A Laboratory Intercomparison of Static Pressure Heads

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Abstract

Barometric air pressure can be affected by dynamic pressure variations caused by wind gusts. To avoid these effects it is necessary to measure air pressure by using a static pressure head outside of buildings. The CIMO Guide (WMO No. 8) points out that there are several pressure heads commercially available but practically no literature on an intercomparison.

Deutscher Wetterdienst (DWD) has conducted a laboratory intercomparison of four different models to assess the attenuation of dynamic pressure effects for all wind directions and inclined flow. Additional consideration was given to icing effects and the effectiveness of heating systems.

Some of the remarkable results show that there is still potential for improvement of the construction of some static pressure heads. The estimated residual pressure error as a function of wind speed is given for each of the tested pressure heads.

Introduction

Barometric pressure is an important basic atmospheric parameter and should be measured at the highest possible accuracy respecting technological and finacial constraints [1]. Since the early 1990's several digital barometers of excellent accuracy and low drift are available [2] and widely used in automatic networks. Meanwhile digital barometers have been further improved and their robustness and insensitivity to temperature changes even allow outdoor installations.

While the CIMO Guide [1] states required expanded uncertainties (*k=2*) for pressure measurements of 0.1 hPa and achievable uncertainties of 0.3 hPa, the latest version of the WMO Observing Systems Capability Analysis and Review Tool (OSCAR) [3] requires only 0.5 hPa for the most demanding applications. In laboratory calibrations modern digital barometers have total uncertainties (including drift) of 0.15 hPa which might lead to the conclusion that all problems are solved for this meteorological parameter.

This view has to be changed for field installations because of the dynamic pressure

$$\Delta p = \frac{\frac{p}{R_S \cdot T}}{2} \cdot v^2 \quad (1)$$

adding an additional error to the measurement, where p is the static pressure, R_S is the specific gas constant for dry air, T is the air temperature and v is the flow velocity of the air. A simple pressure inlet pointing in upwind direction will provide an increased total pressure by this superimposed dynamic pressure component. As an example, a barometric pressure of 1013.25 hPa and a temperature of 20°C wind speeds of 20 m/s will result in a maximum dynamic pressure of 2.4 hPa and in 5.4 hPa for 30 m/s. Pointing the inlet in the opposite direction will result in a total pressure decrease.

Indoor installation of the barometer will generally not remove this effect, because the whole building is subject to the same effect. The dynamic pressure error inside buildings is depending on the wind speed and direction with respect to the building façade, the design of the building and the state of windows and doors (open / closed, leak tightness). Moreover modern buildings can be quite airtight and are airconditioned which will make it impossible to correctly measure the static barometeric pressure inside.

The CIMO Guide therefore recommends to use a static pressure head that should ideally compensate for any dynamic pressure effect. This device should typically be installed about 20 m away from buildings or any other big obstructions and is conntected to the pressure inlet of the barometer by a tube or a hose. Since the 1980’s some Meteorological Services had developed and used proprietary solutions. The CIMO guide also states that „*static pressure heads are commercially available, but there is no published literature on intercomparisons to demonstrate their performance”*. This work was carried out to close this lack of information.

Experiment

The static pressure heads were tested at several wind speeds, wind directions and inclinations in the wind tunnel at DWD in Hamburg (Germany). Residual dynamic pressure errors were measured as a pressure difference between the static air pressure outside the wind tunnel and the total pressure given by the static pressure head inside the wind tunnel. The pressure difference was measured by a differential pressure sensor Druck DPI610 LP with an uncertainty of 0.05 % in a measurement range of ±12.5 hPa.

Tested pressure heads

Four different static pressure heads, shown in Fig. 1, were tested.

