ACCURACY REQUIREMENTS AND LIMITATIONS FOR LOW VELOCITY MEASUREMENTS

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ABSTRACT

Recommendations for the characteristics of anemometers that will ensure accurate velocity measurements are specified in the present standards. Recent research shows, however, that the requirements in the standards are based on incorrect assumptions and are insufficient to perform draught discomfort assessment that meets the accuracy requirements for human comfort specified in the indoor climate standards. Further, the accuracy of low velocity anemometers with omnidirectional velocity sensors available on the market and commonly used for indoor velocity measurements in practice is not sufficient and needs to be improved.

In this paper, results from a recently completed European research project on calibration and requirements for accuracy of thermal anemometers for indoor velocity measurements are presented. The impact of static calibration and dynamic behaviour of thermal anemometers, directional sensitivity of the velocity sensor, free convection flow from the sensor, design of the sensor and the instrument, etc., on the accuracy of low velocity measurements indoors is assessed. New test methods and updated requirements that will improve the accuracy of the velocity measurements are proposed. Further research that will identify the accuracy limitations of thermal anemometers for low velocity measurements indoors is outlined.

KEYWORDS

Air velocity, Measuring instrumentation, Standards

INTRODUCTION

Present standards require measurement of air temperature, mean velocity and turbulence intensity in the occupied zone of rooms in order to assess the risk of draught discomfort. The mean velocity is defined by the instantaneous velocity average over an interval of time, while the turbulence intensity is the standard deviation of the velocity divided by the mean velocity.

Field measurements (Melikov et al. 1997) reveal that the air temperature fluctuations in ventilated rooms are small, with a standard deviation of less than 0.5°C and with a frequency of less than 1 Hz. Comprehensive measurements of airflow characteristics in real-scale test rooms at numerous combinations of ventilation system, air supply device, airflow rate and supply and return air temperature difference, performed by a three-dimensional laser doppler anemometer (Finkelstein, et al. 1996) identify that the frequency of the velocity fluctuations that contribute up to 90% to the standard deviation of the velocity can be in the range 0.3 to 2 Hz.

The accuracy of the mean velocity and turbulence intensity measurements depends on several factors: the calibration of the instrument and its dynamic behaviour, the directional sensitivity of the velocity sensor and the free convection flow it produces, the design of the transducer and the instrument, etc.

PRESENT STANDARDS

Requirements for the characteristics of instruments measuring low air velocity are given in the present standards, ISO 7726 (1985) and its present revision Draft ISO/DIS 7726 (1996), and in ASHRAE 55 (1992). The standards define the range of the velocity, the required and the desirable accuracy of its measurement, measuring time, as well as requirements regarding the dynamic behaviour of the anemometer and directional sensitivity of the velocity transducers. However, the standards do not specify requirements for design of the velocity transducer, correction of measured velocity for changes in the air temperature, sampling rate, etc. which are important factors for the accuracy of low velocity measurements.

Both EN ISO standard 7730 (1995) and ASHRAE standard 55 (1992) specify that less than 15% of the occupants in rooms should complain of draught (DR<15%). The percentage of occupants that will complain of draught in a room can be assessed by an equation which requires the measurement of air temperature, mean velocity and turbulence intensity of the airflow in rooms. Accuracy of the velocity measurements therefore has a significant impact on draught assessment. However, the requirements for accuracy of low velocity (air speed) measurements as specified in the standards (listed in Tables 1 and 2) are not sufficient to assess the thermal environment in rooms. For example, ASHRAE standard 55 (1992) specifies that the mean velocity should be measured with an accuracy of ± 0.05 m/s. With this accuracy the draught rating may be assessed as any value between 12% and 26% in a location in a room where the air temperature is 20°C, the actual mean velocity is 17 m/s and the turbulence intensity is 30%. Thus, two anemometers, both measuring the mean velocity with an accuracy that complies with the requirements in the standards, will measure the environment as acceptable (DR<15%) and unacceptable (DR>15%).

RECENT RESEARCH ON ACCURACY OF LOW VELOCITY MEASUREMENTS

In the following, the most important findings and conclusions from recently completed research (Melikov 1997a, Melikov et al. 1998a) on the accuracy of low velocity measurements indoors by thermal anemometers with an omnidirectional velocity transducer are presented. Updated requirements as well as additional new requirements are developed and suggested for inclusion in future standards.

