WORLD METEOROLOGICAL ORGANIZATION

INSTRUMENTS AND OBSERVING METHODS
REPORT No. 106

WMO FIELD INTERCOMPARISON OF THERMOMETER SCREENS/SHIELDS AND HUMIDITY MEASURING INSTRUMENTS

Ghardaïa, Algeria, November 2008 – October 2009

M. Lacombe (France)
D. Bousri (Algeria)
M. Leroy (France)
M. Mezred (Algeria)

WMO/TD-No. 1579
2011

Chairperson, Publications Board
World Meteorological Organization (WMO)
7 bis, avenue de la Paix
P.O. Box 2300
CH-1211 Geneva 2, Switzerland

Tel.: +41 (0) 22 730 84 03
Fax: +41 (0) 22 730 80 40
E-mail: Publications@wmo.int

FOREWORD

The WMO Combined Intercomparison of Temperature Screens/Shields in Conjunction with Humidity Measuring Instruments was carried out in Ghardaïa, Algeria from November 2008 to October 2009, at the kind invitation of the Algerian Meteorological Service and under the leadership of CIMO. This intercomparison allowed testing the performance of the instruments in desert conditions, in a dry, hot and dusty environment. It was planned to carry out a follow-up intercomparison of similar instruments in an arctic environment at a later stage.

The main objectives of this intercomparison were to gain knowledge on the performance characteristics and operational factors of radiation screens/shields and humidity sensors. This included especially the reliability, accuracy and long-term stability of tested humidity sensors and the estimation of impact of radiation, wind speed, precipitation on humidity measurements inside the different screens/shields. An International Organizing Committee was set up to determine and agree on the rules of the intercomparison and to support its preparation and execution. The IOC was also tasked to agree on the procedures used for the evaluation of the results and to review and agree on their presentation in the final report of the intercomparison.

This report presents in a detailed manner the procedures followed for the data acquisition and the analysis and a comparison of the performance of the instruments relative to the reference. It also contains datasheets for each of the participating instruments, which provide exhaustive information on their performances throughout the intercomparison period, and as a function of different parameters. A number of recommendations were drawn from the results and are directed to users (such as the type of shields to be preferred in desert conditions), to manufacturers, as well as to CIMO for its future activities and conduction of the follow-up intercomparison in arctic environment.

I wish to express my since appreciation, and that of CIMO, to the Algerian Meteorological Service, for hosting this intercomparison, providing suitable facilities and for the support provided by its staff members, in particular to Mrs Djazia Bousri and Mr Mohamed Mezred. I should also like to mention and acknowledge the significant work done by MeteoFrance in analysing the results of the intercomparison, in particular to Mrs Muriel Lacombe and Mr Michel Leroy. Finally, I would like to thank the members of the IOC, who provided regular advice and feed-back on the conduction of the intercomparison and its evaluation.

I am confident that WMO Members and other network managers, as well as data users and manufacturers of such instruments will find this report very useful. It will provide a better understanding of their characteristics and potential use and will contribute to improving temperature and humidity measurements in desert conditions that are of crucial importance among other for climate change monitoring.

B. Calpini

(Prof. B. Calpini)

President
Commission for Instruments and
Methods of Observation

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EXECUTIVE SUMMARY

CONDITIONS OF THE COMBINED INTERCOMPARISON

The WMO Field intercomparison of thermometer screens and humidity measuring instruments was held from the 1st of November 2008 to the 31st of October 2009, at the meteorological station of Ghardaïa, Algeria.

The need of a combined intercomparison of thermometer screens/shields and humidity measuring instruments in hot desert conditions was identified in 2003. The site of Ghardaïa, Algeria, was proposed by the Algerian National Weather Service (ONM) and accepted by the ET & IOC in 2006.

This intercomparison hosted:

- 18 different types of screens/shields both ventilated (7) and non-ventilated (11), most of them installed in pairs (the total number being 29);
- 2 wind sensors from the manufacturer Thies (Germany) for evaluating ultrasonic temperature measurement (proposed by DWD);
- 8 different types of humidity sensors, most of them installed in pairs (the total number being 17)

Météo-France supplied calibrated Pt100 probes for most of the screens. All humidity sensors were delivered to Trappes for calibration in agreement with the manufacturers. An on-site calibration was also performed for a subset of the hygrometers.

The ONM prepared the experimental field and installed 36 platforms for the selected screens/shields and the ancillary sensors (radiation sensors, 2-meter wind, ground temperature…).

All data were filtered with quality control procedures. Over the 12 months period of the intercomparison, more than 500 000 minutes of data are available for the majority of the screens and hygrometers, allowing a deep data analysis.

Generally the intercomparison was successful. It experienced problems in its schedule, due to customs constraints and electrical grounding problems at the beginning.

SCREENS/SHIELDS INTERCOMPARISON

All screens were compared to a temperature probe installed in an Eigenbrodt screen (Germany). This probe appeared to be the most convenient after an analysis was done to determine the working reference. But it was warmer than some other screens during periods with high solar radiation and low wind speed. This shows that this screen, though selected as the working reference, also suffered from some radiation error.

The group of four large Stevenson type screens provided very good results though most of them reacted slower than the working reference.

Some small passive multi-plate screens exhibited warmer temperatures than the reference (~0.5°C). Two had results close to the reference. Only one model gave surprisingly good results, with colder measurements than the reference in case of high solar radiation.

Artificially ventilated screens gave disappointing results, with quite warm temperatures in case of high solar radiation. This may be due to their design and/or some faults in the ventilation during the test (dust and sand reducing the ventilation efficiency).

The air temperature calculated from the Thies ultrasonic anemometers was much colder than all other screens, the absolute difference increasing with solar radiation and decreasing with the wind speed. This indicates that this instrument could be less influenced by radiation than the screens, and thus could be a good candidate for use as a reference. However, a systematic difference between the two sensors, including some scattering, shows either a calibration problem or a principle limitation of the system for measuring air temperature.

Extra analysis gave results during a sand blowing event.

Results are available for an artificially-ventilated screen whose ventilation did not work.

HUMIDITY MEASURING INSTRUMENTS INTERCOMPARISON

Two references were needed for the analysis of humidity measuring sensors. The dew-point hygrometer Thygan was chosen to be the reference initially. After a failure of the transmission module of the Thygan sensors in May 2009, another working reference was chosen: the average of two Vaisala HMP45D installed in the same Eigenbrodt screen. The whole study was conducted with respect to both references.

Though significant differences of temperature were seen between screens, no clear influence on the relative humidity values was detected.

Five models gave very good results over the test period, with no drift (< 0.5%) and more than 98% of the data within ± 3% of the reference. These results are much better than what could be expected from the current knowledge about the state of the art. In addition to the “quality” of the sensors, an explanation may be the mainly dry conditions experienced during the intercomparison. Only few events close to saturation were encountered.

Two models gave medium results.

RECOMMENDATIONS

In desert conditions, non-aspirated, naturally ventilated radiation shields or weather screens may perform better. Aspirated screens using fans tend to be blocked in dusty or sandy environments and may need more frequent maintenance. Manufacturers of artificially ventilated radiation shields are recommended to provide a clear indication of the fan status directly at the screen or its control unit, or the datalogger.

It is recommended that further investigation be conducted on the potential of using ultrasonic devices such as sonic anemometers, as temperature reference systems for screen intercomparisons.

CIMO and manufacturers should aim for a standard laboratory test method to determine the radiation error of weather screens and radiation shields. The proposal is to evaluate the radiation error for a maximum global radiation of 1000W/m^2 and a wind speed of 1m/s.

Field intercomparisons of humidity sensors should be performed by using one type of screen for all sensors. They should use a condensation hygrometer as reference system that measures the dew point (or frost point) directly.

Manufacturers of humidity probes should provide a clearly represented quick installation guide (or card) to assist the user in the first phase of operation.

It should be planned to have at least two meetings for each intercomparison: one meeting before the start and one after the end for finalizing the intercomparison report.

Some of the well-performing screens in this intercomparison should also be used in a follow up intercomparison in arctic regions to have a link between both experiments.

In the CIMO guide, a clear distinction should be made between percentages of relative humidity and percentages as an expression for any other quotient.

ACKNOWLEDGEMENTS

Thanks to all our colleagues of the International Organizing Committee that took part in this intercomparison: Dr Eckhard Lanzinger, Ms Rodica Nitu, Dr Bruce Baker. Their contribution and their expertise during the writing of the final report were precious.

Thanks to all people in Météo-France that were involved in this intercomparison, from calibration of instruments to transportation and customs affairs services.

Thanks to Dr Jérôme Duvernoy, Météo-France, who performed an on-site visit and calibration in Ghardaïa in June 2008 and helped for the beginning of the intercomparison.

Thanks to all people at the ONM in Algiers that were involved in this intercomparison.

Thanks to all the staff of the CNIM that were involved in this intercomparison, for installation, maintenance and customs affairs.

Thanks are extended to the technicians and the observers in Ghardaïa and DRMSE for their precious collaboration.

Thanks to the local authorities of Ghardaïa.

Thanks to the support of CIMO, especially Dr Isabelle Rüedi for organizing all the teleconferences, her predecessor Dr Miroslav Ondráš and Dr Igor Zahumenský for managing the meeting in Ghardaïa, in March 2007.

The authors

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1 INTRODUCTION

1.1 BACKGROUND

Several intercomparisons of radiation screens/shields with respect to temperature measurements were organized by National Meteorological Services in temperate climatic regions (see for example [10]). Except an EUMETNET test program in icing conditions (EUMETNET SWS II project [7]), no such intercomparison was held in artic and tropical regions. Knowledge of the characteristics of temperature measurements in these regions is particularly important for climatological studies and climate change. As a result of an increasing implementation of automatic weather stations many new screen designs are introduced in the networks.

The effect of screen design was in particular evaluated in WMO IOM report No. 66 [9]. Methods for comparing the performance of thermometer shields/screens are defined in an ISO standard (ISO 17714). [4]

Since the last humidity sensor intercomparison was held by WMO in the period 1985-1989, there was a need to update the knowledge about sensors that are available on the market and are widely used.

This intercomparison was organized by WMO under the auspices of the Commission for Instruments and Methods of Observation (CIMO). An International Organizing Committee (IOC) was setup to overview the conduction of the intercomparison. The measurement period lasted from 1 November 2008 to 30 August 2010.

1.2 OBJECTIVES

Defined during the first meeting of the International Organizing Committee (IOC) on Surface Based Intercomparisons held in Trappes in 2003 [1], the main objectives of this intercomparison were agreed on as follows:

a) To update the knowledge on performance characteristics and operational factors of radiation screens/shields tested in the intercomparison;

b) To update the knowledge on performance characteristics and operational factors of humidity sensors tested in the intercomparison;

c) To analyse performance characteristics (especially reliability, accuracy and long-term stability) of tested humidity sensors;

d) To estimate an impact of radiation, wind speed, precipitation on humidity measurements inside the different screens/shields;

e) To improve the accuracy of the humidity measurements using the tested radiation screens/shields;

f) To make available the summary of initial results of the intercomparison within three months after the end of the testing period and to publish the Final Report of the intercomparison within the WMO IOM Report Series within twelve months after the testing is finished;

g) To draft recommendations for consideration by CIMO.

1.3 SITE SELECTION

The first joint of the CIMO Expert Team on Surface-based Instrument Intercomparisons and Calibration Methods (ET) and IOC meeting in Trappes (2003) defined and agreed on the organization of the combined intercomparison of thermometer screens/shields, in conjunction with humidity measurements, in various climatic regions. But it was difficult was to find a WMO Member ready to organize such an intercomparison.

Several Regional Instrumentation Centres (RIC) exist and have been set up for various tasks, including international instrument comparisons and evaluations.

Algiers (Algeria) is one of these centres and was willing to develop its activities. In the framework of a bilateral cooperation (France-Algeria), M. Leroy went to Algeria in September 2005, to check with the Algerian Meteorological Service (Office National de Météorologie, ONM), the possibility to host an international intercomparison of thermometer screens/shields including humidity measurements. The organization of such an intercomparison was thought to be an opportunity both to develop the expertise of the RIC of Algiers and to fulfil the objective of the intercomparison. The proposed assistance of another experienced RIC (e.g. Trappes) was seen to be a great advantage, to organize technically the Intercomparison and/or to calibrate the sensors.

Several potential sites were visited in South Algeria : Ghardaïa, El Goléa, Ouargla and Hassi Messaoud. Though not having the most extreme conditions, the site of Ghardaïa appeared to be the most convenient place to organize an intercomparison:

- a large protected test field,
- 2 kilometres from the airport,
- a new observing station and building,
- a local team with a visible motivation for such an operation.

The other sites were directly located on airports and had constraints due to local military activities on the airport.

The climatology of Ghardaïa indicates maximum temperature up to 46℃ in July, relative humidity ranging from less than 10% to 100% during the year.

During the second meeting of the ET & IOC in Geneva in December 2005 [2], these sites were described. The ET & IOC recognized the interest of a test site in Algeria.

WMO wrote a letter to the permanent representative of Algeria to ask for the possibility of hosting an intercomparison. Algeria answered positively. Therefore, the site of Ghardaïa was selected at the beginning of 2006.

2 INSTRUMENTS

2.1 SELECTION PROCEDURE

The ET/IOC agreed on the procedures for the selection of the participating instruments. It prepared two questionnaires (see Annex 9.1 and 9.2) to assist in the selection procedure. The first one aimed at receiving proposals on potential participants from WMO Members. The second one seeking more detailed information on selected instruments.

Thirty-six responses were received from 19 different countries. Preferences were given to:

- Original physical principles
- Sensors currently used by NWS in hot desert conditions
- Automatic sensors, not manual
- Sensors used in a large number of sites
- Two instruments should be provided

Due to custom problems concerning temporary export to Algeria, the selection was modified in order to have the largest possible number of sensors evaluated during this intercomparison.

Eighteen candidate screens and/or hygrometers were selected during the meeting of the 4^{th} session of the ET/IOC [3].

Screens from manufacturer Metspec could not be delivered in time to Algiers. As ventilated Davis screens had been delivered at the beginning of the test of the acquisition system, it was decided to include them in the participating instruments list, instead of the Metspec screens.

A humidity probe (HMP45DB from Vaisala) was delivered by the Bureau of Meteorology with their screen. As it was possible to log data from the sensor on the data acquisition system, it was decided to include it in the list of participating RH sensors.

The final selection of instruments that participated in this intercomparison included:

- 16 different types of screens/shields both ventilated (7) and non-ventilated (9), most of them installed in pairs (the total number being 29)
- 2 extra wind sensors from manufacturer Thies (Germany) to evaluate ultrasonic temperature measurement, proposed by DWD (see [11]). This would allow to measure the acoustic virtual temperature (no influence from solar radiation) from the sensor. This would also allow the calculation of the air temperature, with additional relative humidity and pressure information
- 8 different types of humidity sensors most of them installed in pairs (the total number being 17)

The list of instruments is available in table 1 and table 2 and in annex 9.3 for a more complete version.

Table 1. List of participating screens/shields

Member country	Manufacturer	Type	Number	Acronym
Algeria	Socrima	Large Stevenson Screen	1	LSOC
Australia	BoM	Small Stevenson screen	1	LBOM
Austria	Lanser		2	LLAN
France	Socrima	BMO1195D	2	SSOC
Germany	Fischer	431411	2	VFIS

Member country	Manufacturer	Type	Number	Acronym
Germany	Vaisala	DTR13 (HMT 330 MIK)	2	SVAI
Germany	Eigenbrodt	LAM630	2	VEIG
Italy	CAE	TU20AS	2	SCAE
Sudan	Casella	Stevenson Screen	1	LCAS
Switzerland	Meteolabor	Thygan VTP37 Airport Thygan VTP37 Thermohygrometer	1 1	VTHY
Switzerland	Rotronic	AG/RS12T	2	VROT
UK/HMEI	Windspeed	T351-PX-D/3	2	SWIN
USA	Davis	PN7714	2	SDAV
USA	Davis	07755	2	VDAV
USA/HMEI	Young	41003	2	SYOU
USA/HMEI	Young	43502	2	VYOU

Table 2. List of participating RH sensors

Member country	Manufacturer	Type in type of screen	Number	Acronym
Australia	BoM	HMP45D in BoM screen (LBOM)	1	LBOM
Germany	Fischer	431411in Fischer screen (VFIS)	2	VFIS
Germany	Vaisala	HMT337	2	SVAI
Germany	Vaisala	HMP45D in Eigenbrodt screen (VEIG)	4	UHMP
Germany	Testo	AG/63379742 in small Socrima screen (SSOC)	2	UTES
Italy	CAE	TU20AS	2	SCAE
Switzerland	Meteolabor	Thygan VTP37 Airport Thygan VTP37 Thermohygrometer	1 1	VTHY
Switzerland	Rotronic	Hygroclip S3 in Rotronic screen (VROT)	2	VROT

The combined instruments or set of instruments, measuring both the air temperature and the relative humidity, are named with the same acronym in these tables and the various graphs in this report. In the data base, the names of the parameters are suffixed by _T for air temperature and _RH for relative humidity, so they are different. In this report, only the prefix, such as SVAI, was used to shorten the text. As each graph in this report deals with either Air Temperature or RH, there is no real ambiguity with the use of the “common” prefix or acronym. For example, the Vaisala set of instruments (HMT337 + DTR13) is labelled by SVAI. The air temperature analysis deals with temperature SVAI_T, measured in the DTR13 screen. The RH analysis deals with relative humidity, SVAI_RH, measured and calculated from the HMT337 dew point sensor and the DTR13 screen.

2.2 PHYSICAL PRINCIPLES

It is well known that temperature and humidity measurements are influenced by a number of environmental parameters, such as:

1. direct and indirect short-wave radiation
2. direct and indirect infrared radiation
3. insufficient natural or artificial ventilation of the air inside the screen
4. psychrometric cooling due to wet surfaces on the screen and/or the sensor
5. the deposit of sand on the outside and inside of the screen and on the sensor especially in Saharan climate.

Humidity probes are also prone to hysteresis effects, i.e. the course of the humidity time series has influence on the humidity measurement as well.

Manufacturers design shields that are made to provide an enclosure with an internal temperature that is both uniform and the same as that of the outside air. It should completely surround the thermometers and exclude radiant heat, precipitation and other phenomena that might influence the measurement.

For these reasons, all the tested screens can be classified as follows.

2.2.1 Classification of screens

2.2.1.1 By shape

a) Louvred (caged) screens: These screens are typically Stevenson wooden screens with louvers. The following participating instruments belong to this group: LBOM BoM (Australia); LLAN Lanser (Austria); LCAS Casella (Sudan); LSOC Socrima (Algeria).

b) Round shaped multi-plate screens: These shields are composed of 7 to 12 plates stacked one on another; the plates are mostly round and some of them rectangular. The following participating instruments belong to this group: SDAV and VDAV Davis (USA); VFIS Fischer (Germany); VEIG Eigenbrodt (Germany); SVAI Vaisala (Germany); SYOU 41003 Young (USA); SSOC Socrima (France); SWIN Windspeed (UK).

c) Specific design: These shields have different designs. The following participating instruments belong to this group: VTHY Thygan (Switzerland), SCAE TU20AS (Italy); VROT Rotronic (Switzerland); VYOU 43502 Young (USA).

2.2.1.2 By size

a) Large screens: These are screens with a large internal volume. The following participating instruments belong to this group: LBOM BoM (Australia); LLAN Lanser (Austria); LCAS Casella (Sudan); LSOC Socrima (Algeria).

b) Smaller screens: These are screens with a diameter of 14 to 33cm and a height of 14 to 50cm. The following participating instruments belong to this group: SDAV & VDAV Davis (USA); VFIS Fischer (Germany); VEIG Eigenbrodt (Germany); SVAI Vaisala (Germany); SYOU 41003 Young (USA); SSOC Socrima (France); VTHY Thygan (Switzerland), SCAE TU20AS (Italy); VROT Rotronic (Switzerland); VYOU 43502 Young (USA).

c) Miniature screens: One candidate screen has a diameter of 7.5cm and a height of 15cm: SWIN Windspeed (UK)

2.2.1.3 By ventilation

a) Naturally ventilated screens: These screens are designed so that the air inside is renewed by ambient wind (natural convection). The following participating instruments belong to this group: LBOM BoM (Australia); LCAS Casella (Sudan); LSOC & SSOC Socrima (Algeria); SCAE TU20AS (Italy); SDAV 07714 Davis (USA); SVAI Vaisala (Germany); SYOU 41003 Young (USA); SWIN Windspeed (UK).

b) Artificially ventilated screens: These screens are equipped with a fan that aspirate the air into the screen (forced convection). If the ventilation is well designed, these screens give colder measurements for large irradiance. The following participating instruments belong to this group: VTHY Thygan (Switzerland), VROT Rotronic (Switzerland); VYOU 43502 Young (USA); VDAV 07755 Davis (USA); VFIS Fischer (Germany).

c) Hybrid screens: these screens have ventilation both natural and artificial. This is the case of VEIG Eigenbrodt (Germany) and LLAN Lanser (Austria).

2.2.1.4 By Material

a) Wood: The following participating instruments belong to this group: LBOM BoM (Australia); LCAS Casella (Sudan); LSOC Socrima (Algeria); LLAN Lanser (Austria).

b) Plastic: The following participating instruments belong to this group: SWIN Windspeed (UK); VEIG Eigenbrodt (Germany); SVAI Vaisala (Germany); SSOC Socrima (France); SDAV & VDAV Davis (USA); SYOU & VYOU Young (USA).

c) Metal: The following participating instruments belong to this group: VFIS Fischer (Germany); VTHY Thygan (Switzerland); SCAE TU20AS (Italy); VROT Rotronic (Switzerland).

2.2.2 Classification of hygrometers

The participating humidity sensors can be classified in two main groups:

a) Capacitive sensors: The active part of the humidity sensor consists of a polymer foil sandwiched between two electrodes to form a capacitor. The electrical impedance of this capacitor provides a measure of the relative humidity. The following participating instruments belong to this group: VFIS 431401Fischer (Germany); UTES Testo (Germany); SCAE TU 20AS (Italy); VROT Hygroclip S Rotronic (Switzerland), UHMP HMP45D (Germany), LBOM HMP45DB (Australia), SVAI HMT337 Vaisala (Germany)

b) Dew point sensors: The dewpoint hygrometer is used to measure the temperature at which moist air, when cooled, reaches saturation and a deposit of dew can be detected on a surface at constant pressure. The temperature of this surface is then by definition the dewpoint temperature from which relative humidity can be calculated for any given air temperature. Only VTHY VTP37 Thygan (Switzerland) belongs to this group.

2.3 ANCILLARY MEASUREMENTS

The field intercomparison site was equipped with additional meteorological measurements to evaluate the effects of wind and radiation on temperature and humidity measurements.

The meteorological data were provided by the following ancillary measurements (see part 4.2 for positioning of instruments).

2.3.1 Wind measurements

Wind measurements at 2-meter height were done using three 2D ultrasonic wind sensors:

- two Thies ultrasonic anemometers
- one Gill Windsonic

Figure 1. Thies ultrasonic anemometer

Figure 2. Gill ultrasonic anemometer

2.3.2 Radiation measurements

Global and infrared radiation was measured with one pyranometer (CM11 from Kipp&Zonen) and one pyrgeometer (CGR4 from Kipp&Zonen) respectively.

An albedometer (CMA11 from Kipp&Zonen) was also installed.

Figure 3. Albedometer & Pyrgeometer

Figure 4. Pyranometer

The sunshine duration was measured by an heliograph CE181 from Cimel Electronique.

Figure 5. Heliograph

2.3.3 Additional temperature measurements

Extra temperature probes were installed on the ground, at 10cm and 50 cm-height above the ground.

Figure 6. Ground, +10cm, +50cm-height temperature probes

2.3.4 Local measurements

Ghardaïa station measurements are made with a Degreane Automatic Weather Station (Xaria). The following parameters are measured: pressure, precipitation, sun duration, wind at 10-meter height, temperature and humidity (1.5-meter height). Pressure, wind and relative humidity were made available for data analysis.

Ghardaïa is also a 24h-manned station. Local observations (present weather, cloudiness) were also available for data analysis.

2.4 MAJOR PROBLEMS ENCOUNTERED

2.4.1 TU20AS CAE

This screen has a double shield to protect the sensors against the radiation. To improve the natural ventilation, the external shield is partly opened in one direction and must be oriented towards north (in northern hemisphere), to avoid any direct solar radiation on the internal shield.
Though this constraint was indicated in the documentation, the two sensors were mistakenly oriented towards south and the results obtained are not significant at all. Therefore, it was decided in agreement with the manufacturer to skip any data from these screens and the results, non significant at all of this equipment, are excluded from this report, both for temperature and relative humidity.

2.4.2 YOUNG artificially ventilated screens (43502)

The data analysis and the field controls showed that the artificial ventilation of these screens was not operative during the first 11 months of the intercomparison. The field control performed on 30th of September 2009 showed that the power supply was out of order. Therefore it was decided to use only the remaining month (October 2009) for the "normal" data analysis. The period with the non operative artificial ventilation was used to illustrate the errors occurring in such conditions.

2.4.3 Grounding problems

The organizer had some grounding problems related to the main power supply. It was one reason for the delayed beginning of the intercomparison and the first two months, some problems remained. These problems were identified in the dataset and some small periods with such problems were discarded during the QA process.

2.4.4 Acquisition system for sensors with serial outputs

The main acquisition system was suitable only for analog inputs (from the majority of instruments). Some instruments had a numerical output on a serial line, with some specific formats and protocols. For these sensors, a specific software was developed and run on a separate PC with a multiport serial card. It appeared that an internal bug lead to the irregular stopping of the software after few hours or days, needing a manual re-launching of the acquisition program. This drawback explained many missing data from the instruments with a serial output (ATHI, SVAI, VTHY).

3 INSTRUMENT CALIBRATION

Prior to the beginning of the field intercomparison almost all temperature and humidity sensors were calibrated at the metrology laboratory of the RIC in Trappes (France). Météo-France had provided calibrated Pt100 probes that are suitable with most of the selected screens/shields. The probes were calibrated in a stirred bath for the following four points: -20℃, 0℃, 20℃ and 40℃. This calibration showed that all probes were within +/- 0.05 K. Therefore, it was decided not to apply any correction to the temperature measurements from these probes. Nevertheless, when available, each datasheet includes information about the calibration of the temperature probe used in the screen.

The temperature probe delivered by Météo-France were mainly calibrated during the beginning of 2006. The instruments delivered by the participants were calibrated during the beginning of 2007, well before the official start of the intercomparison (November 2008).

The calibration results are in the annex 9.4.1. and 9.4.2.

