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Meteorology — Air temperature measurements — Test methods for comparing the performance of thermometer shields/screens and defining important characteristics

Météorologie — Mesurage de la température de l'air — Méthodes d'essai pour comparer les performances d'abris/d'écrans pour thermomètres et définir les caractéristiques importantes

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Foreword

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International Standards are drafted in accordance with the rules given in the ISO/IEC Directives, Part 2.

The main task of technical committees is to prepare International Standards. Draft International Standards adopted by the technical committees are circulated to the member bodies for voting. Publication as an International Standard requires approval by at least 75 % of the member bodies casting a vote.

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Introduction

Commonly used air temperature sensors require protection from influences such as solar and terrestrial radiation, rain and snow. Screens (also known as shields) protect the thermometers from these influences.

At present, there is no commonly accepted reference screen design, nor are there generally accepted test methods to determine performance characteristics of screens. Screens that protect the temperature sensors from daytime heating and nighttime cooling due to radiation transfer are necessary for proper air temperature measurements. In very general terms, a poor design of the screen will tend to give higher daytime and lower nighttime temperatures.

This International Standard was developed to define the most relevant screen characteristics and to provide the methods to determine or compare screen performances.

Air temperature is a basic meteorological variable. Temperature sensors are widely used in all human activities and are well known and controlled. For the measurement of the outside air temperature, the sensor must be protected against external influence, mainly radiation and hydrometeors (e.g. precipitation, fog). The sensor is usually protected by a screen, but even then, measurement errors of up to 5 K may be encountered.

The general function of a screen for operational temperature measurements used in meteorological applications is given in WMO No. 8 [3]. The following text is an extract from this document.

“Radiation from the sun, clouds, the ground and other surrounding objects passes through the air without appreciably changing its temperature, but a thermometer exposed freely in the open can absorb considerable radiation. As a consequence, its temperature may differ from the true air temperature, the difference depending on the radiation intensity and on the ratio of absorbed radiation to dissipated heat. For some thermometer elements such as the very fine wire used in an open-wire resistance thermometer, the difference may be very small or even negligible, but with the more usual operational thermometers the temperature difference may reach 25 K under extremely unfavourable conditions. Therefore, in order to ensure that the thermometer is at true air temperature it is necessary to protect the thermometer from radiation by a screen or shield which also serves to support the thermometer. This screen also shelters it from precipitation while allowing the free circulation of air around it, and prevents accidental damage. Maintaining a free circulation may, however, be difficult to achieve under conditions of rime ice accretion. Practices for reducing observation errors under such conditions will vary and may involve the use of special designs of screens or temperature-measuring instruments.”

Meteorology — Air temperature measurements — Test methods for comparing the performance of thermometer shields/screens and defining important characteristics

1 Scope

This International Standard defines characteristics of a thermometer shield/screen. It also defines test methods to inter-compare the behaviour of different screen designs.

Although screens are usually used for both air temperature and humidity measurements, this International Standard is applicable only to temperature measurements.

Both naturally and artificially ventilated screens are considered.

2 Terms and definitions

For the purposes of this document, the following terms and definitions apply.

2.1
aspiration rate
rate of air flow passing the thermometer.

NOTE This term is only used for an artificially aspirated screen, and is expressed in metres per second.

2.2
internal ventilation factor
ratio between the internal air speed and the external wind speed, at the thermometer height

NOTE This term is only used for a naturally ventilated screen.

2.3
representative height
height above ground at which the air temperature is supposed to be measured

NOTE 1 For naturally ventilated screens, the representative measurement height is usually the height of the temperature sensor.

NOTE 2 For aspirated screens, the representative height can be different from the height of the temperature sensor. It is design dependent, however it is usually the height of the air intake.

2.4
screen
shield or shelter used to protect the thermometer from radiation, precipitation and accidental damage

2.5
screen reference point
location of the thermometer within the screen

2.6
solar radiation errors
overheating error of the measured air temperature, generated by solar radiation

2.7
system response time
time needed for the temperature recorded by the thermometer within the screen to reach 63 % of a step change in the external temperature, with a given external wind speed of 1 $m \cdot s^{-1}$

NOTE 1 The system response time is a combination of the response times of the screen and the thermometer, and depends on the thermometer time constant.

NOTE 2 The response time of the system is also dependent on wind speed. For this reason, a given air speed of 1 $m \cdot s^{-1}$ is used.

2.8
thermometer
device used to measure the air temperature inside a screen

NOTE Examples are platinum resistance thermometer sensors (IEC 60751 [1]) and thermistor sensors (ASTM E 644-04 [2]).

3 Field test conditions

3.1 Field test site

The test site should experience the range of meteorological conditions that are expected at the sites where the screens will be installed. Important influence factors are: radiation, low wind speed, periods with snow cover, falling and blowing snow, blowing dust or sand, wet fog, strong winds and wind-driven precipitation.

It may be necessary to perform testing at more than one site, to address the full range of meteorological conditions.

The meteorological conditions occurring at the site during the intercomparison shall be described, with at least the temperature, wind and daily insolation distribution.

