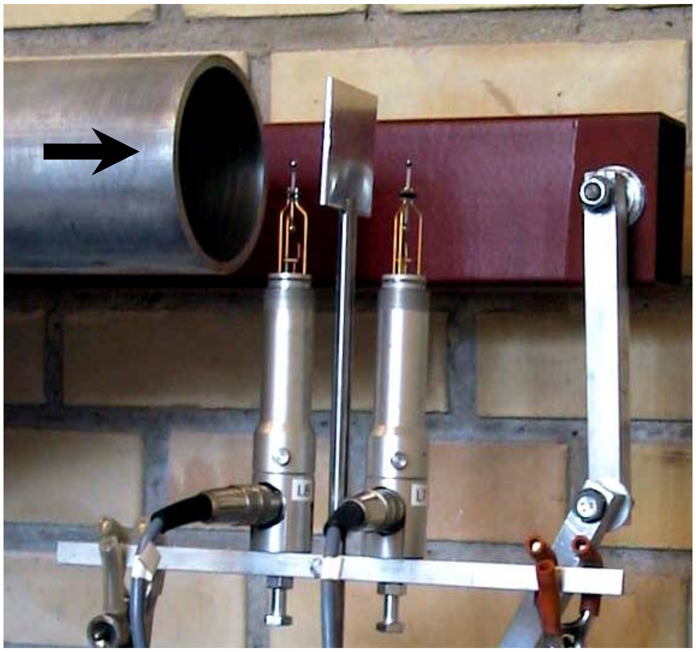

Figure 6. Experimental setup: Measurement of flow direction by two hot-sphere anemometers.

The challenging part of this method is to choose an appropriate size of the shielding plate and distance between the plate and the hot-sphere anemometers. These questions are answered by the results of the experiments described below.

The experiments were conducted to test the method in the upward and downward flow. Two hot-sphere anemometers separated by a plate were placed in the centre at the exit plane of the jet-wind tunnel (Figure 6). Hereafter, the anemometer located closer to the exit plane of the jet-wind tunnel is regarded as the 'front' anemometer and the one located behind the plate is regarded as the 'back' anemometer. A shielding plate of a square form was used for the experiments and tested for three different sizes: 1x1cm, 5x5cm and 7x7cm. The distance between the anemometers and the shielding plate was also investigated. Velocity was measured as one-minute average values, at a 10Hz sampling rate.

Experimental results, aimed to explore the influence of the size of the shielding plate are presented in Figure 7. The difference between velocity measured at the front (V_f) and the back (V_b) anemometer compared in relation to the true air velocity calculated from the pressure difference at the orifice in the jet-wind tunnel (V). The front and back anemometers were placed 3cm away from the plate. The obtained results are identical for the upward and downward flow.

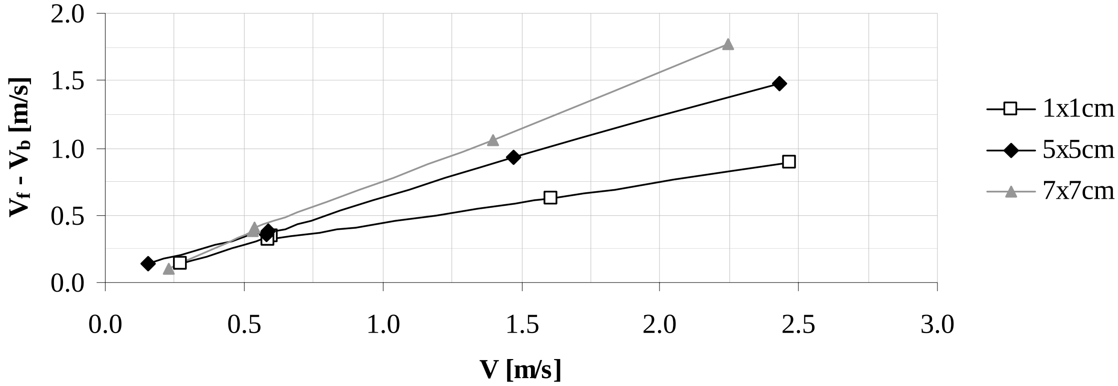

Figure 7. Investigation of size of shielding plate for downward flow.