Screens that do not suit the proposed Pt100 were shipped to Trappes, to calibrate the temperature sensor provided by the manufacturers. This was done in agreement with the manufacturer.

All humidity sensors were also delivered to Trappes for calibration. Humidity calibration was carried out in a generating bath. The calibration was made for the following five points of relative humidity: 11%, 33%, 55%, 75% and 90% at two points of temperature: 23℃ and 40℃.

The calibration results are in the annex 9.4.3 and 9.4.4.

It was decided that calibration data would be used to interpret results and not to correct the measurements.

Due to the delayed start of the intercomparison, a limited calibration has been performed on site, with a portable humidity generator (General Eastern Model C1-RH generator) and two relative reference hygrometers (Vaisala HMI31 and HMP35A). Dr J. Duvernoy, responsible of the metrology laboratory of the RIC of Trappes, brought this equipment and performed this calibration in Ghardaïa, during June 2008. Due to the limited time, only a subset of the hygrometers could be calibrated, on a limited numbers of points, corresponding to the calibration points in laboratory of the reference hygrometers.

The calibration results are in the annex 9.4.5.

It was planned to re-calibrate the temperature probes and the hygrometers in the RIC of Trappes, after the end of the intercomparison. But the very long delays due to custom problems to get back the instruments did not allow it before the compilation of the final report.

Therefore, especially for hygrometers, the period of available calibration data is well outside the common limits for hygrometers and reduces the validity of this data to understand possible drifts of the sensors.

4 METHODOLOGY AND ORGANIZATION

4.1 SITE DESCRIPTION

The city of Ghardaïa is located at 640 km southward of the capital Algiers. The location of Ghardaïa is indicated by the "A" letter on the figure 7.

Figure 7. General situation of Ghardaïa

The Intercomparison campaign was held at the meteorological station of Ghardaïa (32°24 N, 03°48 E, 468 meters above the sea level). It is located near the airport of Noumerate, 20 km to the south east of the city center.

To the North-West of the meteorological station lies the town of Ghardaïa (20km); to the East is the airport of Noumerate (1500m); to the North is an open terrain and in the South the national road No. 1. The soil texture is rocky.

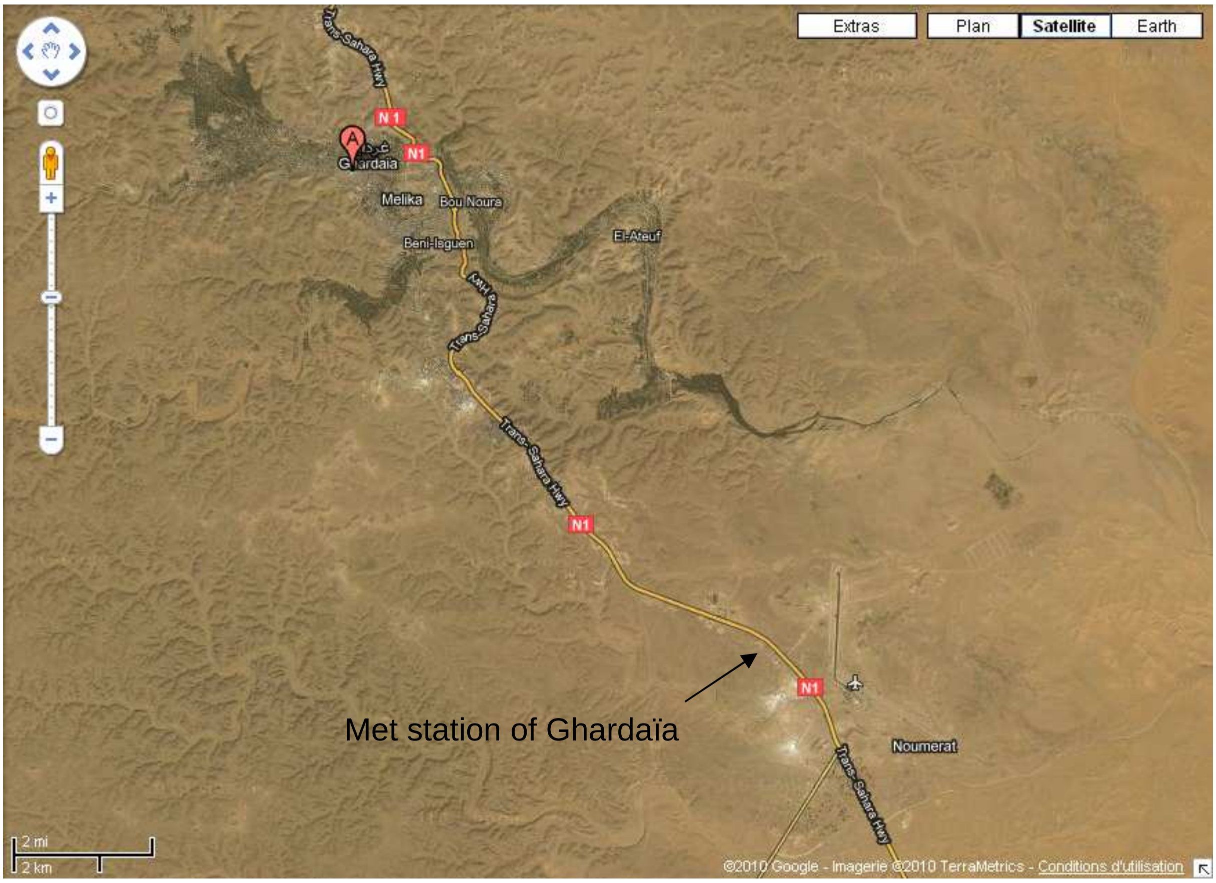


Figure 8. Satellite view of the Ghardaïa region

The climate of the city of Ghardaïa is characterized by low annual precipitation, which is extremely variable, varying from 1 mm to over 100 mm.

The annual distribution of temperature is fairly uniform. The average temperatures of summer vary from 40℃ to 45℃, and the absolute max imum temperature recorded in Ghardaïa is 47℃ in July 2005.

The maximum winds are about 15 m/s, occurring during the spring season, and their directions are predominantly from north-northeast.

In the last decade, the annual average temperatures has shown a slight increase which has a direct impact on the socio-economic life and environment of the area.

The Intercomparison site (figure 9) is a flat area of 1120m^2 and it is equipped with 36 small concrete platforms. Each platform is supplied with a power supply of 220 VDC.

Figure 9. Intercomparison field – Ghardaïa, Algeria

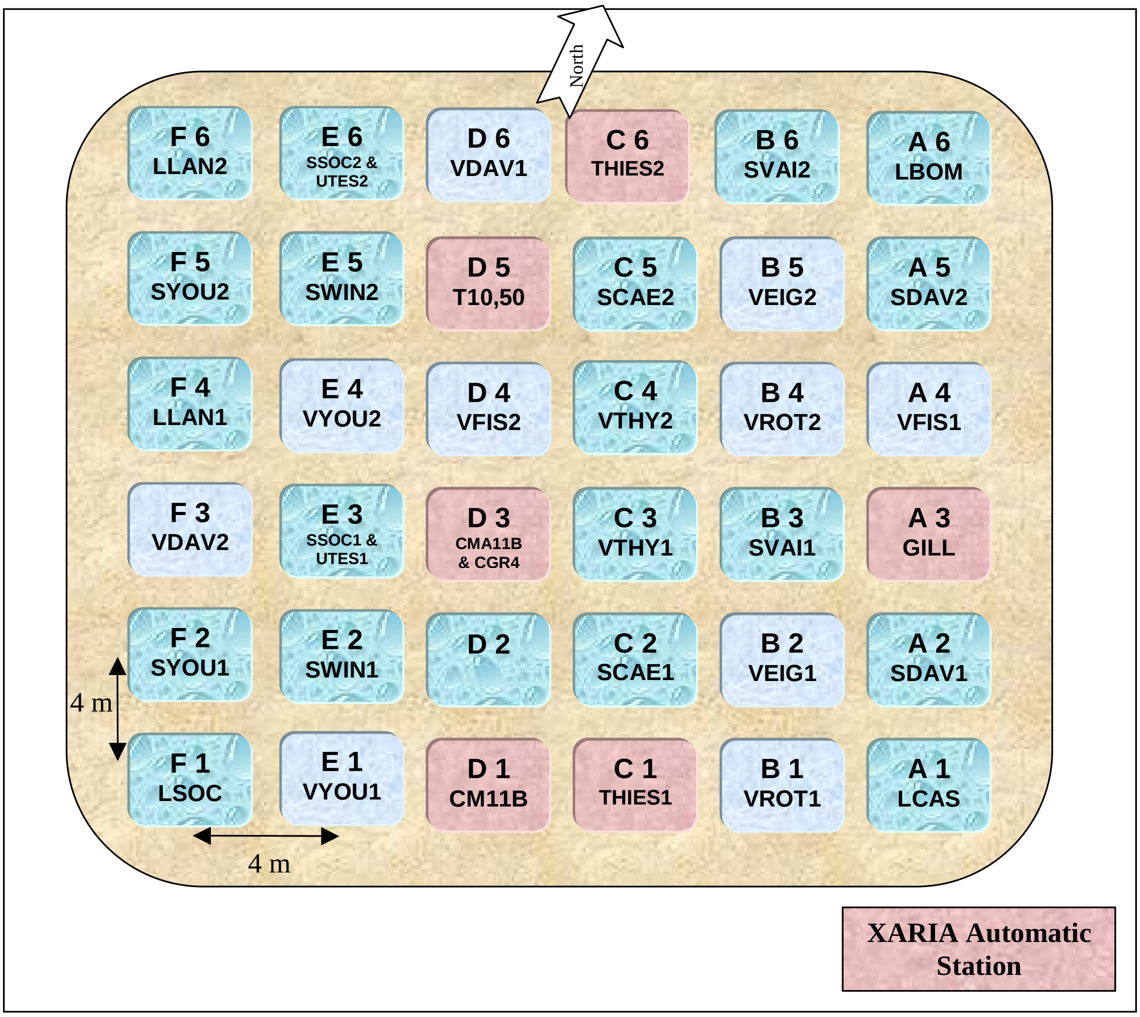
4.2 POSITIONING OF INSTRUMENTS AND INSTALLATION PROCEDURES

The intercomparison site is an area of 1120 m^2, configured over a stony and regular soil, which is a feature of the region around Ghardaïa.

The experimental area is situated at more than 30 meters from the meteorological station building, so chosen as to avoid the influence that the building could generate.

The screens and shields under test have been arranged on a rectangular grid with 4 meters between adjacent instruments, as shown on figure 10.

All screens and shields were installed so that the temperature measurement would be at 1.50-meter height above ground level, except for the two LLAN which were installed at 1.80-meter height (the screens were delivered with their stands). For all screens, the maximum tolerance was ± 5% of the height.



Screens

A1 : Casella
A2, A5 : Davis
A4, D4 : Fischer
A6: Stevenson
B1, B4: RS 12T Rotronic
B2, B5: LAM 630 Eigenbrodt
B3, B6: HMT 330 Vaisala
C2, C5: TU 20 AS CAE
C3, C4: VTP 37 Thygan
D6, F3: Davis
E1, E4: Young
E2, E5: T351 Windspeed
E3, E6: Socrima
F1: Large Socrima
F2, F5: Young
F4, F6: Lanser

Ventilated Non-Ventilated

Ancillary measurements

A3: Windsonic Gill
C1, C6: Ultrasonic Anemometer 2D
D1: Pyranometer CM11B
D3: Albedometer CMA11 B & pyrgeometer CGR4
D5 : Ground, +10 +50 cm temperatures
Xaria : (P,T,U,RR,SD)

Figure 10. Positioning of instruments

The figure 11 gives an overview of the field test before the installation of the instruments.

At each location a small cable box (figure 12) is available, with power and signal cables. Cables are connected to the row connecting box (figure 13). All cables from the test field are eventually connected to the main box (figure 14), before going to the station building. The cable box inside the building is shown on figure 15.

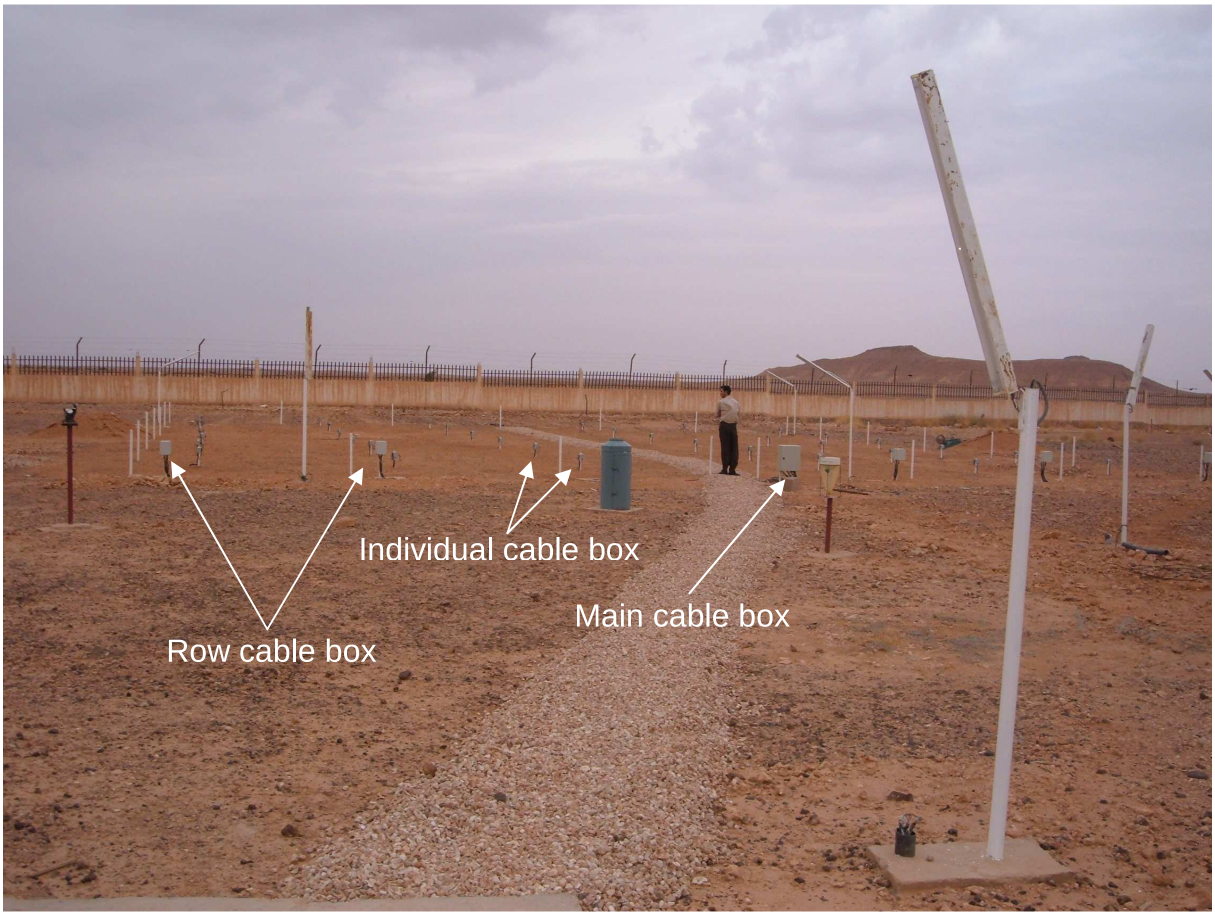


Figure 11. Overall view of the experimental field

Figure 12. Individual box

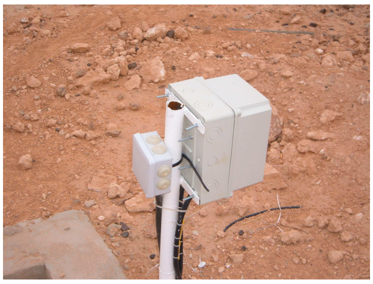


Figure 13. Row box

Figure 14. Main box

Figure 15. Main box inside the building

4.3 DATA ACQUISITION

The acquisition of data from sensors and systems under test was done using two systems: one for analogue sensors (data acquisition system) and the other for digital sensors (multi-channel cards).

4.3.1 Acquisition of analogue sensors

The acquisition of data from the analogue sensors for the intercomparison was done using a data acquisition system (DAS) manufactured by Yokogawa (Japan). In order to reduce the loss of data, an extra identical DAS has been used for the intercomparison. The main DAS did not experience any trouble during the intercomparison.

The Yokogawa DAS is a complex system that enables the acquisition of analog and digital signals. Each DAS is composed of the following modules:

- three main units, model MW100,
- five universal input modules, model MX110-UNV-M10
- seven four-wire RTD input modules MX110-4VR-M06
- one high speed digital input module model MX115-D05-H10

The system is equipped with a battery and an inverter, as back up for the main power system, to ensure its continuity in operations. To protect data acquisition against mains power failure, PCs and experimental field power are connected to a generator set. This generator switches on automatically in case of a power failure.

Each main unit comes with a Web server function, allowing users to easily enter settings and monitor measured data from a PC using a web browser. The time of the DAS is automatically synchronized with the master PC. Each DAS unit provides daily log files.

The main unit MW100 has a capacity of maximum 6 modules per unit. The measurement interval could vary from 10 ms to 60 s; up to three different intervals can be defined per unit. The unit has one slot for a Compact Flash Type II card, which could store the measurement data, the processed data, and the unit configuration.

The five universal input modules, MX110-UNV-M10 have been used for the acquisition of measurements from sensors with a DC voltage output. Each of these modules has 10 inputs. The highest resolution is 100 μV for 2V measurement range.

The seven four-wire RTD input modules MX110-4VR-M06 were used for the acquisition of data from the Pt100 temperature sensors. Each module has 6 inputs. The maximum resolution is 0.01℃.

The digital input module, model MX115-D05-H10, have 10 inputs per module. The input type is non-voltage contact of 5V level.

Figure 16. One of the two Data Acquisition Systems

4.3.2 Acquisition of digital sensors

The acquisition of data from the digital instruments was done using two multiport acquisition cards model AccelePort Xr920, manufactured by Digi International. Each of these cards has eight RS232 serial ports, with baud rates up to 921600 bps. Given the fact that the distance between sensors and the acquisition computer exceeds 15 meters, RS232/RS485 converters were used, to ensure the quality of data received.

Figure 17. AccelePort Xr920 Card

Figure 18. RS 232/RS485 Converter

A dedicated software was developed by Météo-France to acquire the data from all digital sensors.

The acquisition rate for the wind sensors (Thies and Gill) was 2 samples per second. The software processed and recorded one-minute messages with 2-minute and 10-minute averages.

The Thies temperature measurements were stored every 10 seconds and the virtual air temperature was processed later.

4.3.3 Synopsis of the system

The figure 19 represents the synopsis of data acquisition.

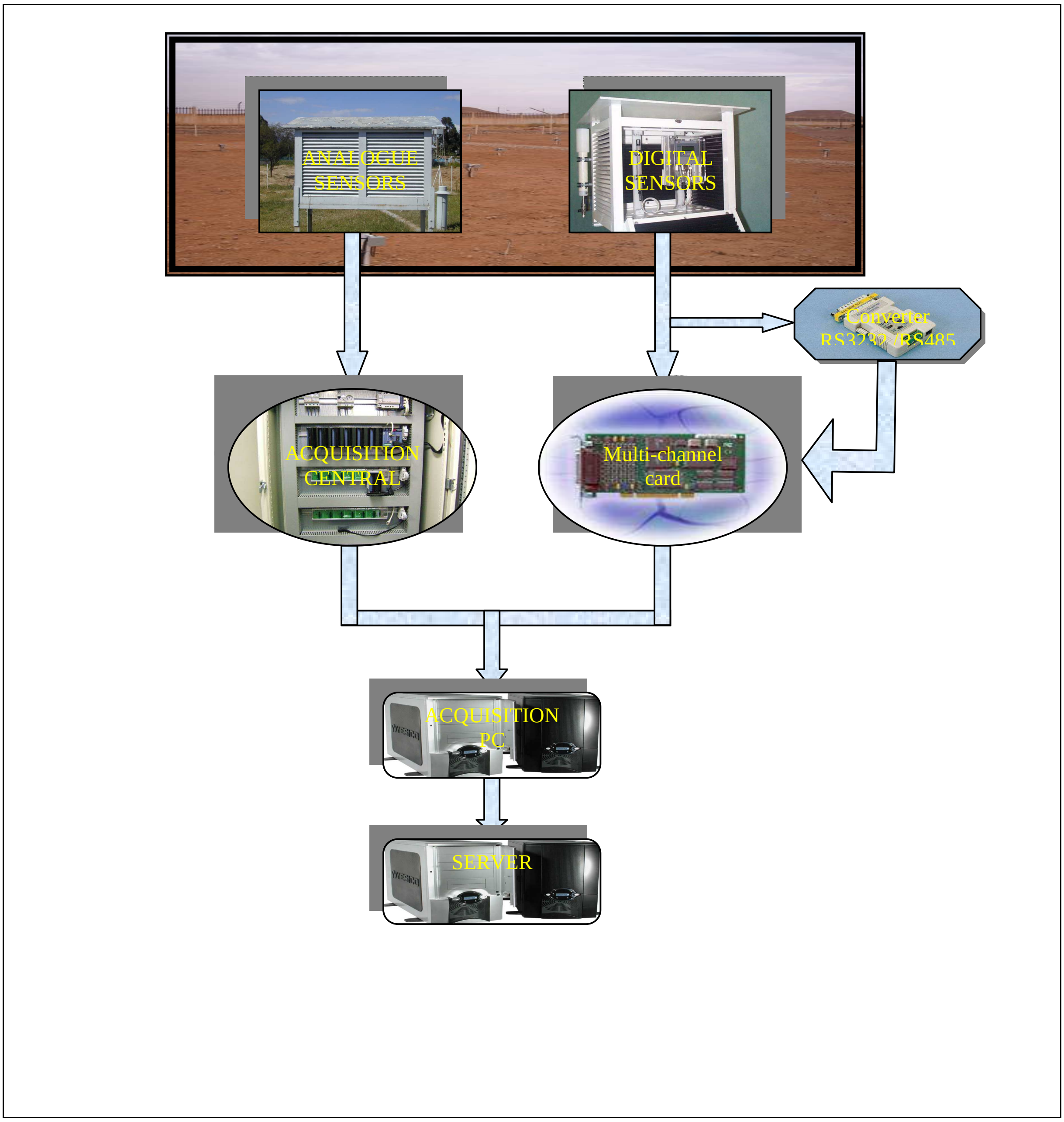


Figure 19. Synopsis of the acquisition collect

4.3.4 Acquisition during the intercomparison period – Storage procedure

Where feasible, the data sampling interval for the digital sensors and on the data acquisition unit was ten seconds (six samples per minute) .

The acquisition data system was configured to collect and store measurement data in CSV or ASCII format.

The Thygan sensors output one measurement only every ten minutes. For ancillary wind measurement, data sampling rate was two samples per second. Ten-minute and two-minute averages and wind gusts were processed and stored, every minute.

The data collected directly from the sensors has been referred to as the “raw data”. All data were entered in a local BDDGEN database. In March 2007, the ET/IOC agreed to use the specific software package “BDDGEN” to handle and analyze large volume of data. This database system was developed by Météo-France. It is based on binary files.

The raw data and the database binary files were stored on the master computer and on an external hard disk in Ghardaïa. In addition to that, the database binary files were downloaded in Trappes by modem line every month during the intercomparison period.

4.4 QUALITY ASSURANCE AND SUPERVISION OF INSTRUMENTS

The local staff performed a daily visual check using the MW100 viewer and the software developed by Météo-France.

Once per month, radiation sensors and solar panels were cleaned. Pictures of the instruments were taken.

All information on visual inspection, maintenance and repair were stored in an electronic local logbook.

4.5 DATA POLICY

The following are the guiding principles for data policy of the intercomparison that was agreed by the ET/IOC:

The WMO has the copyright on the intercomparison dataset.

The complete intercomparison dataset is kept by WMO Secretariat, the ET/IOC chair, the Project Leader. WMO may, if requested by the ET/IOC, export whole or part of the comparison dataset on to the CIMO/IMOP website, or other website controlled by the ET/IOC members, as soon as the Final Report is published. In particular, the Data Sheets prepared for each of the instrument involved can be published on the Web site as soon as the Final Report is published.

After the Intercomparison, every participant could get a copy of the comparison dataset, containing any further raw data obtained during the tests, related to its own instruments.

The WMO authorizes the Project Leader with the agreement of the ET/IOC chair, to publish full results in a Final Report of the intercomparison on behalf of the ET/IOC.

The ET/IOC members may publish their partial scientific results if demanded by the scientific community before the end of the intercomparison, provided the publication was authorized by the Project Leader and that the participating instruments remain anonymous in that publication.

The comparison dataset may be provided to other parties for the purpose of scientific studies on the subject. This requires an approval of the ET/IOC chair, and is possible only after the full results of the intercomparison have been published.

For publication and for presentation to third parties, the participants are only allowed to use data of their own instrument. In doing so, they will avoid qualitative assessment of their instruments in comparison with other participating instruments.

5 DATA ANALYSIS AND RESULTS

5.1 DATA PROCESSING AND QUALITY CONTROL

Data processing for the intercomparison is provided by both BDDGEN software (in Météo-France) and MySQL server (in Algeria).

5.1.1 Processing of the 10-second data

The ASCII files generated by the DAS and the numerical sensors acquisition software were locally processed to generate 10-second data. These database binary files were transferred from Ghardaïa to Trappes by modem line every month during the intercomparison period.

Météo-France has developed a specific software to process one-minute averages and quality control for all parameters from the 10-second data. The quality control of data was processed according the specifications of CBS-IOS ET-AWS-4 final report [6]. The main criteria of this report are recalled below.

All data were flagged using five QC categories:

- "0" - good (accurate; data with errors less than or equal to a specified value);
- "1" - inconsistent (one or more parameters are inconsistent; the relationship between different elements does not satisfy defined criteria);
- "2" - doubtful (suspect);
- "3" - erroneous (wrong; data with errors exceeding a specified value);
- "7" - missing data (for any reason).

There should be at least 66% (2/3) of the samples available to compute an instantaneous (one-minute) value. If less than 66% of the samples were available in one minute, the value was flagged as missing.

The table 3 gives the acceptable range and maximum allowed variability for instantaneous values. If a data were outside the acceptable limit, it was flagged as erroneous. The maximum allowed variability of the instantaneous values are also shown for each parameter.