3.2 Respective location of screens

For the field test, all the screens shall be installed above a level area covered by homogeneous natural ground cover. The vegetation at the test site should completely cover the surface and the type of vegetation shall be defined. It should be kept at a height below 10 cm. All screens should be freely exposed to sunshine and wind and should not be shielded by, or close to, trees, buildings and other obstructions (see A.8). The screens should be installed at a minimum distance of 30 m from any heat source or other construction that could artificially influence the air temperature, such as concrete, asphalt, buildings, standing water, etc.

The separation between screens is a compromise, and should be large enough to ensure that interaction between screens is insignificant, while being small enough to minimise temperature variations across the site. The distance between each screen should be at least 3 m. A representative height between 1,25 m and 2 m should be chosen for the test to meet the WMO recommendations. The representative height shall be the same for each screen, with a maximum tolerance of ± 5 % of the height.

When testing artificially ventilated screens, the probe orientation and the inlet/outlet orientations shall be documented, as wind direction may influence the aspiration rate.

3.3 Screens

Two or more screens of each design should be included in the test. This allows assessment of measurement repeatability of a given screen design and also for measurement of homogeneity of the test site.

At least two reference screens with identical thermometers shall be used.

During an intercomparison, observations of the screens are required to determine if they are wet, covered with ice, clogged with snow, dirty, if the aspirator (if any) is working, etc.

3.4 Thermometers

The thermometers and associated data acquisition system(s) should be matched to ensure equivalent response characteristics, such as the time constant. WMO [3] recommends the use of thermometers with a time constant of about 30 s. The sensors and measuring system shall be calibrated and used in such conditions that there is no significant self heating of the thermometer due to an excessive measuring current. The uncertainty of the temperature measurements shall be 0,2 K or better.

3.5 Additional meteorological variables

In addition to the air temperature measurements, the following parameters should be measured and recorded during an intercomparison.

— Solar global radiation on a horizontal plane.

— Sunshine (yes/no).

— Scalar average 1 min or 2 min wind speed and direction. This should be measured at a position that is as close as possible to the representative height of the temperature measurement. Where the test array of screens can shelter the anemometer in certain wind directions, then it is preferred that the anemometer is raised slightly above the level of the top of the screens and this measurement height recorded. The anemometer used should be capable of calibrated measurements of wind speeds at 0,5 $m \cdot s^{-1}$ and above. Sonic anemometers may be good candidates for these measurements.

— Scalar average 1 min or 2 min wind speed and direction at 10 m height (standardized meteorological height). Wind measurements at 10 m allow a comparison between meteorological conditions during the test and climatological conditions (as 10 m measurements are currently used in climatological records).

— Relative humidity of air.

— Cloud cover.

— Precipitation occurrence, type and intensity. Manual observations may be required to determine precipitation occurrence and type.

— Sun azimuth and elevation angle.

— Surface albedo (ground conditions, snow cover, etc.)

It is also desirable to measure

— direct solar radiation, and

— long-wave net radiation or cloud cover at night.

The type of instruments used and their siting shall be documented. The instruments used shall be calibrated and regularly maintained, and should be installed and used following the recommendations of WMO [3].

3.6 Data sampling

When making the screen intercomparison, a data base of all measurements should be constructed to represent averages from samples taken during 1 min periods. The data sampling rate should be at least 6 samples per minute.

For wind measurements, the data sampling rate should be at least 1 Hz.

3.7 Reference values

There is no recognised reference system for measuring the true air temperature. Statistically, radiative errors of any screen lead to warmer (than the true air temperature) temperature measurement during the day, and cooler temperature measurement during the night. So when different screen designs are compared, those that are cooler during the day and warmer during the night are likely to be giving measurements that are closest to the truth. By design, it is generally the case that there will be a fast response thermometer inside an artificially ventilated screen. However, not all designs of artificially ventilated screens that are available on the market are satisfactory for use as a reference.

If an artificially ventilated screen is to be used as a reference, then its performance shall be fully tested.

— Check for potential psychrometric cooling effects after high humidity events or dew deposition.

— Check the effect of the ambient wind on the airflow in an artificially ventilated screen, as designs have been found where airflow across the thermometer is reduced or reversed in some wind conditions.

— Check if a large aspiration rate may cause heating of the air.

— Check if the air exhausted by the fan may re-circulate and influence the incoming air.

— Check the sensor and screen for dirt and contamination that could obstruct the airflow or influence the temperature.

A potential candidate for measuring the reference air temperature is the use of a very thin resistive wire (thickness < 15 µm, [4, 5] in the Bibliography), acting as a thermometer. If it is very thin, the wire may be exposed freely to the air, with no radiation screen. The problem with this technique is how to design a wire that has stable characteristics and will survive for long enough periods outside in all weather conditions; a suitable sensor has yet to be designed.

If the purpose of the intercomparison is to check the behaviour of new designs against a specific screen model widely used (in a country and/or in the past), this screen may be used as a 'relative' reference. In this case, the new screen may exhibit better characteristics than the reference, and the performance may be explained by considering the influence factors detailed in Annex A.

In any case, the reference screen used should be fully described: geometry, sensors and their time constants, materials used in the construction of both the screen and its supporting structure, any attached boxes, airflow tests and other relevant matters.