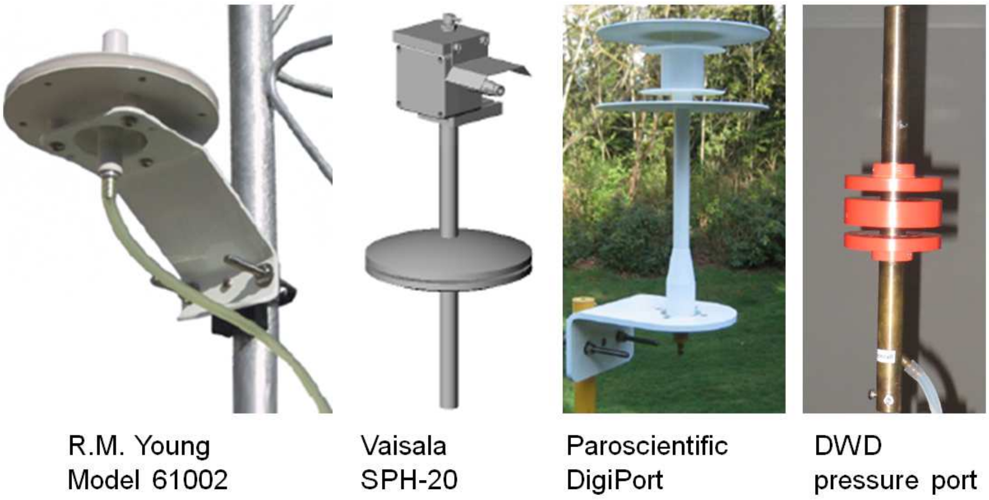

Fig. 1: These four static pressure heads were compared in laboratory experiments. The DWD pressure port has been developed by Deutscher Wetterdienst in the 1980’s for measurements on ships. All other pressure heads are commercially available.

The commercial products Model 61002 from R.M. Young, SPH-20 from Vaisala and Digiport from Paroscientific were compared to the DWD pressure port that was originally developed for measurements on ships.

Measurements

For characterizing the static pressure heads, the following experiments were conducted:

- Horizontal Rotation of the pressure heads by 360° around their vertical axis to analyse the *influence of wind direction on the performance of the pressure heads*. Horizontal rotation of the pressure heads in the wind tunnel experiment was done in angular steps of 4° by a computer controlled precision stepper motor. The dwell time at each horizontal angle for sampling the pressure values was 9 s. Wind speed was set fixed at 20 m/s for this experiment.
- By tilting the pressure head in the range of ±30° the *influence of an inclined flow on the dynamic pressure compensation* was evaluated. This would also give an indication of the expected errors due to turbulent air flow. Tilting of the pressure heads could not be done directly by a separate stepper motor and was therefore effected by a special tilt mount shown in Fig. 2. A horizontal rotation by 180° is simultaneously transferred into a tilting motion by ±30°.

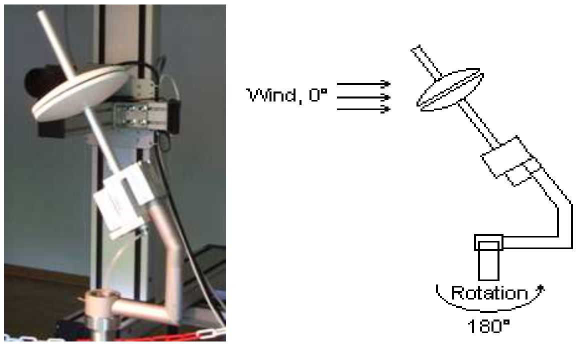

Fig. 2: Tilt mount with an angle of 30°. By horizontal rotation of 180° the test device is simultaneously tilted by ±30° in the vertical direction.

- The *influence of snow or ice accretion* on the pressure head was analysed. Ice accretion on the pressure heads was simulated by taping several layers of bubble wrap onto the device. Wind tunnel results were compared with those of the uncovered pressure head. There is currently only one model with integrated heater available, and it was a question whether this feature is needed. The effectiveness of the heating was also tested in a temperature chamber.

Results

Direction and inclination

As mentioned in the introduction, modern digital barographs can measure barometric pressure with a total uncertainty of 0.15 hPa. Thus for meeting the achievable uncertainty of 0.3 hPa, stated in the CIMO Guide, the dynamic pressure error of the static pressure head should not exceed 0.15 hPa. This value is depicted as a blue line in the following graphs.

Fig. 3 shows the results for the static pressure head model 61002 from R.M. Young. The left graph represents the pressure difference, i.e. the error by the residual dynamic pressure, as a function of wind direction for the untilted pressure head. The differences are ranging between -0.15 hPa and -0.5 hPa with a notable angular dependency. It is obvious that most of the effect is caused by the support for mounting the pressure head on a mast. When the support is behind (0°) or ahead (180°) of the pressure head the pressure differences are largest. This demonstrates that a pressure head should be as symmetric as possible.

The right graph in Fig. 3 is representing the response to an inclined flow from +30° to -30° at wind speeds of 10 m/s, 20 m/s and 30 m/s. Positive inclination angles are used for downward vertical wind directions and vice versa. The performance is depending strongly on the vertical wind direction and again not symmetric.