Table 3. Limits for instantaneous values

		Temperature (℃)	Relative humidity (%)	Global radiation (W/m²)
Acceptable range	Minimum value	-5	0	-50
	Maximum value	50	125	1600
Maximum variability	Limit for doubtful	3	10	800
	Limit for erroneous	5	15	1000

The software also processed the temperature data from Thies sensors. Their virtual air temperature was corrected with the AWS pressure and relative humidity according to an algorithm developed by the DWD (see References section for more details).

5.1.2 MySQL database

MySQL server is a relational database management system that runs as a server providing multi-user access several databases. The server is accompanied by several related scripts that perform setup operations when you install or provide assistance to administer the server.

Single language for describing, manipulating, controlling access and query relational databases is SQL (Structured Query Language). It is a declarative language.

Data are imported into MySQL server. PHP is used to manage, visualizing data imported and to analyze the experimental data according to ISO 17714. Programs in PHP were developed on the website http://www.meteo.dz/meteo.dz/station/index_gha.php. It works with the browser Mozilla Firefox.

5.1.3 BDDGEN database

This specific software package called “BDDGEN” was developed by Météo-France to handle and analyze large volume of data.

It includes many programs, such as:

- Visualisation of time series
- Statistical processing: calculation of minima, maxima, sums…
- Statistical charts: histograms, box plots…
- Useful tools: sun height and azimuth processing, filters…

5.2 SUMMARY OF AVAILABLE DATA

The field intercomparison has been continuously managed for 12 months in all weather conditions. It was conducted from the 1st of November, 2008 to the 31st of October, 2009.

5.2.1 Screens/shields

Figure 20 gives a summary of available temperature data for the intercomparison period for the different quality levels. Numerical values are available in table 4.

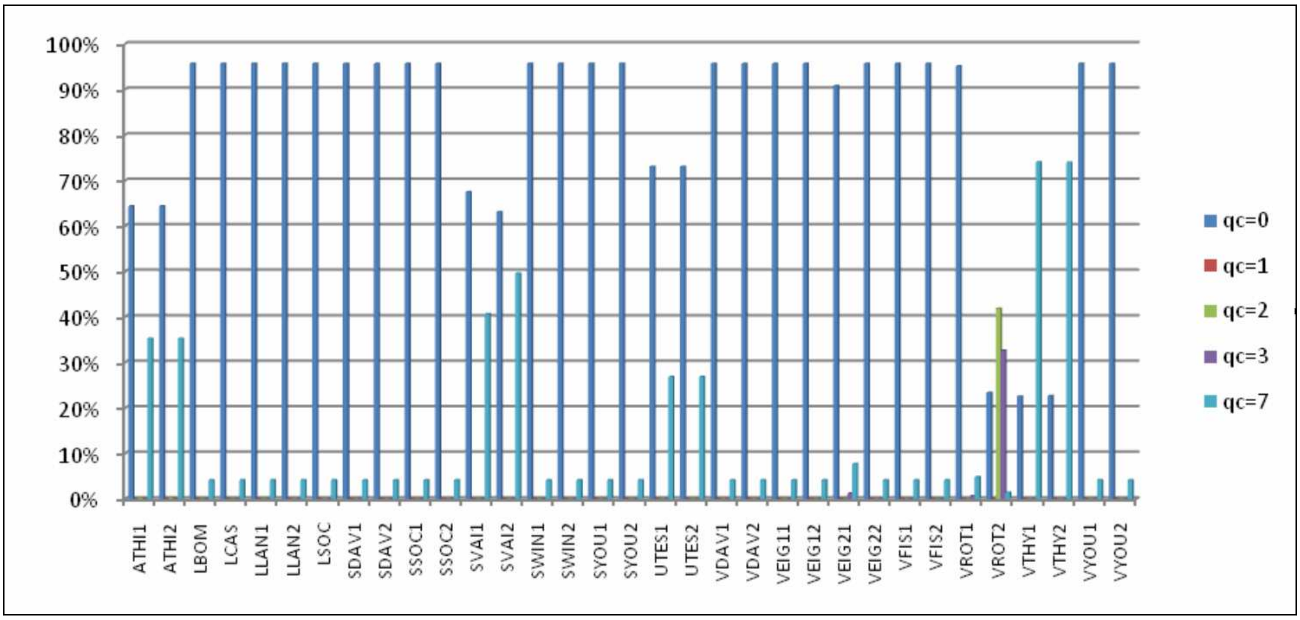


Figure 20. Temperature quality control information

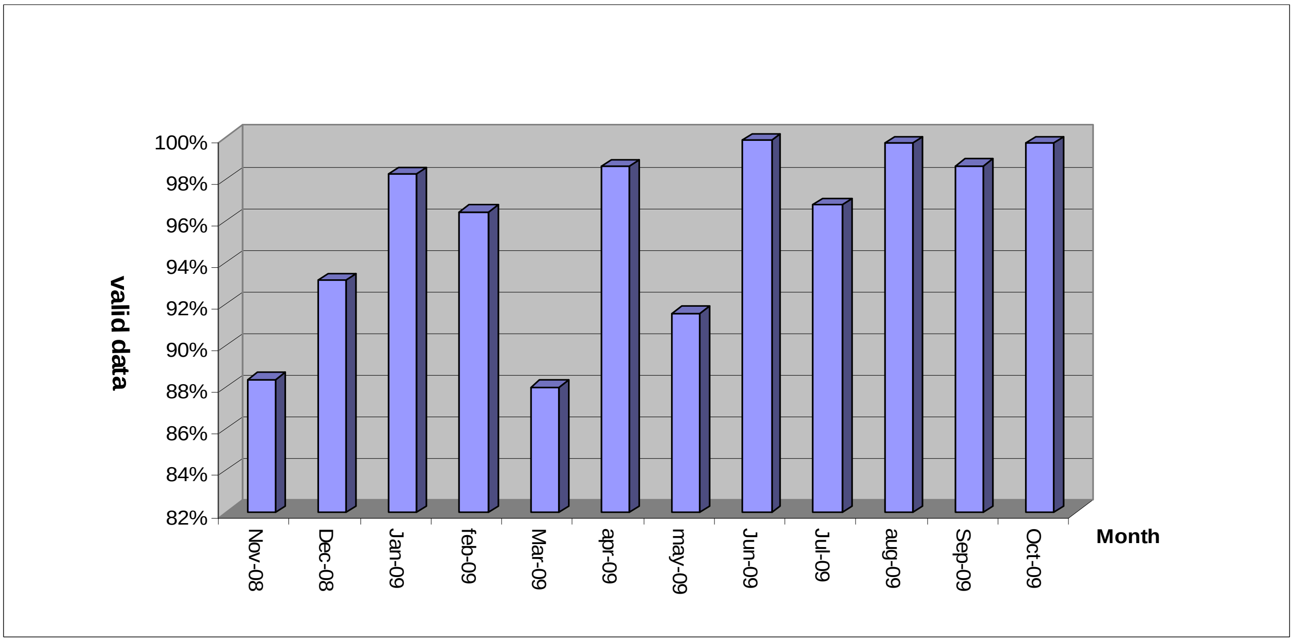


Figure 21. Data validation by month

Figure 20 reveals some problems:

- The VROT2 screen provided a signal that was not correlated with temperature. No explanation was found. Therefore, VROT2 is no longer taken into account in the following text;
- The VTHY sensors suffered some critical malfunctions: both gave no values after May 2009 due to a problem of overvoltage.

According to the QC daily reports the maximum total availability of valid data was 95.75%. The following screens gave the highest percentage (95.75%) of valid data for temperature measurements corresponding to more than 500000 minutes for almost each of the screens : LBOM, VFIS1, VDAV2, LCAS, SDAV1 VFIS2, SDAV2, VEIG11, VEIG12, VYOU1, SWIN1, SSOC1, VYOU2, SWIN2, SSOC2, LSOC, SYOU1, VDAV1, LLAN1, SYOU2, LLAN2.

Table 4. Data availability for screens/shields

Screen	QC=0	QC=1	QC=2	QC=3	QC=7
	valid	inconsistent	doubtful	erroneous	missing
ATHI1	64.4%	0.0%	0.3%	0.0%	35.3%
ATHI2	64.4%	0.0%	0.3%	0.0%	35.3%
LBOM	95.7%	0.0%	0.0%	0.0%	4.2%
LCAS	95.7%	0.0%	0.0%	0.0%	4.2%
LLAN1	95.7%	0.0%	0.0%	0.0%	4.2%
LLAN2	95.7%	0.0%	0.0%	0.0%	4.2%
LSOC	95.7%	0.0%	0.0%	0.0%	4.2%
SDAV1	95.7%	0.0%	0.0%	0.0%	4.2%
SDAV2	95.7%	0.0%	0.0%	0.0%	4.2%
SSOC1	95.7%	0.0%	0.0%	0.0%	4.2%
SSOC2	95.7%	0.0%	0.0%	0.0%	4.2%

Screen	QC=0	QC=1	QC=2	QC=3	QC=7
	valid	inconsistent	doubtful	erroneous	missing
SVAI1	67.5%	0.0%	0.0%	0.0%	40.7%
SVAI2	63.1%	0.0%	0.0%	0.0%	49.6%
SWIN1	95.7%	0.0%	0.0%	0.0%	4.2%
SWIN2	95.7%	0.0%	0.0%	0.0%	4.2%
SYOU1	95.7%	0.0%	0.0%	0.0%	4.2%
SYOU2	95.7%	0.0%	0.0%	0.0%	4.2%
VDAV1	95.7%	0.0%	0.0%	0.0%	4.2%
VDAV2	95.7%	0.0%	0.0%	0.0%	4.2%
VEIG11	95.7%	0.0%	0.0%	0.0%	4.2%
VEIG12	95.7%	0.0%	0.0%	0.0%	4.2%
VEIG21	90.8%	0.0%	0.0%	1.3%	7.8%
VEIG22	95.7%	0.0%	0.0%	0.0%	4.2%
VFIS1	95.7%	0.0%	0.0%	0.0%	4.2%
VFIS2	95.7%	0.0%	0.0%	0.0%	4.2%
VROT1	95.2%	0.0%	0.0%	0.7%	4.9%
VTHY1	22.6%	0.0%	0.0%	0.0%	74.1%
VTHY2	22.7%	0.0%	0.0%	0.0%	74.0%
VYOU1	95.7%	0.0%	0.0%	0.0%	4.2%
VYOU2	95.7%	0.0%	0.0%	0.0%	4.2%

The average percentage of missing data for the SVAI and ATHI sensors is around 38%. The main reason is frequent failures of the acquisition software, not problems of the sensors. We note more than 73% of missing values for Thygan sensors, due to frequent failures of the acquisition software and the stop of transmission from Thygan sensors from May 2009..

For the above reasons the data of SVAI1, SVAI2, VTHY1, VTHY2, ATHI1 and ATHI2 can only be used for a restricted analysis.

For the screen/shield data analysis, periods lasting at least six hours with steady conditions of cloudiness during day or night were identified. Clear sky is defined by cloudiness less or equal to 1 okta. Overcast sky is defined by cloudiness greater or equal to 7 okta. Table 5 gives the number of events and the total duration for each specific condition.

Table 5. Identification of specific periods

	Day	Night
Clear sky	131 events ↔ 1205 hours	182 events ↔ 1648 hours
Overcast	21 events ↔ 150 hours	24 events ↔ 187 hours

The distribution of these events is shown in figure 22. The number of events that occurred during the considered month is indicated above each bar.

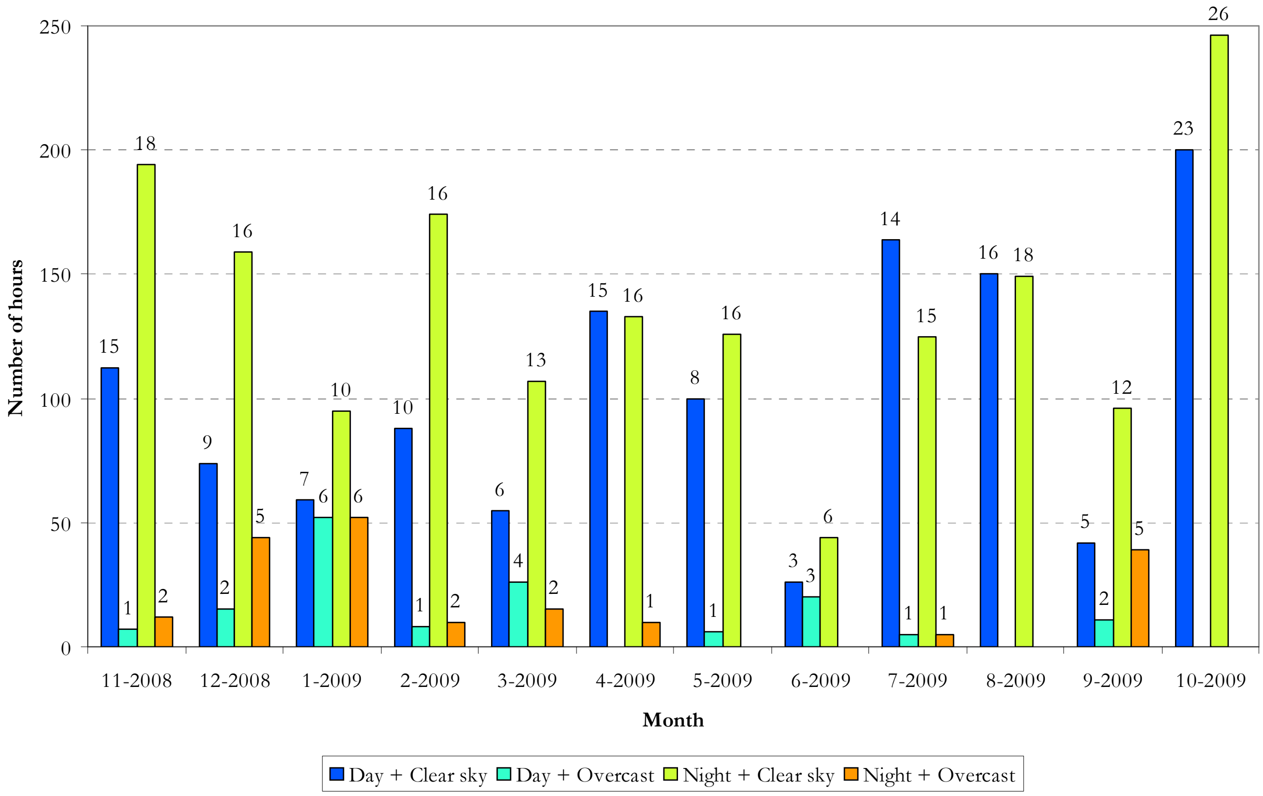


Figure 22. Distribution of long periods with specific sky conditions.

5.2.2 Humidity sensors

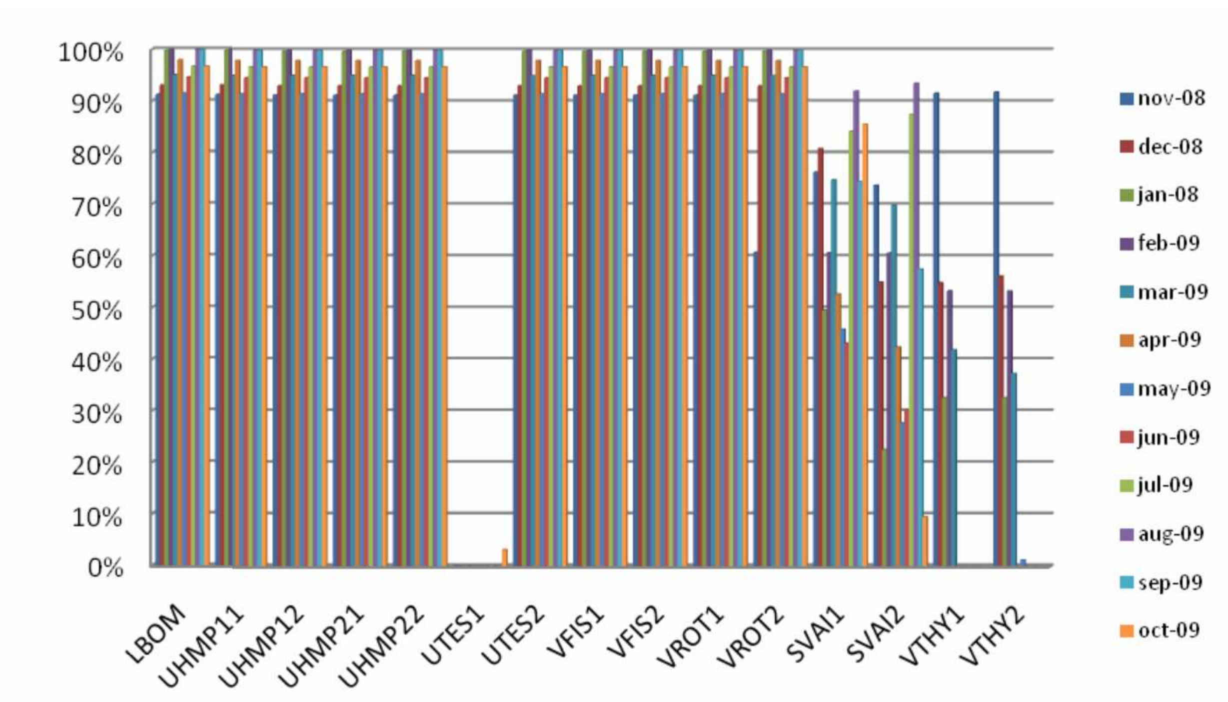


Figure 23. Total availability for relative humidity sensors

As shown in figure 23, some critical malfunctions were found:

- UTES1: humidity sensor failed during the whole period of the intercomparison The suspected reason for this fault is a problem of power supply and connection;
- SVAI2: few data received on January, February, April, May and June 2009;
- The dew point hygrometers VTHY1 and VTHY2 suffered from some critical malfunctions: both gave no values after May 2009 due to a problem of overvoltage.

Figure 24 gives a summary of available relative humidity data for the intercomparison period for the different quality levels. Numerical values are available in table 6.

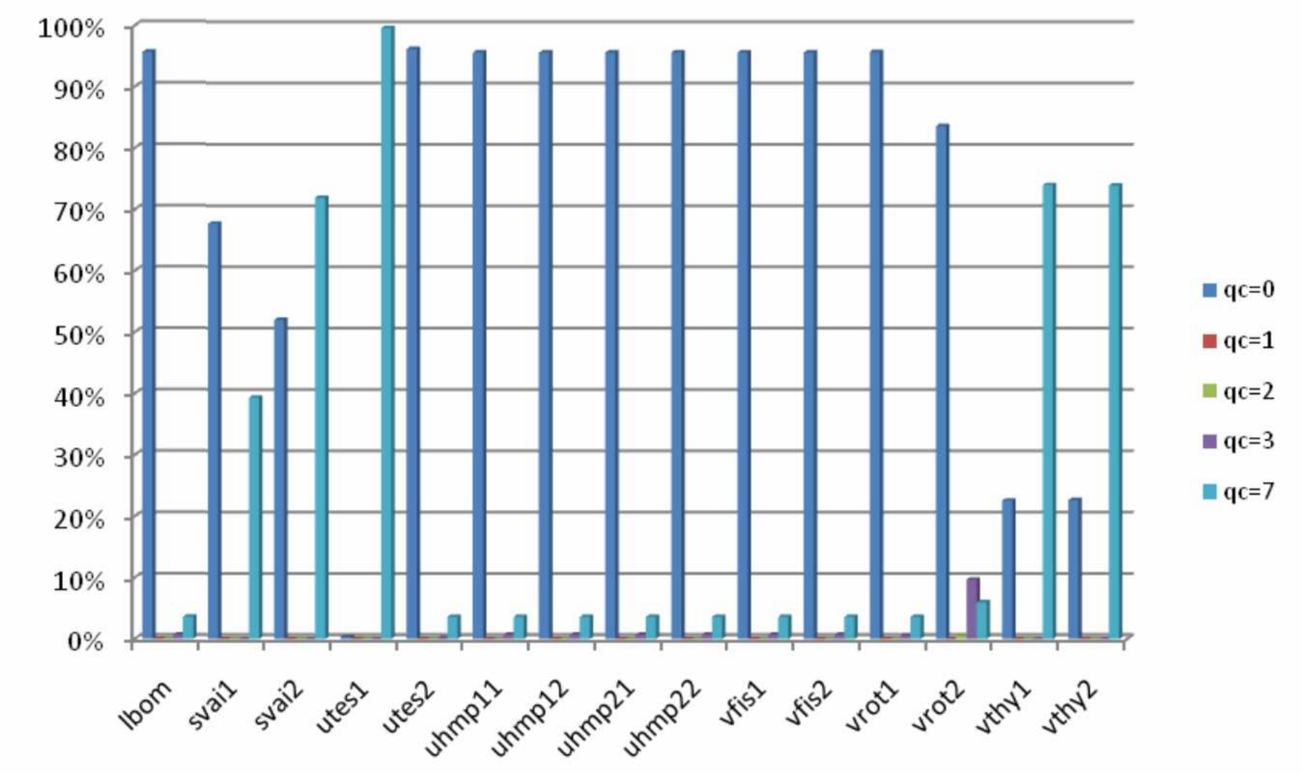


Figure 24. QC flags of relative humidity sensors

The percentage of missing data for the screens SVAI1 and SVAI2 amount to 35% up to 59%. The main reason is frequent failures of the acquisition software, not problems of the sensors. Due to these problems and the stop of transmission from Thygan sensors from May 2009, the percentage of missing data for both Thygans is more than 73%.

For this reason the data of the humidity sensors UTES1, VTHY1, VTHY2 and SVAI2 can only be used for a restricted analysis.

Table 6. Data availability for relative humidity sensors

Sensor	QC=0	QC=1	QC=2	QC=3	QC=7
	valid	inconsistent	doubtful	erroneous	missing
LBOM	95.7%	0.0%	0.0%	0.7%	3.6%
SVAI1	67.8%	0.0%	0.0%	0.0%	39.4%
SVAI2	52.1%	0.0%	0.0%	0.0%	72.0%
UTES1	0.0%	0.0%	0.0%	0.0%	100.0%
UTES2	96.3%	0.0%	0.0%	0.1%	3.6%
UHMP11	95.7%	0.0%	0.0%	0.7%	3.6%
UHMP12	95.7%	0.0%	0.0%	0.7%	3.6%

Sensor	QC=0	QC=1	QC=2	QC=3	QC=7
	valid	inconsistent	doubtful	erroneous	missing
UHMP21	95.7%	0.0%	0.0%	0.7%	3.6%
UHMP22	95.7%	0.0%	0.0%	0.7%	3.6%
VFIS1	95.7%	0.0%	0.0%	0.7%	3.6%
VFIS2	95.7%	0.0%	0.0%	0.7%	3.6%
VROT1	95.8%	0.0%	0.0%	0.6%	3.6%
VTHY1	22.6%	0.0%	0.0%	0.0%	74.1%
VTHY2	22.7%	0.0%	0.0%	0.0%	74.0%

5.2.3 Ancillary sensors

In figure 25 and figure 26 data availability is shown for each month during the period of intercomparison for global radiation and the wind speed measured by the Gill ultrasonic anemometer.

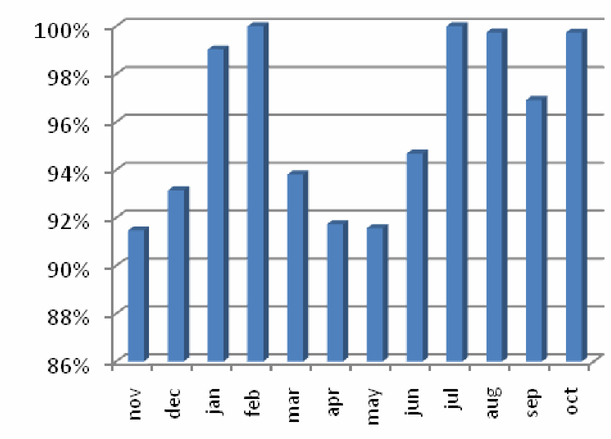


Figure 25. Total availability for the global radiation

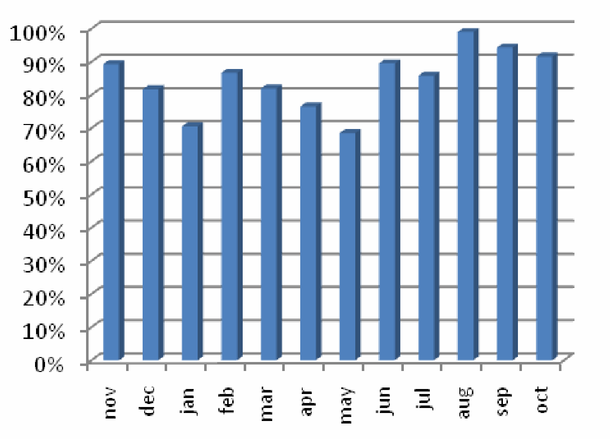


Figure 26. Total availability for the Gill wind speed

5.3 CLIMATOLOGY OF THE TEST PERIOD

5.3.1 Temperatures and relative humidity

The monthly mean temperature of Ghardaïa is 10.4 ℃ in January and 36.3 ℃ in July, as shown in figure 27. As shown in figure 28, monthly mean amplitudes of temperatures are more moderate in the winter than in the summer (average 11℃ in winter and 13.5℃ in summer). They fluctuate around 20℃.

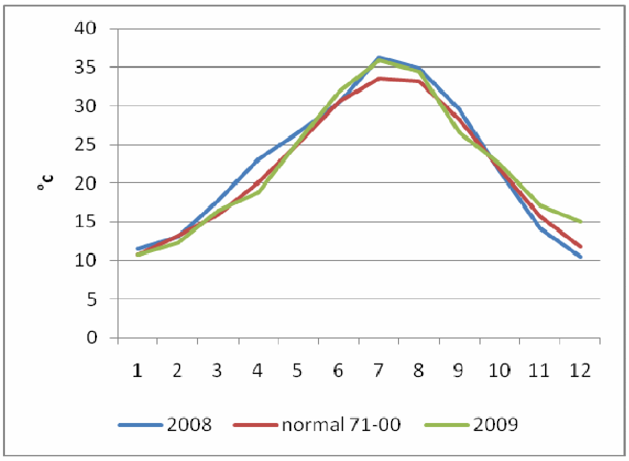


Figure 27. Monthly mean temperatures

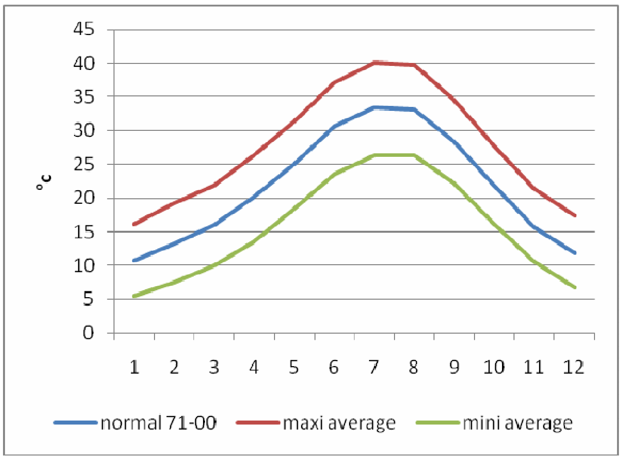


Figure 28. Monthly mean thermal amplitudes

The daily extreme temperatures are calculated from the valid 1-minute values.