3.8 Quality control

Data quality control shall be carried out before and during the analysis, to avoid erroneous data from being used. Times and details of any interventions during the test that could cause erroneous measurements to be recorded shall be noted, so that such data are not used.

Automatic checking of the data usually allows the detection of gross errors, such as out-of-range values.

The use of two identical screens of each type under test (including the reference), enables checks of differences between similar pairs, to reveal any data that are significantly different.

Another effective quality-control check is to visualise the different parameters to detect strange or abnormal behaviour using time graphs of all data on a daily basis. It is also possible to detect potential anomalies by looking for extreme values during the data analysis; the time of occurrence of these extreme values should be noted and the data should be graphically displayed during these occurrences. This method is also a good way to detect the specific behaviour of screens during the typical conditions listed in 3.10.

3.9 Long-term intercomparison

It is very difficult to generate and control all the factors that influence the performance of a screen in the laboratory. By making measurements of performance at a field test site, most important meteorological conditions will be experienced, if sufficient time is allocated for the test. A long-term intercomparison is therefore recommended, extending over the summer and winter periods and typically of one year duration for a comprehensive test. If the test is conducted in an area with less seasonal change, the duration of the test can be reduced.

During this long-term intercomparison, the effects of the following combinations of influence factors should be analysed:

— solar radiation;

— wind;

— solar radiation and low wind speed (< 1 m·s^{-1}); a sensitive anemometer is required;

— insolation relating to the sun's elevation and wind speed (as direct radiation is a major influence factor, this analysis may be more representative than the previous one);

— cloud cover at night, combined with wind speed, to assess long-wave radiation cooling;

— precipitation, fog and rime events, their onset, duration and termination;

— cleanliness and aging of the screen.

These effects should be analysed using the whole database and specific filters on the influence parameters.

3.10 Typical conditions

The advantage of long-term comparisons is that they enable data collection during a wide range of meteorological conditions representative of the test site.

A disadvantage may be that the conditions leading to extreme measurement errors of the air temperature are not readily apparent. This can be overcome by identifying extreme differences between the tested screen and the reference, and then investigating the current meteorological conditions during these differences. If the screens have different time constants and the air temperature variation with time is high, this may be the cause of such differences. Therefore, such a comparison is more representative when conducted on daily extreme values.

Another solution is to identify typical meteorological conditions and to analyse the behaviour of the tested screens to get a detailed knowledge of the screen behaviour in known conditions. This may allow an extrapolation of the screen behaviour in climatic regions other than the test site.

Typical conditions could be periods of at least 6 h with the following conditions.

— Day with a clear sky and periods with wind speed below 1 m·s^{-1} (for solar radiation effects).

— Day with a clear sky and periods with wind speed above 5 m·s^{-1} (for solar radiation effects).

— Day with intermittent opaque cloud cover and wind speed below 2 m·s^{-1} (for analysis of solar radiation effects).

— Summer night (or night with high diurnal temperature variation) with a clear sky and wind speed below 1 m·s^{-1} (for analysis of screen thermal inertia).

— Winter night (or night with a 12 h duration or more) with a clear sky and wind speed below 1 m·s^{-1} (for analysis of IR radiation cooling).

— Night with overcast conditions and wind speed above 2 m·s^{-1} (where only small differences might be expected). These conditions can also be used to regularly verify the data from each of the sensors.

— Period with fog.

— Period with precipitation.

3.11 Documentation

A test report shall include documentation of the field test site(s). It should at least contain details of the height and position of screens, screens tested, thermometers used, additional meteorological sensors, data sampling, screens used as a reference, quality control conducted, and meteorological conditions experienced during the intercomparison.

4 Field test methods

4.1 Comparability analysis

The reference screens shall be compared to detect any differences between their measurements which could disturb the data analysis. Periods with differences between the reference screens larger than 0,2 K should be excluded from the data analysis, and periods with rapidly changing temperature more than 0,2 K per minute may be excluded. For remaining periods, the reference air temperature may be one of the reference screens or the mean value.

The analysis should also be conducted to evaluate the comparability of the measurements from other identical screens. Periods with excessive differences should be investigated to determine the causes, documented in the report and possibly excluded for further analysis.

4.2 Global analysis of air temperature

The 1 min difference values (tested screen value minus reference value) of the air temperature should be analysed. A histogram of these differences should be displayed for the whole period, to give a first indication of the observed temperature differences (see an example in Figure B.1). A more detailed statistical analysis should also be made to enable differences to be quantified.

4.3 Analysis of extreme values

Daily extreme values (minimum and maximum of the air temperature) and time of occurrence should be computed for each screen using the data from the 1 min database. The histograms of the differences of these daily extreme values and of the time of occurrence should be displayed for the whole period and a statistical analysis should be made to quantify differences between screen designs (see an example in Figure B.2). The dates of occurrence of the extreme differences should be identified and example graphs should be plotted alongside those for radiation, wind and temperature (see an example of temporal variation curves in Figure B.4).