Dynamic behaviour of the anemometer

Figure 1 compares the dynamic response of four tested low velocity thermal anemometers. The standard deviation ratio as a function of the frequency of the velocity fluctuations is presented in the figure. The standard deviation ratio is defined as the standard deviation of the velocity measured by the tested anemometers divided by the standard deviation of the velocity measured by a hot-wire anemometer used as a reference. With all other conditions identical, the standard deviation of the velocity measured by the tested instruments decreased when the frequency of the velocity fluctuations increased. The response of the anemometers was only slightly influenced by the mean velocity of the flow and the amplitude of the velocity fluctuations. The accuracy of measuring the standard deviation of the velocity fluctuations improved when the time constant of the instruments decreased and the overheating temperature of the velocity sensor increased (Melikov et al. 1998b).

Large differences in the shape of the dynamic response curves of the anemometers were identified. The dynamic response curves for three of the five anemometers tested could not be described by a 1st order transfer function as assumed in the present standards. Therefore the test method of step-change of the velocity recommended in the present standards (ASHRAE Standard 55 1992, ISO Standard 7726 1985) and the method of cut-off-frequency recommended in the Nordtest method NT VVS 089 (1991) for studying the dynamic response of low velocity anemometers cannot always be applied. Furthermore, the above recommended

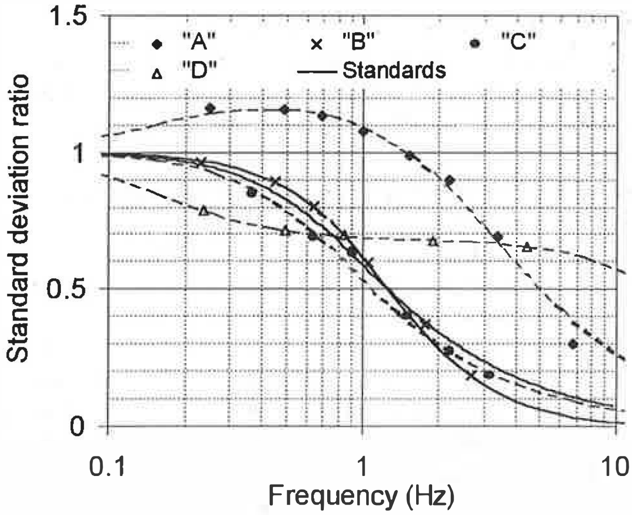

Figure 1 Comparison of the dynamic response of four low velocity thermal anemometers “A”, “B”, “C” and “D” at 0.4 m/s with the dynamic response of a low velocity anemometer with a response time of 0.5s, as assumed in the standards (ASHRAE 55 1992, ISO 7726 1985).

methods require an anemometer with an analogue output for the measured instantaneous velocity, which is not the case in practice.

A concept of the upper frequency is proposed (Melikov et al. 1998b) to describe the dynamic response of low velocity anemometers. The upper frequency defines the highest frequency of sinusoidal velocity fluctuations up to which the low velocity anemometer should be able to measure the standard deviation of the velocity with a defined accuracy.

A new test method for describing the dynamic behaviour of low velocity anemometers is outlined and suggested for inclusion in future indoor climate standards. The method is based on the upper frequency and can be applied to any anemometer (Melikov et al. 1998b).

Directional sensitivity of low velocity sensors

At present there is no standard method for testing the directional sensitivity of low velocity thermal anemometers with an omnidirectional type velocity sensor. These anemometers are recommended in the standards and are those most used in practice for indoor measurements, especially within the occupied zone of rooms. A common procedure for the manufacturers and the users of these anemometers is to test so-called "yaw" and "roll" sensitivity of the sensor. This test is performed by positioning the sensor at a point in a uniform isothermal laminar airflow with known velocity. Typically the velocity probe is positioned so that its axis is perpendicular to the flow direction. Several measurements of the mean velocity are performed by rotating the probe at different "roll" angles, ω, and different "yaw" angles, φ. The "roll" angle is defined by rotating the probe around its axis, while the “yaw” angle is defined by rotating the probe around an axis through the velocity sensor’s centre and perpendicular to the axis of the probe. The mean velocity is measured and presented as a function of the roll and yaw angles. Most omnidirectional probes have acceptable roll characteristics, i.e. small deviations of the mean velocity measured at different roll angles from the reference velocity are observed. However, the yaw characteristic shows rather large deviations (Melikov 1997, Stannov et al. 1998).