The maximum temperature Tx of day D is the warmest temperature between day D 06:01 and day D+1 06:00.

The minimum temperature Tn of day D is the coldest temperature between day D-1 18:01 and day D 18:00.

Each day, both Tn and Tx are validated when at least 1430 of the 1440 possible values are valid (QC=0). A special rule is applied to SVAI screens: due to acquisition problems, about 10% of their 1-minute values are not available (about one missing value every 10 minutes), so Tn and Tx are computed if at least 1300 of the 1440 daily 1-minute values are valid.

The plot of the daily maximum and minimum temperatures during the test period is given in the figure 29. These data were measured by the VEIG22 temperature sensor.

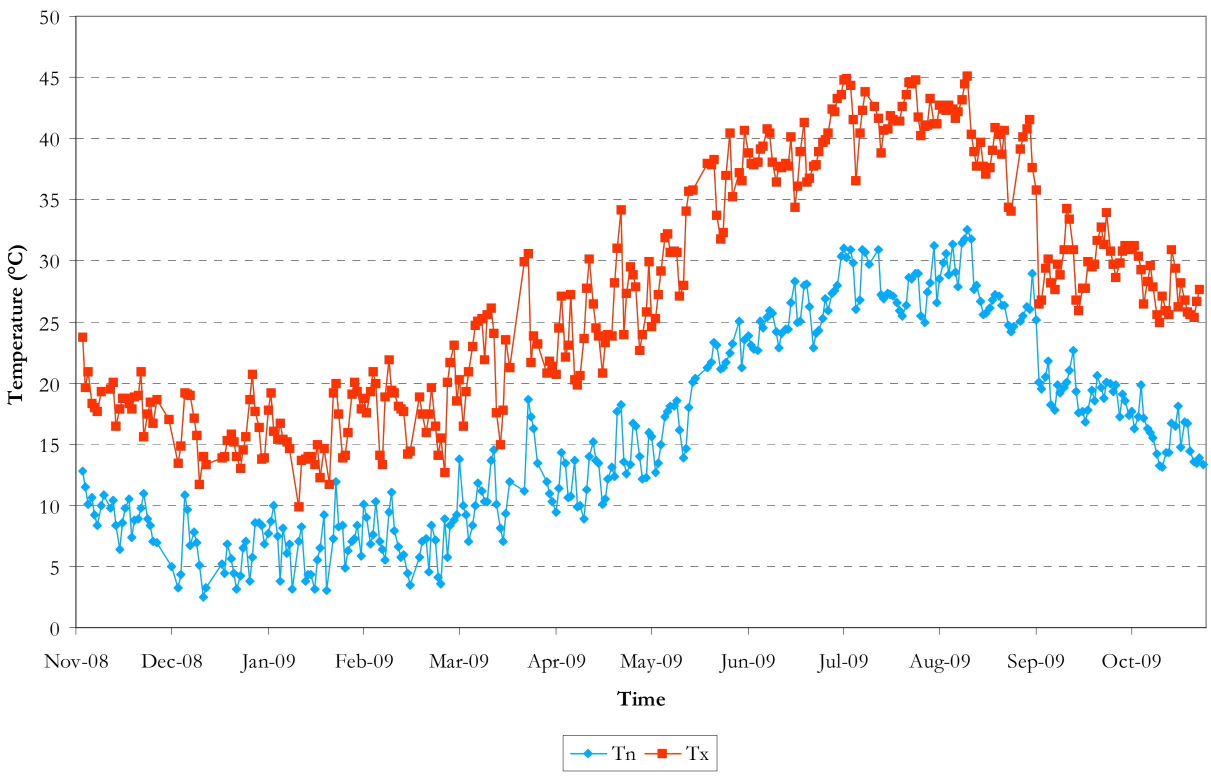


Figure 29. Daily extreme temperatures

The daily extreme values of relative humidity are calculated from the valid 1-minute values.

Maximum (resp. minimum) relative humidity RHx (resp. RHn) of day D is the highest (resp. lowest) relative humidity between day D 00:01 and day D+1 00:00.

Each day, both RHn and RHx are validated when at least 1430 of the 1440 possible values are valid (QC=0). A special rule is applied to SVAI screens: due to acquisition problems, about 10% of their 1-minute values are not available (about one missing value every 10 minutes), so RHn and RHx are computed if at least 1300 of 1440 daily 1-minute values are valid.

The plot of the daily maximum and minimum relative humidity during the intercomparison is given in figure 30. These are data from the UHMP22 sensor.

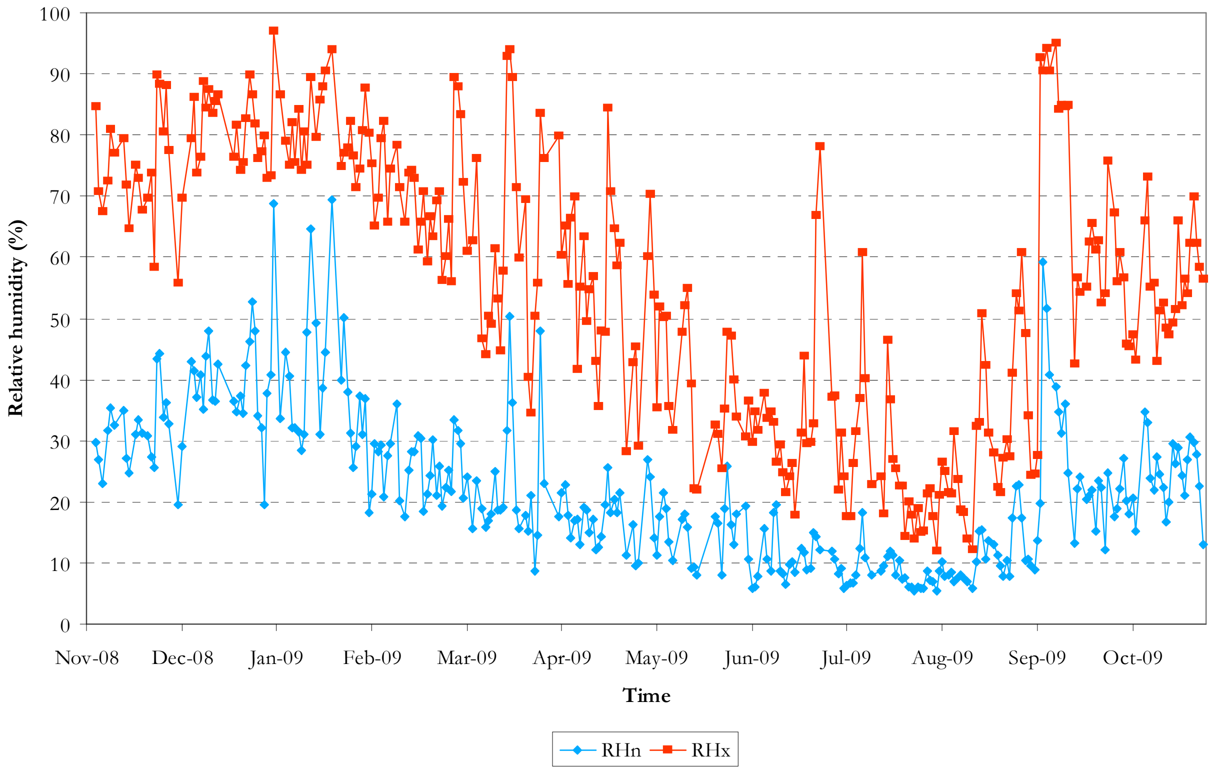


Figure 30. Daily extreme values of relative humidity

5.3.2 Wind

Stronger winds in the region of Ghardaïa are mostly prevailing during the period from March to June. On average 3.3 days of dust storms and 49 blowing sand events occur per year.

The average wind speed is around 5 m/s to 6 m/s; blowing between 9h and 18h and generally occurring from April to June (see figure 31). The maximum wind speeds are generally between 6 m/s and 10 m/s occurring from September to January. Wind maxima exceeding 20 m/s (over 75 km/h) are also quite frequent and can mainly be observed from February to May.

The maximum number of days of calm winds was noted in July and August and at night as shown in figure 31.

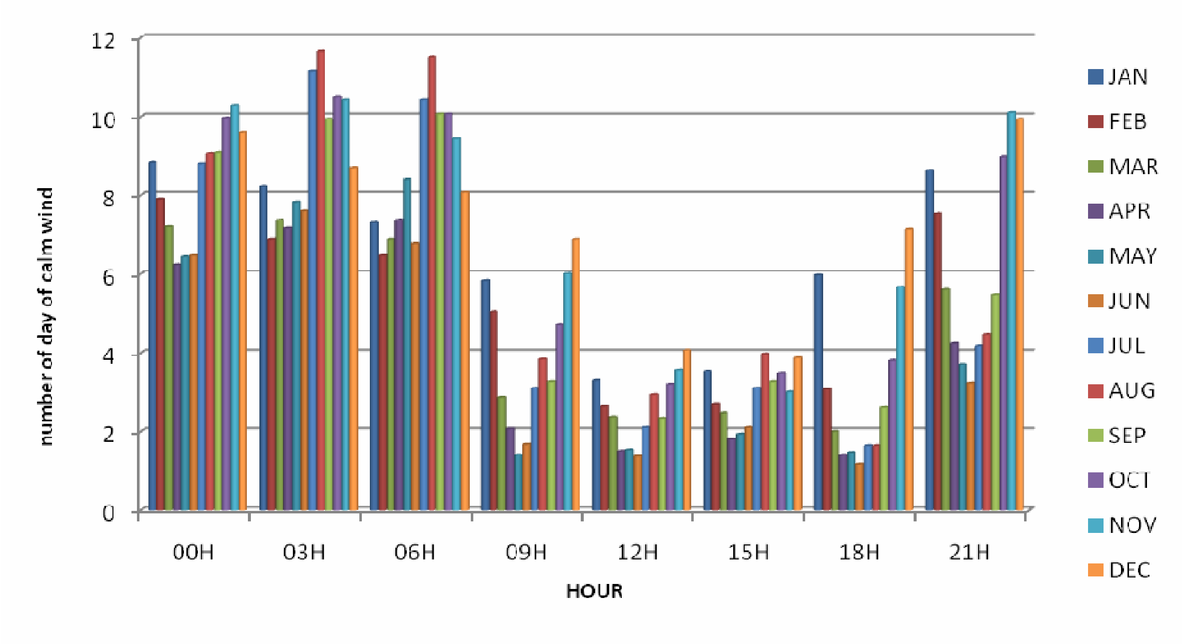


Figure 31. Average number of days of calm winds during the period 1971-2000

Prevailing wind direction in winter and spring is North to North East, with average speeds up to 10 m/s and 13 m/s respectively. In summer wind directions are mainly North East to South with average speeds up to 12 m/s. In late autumn wind directions are changing to North West, East and South, with average speeds up to 11 m/s as shown in figure 32.

The most frequent wind speed is between 5 to 9m/s which can also be recognized on the figure 33. Wind directions from North to North-East are dominant with frequencies of 14.8% and 11.6% respectively.

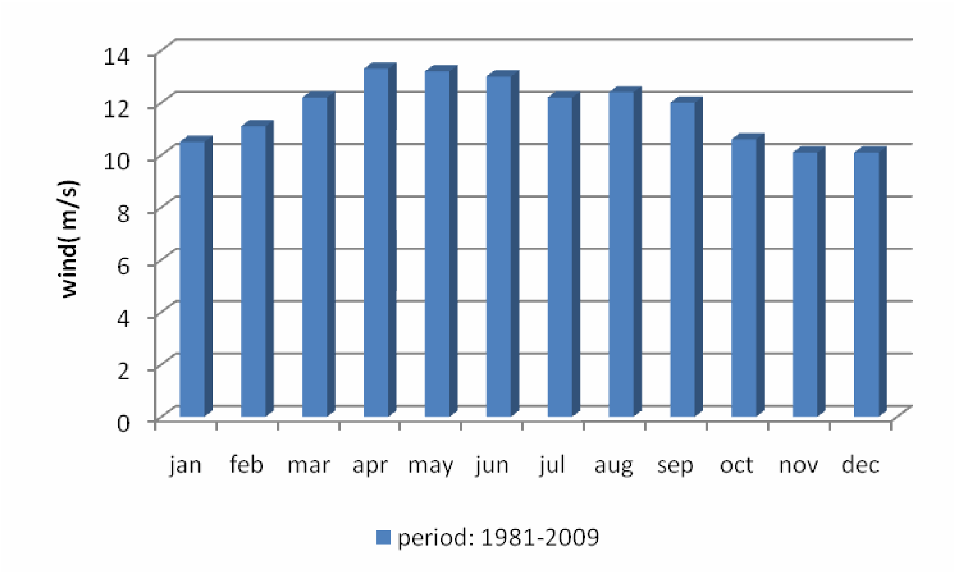


Figure 32. Average maximum wind speed

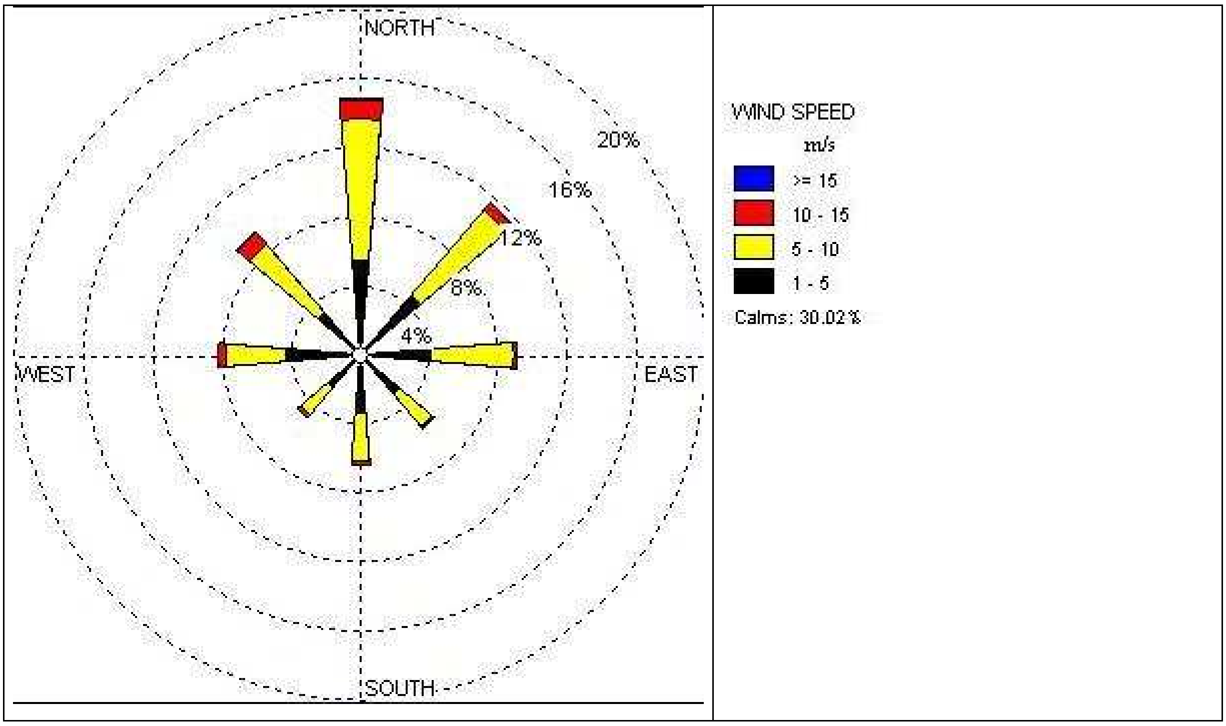


Figure 33. Mean annual frequency of wind directions for wind speed classes (1998-2008).

5.3.3 Sunshine duration

The mean monthly totals of sunshine duration show a maximum of 350 hours in May 2009 and a minimum of 195 hours in January 2009. April, May and October 2009 had significantly greater values of monthly sunshine duration than the normal. The yearly maximum event occurred in May and not in August as usual as shown on figure 34.

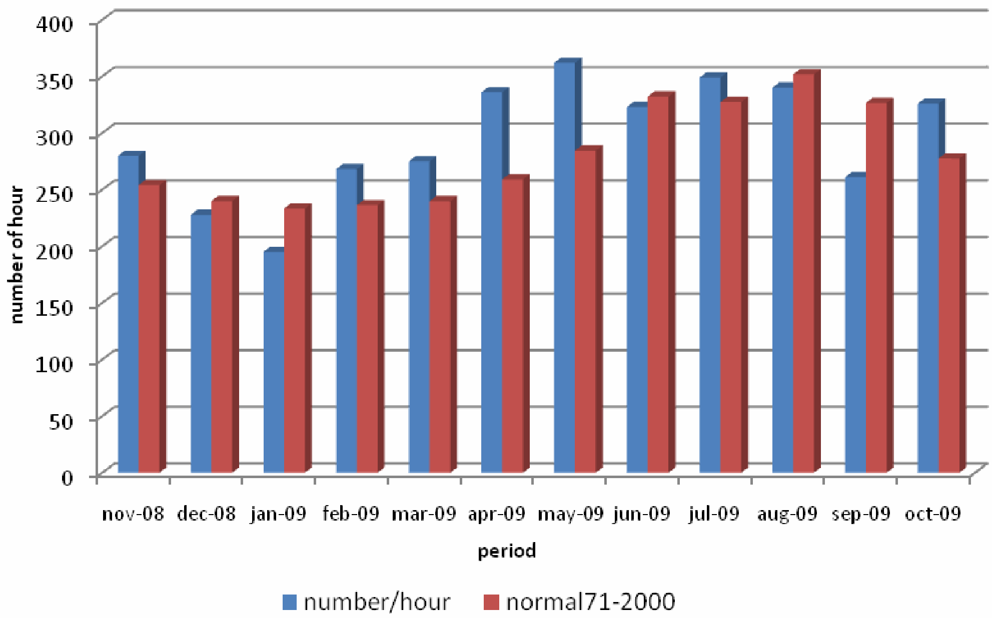


Figure 34. Sunshine duration

5.3.4 Albedo measurements

The albedo is the ratio between the reflected radiation and the incident radiation. It was measured by the albedometer CMA11. In Ghardaïa, it is around 0.38 when the soil is dry, between 0.28 and 0.29 when it is humid. The figure 35 shows the albedo (top chart), on the 18th and 19th of January, 2009. The first day was sunny, the soil was dry. On the second day, a strong shower is recorded from 07:00 to 8:40. Here the albedo is calculated for valid values of reflected and incident radiation. Moreover, only values above 50 W/m^2 were considered, in order to avoid out of range values, coming from the ratio of small radiation values.

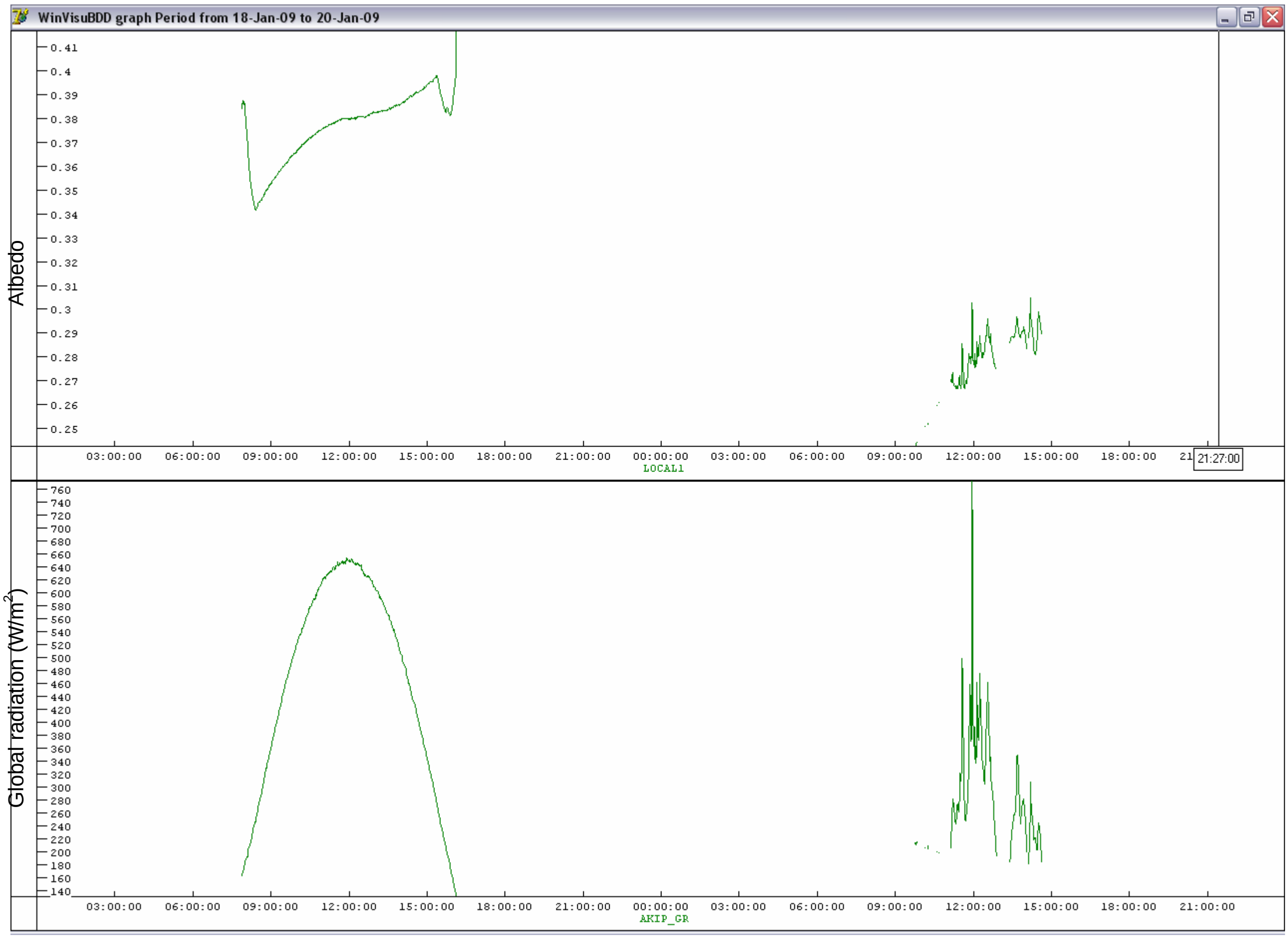


Figure 35. Albedo measurements

5.3.5 Precipitations

Rainfall events in Ghardaïa may be compared to Mediterranean-type or arid tropics rainfall events: they are highly variable from 1 to 100 mm/h when violent thunderstorms occur.

During the winter and spring of 2008 the amount of rainfall was relatively small, as depicted in figure 36. At the end of September 2008, an episode of torrential rain (150mm within one hour) hit the city of Ghardaïa causing exceptionally large floods. In January and September 2009, two peaks appeared in the monthly rainfall statistics where the monthly rainfall amount exceeded the long term climate normal.

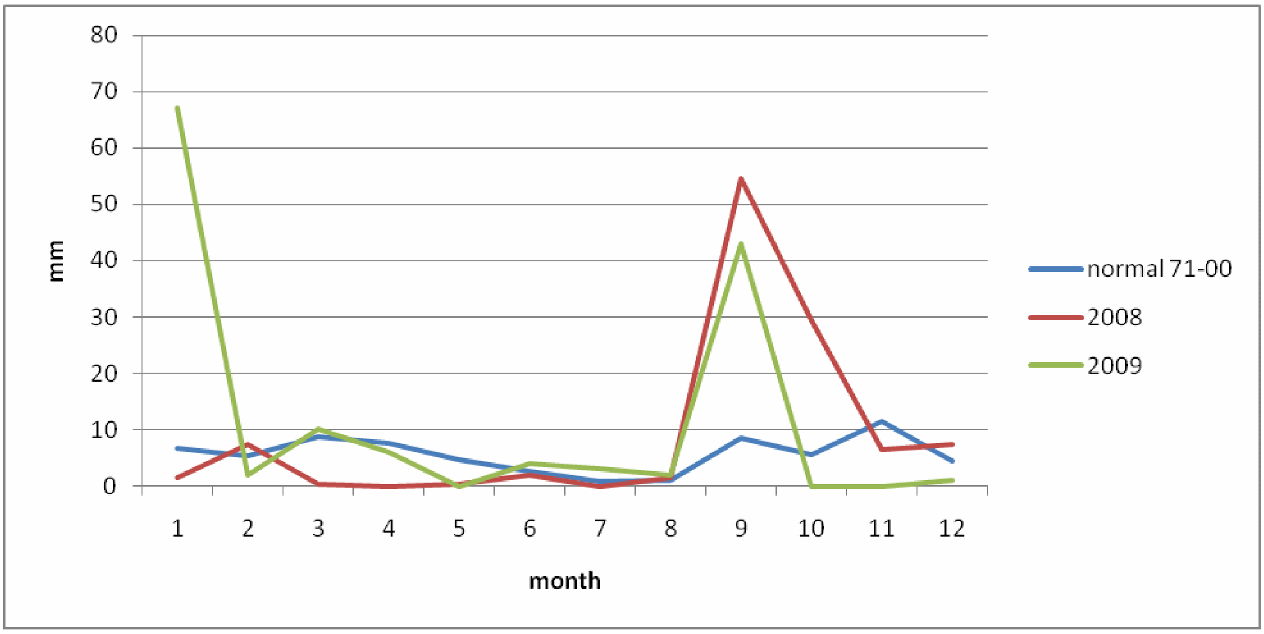


Figure 36. Monthly rainfall amounts in Ghardaïa

5.4 SCREENS

5.4.1 Choice of the reference

According to standard ISO17714:2007, screens "that are cooler during the day and warmer during the night are likely to be giving measurements that are closest to the truth". Therefore, screens that give the coolest/lowest daily maximum temperatures are examined here.

For the selection of the reference screen, the screens performance in reporting the maximum and minimum temperature, relative to each other, was examined.