4.4 Statistical analysis of radiation error

A statistical analysis of the temperature differences (tested screen value minus reference value) for different classes of meteorological conditions should be conducted. The range of meteorological conditions to be addressed during testing is shown as a flow chart in Figure 1. The solar radiation should be the global radiation measured by a pyranometer on a horizontal plane. This analysis should be conducted with different filters (see example in Figure B.3).

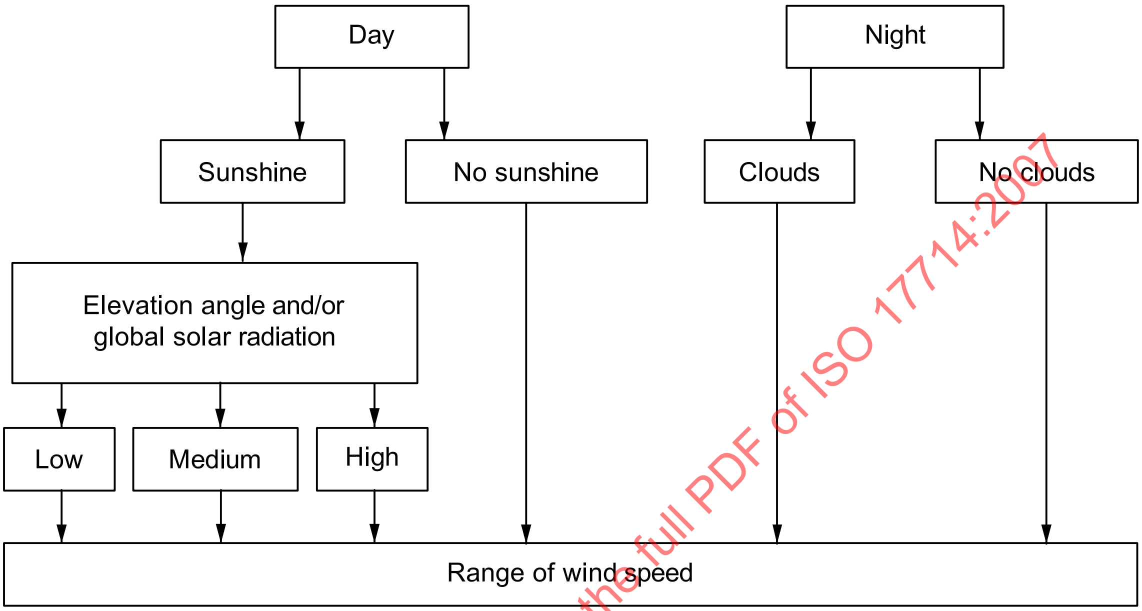

Figure 1 — Diagram for analysis of radiation error

The range of wind speeds at the screen level to be considered are typically:

— wind speed $\leqslant$ 1 m·s^{-1};

— wind speed in the [2 m·s^{-1} - 4 m·s^{-1}] interval;

— wind speed $\geqslant$ 5 m·s^{-1}.

4.5 Influence of surface albedo

An analysis with a high ground albedo value should be conducted. This analysis may be conducted if periods with snow on the ground and insolation occurrence are available. In this case, it is recommended that the differences obtained are compared with the differences in identical conditions (radiation, wind) but without snow on the ground.

An artificially high albedo may be generated by various means (see A.9). Experience shows that screen designs normally exhibiting high radiative errors also show an increase in the radiative errors when there is a high ground albedo.

4.6 Selection of typical conditions

A graphical description of the weather experienced during the intercomparison should be drawn, with temporal curves of temperature, global solar radiation, wind speed and precipitation (see an example in Figure B.4). From this description, periods with “typical conditions” (3.10) should be identified. Temperature differences (tested screen temperature minus reference temperature) should be displayed for a good selection of these “typical” periods. These curves should help to explain the screen behaviour and to understand the origin of the differences. Differences plotted against time quickly show the changes with respect to the changes in weather conditions.

5 Measurement of screen characteristics

5.1 Aspiration rate

This applies only to artificially ventilated screens. The aspiration rate should be measured by means of a small hot-wire anemometer installed in place of the thermometer. Ideally, the size of this probe should be close to the size of the thermometer. Instruments are available to fit most screen designs.

The measurement should be made for different wind speed conditions.

a) First, test for calm conditions with an external wind speed below 1 $m \cdot s^{-1}$. This test may be done in a laboratory or in a wind tunnel.

b) For evaluating the potential disturbance of the aspiration rate by the external wind speed:

   — Use a wind tunnel large enough to include the screen, to rotate it and to maintain the wind speed stable.

   — Set the wind tunnel speed to approximately 5 $m \cdot s^{-1}$.

   — Rotate the screen in the air flow to find the direction for which the maximum decrease of aspiration rate is observed. During this rotation, draw a wind rose of the internal ventilation factor with external wind direction.

   — Set the screen orientation to this worst-case direction.

   — Increase the wind speed until the air flow inside the screen is reversed or the wind speed reaches 20 m/s.

   — Record the wind speed and internal aspiration rate during the test.