In practice the air velocity changes its magnitude and direction in a wide range (Finkelstein et al., 1996). It is not possible by simple “yaw” and “roll” tests to describe the impact of velocity changes on the accuracy of the velocity measurements by omnidirectional velocity probes. Therefore, a test method for describing the directional sensitivity of omnidirectional velocity sensors is proposed and used experimentally (Melikov, 1997, Stannov et al. 1998). The test method can be used to define the impact of the directional sensitivity of an omnidirectional sensor on the accuracy of the mean velocity and the turbulence intensity measurements. The proposed method can be used to improve the accuracy of the velocity measurements by optimizing the static calibration of low velocity anemometers and the positioning of the velocity probe during field measurements.

Free convection flow from low velocity sensors

The results of the research showed that the impact of free convection flow from the heated velocity sensor on the accuracy of the mean velocity measurements and the standard deviation of velocity (turbulence intensity) measurements was significant for velocity sensors with a high overheating temperature and of a large size, especially at downward velocities below 0.15 m/s. The accuracy of the measured mean velocity increased and that of the standard deviation of the velocity decreased when the amplitude of the velocity fluctuations in the flow (turbulence intensity) increased. The impact of free convection on the accuracy of the velocity measurements was not affected by the frequency of the velocity fluctuations of the downward flow (Popiolek et al. 1998).

The impact of free convection on the accuracy of the velocity decreases when the overheating temperature of the velocity sensor is low. This, however, will have a negative impact on the dynamic response of the low velocity thermal anemometer. This antagonistic impact of the overheating temperature has to be very carefully considered during the design of the instrument.

Temperature compensation

Thermal anemometers used at present correct automatically for changes of the air temperature during measurement. The air temperature is measured by an unheated sensor. The correction is needed because the static calibration of the transducers is performed at a constant air temperature, typically different from the air temperature during field measurements. Depending on its overheating temperature, the velocity sensor can measure the mean velocity with a difference of 15% to 30% from that of the real velocity of the flow if no correction is made for the difference between the air temperature of calibration and the air temperature of the measurement even if only by 1°K.

The response time of the sensor used to correct the measured velocity for changes of the air temperature is not specified in the present standards. Often it is chosen by the manufacturers to be much longer than the response time of the velocity measuring sensor. Recent research (Melikov et al. 1998c) identifies that the accuracy of the mean velocity measurements is not affected significantly by the air temperature fluctuations. However, the air temperature fluctuations may have a significant impact on the accuracy of the measured standard deviation of the velocity.

Design of low velocity sensors

Often the transducers have a special protection of the velocity sensor against damage. This protection may cause a drop in the mean velocity of up to 50% (Melikov et al. 1998a). Sawachi and Melikov (1993) identified that a protection, designed as a dense mesh around the sensor, damped the velocity fluctuations in the flow. Thus the measured standard deviation was lower than the actual standard deviation of the velocity.

The distance between the heated sensor and the unheated sensor of the transducer has to be great enough to avoid disturbances between the two sensors and at the same time short enough to avoid impact of spatial temperature gradients. Melikov et al. (1997) identified that a distance of 20-30 mm and even 50 mm between the two sensors will be sufficient to perform accurate velocity measurements in the occupied zone of rooms in practice.

Measuring time

The results of the present study confirmed that a measuring period of 180 s (3 min) as specified in the present standards (ASHRAE Standard 55 1992 and ISO Standard 7726 1985) is enough to perform mean velocity and turbulence intensity measurements with an accuracy better than ±10%. Further, it is recommended that the mean velocity is calculated as an average value of three or more measurements when velocity fluctuations with a period longer than 60 s occur in rooms.

Sampling rate

The mean velocity and the standard deviation of velocity (turbulence intensity) are statistical parameters. It is the combination of sampling rate and number of samples that determines the final accuracy of the statistics. In order to obtain the best accuracy of the mean and standard deviation of instantaneous velocity, i.e. a random stationary process, the optimum sampling rate should be twice the integral (Eulerian) time scale of turbulence (airflow characteristics in rooms are discussed in Hanzawa et al. 1987). In this way, the individual samples will be statistically independent. The results confirm that the accuracy of mean velocity and turbulence intensity (standard deviation) measurements will be better than 1% when the number of samples is 900 and higher. The accuracy is thus not increased by increasing the number of samples for a fixed measuring time of 4 or 5 minutes. It may be concluded that 900 samples at evenly distributed intervals over a measuring time of 3 min will be sufficient to provide accurate statistics in low velocity indoor flows.

NEW UPDATED REQUIREMENTS

The research described in this paper enabled the requirements for the characteristics of low velocity anemometers to be updated and new requirements to be developed that will improve the accuracy of low velocity measurements indoors (Melikov et al. 1998a). The updated and the new requirements are listed in Tables 1 and 2.