Each day, the median of maximum temperatures of all screens is computed. The following two plots show the distribution of differences between the maximum temperature reported from each screen and the computed median maximum temperature, for the whole period of the intercomparison.

The median maximum temperature was processed separately for the naturally ventilated screens and for those artificially ventilated, and the plots were organized function of the ventilation type of the screens.

Due to ventilation problems, only data in October 2009 are considered for VYOU screens. A separate study considering measurements of VYOU screens with no artificial ventilation is available in annex 9.6.

In each case, the warmer screens are above the y=0 line, while the cooler screens are below it.

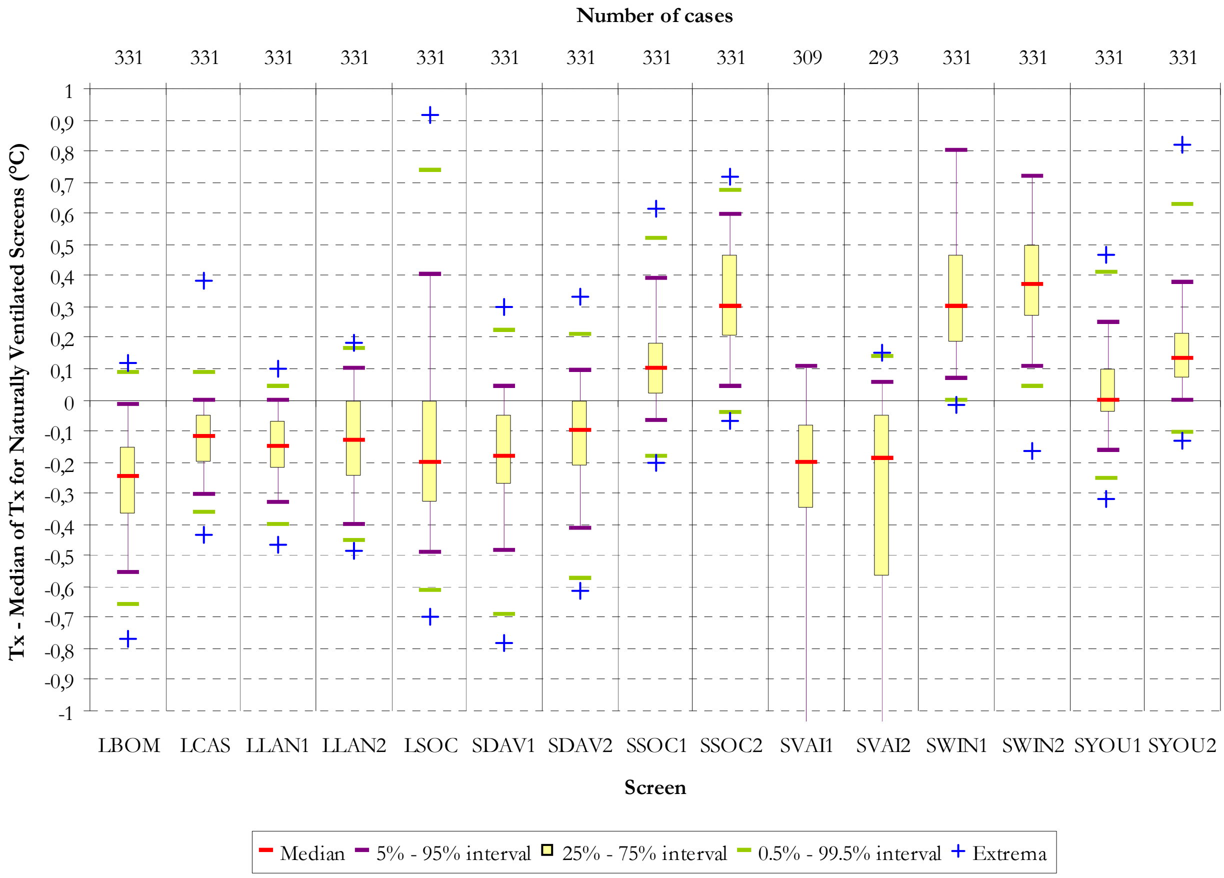


Figure 37. Daily maximum temperatures of naturally ventilated screens

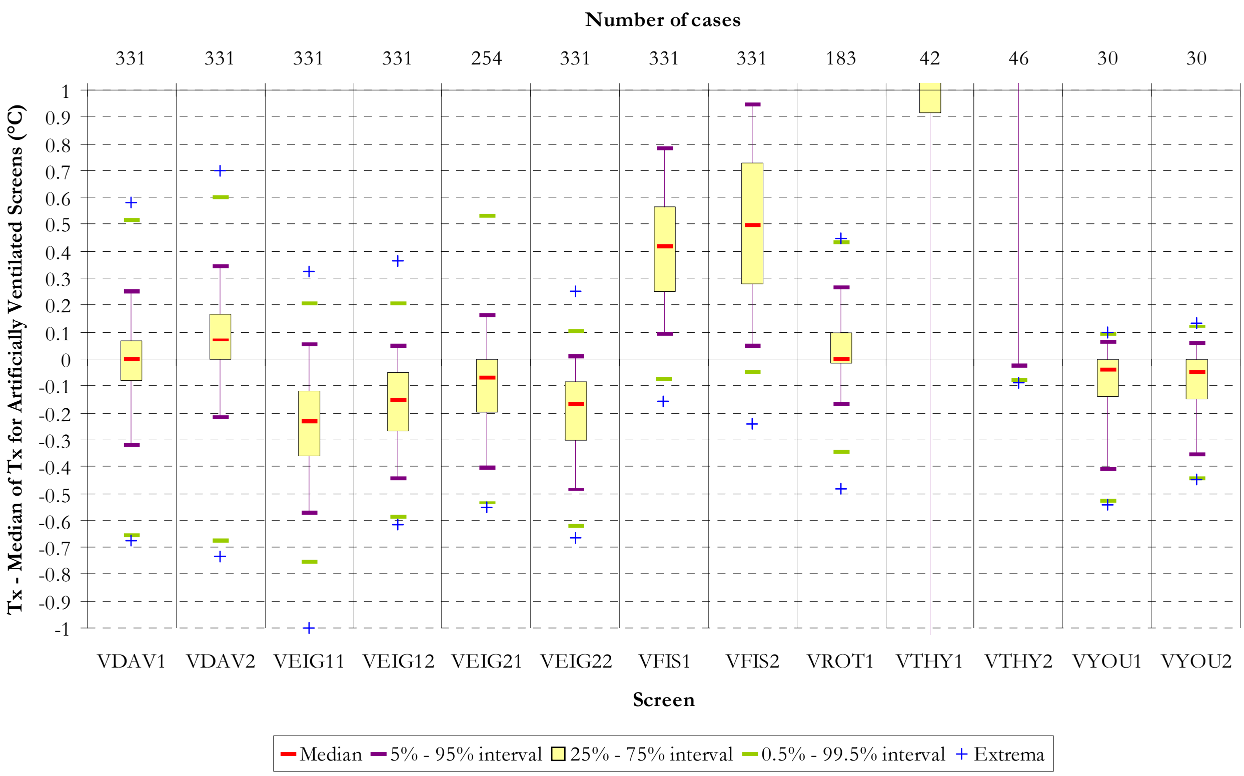


Figure 38. Daily maximum temperatures of artificially ventilated screens

The comparison between the median of daily maximum temperatures of naturally versus artificially ventilated screens shows that both are very close to the y=x line, with a y-intercept of -0.2℃.

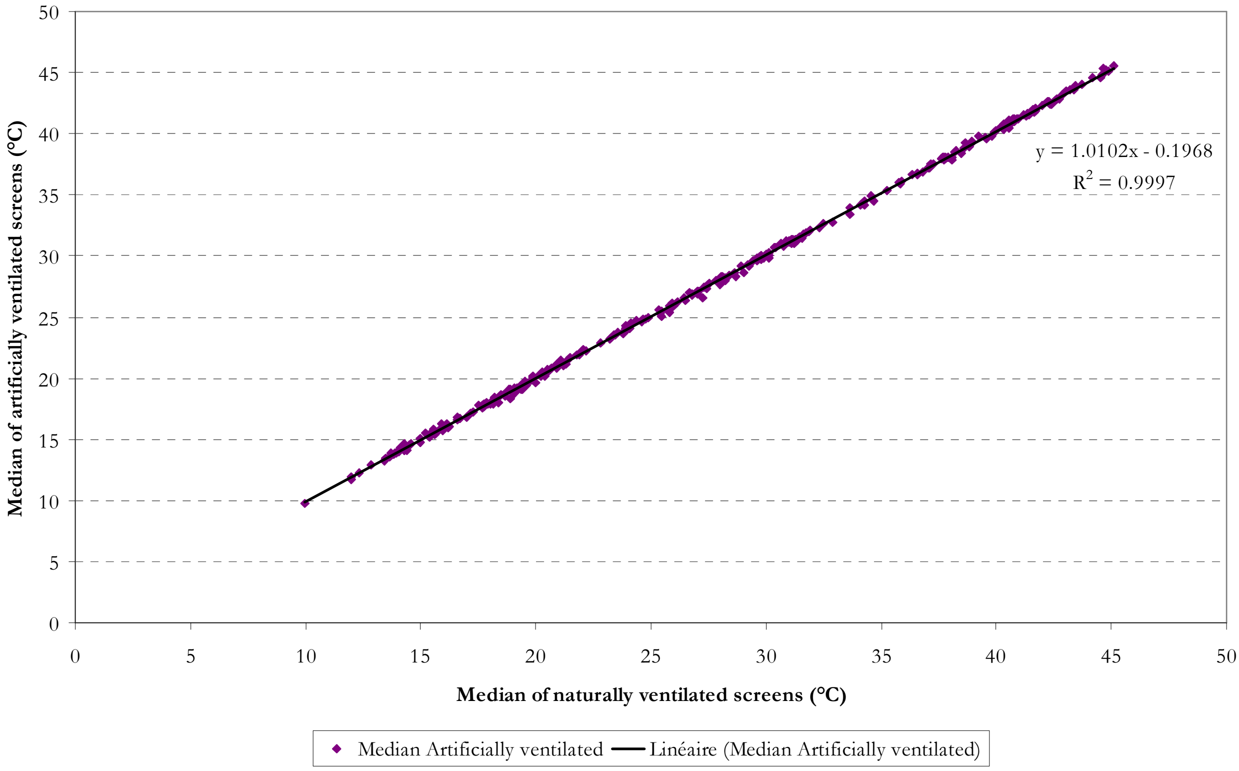


Figure 39. Comparison between naturally and artificially ventilated screens for daily maximum temperatures

The group of large Stevenson screens shows colder values. But it is suspected that this could be due to the time lag of these screens. The figure 40 shows one day of temperature measurements from two screens, VEIG11 (artificially ventilated) and LSOC (large Stevenson, naturally ventilated). The signal from LSOC is smoothed and delayed compared to VEIG11.

Figure 40. Case study: 27th of August, 2009

A similar analysis is conducted for the daily minimum temperatures, by plotting the differences between the minimum temperature reported from each screen and the computed median minimum temperature, for the whole period of the intercomparison.

The plots were organized function of the ventilation type of the screens.

In each case, the warmer screens are above the y=0 line, while the cooler screens are below it.

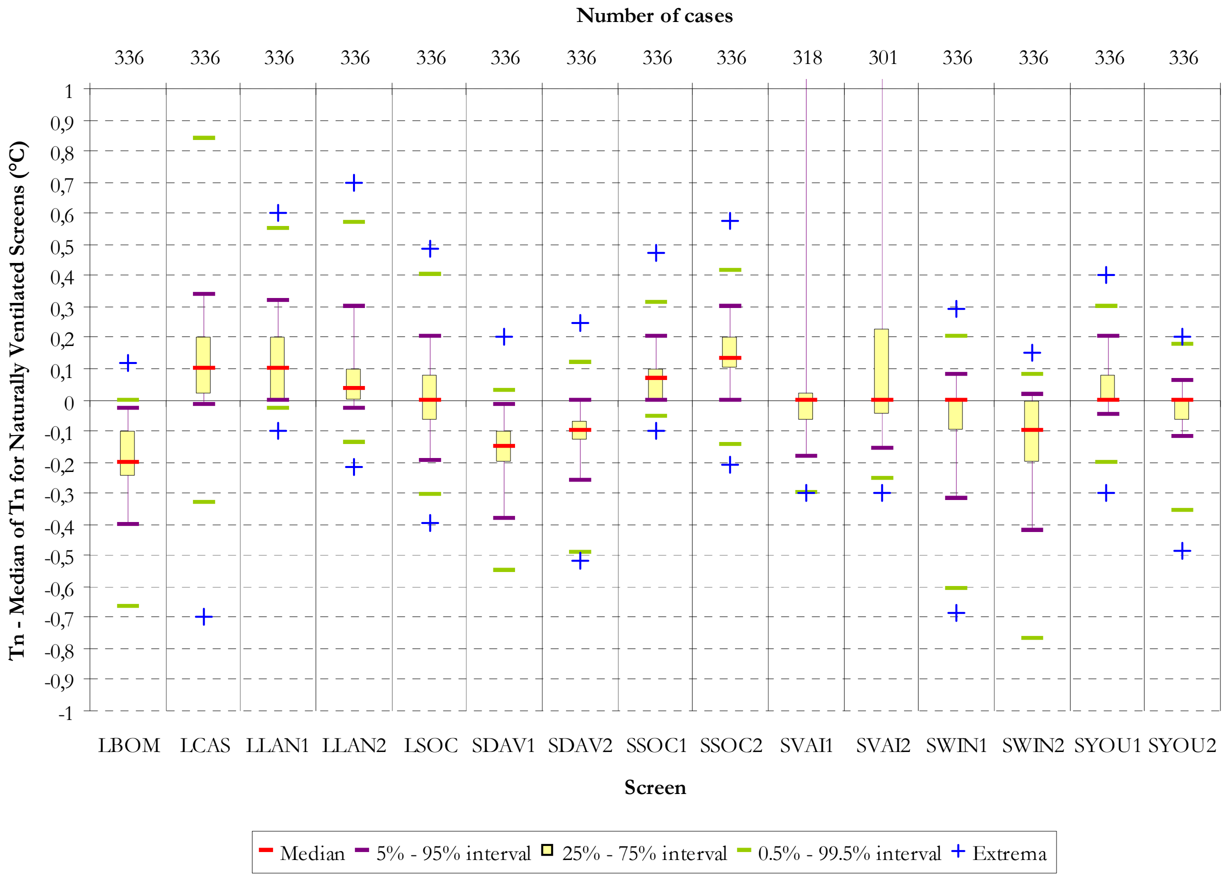


Figure 41. Daily minimum temperatures of naturally ventilated screens

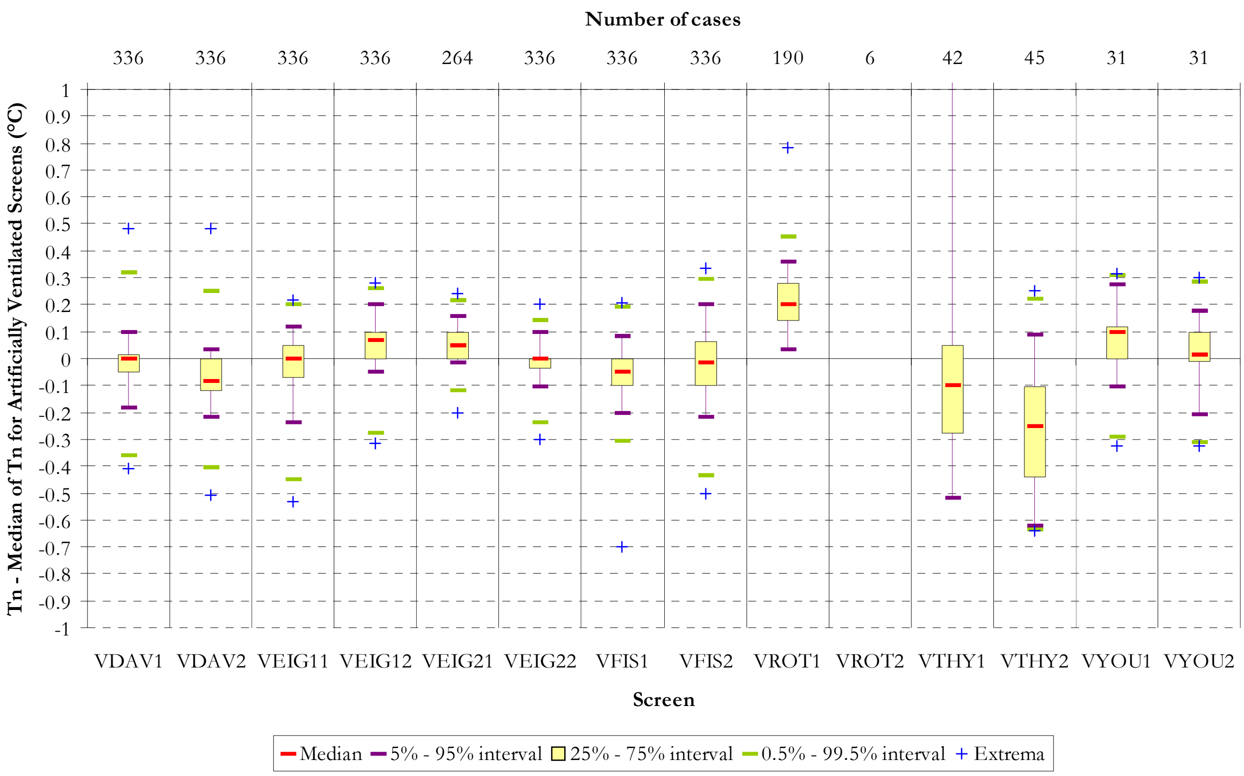


Figure 42. Daily minimum temperatures of artificially ventilated screens

Similar to the reporting of the maximum temperature, the two medians for the two types of screens show that they are very close to the y=x line, a slope very close to 1, and with a higher y-intercept than for maximum temperatures, -0.14℃.

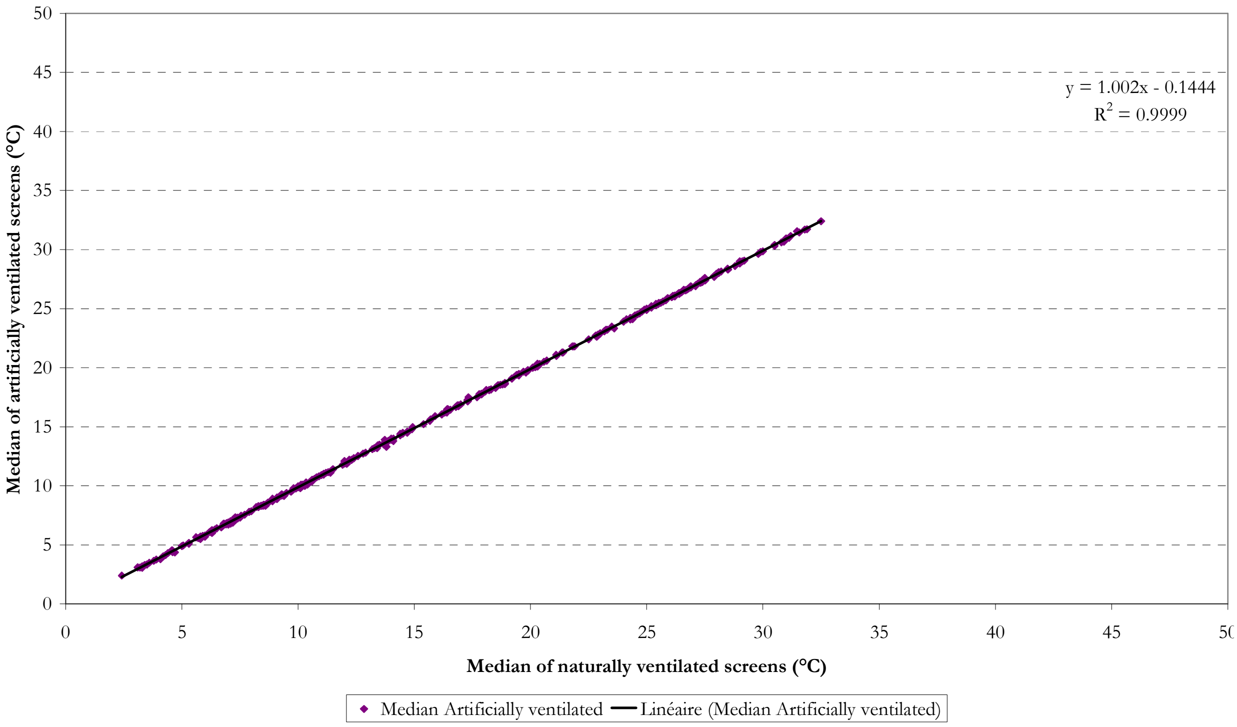


Figure 43. Comparison between naturally and artificially ventilated screens for daily minimum temperatures

The reference screen should ideally have a fast response which is generally the case for artificially ventilated screens.

Given the performance during the intercomparison, the following screens should not be chosen as the reference:

- VROT and VTHY have a very low number of data points,
- VDAV, VFIS and VYOU were warmer than the median temperature in at least 50% of the cases

Based on the information available, the VEIG screens are the most legitimate to be chosen as reference. Each VEIG screen has two temperature probes, which offers the option of selecting one of these probes as the reference, or the average of the two probes in the same screen. In each screen, one probe in installed towards North, the other towards South.

In order to see if the position of the sun could influence the probes inside VEIG screens, the distribution of the differences VEIG12-VEIG11 and VEIG22-VEIG21 are plotted, classified according the azimuth of the sun. Here are considered only the data where the sun elevation is positive.

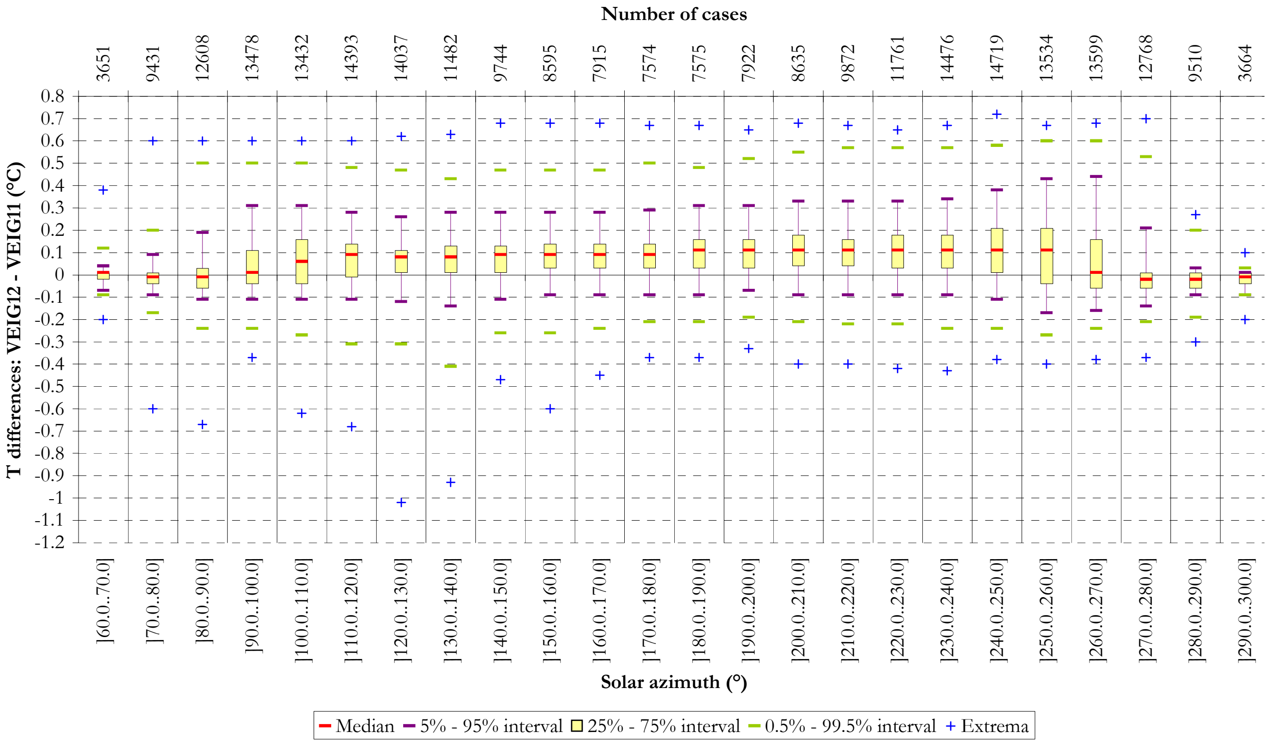


Figure 44. Temperature differences of the two probes of VEIG1 screen

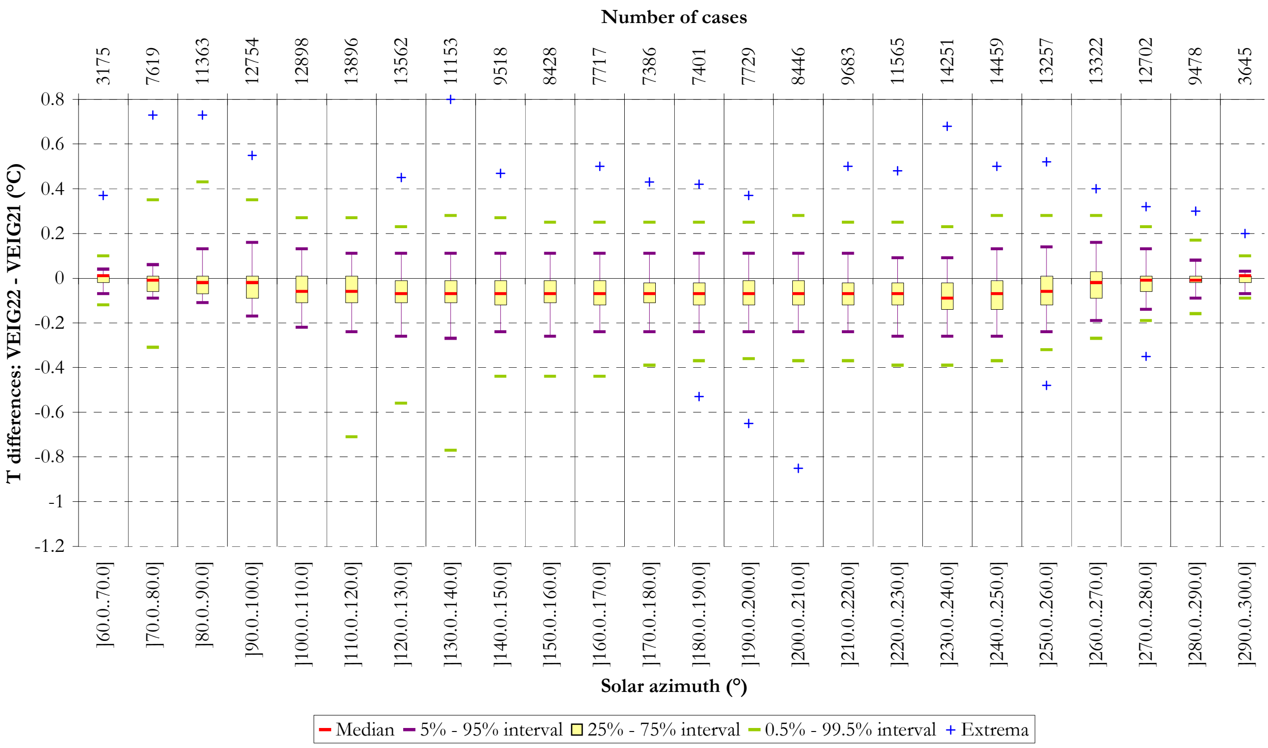


Figure 45. Temperature differences of the two probes of VEIG2 screen

On both plots a difference can be seen, corresponding to the east and west positions of the sun, compared to the south position. The plots are quite symmetric. The differences are smaller for the cases when the sun elevation is very low, for the classes (60..100) and (260..300): This could be interpreted as the absence of a radiation effect. No real difference can be seen between the east and west position of the sun.