5.2 Internal ventilation factor

This test applies only to naturally ventilated screens. It can be carried out in a wind tunnel or outside. If outside, the wind speed shall be measured at the representative height (2.3). Measure the internal air flow speed at the thermometer location inside the screen. A small hot-wire anemometer may be used. The size of the anemometer probe shall be small enough not to block the air flow inside the screen.

— Take 1 min mean values and use them to calculate the internal ventilation factor for several wind speeds between 1 $m \cdot s^{-1}$ and 5 $m \cdot s^{-1}$.

— Take into account the wind direction (or rotate the screen) to identify potential variations of internal ventilation factor with wind direction, and report minimum, maximum and corresponding directions.

5.3 Representative height and screen reference point

The screen reference point (2.5) and the representative height (2.3) shall be clearly documented. For some designs, the height above ground of the reference point can be different from the representative height. Report the screen reference point and representative height provided by the manufacturer, if available.

5.4 System response time

If different types of thermometers are intended to be used inside the screen, the system response time should be stated for the different possible combinations. To get information about the screen itself, the system response time should also be measured with a very small and fast response sensor.

It is very difficult to generate a stepped temperature necessary for determination of the system response time. Several laboratory tests have suggested the following to be a practical method.

a) Use a wind tunnel or an apparatus large enough to include the screen, and located in a space with a uniform temperature.

b) Isolate the screen within a box or insulating blanket and artificially heat the screen (and the air inside) with a hot air blower, or place it within a climatic chamber and let the screen temperature stabilise. In this way, the temperature of the screen should be raised by 5 K to 10 K above ambient temperature.

c) Continuously record the output of the thermometer internal to the screen at a 1 Hz rate.

d) Remove the heating device and allow the thermometer output to stabilise. If the screen was heated inside a climatic chamber, use an insulating blanket while removing the screen from the chamber.

e) Set the wind speed to 1 m·s^{-1} ± 10 % and immediately remove the isolating apparatus.

f) Continuously record the upstream air temperature, the thermometer temperature, the wind speed and time. This wind speed should be kept to 1 m·s^{-1} ± 10 %, the upstream air temperature being constant within ± 0,5 K.

g) Compute the system response time by evaluating the 63 % level of temperature decrease. One difficulty with this procedure is how to fully control the upstream temperature, the starting and final temperatures. The following method uses the shape of the temperature decrease with time, to avoid the need to accurately know the starting and final values of the temperature step (see Figure B.5).

   1) Let us call t the time and T the thermometer temperature at time t.

   2) Choose a point (t_1,T_1) close to the maximum temperature just after removing the isolating apparatus.

   3) Choose a point (t_2,T_2) close to the final temperature inside the screen, which should be close to the upstream temperature. Choose the point such that it represents approximately 80 % of the temperature change.

   4) Choose a point (t_3,T_3) such that t_3 is halfway between t_1 and t_2 ($t_3 = (t_1 + t_2)/2$).

   5) It can be easily demonstrated that if the temperature decrease with time follows a first-order function with a time constant τ, then $\tau = \dfrac{t_3 - t_1}{\ln\left(\dfrac{T_3 - T_1}{T_2 - T_3}\right)}$.

   6) τ provides an estimate of the system response time.

NOTE In reality, the system response time is unlikely to be a true first-order function since it depends on two different response times, that of the thermometer, and that of the screen. However, this method will give a useful indication of overall system response time for a screen used with the recommended thermometer.

Annex A
(informative)

Influence factors

A.1 General

Many thermometer screen intercomparisons have been conducted ([6] to [27] in the Bibliography). Influence factors for the measurement of the air temperature are quite well identified from such works and also from the theoretical physical analysis of the phenomena ([28] to [31] in the Bibliography). These influence factors are presented and discussed here.

A.2 Radiation

A.2.1 General

This is probably the cause of the greatest errors when making air temperature measurements. For this application, radiation consists mainly of solar and terrestrial radiation [primarily in the Infrared (IR) band] ([32] in the Bibliography). The influence of solar radiation is much more important than the IR radiation.

A.2.2 Solar radiation

Solar radiation received by a surface perpendicular to the sun direction can exceed 1 000 $W \cdot m^{-2}$. Such a high intensity can lead to serious heating of both the thermometer and the screen ([33] to [35] in the Bibliography).

The screen itself can be heated by the received solar radiation; this first generates a small IR imbalance and the air passing through the screen is also warmed. To limit the heating of the screen, it should be made of reflecting material or have a white surface, but this can also increase the radiation reaching the sensor. Therefore, consideration should be given during the design as to whether some parts should have a matte surface in preference to a shiny one, or whether the inside should be black to limit reflections.

If direct solar rays reach the thermometer, it will be heated and all the screens should be designed to avoid heating of the thermometer by direct reception of solar radiation. However, some radiation can reach the thermometer by reflection from the ground and from the screen itself. The magnitude of this solar radiation effect is affected by the screen design (including colour), which is usually such that several reflections are necessary before radiation can reach the sensor. The amount of screen-reflected solar radiation reaching the sensor can depend on the elevation of the sun. In general, most screen designs tend to prevent reflected radiation from reaching the sensor more effectively when the sun elevation is high, rather than at low elevation angles.