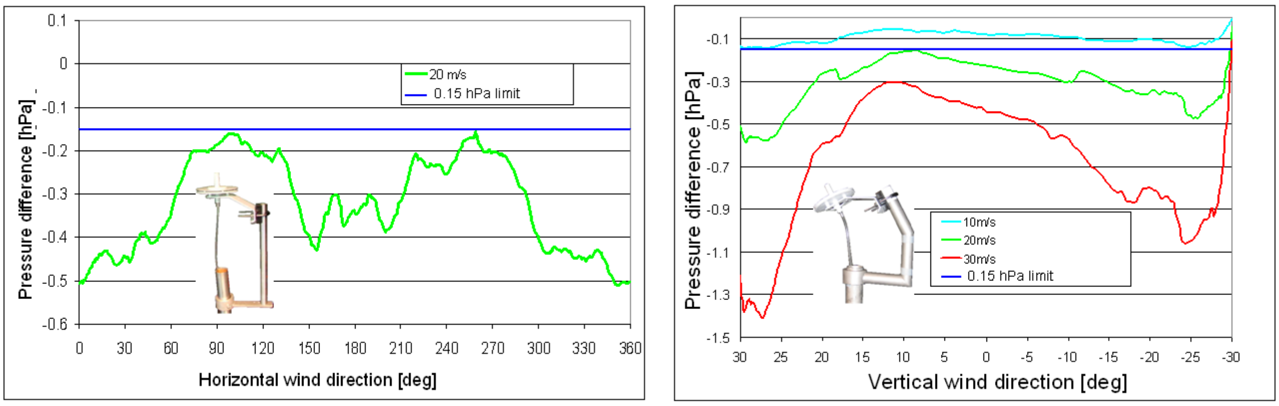

Fig. 3: Results for R.M. Young model 61002. Dependency of wind direction (left) and inclined flow (right).

The graphs in Fig. 4 are showing the results for the Vaisala SPH-20, which is the only heated pressure head available. The pressure differences are between -0.05 hPa and -0.22 hPa showing some features of asymmetries. We had suspected that the electronics box at one end of the middle bar is causing this effect. Removal of the box led to a small but not substantial improvement, suggesting that the asymmetric curve could be caused by some features in the internal construction. If some of the dips in the curve could be removed, it would be possible to stay within the 0.15 hPa limit for wind speeds up to 20 m/s.

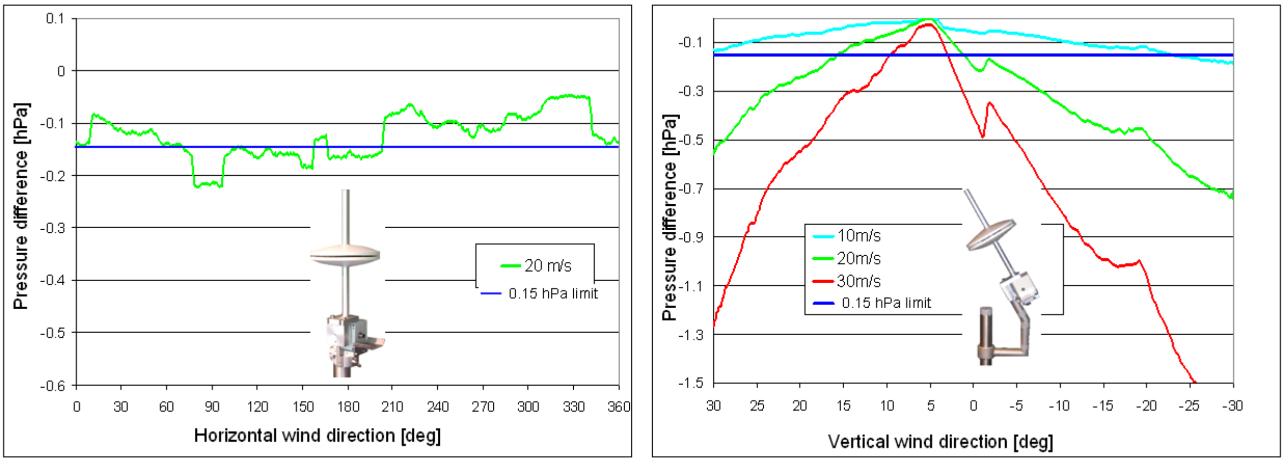

Fig. 4: Results for Vaisala SPH-20. Dependency of wind direction (left) and inclined flow (right).