It is obvious that with increase of the plate size, the difference between readings from the front and back anemometer becomes much more noticeable and it turns out to be much easier to distinguish between the flow directions.

The importance of distance between the plate and the anemometers is investigated using a 7x7cm plate. The distance between the front anemometer and the plate is marked as (*f*) and the distance between the back anemometer and the plate is regarded as (*b*). The results are similar for the upward and downward flow (Figure 8).

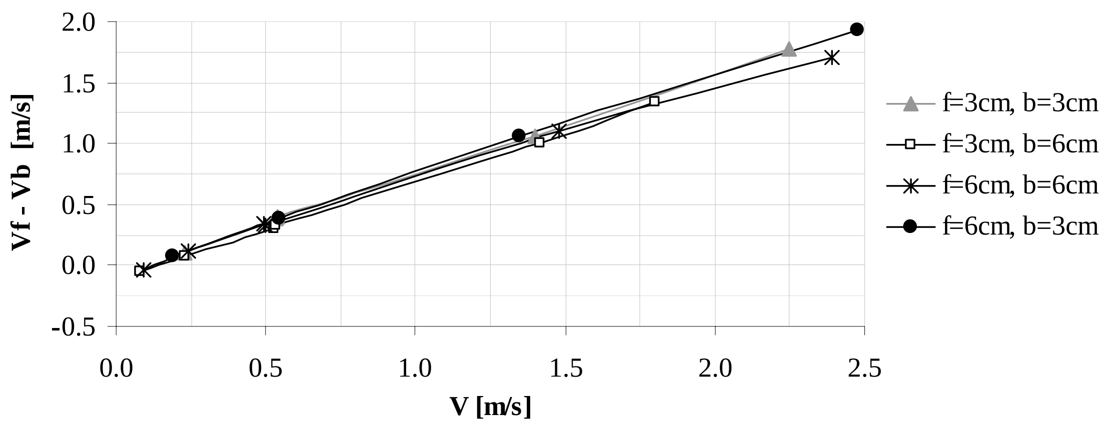

Figure 8. Investigation location of hot-sphere anemometers in relation to the shielding plate for downward flow.

Apparently, the distance between the plate and the anemometers is not as crucial as the size of the plate. Tested distances between 3 and 6 cm appear to be applicable to this sort of measurement, but still the location of the back anemometer too far from the shielding surface can be damaging because of disturbance from the turbulent vortices after the plate. Meanwhile, for the measurements performed in the jet-wind tunnel, the location of the front sensor is less sensitive to the disturbances. Still, it is necessary to keep it closer to the plate as it acts as the reference measure.

If the method is used for the measurements in the DSF cavity then the flow direction changes rapidly due to the wind fluctuation and the described subdivision of anemometers to the front and back does not exist any more, as both of them share these functions. That is the reason why both of them must be placed at the same distances from the plate, and in order to avoid turbulent vortices, a distance of 3 cm from the plate to the anemometers is best.

Because of DSF exposure to solar radiation, as explained before, the plate will be heated and will emit a convective heat flux from the surface and may result in a faulty measurement. In order to avoid this situation, it is recommended that the plate be made of material with low absorption property.

SUMMARY

Three different test cases are described in the testing of the hot-sphere anemometers for their further application in the DSF cavity. Although the hot spheres are mainly used for the measurements in the occupied zone and the conditions in the double-façade cavity are very different from the ones in the occupied zone, the obtained results show that the hot-sphere anemometers present a good solution for investigating the air flow element in the DSF cavity. It is demonstrated that the hot spheres respond well to the fluctuations, at a frequency up to 1Hz. Higher fluctuation frequency mainly results in over prediction of the low velocities. Solar radiation does not influence readings from the hot-sphere anemometers, and they can be used for the velocity measurements in the DSF cavity. Finally, it is possible to distinguish the flow direction in the DSF cavity when using hot spheres and the procedure for that is also described.

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