The ground albedo can range from 0,2 for grass or natural surfaces to 0,9 for a fresh snow cover. High albedo surfaces reflect a larger amount of solar radiation towards the screen, which can cause an increase of solar radiation heating. Therefore, screens need special design considerations in high albedo areas.

A.2.3 IR radiation

All objects emit and receive radiation, depending on the temperature (and emissivity, of which the value usually ranges between 0,90 and 0,95 for natural objects). The screen and the thermometer emit IR radiation as a function of their temperatures, and receive IR radiation from the external environment. If this environment is at a lower (higher) temperature, the screen and/or the thermometer receives less (more) IR radiation than it emits and therefore is cooled (warmed). A difference of 1 K in temperature generates an IR radiative imbalance of about 5 $W \cdot m^{-2}$ and this mainly occurs with radiation emitted by the ground or sky. The IR radiation emitted by the sky mainly depends on the cloud cover. With a clear sky, the equivalent radiative temperature of the sky is approximately –30 °C or lower.

This radiation imbalance also occurs within the screen itself. If the design of the screen is such that the sensor is well protected against radiation, the effect of IR radiation from the external environment on the sensor is greatly reduced. In this case, the sensor mainly receives IR radiation from the screen, the temperature of which should be close to the air temperature (in any case, much closer to the air temperature than the radiative temperature of sky or ground). Thus, with a good design, the direct influence of IR radiation on the thermometer is small. The main effect of an IR radiation imbalance is the cooling of the screen itself, leading to the cooling of the air passing through it. This effect is dependent on ventilation or wind speed.

A.3 Wind and ventilation

Wind or artificial ventilation has a beneficial influence on the screen performance and, in the absence of ventilation, the radiation effects can be dramatic ([35] in the Bibliography). Well-designed artificially ventilated screens can greatly reduce the problems generated by radiation. For such screens, the forced aspiration usually has a velocity between approximately 2,5 $m \cdot s^{-1}$ and 10 $m \cdot s^{-1}$. Care should be taken to avoid drawing warm air from the screen exhaust into the screen intake. Aerodynamic effects can overcome the differential pressure of the fan. In this case, the effective aspiration can be greatly reduced or even reversed as wind speed increases and the temperature measurement can be influenced by the temperature of the screen or the heat of the motor.

Naturally ventilated screens require no electric power and are more commonly used than forced aspiration screens. Ventilation is made only by the natural wind and past intercomparisons have shown that, for many designs, natural ventilation becomes effective as soon as the wind speed is greater than 1 $m \cdot s^{-1}$. For a high wind speed (usually above 5 $m \cdot s^{-1}$), the measurement becomes more representative of the true air temperature.

In typical naturally ventilated screens, the internal ventilation factor can range between 0,1 and 0,5.

Wind speed also has an effect on the system response time of the measurement.

A.4 Water

The screen protects the temperature sensor against precipitation and the screen material should be non-hygroscopic. Some events, such as fog, dew deposition or other precipitation, can deposit water/ice on the screen and psychrometric cooling can occur. This psychrometric effect is dependent on the wind speed, especially low wind speed, and also on the ambient relative humidity.

Psychrometric cooling can be amplified with artificially ventilated screens. In special circumstances, amplified psychrometric cooling of up to 2 K, lasting for 3 h, has been seen in past intercomparisons.

Another effect is that the temperature of the precipitation is generally lower than the temperature of the air, especially for snow events during spring. This can suddenly cool the screen at a different rate than the air (up to 5 K in 5 min).

A.5 Height of measurement

WMO [3] recommends a measurement height between 1,25 m and 2 m. Differences of up to 0,5 K may occur between these 2 heights, because the temperature gradient usually decreases with height.

A.6 Screen design

Early screens were designed to allow a visual access to the sensors. These designs usually include a door, facing north (in the northern hemisphere). A well-known design is the Stevenson screen, with double-louvred walls, having a large internal volume which allows the use of several sensors and chart recorders for temperature, humidity, evaporation, etc. The more recent screen designs are usually smaller and are used with electronic sensors, and a direct visual access may no longer be possible. Some screens house an additional thermometer which is maintained as a wet bulb to enable humidity measurements to be made. In this case, the screen needs to provide easy access to allow the wet bulb to be properly maintained.

The internal air flow, and therefore the effective sensor ventilation, is very design dependent. The sensor position inside the screen should be clearly defined. A central position is normal. Differences of about 0,5 K have been seen between two measurements (one central, one close to the wall) in a Stevenson screen.

Snow can block the screen and greatly reduce the internal ventilation, and some designs are not suitable for very snowy regions.

A.7 Aging of the screen

The surface characteristics, externally and internally, of a screen can change with time, due to UV radiation or pollution deposition. This has been seen for several designs for which the initial shiny white coating became matt. A difference of about 0,3 K has been observed during high-radiation events in an intercomparison of newer and older screens, the shinier screen being warmer.

A.8 Siting

The importance of siting is described by WMO No. 8 [3].