The inclined flow graph on the right hand side of Fig. 4 shows asymmetry and characteristic features at certain inclination angles. The deviations with respect to vertical wind direction are comparable to the results of the R.M. Young model 61002.

The results for the Paroscientific Digiport (Fig. 5) are excellent. The pressure difference is uniformly between -0.05 hPa and -0.1 hPa and does not show asymmetries. The values stay well within the 0.15 hPa limit for 20 m/s. The influence of the inclination angle is about half compared to the two preceding pressure heads and they are comparatively uniform at inclination angles between +10° and -10°.

The DWD pressure port (Fig. 6) shows pressure differences in the range of -0.1 hPa and +0.05 hPa and its average deviation is closest to zero of all tested static pressure heads. Some minor asymmetries at around 90° and 270° leading to larger absolute deviations from the mean than for the Paroscientific pressure head, which has a higher precision.

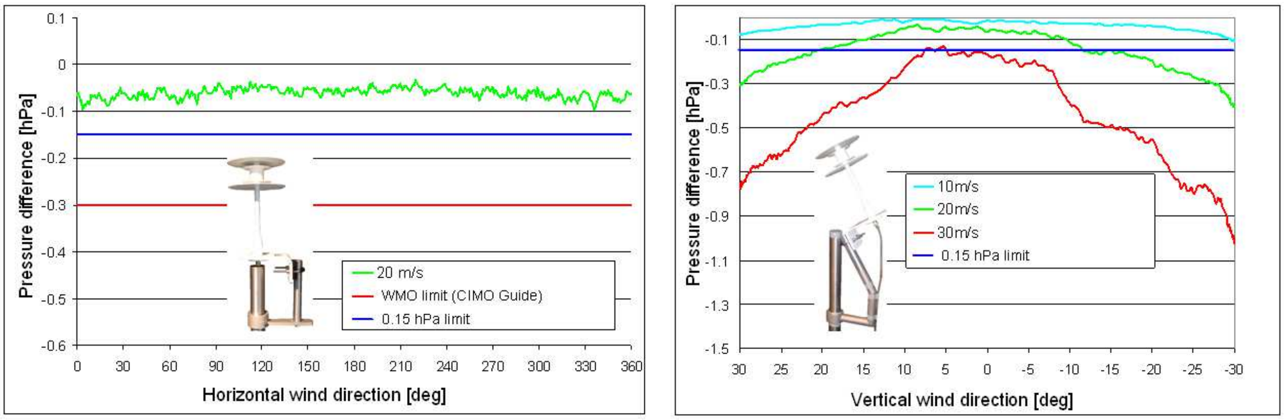

Fig. 5: Results for Paroscientific Digiport. Dependency of wind direction (left) and inclined flow (right).

The response to inclined flow is remarkably good for the DWD pressure port showing a wide plateau of small deviations of less than 0.15 hPa for angles of ±25° up to wind speeds of 20 m/s. Even for 30 m/s the pressure differences stay below 0.2 hPa at least for inclination angles of ±20°.