FURTHER RESEARCH

The thermal anemometers for low velocity measurements are those most used at present. They are inexpensive and easy to operate. They are used for the assessment of the indoor environment and for multi-point measurements of airflow characteristics (mean velocity and turbulence intensity) when HVAC systems and components have to be developed. Only for very limited special applications can the low velocity anemometers be replaced by LDA, ultrasonic anemometers or other low velocity measuring techniques. The present research shows that the accuracy of the low velocity anemometers with omnidirectional velocity transducer is not enough to perform accurate velocity measurements that will ensure realistic assessment of the indoor environment as required in the standards. It is of prime importance to improve the dynamic characteristics of the low velocity thermal anemometers and so to improve the accuracy of the velocity measurements. However, low velocity thermal anemometers, as any other measuring instrument, have limitations regarding their accuracy. These limitations must be known in order to define the highest realistic possible accuracy for draught measurement in practice and to set realistic draught requirements in the standards. This knowledge will also provide manufacturers with design criteria for modification of the present instruments and development of new instruments. In order to achieve this the following research is needed: 1) to improve the dynamic behaviour of low velocity thermal anemometers and to establish accuracy limitations for turbulence intensity measurements made with low velocity thermal anemometers; 2) to analyse combined effects of error sources for low velocity thermal anemometers and to establish accuracy limitations for draught measurement in practice; 3) to make new specifications for draught discomfort in future indoor climate standards.

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Table 1 Requirements for the characteristics of low velocity measuring instruments.

Parameter	ISO 7726 (1985) (Draft ISO 7726, 1996)	ASHRAE Standard 55 (1992)	NEW REQUIREMENTS
Measuring range	0.05 to 1 m/s	0.05-0.5 m/s (10-100 fpm)	0.05 to 1 m/s
Accuracy of air velocity measurements as calibrated	Required: $\pm(0.05 + 0.05\ Va)$ m/s Desirable: $\pm(0.02 + 0.07\ Va)$ m/s These levels shall be guaranteed whatever the direction of flow within a solid angle $(\Omega) = 3\ \pi$ st	±0.05 m/s (±10fpm) It is important to consider the natural convection from the sensor.	Measuring range 0.05+1.0 m/s: ±0.03 m/s The readings in downward, horizontal and upward flow with a velocity higher than 0.1 m/s shall be equal or differ less than 0.01 m/s.
Dynamic behavior	Response time (90%): Required - 1s (0.5 s) Desirable - 0.5 s (0.2 s)	Response time (90%): Required - from 1 to 10 s. Desirable - 0.2 s.	Required upper frequency: 1 Hz[a] Desirable upper frequency: 2 Hz[a]
Directional sensitivity	Except in the case of unidirectional current, the air velocity sensor shall measure the velocity whatever the direction of the air	shall be omnidirectional or must be carefully orientated.	The mean velocity directional sensitivity of the velocity sensor should be within the range of ±5%. The turbulence intensity directional sensitivity should be less than ±10%.[b] The placement of the sensor in regard of the mean flow direction shall be as close as possible to the placement of the sensor in the flow, where it was calibrated.[b]

[a]The upper frequency can be determined by the test method suggested by Melikov et al. 1998b.
[b]The mean velocity directional sensitivity and the turbulence intensity directional sensitivity of low velocity probes can be determined by the test method suggested by Stannov et al. 1998.

Table 1 Requirements for the characteristics of low velocity measuring instruments (contd).

Parameter	ISO 7726 (1985) (Draft ISO 7726, 1996)	ASHRAE Standard 55 (1992)	NEW REQUIREMENTS
Temperature compensation	no requirement	no requirement	The temperature compensation shall be made in such a way that the change of the air temperature (from the temperature of calibration) will have an impact on the accuracy of the measured velocity of not more than 1% per °K for the air temperature range 15-35°C.
Design of transducer	no requirement	no requirement	Any protection against damages shall not influence the accuracy of the velocity measurements. The distance between the velocity sensor and the sensor used for temperature compensation shall be as close as possible but not more than 50 mm. The two sensors shall not influence each other.

Table 2 Requirements for signal processing.

Parameter	ISO 7726 (1985)	ASHRAE Standard 55 (1992)	NEW REQUIREMENTS
Measuring period	Desirable: 3 min.	3 min. or 30 times the 90% response time of the instrument.	Required: 3 min. Average value of three or more measurements are recommended when the period of the velocity fluctuations is more than 60 seconds.
Sampling rate	no requirement	no requirement	5 or more samples per second