“In order to achieve representative results when comparing thermometer readings at different place and at different times, a standardised exposure of the screen and, hence, of the thermometer itself is also indispensable. For general meteorological work, the observed temperature should be representative of the free air conditions surrounding the station over as large an area as possible, at a height of between 1,25 m and 2 m above ground level. The height above ground level is specified because large vertical temperature gradients may exist in the lowest layers of the atmosphere. The best site for the measurements is, therefore, over level ground, freely exposed to sunshine and wind and not shielded by, or close to, trees, buildings and other obstructions. A site on a steep slope or in a hollow is subject to exceptional conditions and should be avoided. In towns and cities, local peculiarities are expected to be more marked than in rural districts. Observations of temperature on the top of buildings are of doubtful significance and use because of the variable vertical temperature gradient and the effect of the building itself on the temperature distribution”.

The distance to heat sources, such as concrete surfaces, can influence the air temperature and the relative measurements with screens located at different distances to these heat sources ([36] in the Bibliography).

Care should be taken to ensure that differences between measurements from screens are due to their design, and are not a function of their siting. Where there is any doubt, consideration should be given to carrying out additional trials with the positions of screens interchanged, so that effects of siting can be determined.

A.9 Ground albedo

High ground albedo can increase radiation heating of the screen or thermometer inside the screen. When conditions of high albedo are not available during a test (lack of snow for example), an artificially high albedo may be generated with a diffuse white painted surface set on the ground under the screen. Such a surface can be made of an assembly of painted wooden boards, arranged to form a disk of 2 m radius, set towards the direction of the sun to allow for reflection of solar rays with low elevation angles. It is recommended that such an artificial reflective surface be placed under the tested screen, and the temperature differences are compared with the temperature differences obtained from a screen of the same type above the natural ground. This test should be conducted during at least one day with realistic solar elevation, so that the test is representative of solar elevation conditions occurring during periods with snow cover (the screen should also be tilted to simulate different elevations). When this test is done, possible interaction with other screens should be taken in account to avoid corrupting the data base.

Annex B
(informative)

Examples of useful test-report graphs

B.1 Example of global analysis of air temperature

The horizontal axis shows the difference in kelvins, by steps of 0,1 K, between a given screen and a 'reference'. The vertical axis indicates the frequency in percent (%) for the different values of the differences.

In this graph, differences between the daily maximum temperature recorded in one screen and the daily maximum temperature recorded in another screen are plotted. These differences have been calculated for a 1 year period. The histogram of the differences, sorted by 0,1 K intervals, is plotted.

The mean value, median and standard deviation of differences are indicated in the bottom line of Figure B.1.

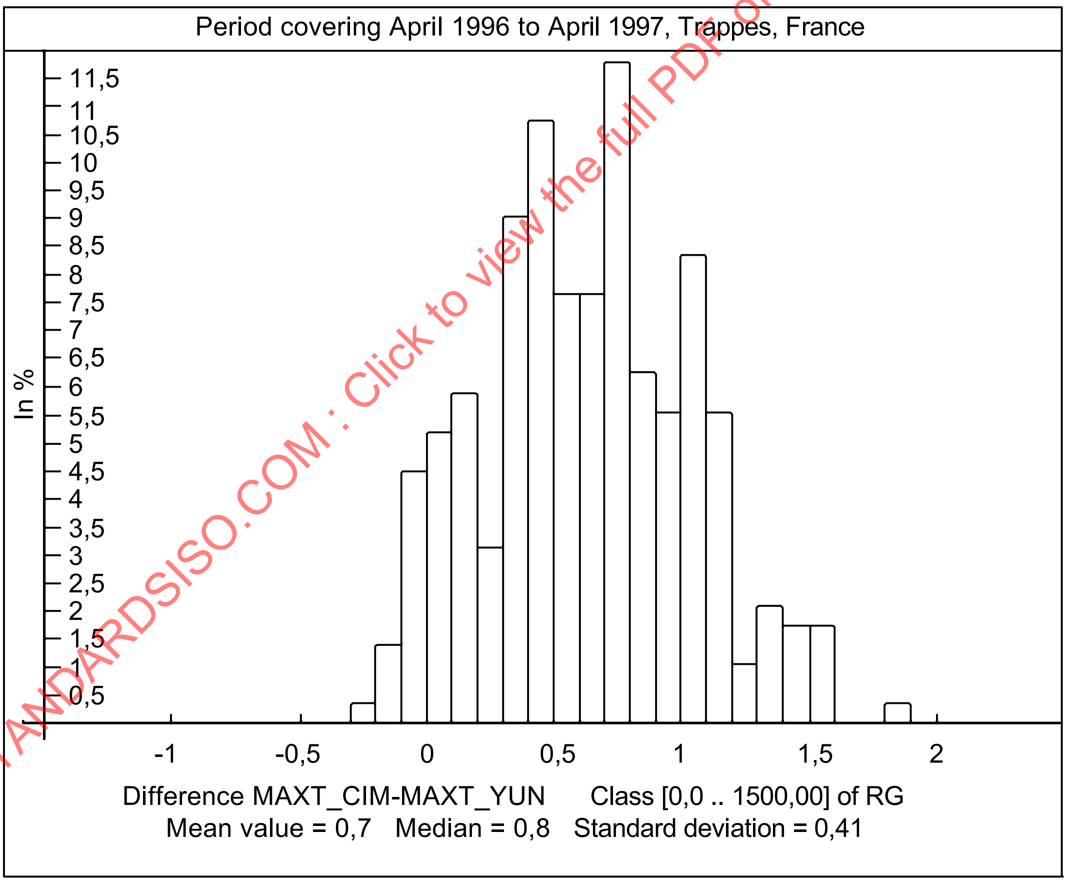

Figure B.1 — Histogram of differences of daily maximum temperatures between a given screen and a 'reference'

B.2 Example of analysis of extreme values

The horizontal axis shows the difference in kelvins, by steps of 0,1 K, between the two screens. The vertical axis indicates the cumulative frequency of cases when the differences have been below the X value.