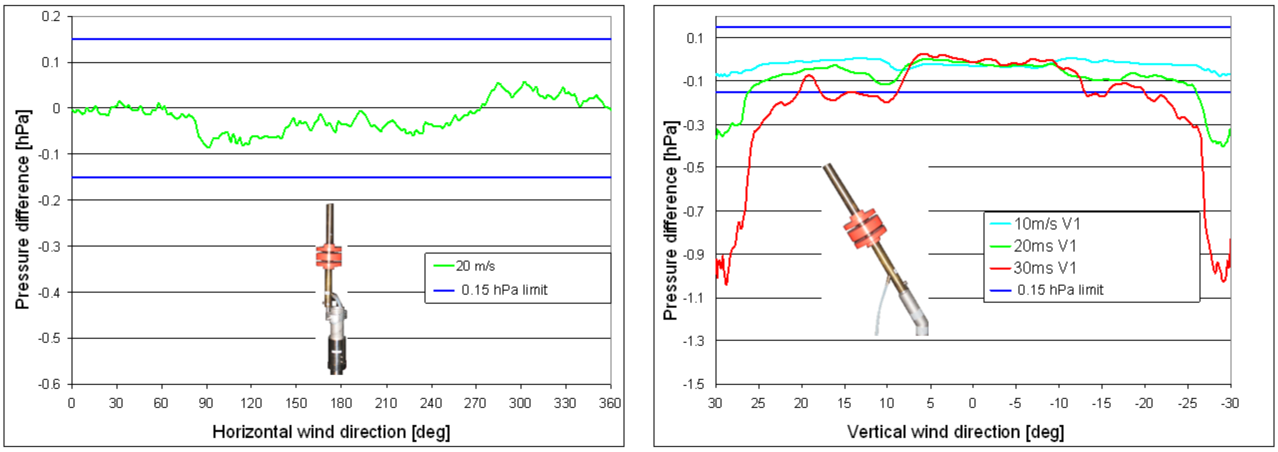

Fig. 6: Results for DWD pressure port. Dependency of wind direction (left) and inclined flow (right).

The final results for maximum dynamic pressure errors (worst case) at horzontal flow are summarized in Fig. 7 as a function of wind speed. By taking the largest deviations found at a wind speed of 20 m/s and applying formula (1) the expected maximum error curves can be plotted for each pressure head.

The dashed blue line represents the unattenuated dynamic pressure, i.e. the maximum possible value for a given wind speed. The horizontal dashed lines are displaying the above mentioned 0.15 hPa limit and the 0.3 hPa CIMO Guide limit to show up to which wind speed each of the pressure heads meets these requirements.

In comparison to the unattenuated dynamic pressure the R.M Young model 61002 pressure head decreases the influence of wind speed at least by a factor of 5. The Vaisala SPH-20 shows a reduction of dynamic pressure by at least a factor of 10, whereas the Paroscientific Digiport reduces dynamic pressure effects by a factor of 24 or more. The DWD pressure port attenuates the dynamic pressure influence by a factor of 28. The Paroscientific Digiport showed the best symmetry of all tested devices but due to a small negative bias, its dynamic pressure reduction was a little bit lower than for the DWD pressure port.

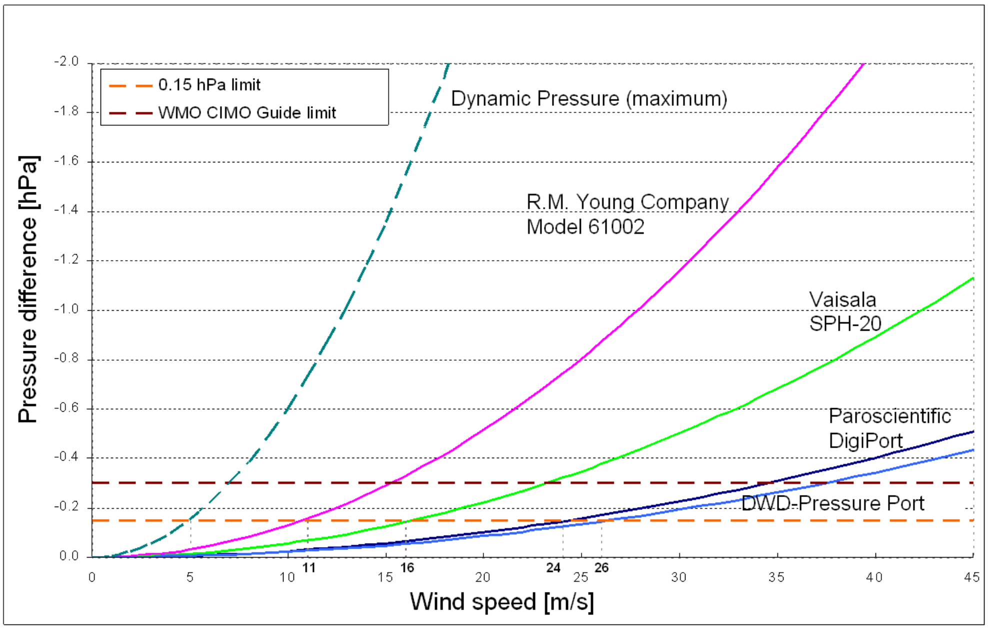

Fig. 7: Maximum dynamic pressure errors for each tested pressure head as a function of wind speed.