The VEIG2 probes show less dispersion than VEIG1 probes. This recommends the probes in the VEIG2 as more suitable as the screens reference.. Of the two probes in VEIG2, VEIG22 has a higher number of available data, and is also colder than VEIG21.

Therefore the VEIG22 probe is considered as the working reference for temperature measurement.

5.4.2 Data analysis

This part includes general analysis for all screens. Detailed individual results are available in the datasheets.

5.4.2.1 Global radiation data

Very high values of global radiation were measured during the intercomparison period. The pyranometer was calibrated before and after the experiment by the calibration service of the NWS of Algeria. The calibration coefficient has changed by only 2.4% during the experiment from 5.17µV/(W m^{-2}) to 5.05µV/(W m^{-2}).

For the evaluation, global radiation was processed with an average coefficient of 5.1µV/(W.m^{-2}).

Extremely high values of global radiation (greater than 1100W/m^2 and up to 1300W/m^2) could be found on partly cloudy days. These peak values are caused by scattered sunlight from the surface of very white clouds leading to high values of diffuse radiation in addition to maximum values of direct radiation.

Figure 46 shows two consecutive days: the first one is a partly cloudy day where global radiation values are above usual values, followed by a clear sky day where global radiation values do not exceed 1020W.m^{-2}.

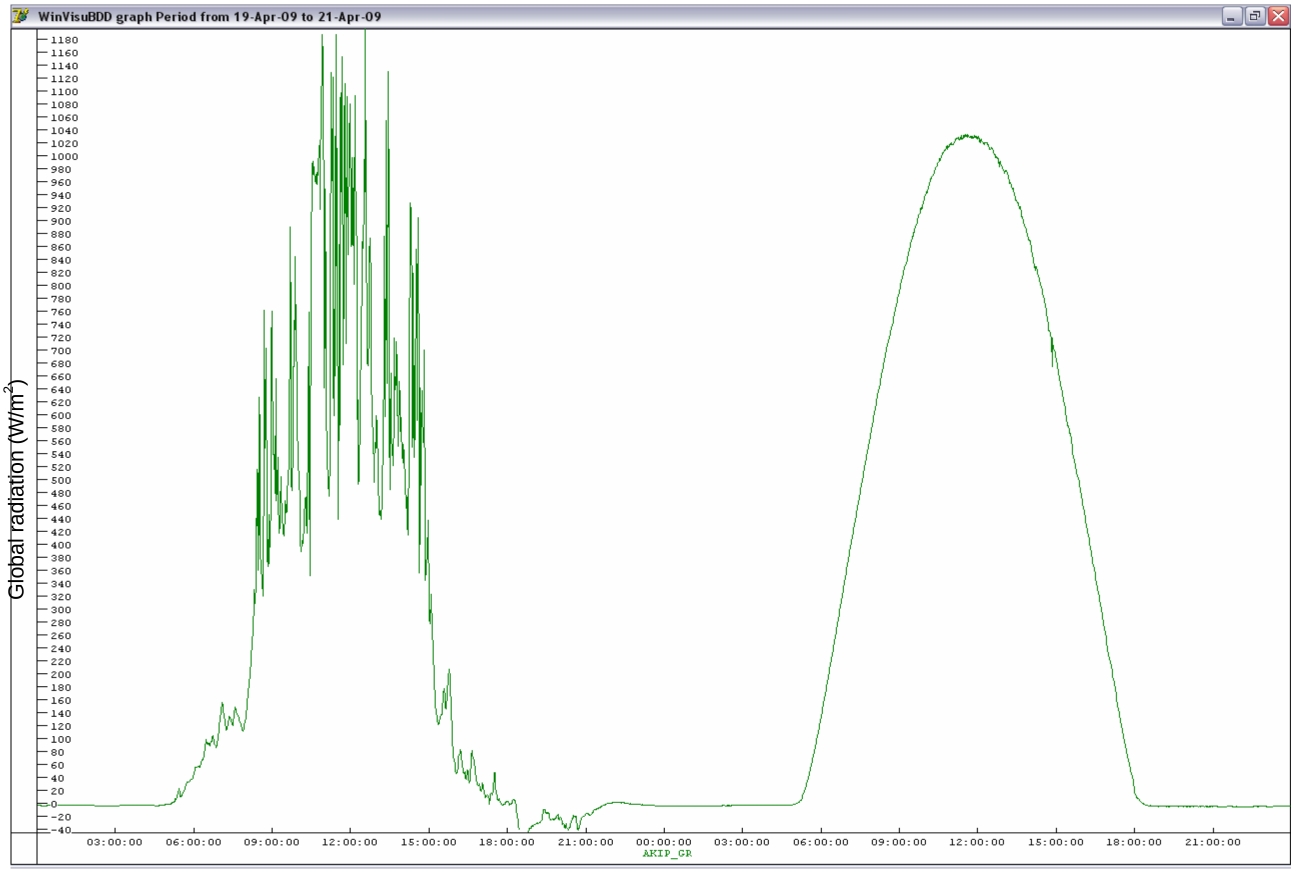


Figure 46. Global radiation: very high values during partly cloudy days

5.4.2.2 Wind and global radiation

Figure 47 shows the distribution of wind speeds for different classes of global radiation.

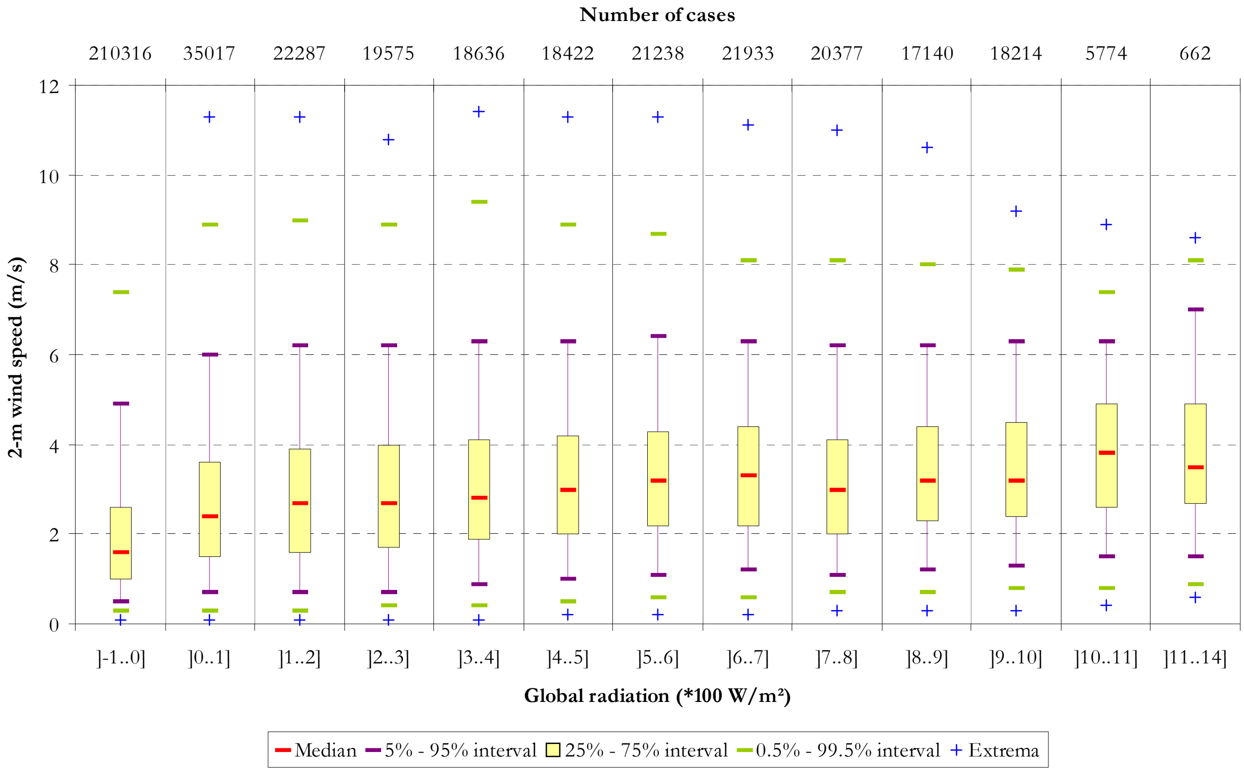


Figure 47. Distribution of wind speed vs global radiation

In every global radiation class, a wide range of wind speeds is available in the data set. However for high radiation values, large wind speeds (above 10m/s) and calm winds (below 1m/s) did not occur during the test period.

5.4.2.3 Method of data analysis and first results

For each sensor, its mode (most frequent value) and its mean are plotted. The figure 48 shows for most screens the differences are symmetric about zero (the mode varies between -0.2℃ and +0.2℃). A bell shape is not det ected. It is not the case for VROT1, VTHY1 et VTHY2: the graphical representation is not symmetrical. The average is -0.57℃ for the ATHY2 values.

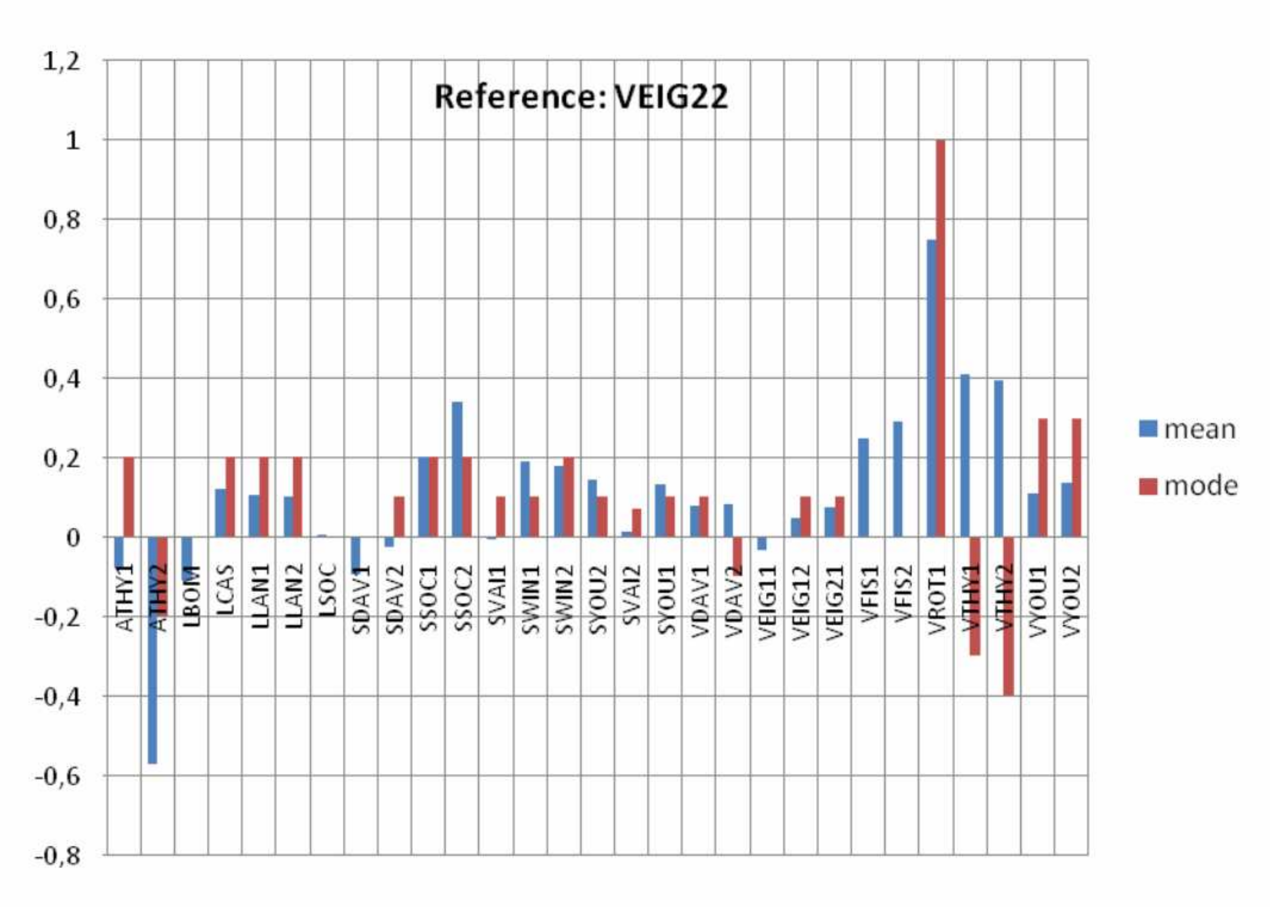


Figure 48. Screen diagram with VEIG22 reference

A detailed analysis of histograms is available in annex 9.5.

5.4.2.4 Distribution of differences with VEIG22 reference

The figure 49 shows the distribution of the differences with the reference, for each screen. It is based on 1-minute data.

The figure 50 is the same plot as the one before, but zoomed in, in order to emphasize details around 0.

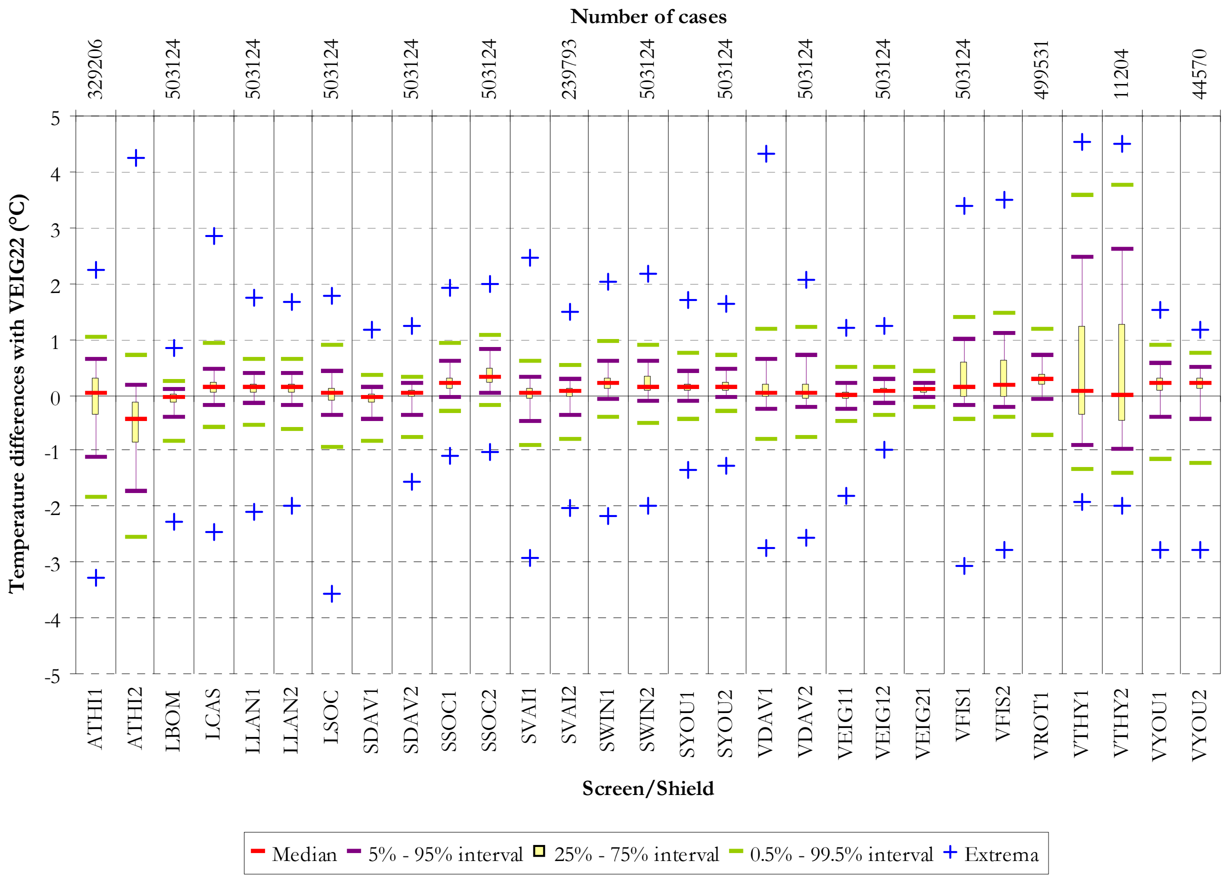


Figure 49. Temperature differences with the reference (1-minute data)

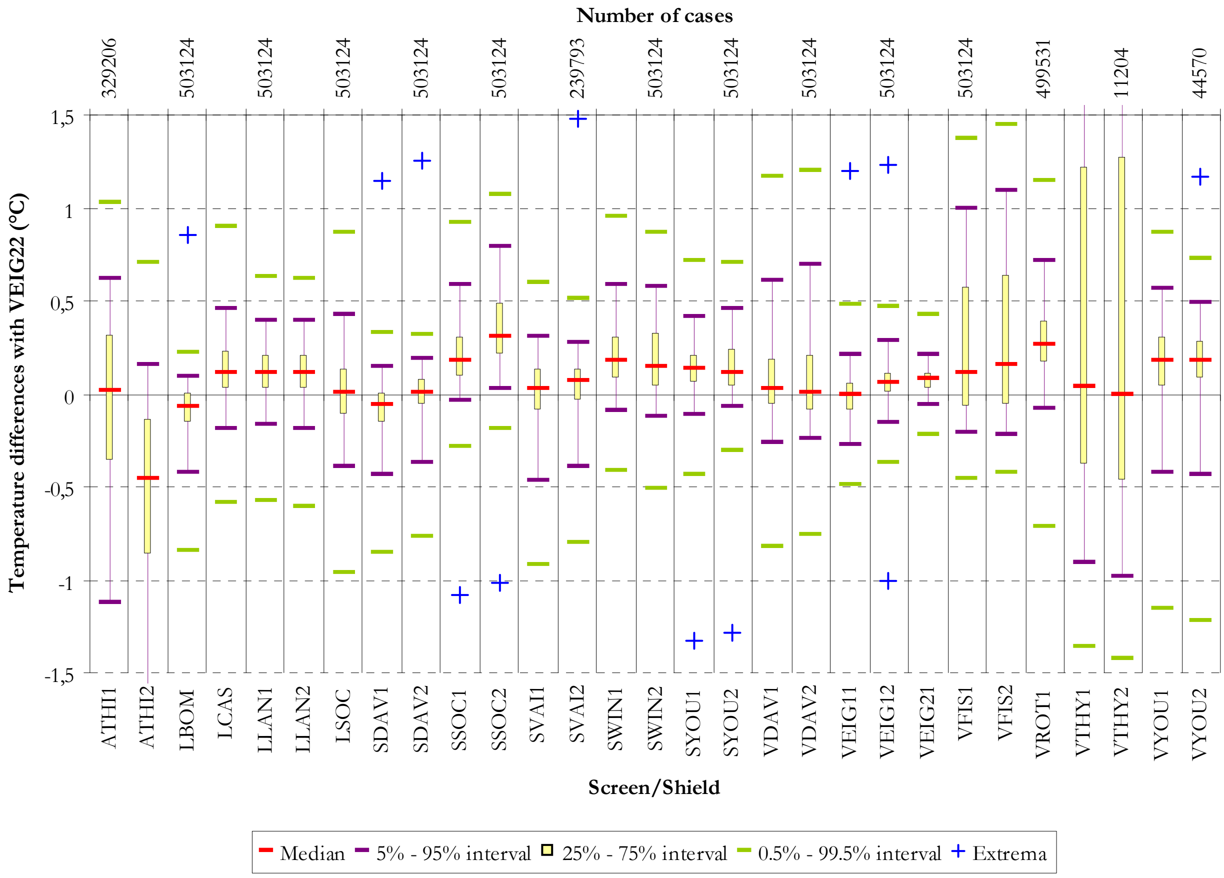


Figure 50. Temperature differences with the reference (1-minute data), zoomed in

5.4.2.5 Determination of time lag of the screens

To evaluate the time lag of the screens, during the calculation of daily maximum and minimum temperatures, the corresponding times when they occurred were also recorded. The distribution of the time differences in minutes when Tx occurred for the reference and for the other screens/shields is plotted in figure 51. A positive difference means that the maximum temperature of the screen under consideration occurs delayed with respect to the reference. Thus a negative difference corresponds to an earlier occurrence of the extreme value.

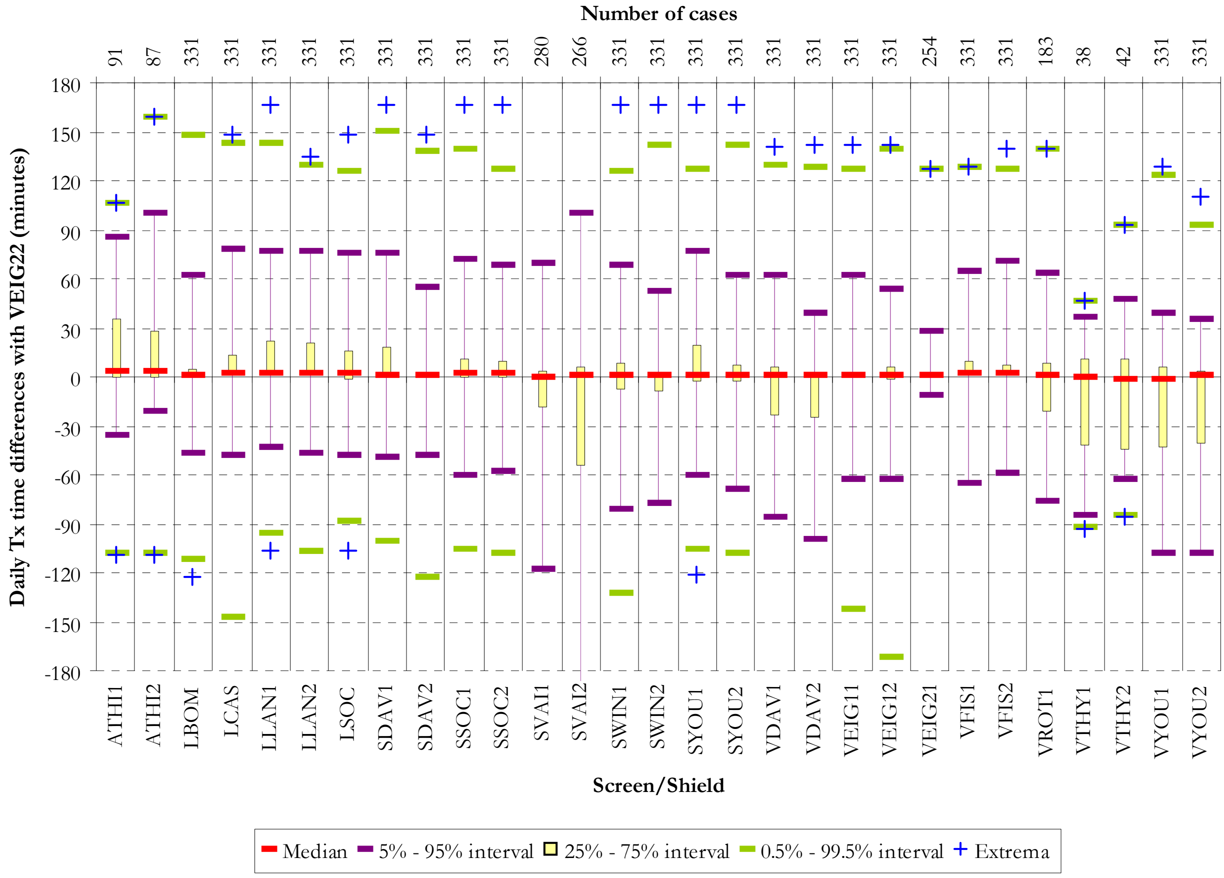


Figure 51. Distribution of the differences in the time of occurrence of daily maximum temperatures

A first conclusion is that many screens/shields have medians around 0, i.e. most screens are reporting Tx at the same time. On the other hand some extreme differences occurred with more than 180 minutes in some cases corresponding to days where the screens have recorded their Tx at completely different times compared to the reference.

More than the median values, yellow boxes (intervals with 50% of values) may be most representative of a screen's temporal behaviour. All large screens show a delay with their yellow boxes shifted to positive values. Some ventilated screens show an advance.

A similar chart for daily minimum temperatures Tn is shown in figure 52. Yellow boxes are very small: the majority of Tn occurred at the same time. This is due to the fact that the majority of Tn appears at the end of the night, with a slow decrease of temperature.