Three curves are presented in Figure B.2: one for the differences of daily minimum temperature, one for the differences of 'instantaneous' (1 min) temperature, and one for the differences of daily maximum temperature. For a given X-axis value (given temperature difference between 2 screens), the value on the Y axis gives the frequency of cases when the differences have been below the given difference. The complement to 100 % gives the frequency of cases when the differences are above the given difference. Such a diagram is a very effective means to document the behaviour of a screen (compared to the chosen reference) over a long period.

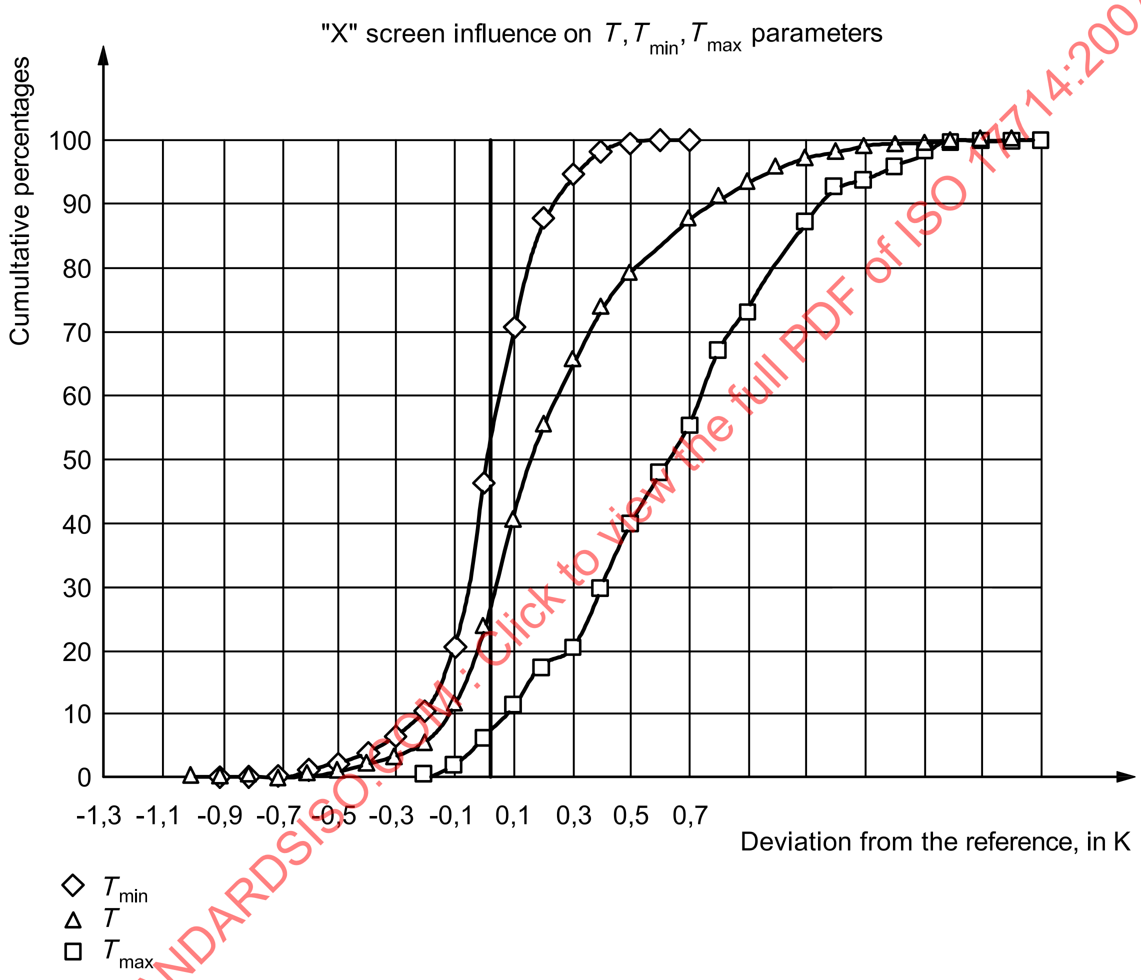

Figure B.2 — Cumulated distribution curves of differences between 2 screens

It can be seen on this graph that 50 % of the daily maximum temperatures of the screen X are 0,6 K (or °C) warmer than the daily maximum temperature of the reference screen: intersection of the 50 % cumulative value horizontal line with the T_{max} curve.