Effect of icing

A simulation of potential snow or ice accretion on the pressure head was performed for all pressure heads by taping on multiple layers of bubble wrap, as shown on the inserted picture in Fig. 8. By varying the number of layers the severity of ice accretion was changed to analyse the effect with respect to the achievable dynamic pressure reduction. These tests were conducted at a wind speed of 20 m/s. The results in Fig. 8 show that icing or snow will disturb the delicate symmetry of pressure ports leading to unacceptable deviations for heavy icing. One layer of bubble wrap, corresponding to minor icing or snow accumulation, will have a noticeable but still acceptable influence.

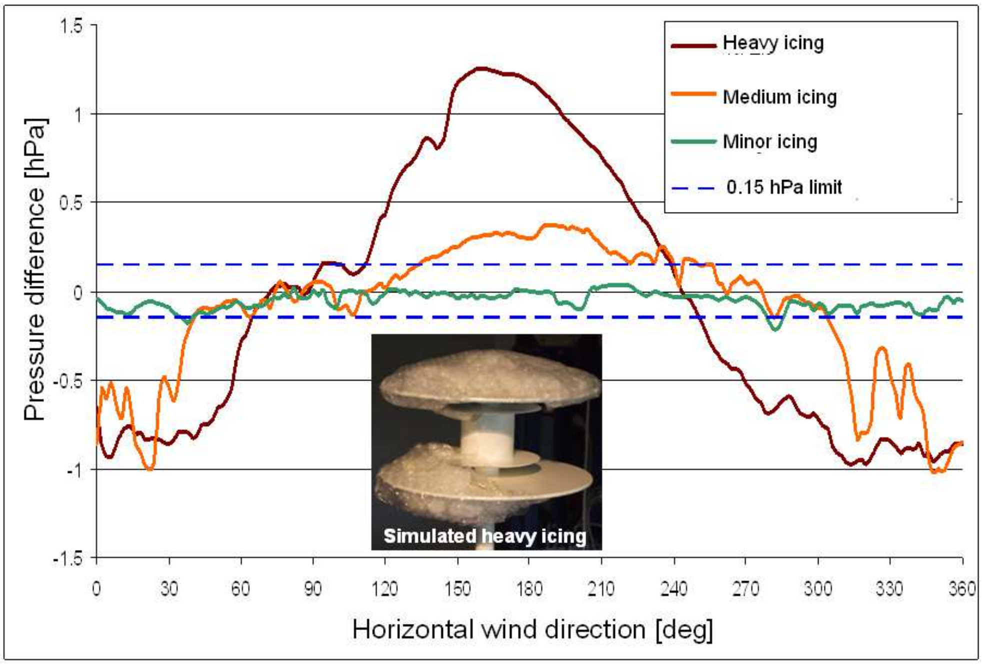

Fig. 8: Effect of snow cover and icing on the pressure head at 20 m/s. The icing was simulated by taping several layers of bubble wrap on the surface of the device.

It is therefore recommended to keep a static pressure head free of ice and snow at any time. For automatic operation a heating of the device should be foreseen if snow and icing can occur at the site.

The 70 W heater system of the Vaisala SPH-20 has proven to remove any icing very effectively. The pressure head was mounted in a temperature chamber at -15°C. By spraying water onto the unheated pressure head an ice layer was built up. After switching on the heater the ice melted away within a few minutes.

Conclusions

A laboratory intercomparison of four different models of static pressure heads has been conducted to assess the attenuation of dynamic pressure effects for all wind directions and for an inclined flow in the range of ±30°. The estimated residual pressure errors as a function of wind speed are differing significantly for the tested pressure heads. The best static pressure heads are providing a dynamic pressure attenuation of a factor 25 or better. In combination with a good digital barometer these static pressure heads will provide a total measurement uncertainty of 0.3 hPa for wind speeds up to 25 m/s. For some pressure head there is still potential for improvement of the symmetry, which is necessary for a uniform performance for all wind directions.

Heating of pressure heads is necessary where snowfall and ice accretion can occur. There is currently only one static pressure head with a built-in heating commercially available.

References

[1] WMO, *Guide to Meteorological Instruments and Methods of Observation*. WMO-No. 8, 7th edition, Genf, 2008.

[2] Van der Meulen, J.P., *The WMO Automatic Digital Barometer Intercomparison*, WMO (Geneva, 1992): Instruments and Observing Methods Report No. 46, WMO/TDNo. 474.

[3] WMO, Observing Systems Capability Analysis and Review Tool (O.S.C.A.R.): http://www.wmo-sat.info/oscar/