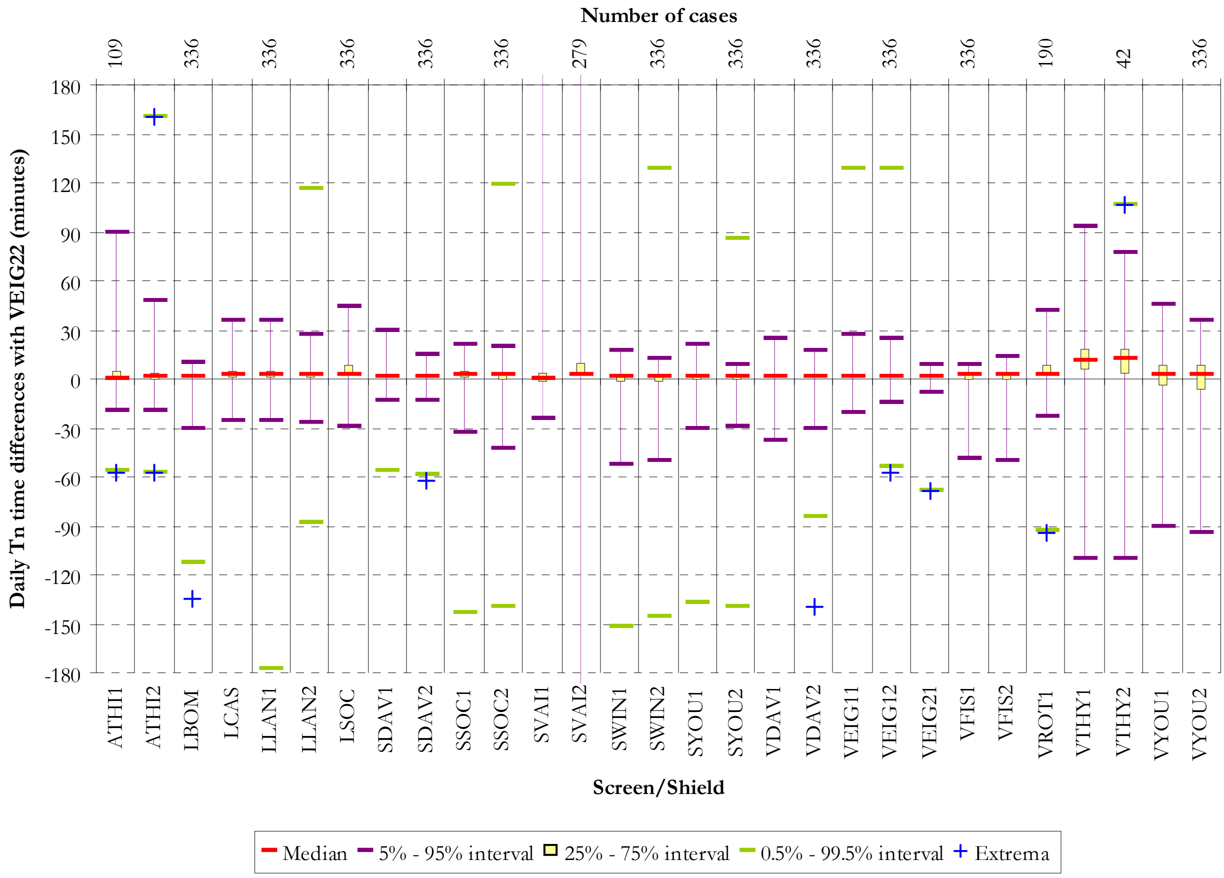


Figure 52. Distribution of the differences in the time of occurrence of daily minimum temperatures

5.4.2.6 Behaviour of all screens for low wind speeds

Figure 53 shows the distribution of temperature differences with the reference during clear days and wind speeds at 2-meter height below 2m/s (2-minute average), for the whole period of the intercomparison. In these cases the screens are more affected by high solar radiation in combination with low natural ventilation which could reveal a possible radiation error. A wind speed threshold of 1 m/s would be better, but the number of points would be too low. The analysis was done, and results were not so different.

The ATHI sensors are significantly colder than the reference by about 1℃. The VTHY screens are significantly warmer. Artificially-ventilated screens are not colder, as could be expected in such conditions. On the contrary, some small naturally-ventilated screens are colder than the reference: SDAV, SVAI.

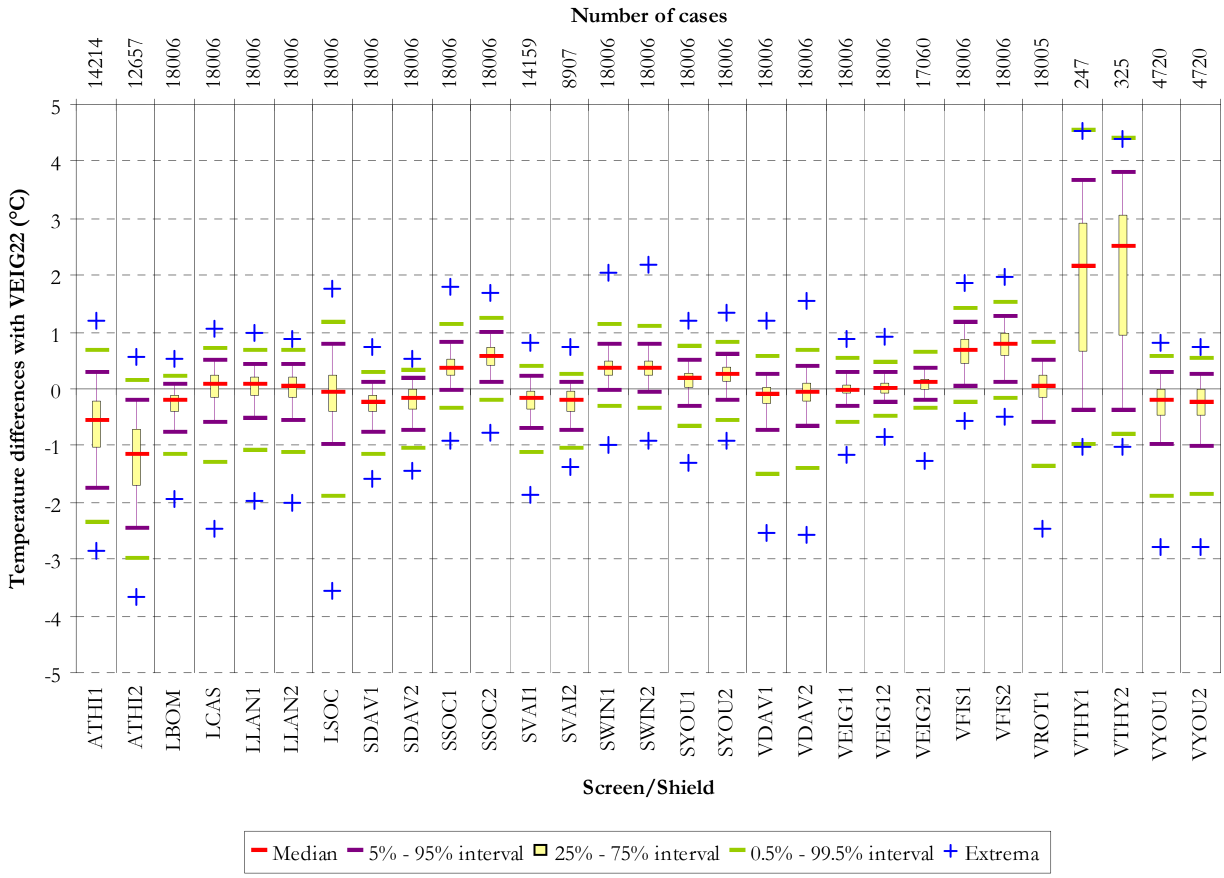


Figure 53. Temperature differences during clear days and wind speeds below 2m/s

5.4.2.7 Behaviour of screens during a sand blowing event

The complete study is available in annex 9.7.

5.5 HYGROMETERS

5.5.1 Choice of the reference

An Assmann Aspiration Psychrometer [8] could be used as a reference, but was not available in this intercomparison. The CIMO guide [5], section 4.4, considers that "the chilled-mirror hygrometer is used for meteorological measurements and as a reference instrument both in the field and in the laboratory". So, in previous meetings, the reference of humidity measurement was designated to be the Thygan from MeteoLabor. During the intercomparison it turned out that both Thygan sensors were not able to send valid measurements from May 2009 until the end of the measurement period (because of data acquisition system failure). Therefore only five months of reference data are available for analysis. As a consequence, Thygan sensors were used as a primary reference to choose another sensor as a working reference. This could be the sensor that gives the closest measurements to the Thygan during the first five months.

In order to choose the working reference, the measurements from both Thygan sensors are considered. They give very close results and so VTHY2 was selected as the primary reference as it gave a larger number of data.

From this point, the unit used to express a difference of relative humidity is "%", as it is in the CIMO guide. This is a difference expressed in % of RH. Therefore, a positive difference of 2% between one sensor and a reference measuring a relative humidity of 50%, means that this sensor has measured a relative humidity of 52%.

For each valid measurement, the differences between a given sensor (quality checked 1-minute values) and VTHY2 are computed. Figure 54 depicts the distribution of these differences. "Average 11 12" are the averages of UHMP11 and UHMP12 both being installed in the same screen VEIG1. "Average 21 22" represents the averages of UHMP21 and UHMP22 installed in screen VEIG2. These averages are computed only when the absolute difference between both measures is less than 1%.

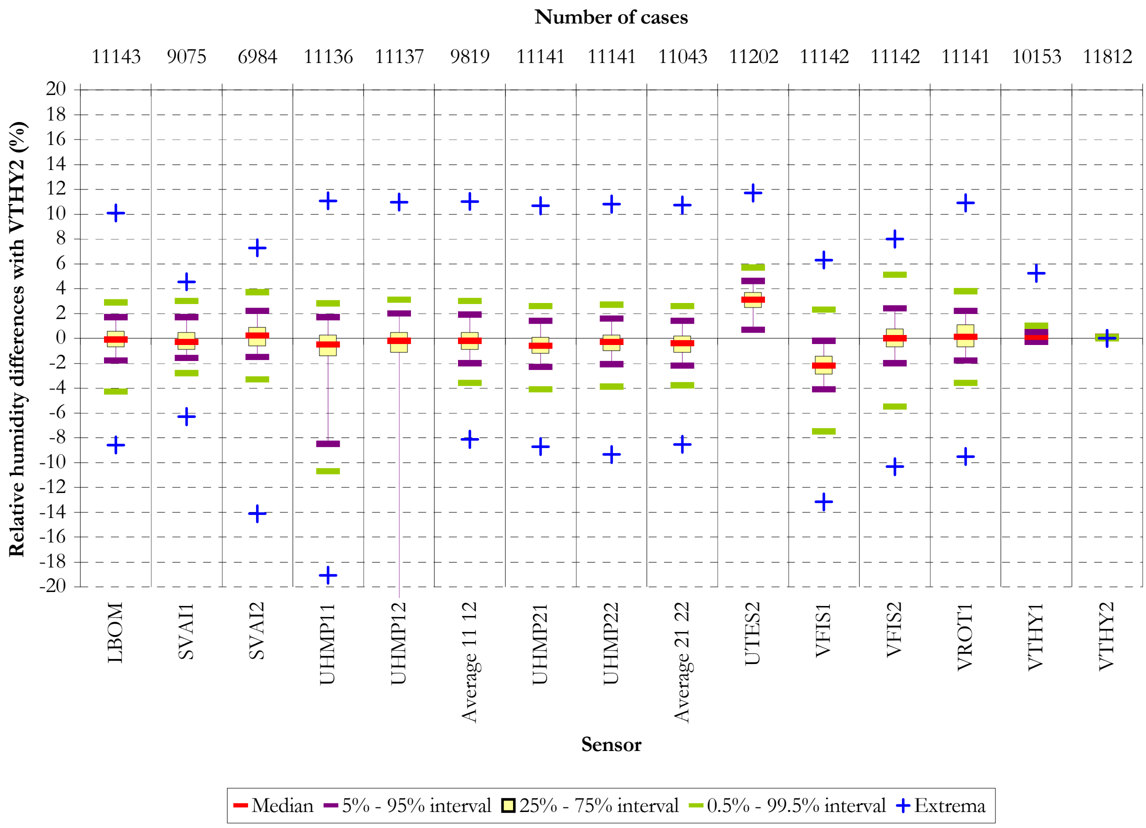


Figure 54. Distribution of differences with VTHY2 for all relative humidity sensors

Many sensors gave low differences with the Thygan, which is quite a good surprise. These sensors can not be chosen as a reference:

– LBOM because this probe was added in the intercomparison after the meeting in Ghardaïa (March 2007) and the results of the calibration performed before the intercomparison were not known. Nevertheless, this sensor gave quite good results!
– SVAI because they gave a low number of valid data (because of data acquisition system failure)
– UTES, VROT because differences with VTHY2 are quite scattered

For the above reasons the second working reference should preferably be chosen among the VFIS or UHMP sensors. UHMP sensors were selected, since two probes are installed in each of the VEIG screens. Under the condition that the difference between both probes is less than 1%, their average can be considered as a safe value. Probes in screen VEIG2 gave more data than those in screen VEIG1. Moreover, they are in the same screen than the temperature probe that was chosen for the temperature reference measurement.

Therefore it was decided that the second working reference for humidity measurements, after VTHY2, is processed by averaging UHMP21 and UHMP22, when their absolute difference is less than 1%. When the absolute difference was larger, data was discarded.

With these assumptions, the distribution of reference humidity measurements over the whole period of the intercomparison can be plotted (see figure 55).

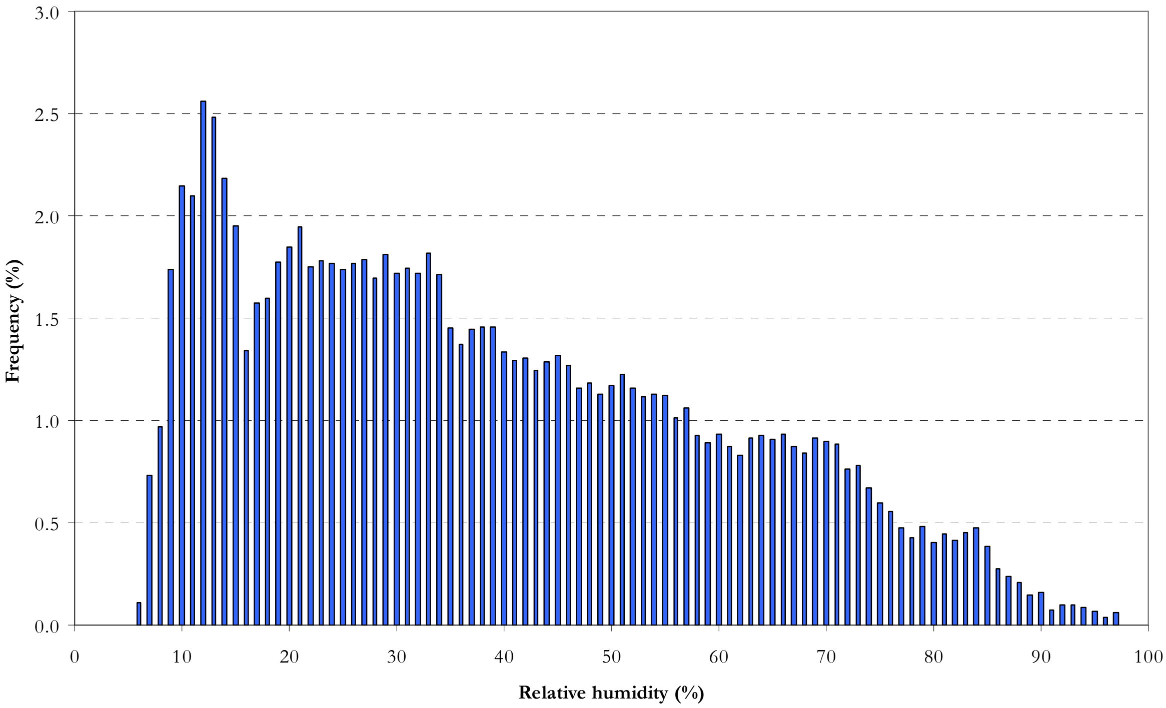


Figure 55. Distribution of relative humidity measured by the reference over the whole period of intercomparison

464168 values of the working reference (UHMP) are available over the period, out of the 525600 possible values, giving a data availability of 88.3%. These missing values are mainly explained by the fact that UHMP sensors had grounding problems during several days in May and October 2009. These erroneous data could easily be filtered out because every time when these problems occurred, both sensors differed by more than 1 %.

The minimum value of 5.6% was obtained on the 4th August 2009 at 15:03. The maximum value of 96.7% was measured on the 20th January 2009 at 08:22. The median humidity value is 34.2%.

The distribution of relative humidity against classes of temperature is plotted in figure 56. High values of relative humidity were obtained for low temperatures. Low values of relative humidity were obtained during hot periods.

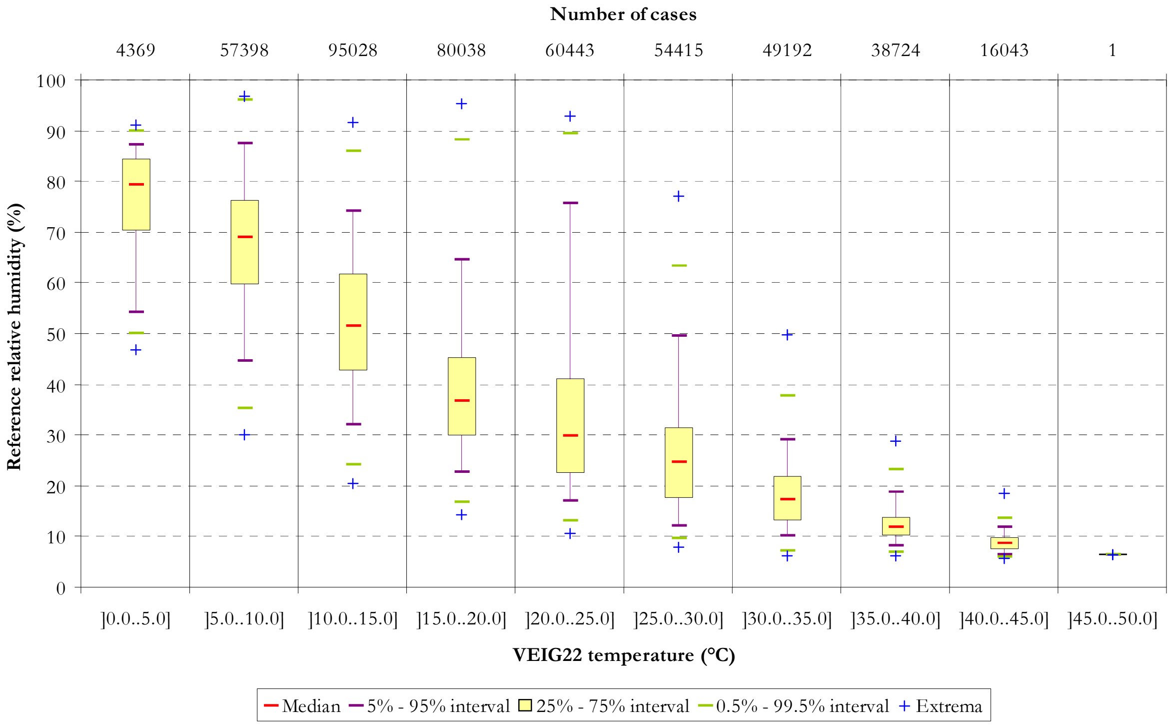


Figure 56. Distribution of relative humidity against temperature classes

5.5.2 Data analysis

This part includes general analysis for all relative humidity sensors. Detailed individual results are available in the datasheets.

5.5.2.1 Consequences of an overestimation of temperature on relative humidity

As screens/shields may induce errors on temperature measurements, it is relevant to estimate what would be the error on relative humidity if the temperature is overestimated by 1℃, for a given dew point.

According the CIMO Guide, the relative humidity *U* (in %) is defined by:

$$U(t,t_d,p) = 100\frac{e_w^{'}(p,t_d)}{e_w^{'}(p,t)}$$

where t is the air temperature, t_d is the dew point temperature, p is the atmospheric pressure and e'_w is the saturation vapour pressure with respect to water.

The error on relative humidity if there is an overestimation of 1℃ on temperature, for a given dew point is given by:

$$\Delta = U(t+1,t_d,p) - U(t,t_d,p) = U(t,t_d,p)\left(\frac{e_w^{'}(p,t)}{e_w^{'}(p,t+1)} - 1\right)$$

In addition, the saturation vapour pressure is given by the formula:

$$e_w^{'}(p,t) = \left(1.0016 + 3.15\cdot 10^{-6}\,p - \frac{0.074}{p}\right)\cdot 6.112e^{\frac{17.62t}{243.12+t}}$$

The figure 57 gives the result, for the atmospheric pressure of 950 hPa. This value is chosen because the atmospheric pressure varied from 943 to 975 hPa during the intercomparison period.

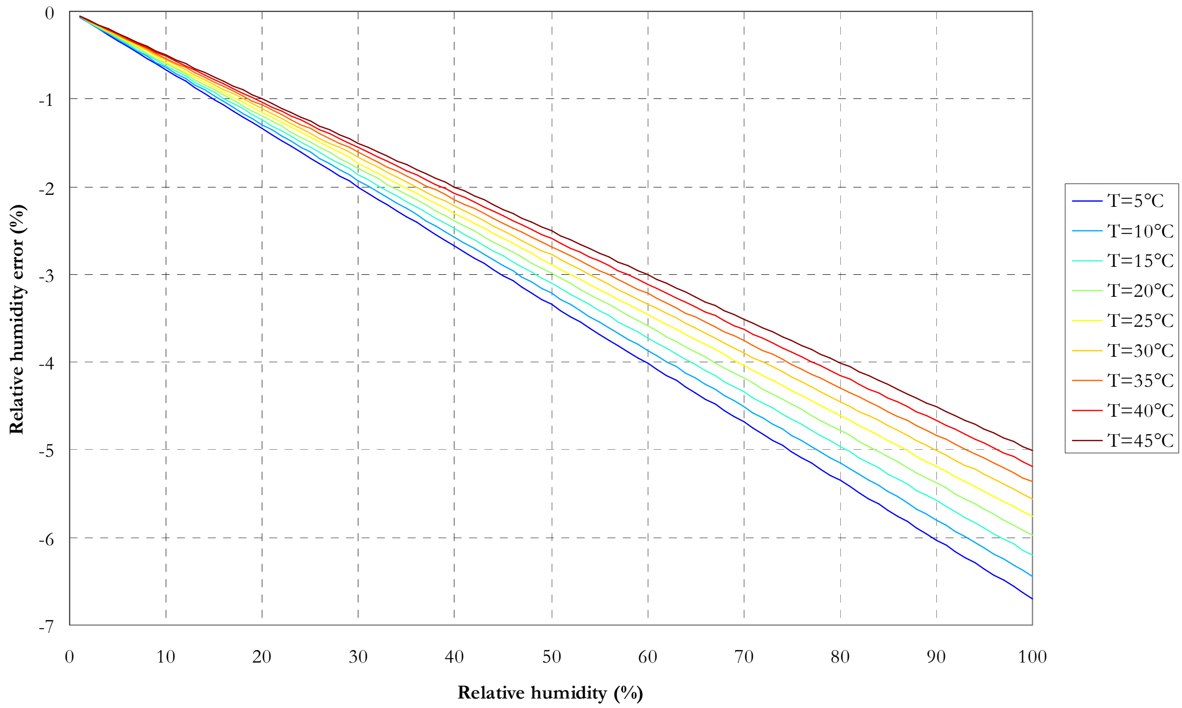


Figure 57. The error on relative humidity for an overestimation of temperature of 1℃

As expected, the influence of temperature is larger for high values of relative humidity: the relative humidity is 6% lower at saturation if the temperature is 21℃ instead of 20℃. For low values of humidity, an overestimation of 1℃ of temperature leads to an underestimation of humidity of about 1% at 45℃ and 15% of relative humidity.

Therefore, differences of temperature inside various screens may generate differences of relative humidity of few percents. But the detailed analysis of relative humidity shown in the datasheets did not exhibit many differences. This may be due to the fact that the larger differences in temperature occurred during periods of high solar radiation, which occurred with low values of relative humidity. The influence of an error of temperature is reduced to 2 or 3% in such conditions.

5.5.2.2 Method of data analysis and first results

For each sensor, its mode and its mean (most frequent value) are plotted, for both working references (cf figure 58 and figure 59). For most sensors the differences are symmetric about zero without a bell shape. The graphical representation is not symmetrical for sensors UTES2, VFIS1.

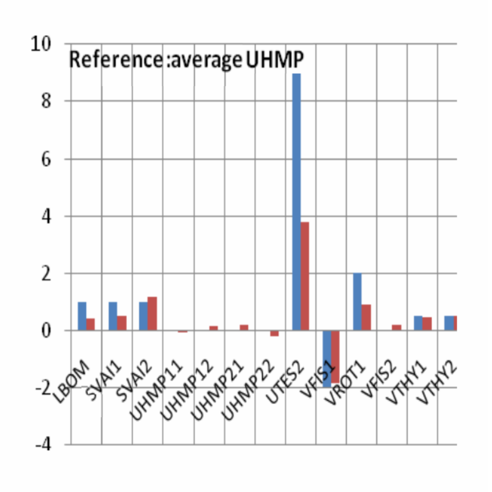


Figure 58. Diagram with UHMP reference

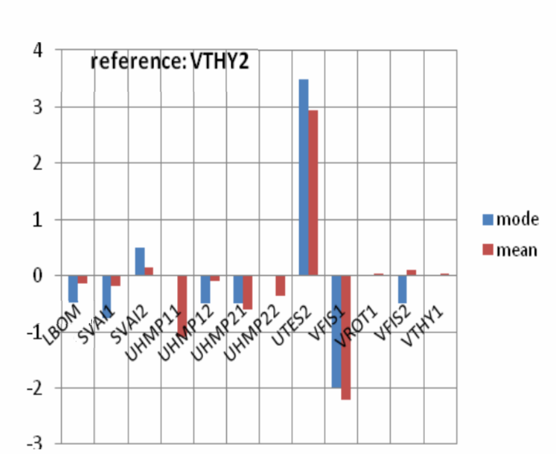


Figure 59. Diagram with VTHY2 reference

5.5.2.3 Distribution of differences with UHMP2 reference

For each valid measurement, the differences between a given sensor (quality checked 1-minute values) and UHMP2 are computed. The figure 60 shows the distribution of these differences.

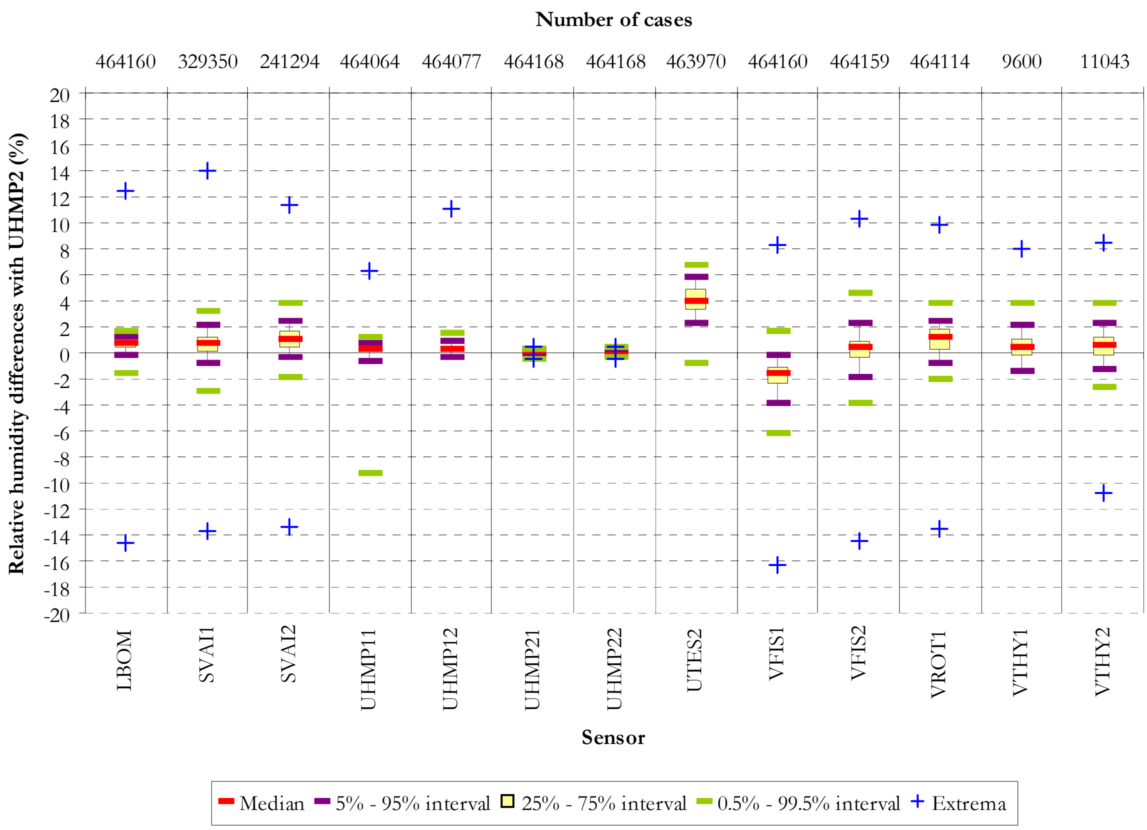


Figure 60. Distribution of differences with UHMP2 reference

5.5.2.4 Behaviour of sensors for very low values of relative humidity

The figure 61 shows the distribution of differences with UHMP2 when the reference relative humidity is below 20% and the temperature is above 30℃.

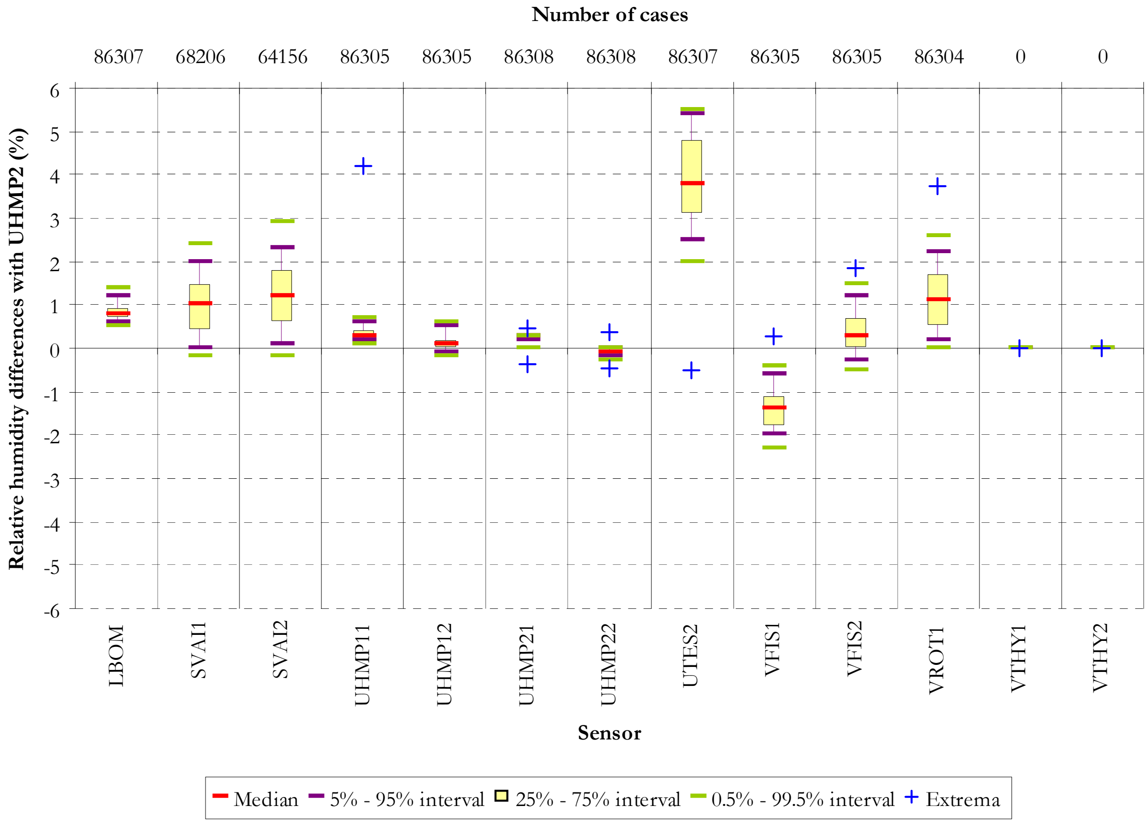


Figure 61. Distribution of differences for relative humidity below 20%

6 CONCLUSIONS

6.1 GENERAL

- Despite the difficulties encountered, the intercomparison was successful.
- The Ghardaïa Intercomparison experienced problems in its schedule, due to customs constraints and electrical grounding problems at the beginning.
- The data acquisition software and system for sensors with a numerical output experienced some problems, leading to gaps in the dataset.
- Nevertheless, over the 12 months period of the intercomparison, more than 500 000 minutes of data are available for the majority of screens and hygrometers, allowing a deep data analysis.

6.2 SCREENS

- Some uncertainties exist concerning the efficiency of the artificial ventilation of some screens, which might not have been working correctly.
- The Eigenbrodt LAM630, a multi-plate screen with artificial ventilation, was selected as a working reference, but was warmer than some other screens in case of high solar radiation and low wind speed. This shows that this screen, though selected as the working reference, also suffers from some radiation error.
- The air temperature calculated from the Thies ultrasonic anemometers was much colder than all other screens, the absolute difference increasing with solar radiation and decreasing with the wind speed. This indicates that this instrument could be less influenced by radiation than the screens, and thus could be a good candidate for use as a reference. However, a systematic difference between the two sensors, ranging from 0.4 to 0.7℃ with some scattering, shows either a calibration problem or a principle limitation of the system for measuring air temperature. Due to these issues, this sensor was not used as a reference.
- The group of four large Stevenson type screens provided very good results. They reacted slower than the working reference, though the BoM design exhibited a surprisingly fast response (in comparison to its size).
- Some small passive multi-plate screens exhibited warmer temperatures than the reference (~0.5℃). Two had results close to the reference. One model, the DAVIS 07714, gave surprisingly good results, with colder measurements than the reference in case of solar radiation. This result of DAVIS is surprising because past intercomparisons in other environments did not exhibit so good results in some other tests, done by individual members.
- Other artificially ventilated screens gave disappointing results, with quite warm temperatures in case of solar radiation. This may be due to their design and/or some faults in the ventilation during the test (dust and sand reducing the ventilation efficiency). For example, the ventilated DAVIS gave worst results (warmer temperatures during day) than the passive DAVIS, which was not expected.
- A summary of the performances found during the intercomparison is given in table 7. A rating of the performances, in comparison to the working reference, seen during this intercomparison is proposed, ranging from one star (*) to five stars (*****). The rating principles are given in annex 9.8.
- The working reference was found to be warmer than some other screens during high solar radiation and low wind speed, showing that this working reference was not the

"best" screen in all circumstances. Therefore the rating in comparison to the working reference is also completed by an additional and more "absolute" rating, taking into account the characteristics of the reference screen itself.

Table 7. Global results for screens

Acronym	Screen name	Consistency between screens	System time response compared to the reference	Radiation error	% within ± 0.5℃ of the reference	Comment	Comparison with the working reference (VEIG)	More "absolute" Rating
LSOC	Socrima, abri grand modèle	NA	slower	0.2℃ colder, downto 0.5℃ for high GR and low WS	94% T 99% TN 87% TX	Globally colder. Warmer only during day and high WS	****	****
LBOM	BOM	NA	slower	0.2℃ colder, downto 0.5℃ for high GR and low WS	96% T, TX 98% TN	Globally cooler than the reference, low dispersion of differences.	*****	*****
LLAN	Lanser	± 0.2℃	slower	0.2℃ warmer for low and medium GR. 0.2℃ colder for high GR and low WS	98% T, TX 97% TN	Close to the reference with both colder and warmer T°	*****	****
LCAS	Casella, Stevenson screen	NA	slower	0.2℃ warmer for low GR and low WS	96% T, TN > 99% TX	Close to the reference. No day-night and clear sky-overcast differences	*****	****
SSOC	Socrima BMO 1195	± 0.4℃ with a systematic 0.2℃ difference	slower	0.5℃ warmer with maximum for medium GR	80% T 98% TN 62 - 92% TX	Low influence of WS on radiation error	***	***
SVAI	Vaisala DTR13	± 0.5℃	faster for T↓ slower for T↑	0.3℃ colder for high GR 0.1℃ warmer for other GR	95% T 76% TN 85% TX	Colder for high GR and low WS	***	****

Acronym	Screen name	Consistency between screens	System time response compared to the reference	Radiation error	% within ± 0.5℃ of the reference	Comment	Comparison with the working reference (VEIG)	More "absolute" Rating
SWIN	Windspeed T351-PX-D3	± 0.3℃	slower for T↓ faster for T↑	0.4℃	92% T 98% TN 60% TX	Warmer than the reference during day, with no influence of the WS	***	***
SDAV	Davis 07714	± 0.3℃	faster	0.2℃ colder, down to 0.5℃ colder for high GR and low WS	97% T >99% TN 99% TX	Surprisingly good results for a low cost screen. Better than the VDAV	*****	*****
SYOU	Young 41003	± 0.3℃	slower for T↓ = for T↑	~0.2℃ Colder for high GR and low WS	97% T >99% TN 92% TX	0.2℃ warmer than the reference during day	****	***
VFIS	Fisher 439102	± 0.3℃	slower	up to 1℃	70% T >99% TN 30% TX	Radiation error decreases with increasing WS. Fan ventilation OK	**	**
VEIG	Eigenbrodt LAM 630	± 0.2℃	= reference	= reference	>99% T, TN ~98% TX		*****	****
VTHY	Thygan VTP37	± 0.1℃		up to 2℃	~50% T, TN <3% TX	Unexpected results : flow rate of the ventilation reduced ?	**	*
VROT	Rotronic RS12T	NA	slower	up to 1℃	85% T, TX 97% TN	Cooler than the reference for low WS, warmer for high WS	***	***

Acronym	Screen name	Consistency between screens	System time response compared to the reference	Radiation error	% within ± 0.5℃ of the reference	Comment	Comparison with the working reference (VEIG)	More "absolute" Rating
VDAV	Davis 07755	± 0.2℃	slower for T↓ faster for T↑	up to 1℃	90% T 99% TN 85% TX	Cooler than the reference for low WS, warmer for high WS	***	***
VYOU	Young 43502	± 0.2℃	slower for T↓ faster for T↑	0.6 ℃ colder for low WS, up to 0.7℃ warmer when WS increases above 3 m/s.	90% T 100% TN 91% TX	No ventilation the first 11 months. Analysis only over the last month	****	****
ATHI	THIES CLIMA Ultrasonic anemometer 2D	± 0.3℃ with a systematic 0.5℃ difference		up to 2℃ colder	60% T, TN 30-60% TX	Much colder than the reference. Differences decrease when WS increases	**	**

6.3 HYGROMETERS

- The Meteolabor VTP37 (Thygan) chilled mirror hygrometer was the preferred reference chosen by the IOC. But after an electric overload, no data were available since May 2009.
- Therefore a second working reference was defined as the mean value of two HMP45D hygrometers installed inside the Eigenbrodt screen. This working reference was available during the whole period.
- Five (5) models gave very good results over the test period, with no drift (< 0.5%) and more than 98% of values within ± 3% of the reference. These results are much better than what could be expected from the current knowledge about the state of the art. In addition to the "quality" of the sensors, an explanation may be the dry conditions mainly experienced during the intercomparison. Only few events of high RH close to saturation were encountered.
- Two (2) models gave medium results with deviations up to 4%.
- One (1) model gave poor results with deviations up to 12%.
- In principle, if the temperature inside the screen with an installed hygrometer is different from the temperature of the screen of the reference, an influence of several % (up to 6% close to saturation) should occur on the RH measurement. Though significant differences of temperature were seen between screens, no clear influence on the RH values was detected.
- A summary of the performances found during the intercomparison is given in table 8. A rating of the performances, <u>in comparison to the working reference and the Thygan</u>, seen during <u>this intercomparison</u> is proposed, ranging from one star (*) to five stars (*****). The rating principles are given in the annex 9.8.

Table 8. Global results for hygrometers

Acronym	Hygrometer name	Screen	Consistency between hygrometers	Annual drift	Influence of temperature (5°--> 45℃)	Influence of RH (5% --> 100%)	% within ± 3% of the reference	Comment	"Quality" of the hygrometer
LBOM	Vaisala HMP45	BOM	NA	< 0.5%	no influence	no influence	98% Thygan 99.7% UHMP2	HMP45 delivered and calibrated by BOM in 2007. Same type than UHMP2.	*****
VFIS	Fisher&co 431411	Fisher	dispersion < 1% around differences of about 2.5%	< 0.5%	5%	4%	80% sensor 1 96% sensor 2	Sensor 1 drier by 2%	**
SVAI	Vaisala HMT337	Vaisala HMT330 MIK	± 1.5%	< 0.5%	< 2%	< 2%	98.5%		****
UHMP	Vaisala HMP45	Eigenbrodt/LAM630	± 1%	< 0.5%	no influence	no influence	98% Thygan 99.6% UHMP2	Same type than UHMP2. ~2% drier than Thygan above 85% RH	*****
UTES	Testo AG 63379742	Small Socrima	NA	~1.5 %	~3%	~2%	52% Thygan 18% UHMP2	Over-estimation of about 4%, not consistent with laboratory and site calibration	**
VTHY	Meteolabor VTP37	Meteolabor VTP37	± 0.5%	NA	no influence	no influence	98% UHMP2		*****
VROT	Rotronic AG/C94	Rotronic RS12T	NA	< 0.5%	2%	4%	98%	Output of sensor 2 not recognized	****

7 RECOMMENDATIONS

1. In desert conditions, non-aspirated, naturally ventilated radiation shields or weather screens may perform better. Aspirated screens using fans tend to be blocked in dusty or sandy environments and may need more frequent maintenance.
2. It is recommended that further investigation be conducted on the potential of using ultrasonic devices, such as sonic anemometers, as temperature reference systems for screen intercomparisons.
3. Manufacturers of artificially ventilated radiation shields are recommended to provide a clear indication (e.g. a LED light) of the fan status directly at the screen or its control unit, or the datalogger. This would allow maintenance staff to check whether the fan is functioning properly by visual inspection. Additionally the fan status and preferably the fan speed should be provided in the data output for automatic monitoring purposes.
4. CIMO and manufacturers should aim for a standard laboratory test method to determine the radiation error of weather screens and radiation shields. From the result of this intercomparison, the proposal is to evaluate the radiation error for a maximum global radiation of 1000W/m^2 and a wind speed of 1m/s. This could stimulate improvements in screen design and provide valuable information prior to field intercomparisons.
5. Field Intercomparisons of humidity sensors should use a condensation hygrometer as reference system that measures the dew point (or frost point) directly. If several screens are used in an intercomparison of humidity sensors, temperature differences can have an influence on the measured relative humidity values.
6. Field Intercomparisons of humidity sensors should be performed by using one type of screen for all sensors. Whenever possible several humidity sensors should be installed in one screen in order to provide nearly the same air temperature for all tested sensors.
7. Manufacturers of humidity probes should provide a clearly represented quick installation guide (or card) to assist the user in the first phase of operation.
8. It is recommended for future intercomparisons to separate the data acquisition of sensors planned to be used as references (at least cabling, if possible the acquisition system itself): if a failure occurs on one sensor, it should not affect another sensor.
9. For future intercomparisons, it should be planned to have an on-site meeting, shortly after the official beginning of the intercomparison, to check on site all the instruments, data acquisition system and procedures, preferably with all the participants wishing to participate and to check their instruments.
10. For future intercomparisons it should be planned to have at least two meetings for each intercomparison: one meeting before the start of the intercomparison and one after it for finalizing the intercomparison report. This is necessary to provide the final report promptly. Even an extensive use of telephone conferences cannot replace direct communication.
11. Some of the well-performing screens in this intercomparison should also be used in a possible follow up intercomparison of thermometer screens and humidity measuring instruments in arctic regions to have a link between both experiments.
12. In the CIMO guide a clear distinction should be made between percentages of relative humidity and percentages as an expression for any other quotient.

8 REFERENCES

[1] WMO Final Report of the first session of the CIMO Expert Team Meeting SBII&CM, Trappes (France), 24-28 November 2003

[2] WMO Final Report of the second session of the CIMO Expert Team Meeting SBII&CM, Geneva (Switzeland), 5-9 December 2005

[3] WMO Final Report of the forth (reduced) session of the CIMO Expert Team Meeting SBII&CM, Ghardaïa (Algeria), 19-23 March 2007

[4] ISO 17714:2007 Standard: Meteorology - Air temperature measurements - *Test methods for comparing the performance of thermometer shields/screens and defining important characteristics*, 2007

All the WMO reports are available at this page:
http://www.wmo.int/pages/prog/www/IMOP/reports.html

[5] Guide to Meteorological Instruments and Methods of Observation ("CIMO Guide"), WMO publication n°8, 7th edition, 2008, available at: http://www.wmo.int/pages/prog/www/IMOP/publications/CIMO-Guide/CIMO Guide 7th Edition, 2008/CIMO_Guide-7th_Edition-2008.pdf

[6] WMO Final Report of the forth session of the CBS-IOS Expert Team on the Requirements for Data from Automatic Weather Stations, Geneva (Switzeland), 20-24 March 2006, available at:
http://www.wmo.int/pages/prog/www/CBS-Reports/IOS-index.html

[7] Tammelin, B., Heimo, A., Leroy, M., Rast, J. and Säntti, K., 2001. Meteorological measurements under icing conditions - EUMETNET SWS II project. Reports 2001:6. Finnish Meteorological Institute. 52 p.

[8] World Meteorological Organization, 1989*a*: *WMO Assmann Aspiration Psychrometer Intercomparison* (D. Sonntag). Instruments and Observing Methods Report No. 34, WMO/TDNo. 289, Geneva.

[9] World Meteorological Organization, 1998*a*: *Recent Changes in Thermometer Screen Design and their Impact* (A. Barnett, D.B. Hatton and D.W. Jones). Instruments and Observing Methods Report No. 66, WMO/TD-No. 871, Geneva.

[10] World Meteorological Organization, 1989*b*: *WMO International Hygrometer Intercomparison* (J. Skaar, K. Hegg, T. Moe and K. Smedstud). Instruments and Observing Methods Report No. 38, WMO/TD-No. 316, Geneva.

[11] Lanzinger E., Langmack H., *Measuring Air Temperature by using an Ultrasonic Anemometer*, Poster presented at TECO-2005, Bucharest, Romania, available at:
http://www.wmo.int/pages/prog/www/IMOP/publications/IOM-82-TECO_2005/Posters/P3(09)_Germany_4_Lanzinger.pdf (in World Meteorological Organization, 2005: Instruments and Observing Methods Report No. 82, WMO/TD-No. 1265, Geneva).

9 ANNEXES

9.1 QUESTIONNAIRE 1

WORLD METEOROLOGICAL ORGANIZATION

QUESTIONNAIRE I

to potential participants

of the WMO Combined Intercomparison of Thermometer Screens/Shields

in Conjunction with Humidity Measuring Instruments

Ghardaïa**,** Algeria

1. Member Country: ……………………………………………………………………………..
2. Expert (point-of-contact) for the intercomparison:
   Name, First Name:……………………………………………………………………………..
   Address: ……………………………………………………………………………………….
   Tel./Fax: ……………………………………………………………………………………….
   E-mail: …………………………………………………………………………………………
3. Basic information on the humidity sensor or screen/shield foreseen in the intercomparison: (1), (2)
   Thermometer screen/shield natural ventilated [ ]
   Thermometer screen/shield artificially ventilated [ ]
   Humidity sensor [ ]

3.1 Short description of the proposed humidity sensor or screen/shield:

……
……
……
……

3.2 Type of the humidity sensor or screen/shield:

a) Model/Type:……………………………………………………………………………
b) Manufacturer:………………………………………………
   Country:…………………………………
c) Number of sites where the sensor or screen/shield is in operational use or is intended to be in your country: ………………………………………………………………………………………………………
d) Will you submit **one [ ]** or **two [ ]** identical instruments (2), (3)

3.3 Detailed information on the sensor or screen/shield:

3.3.1 **Thermometer screen/shield**:

- Performance characteristic (operating range): ……………………..………………
- Estimated radiation error:…………………………………………………………………
- Material used (construction):……………………………………………………………….
- Aspiration rate (in case of artificially ventilated screen/shield):……………………
- Suitable for the described temperature probe(4) [ ] or must be used with a particular type [ ] (2)
  - If only for a particular, please specify the sensor or limits:

……………………………………………………………………………………………
……………………………………………………………………………………………
……………………………………………………………………………………………

- Suitable for any type of humidity sensor [ ] or only a particular type [ ] (2)
  - If only for a particular, please specify the sensor or limits:
    ……………………………………………………………………………………………
    ……………………………………………………………………………………………
    ……………………………………………………………………………………………

3.3.2 **Humidity sensor:**

- Parameter reported: Relative humidity [ ] Dew-point temperature [ ] (2)
- Principle of measurement:…………………………………………………………………
- Measuring range:……………………………………………………………………………
- Performance characteristic (operating range): …………………………………………
- Uncertainty: …………………………………………………………………………………
- Time constant:………………………………………………………………………………
- Resolution:……………………………………………………………………………………
- Long-term stability:…………………………………………………………………………
- Sampling interval (internal or recommended):……………………………………………
- Averaging interval (internal or recommended):……………………………………………
- Time resolution (if applicable):………………………………………………………………
- Output averaging time (if applicable): ………………………………………………………

____________________ ___________________________________

Date Signature of the Permanent Representative

NOTES:

Further information on organizational and technical issue for the preparation of the intercomparison will be distributed in due course to the experts designated by you, as appropriate.

It is intended to calibrate the temperature probes and the humidity sensors in laboratory before and after the intercomparison. Meteo-France offered to do this calibration in its laboratory in Trappes (near Paris). Nevertheless, the sensors must be calibrated and adjusted by the manufacturer or the member country proposing the sensors.

(1) In case it is intended to submit more types of sensors, attach another completed copy(ies) of this questionnaire.

(2) Please tick the appropriate box.

(3) To achieve more confidence in the results, preferences will be given to testing of two identical instruments; however this is not a condition for participation.

(4) For the intercomparison of the screens, it is preferred to use the same type of temperature probe. Meteo-France (MF) has offered calibrated temperature probes, with characteristics given in the Attachment. Such a probe will be used in each screen with which it is compatible. Therefore, the compatibility between the MF probe and the proposed screen must be indicated. If there is any reason for not

using the MF probe (size, probe characteristics, calibration uncertainty, etc., this should be indicated.

Please return the completed questionnaire, as soon as possible,
but not later than **17 April 2006** to the WMO Secretariat, to the attention of:

Dr Miroslav Ondráš

Senior Scientific Officer, Observing System Division

World Weather Watch Department

P.O. Box 2300

1211 Geneva 2, Switzerland

Tel.: +(41 22) 730 8409

Fax: +(41 22) 730 8021

E-mail: mondras@wmo.int

Attachment to Questionnaire I

Pt100 temperature sensor used by Meteo-France
for air temperature measurements in the operational network

Technical parameters

Measuring range: - 40 ℃ to + 60 ℃.

Uncertainty: ± 0.1 ℃.

Metallic sheathed cable (4 wires) silver-welded on sensitive part. Cable length: 5 m.

Sense current must not exceed 3 mA (AC efficient current).

Metrology

Platinum wire resistance is equal to:

92.16 ± 0.04 ohms at - 20 ℃

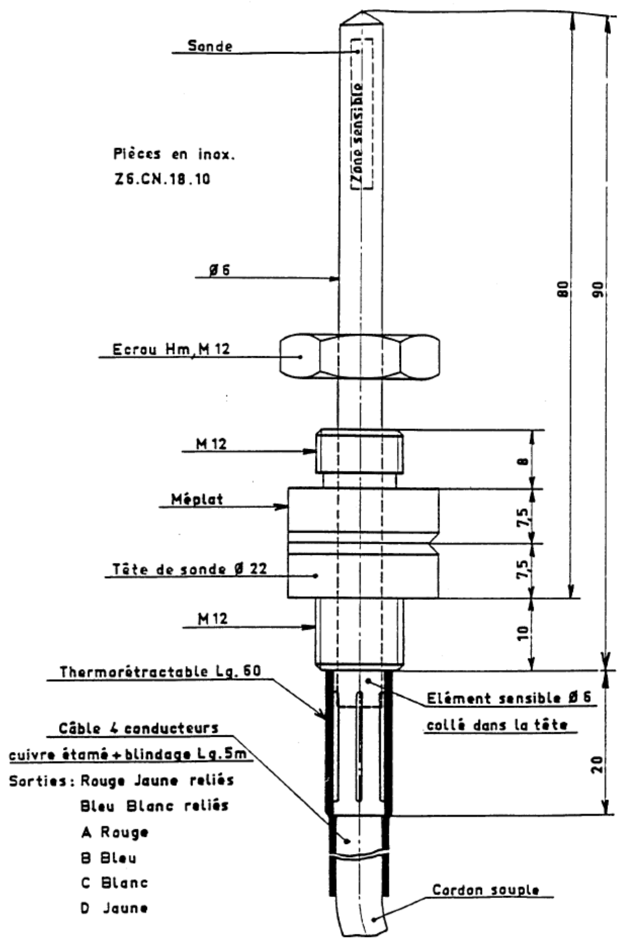
100.00 ± 0,03 ohms at 0 ℃

107.79 ± 0.04 ohms at + 20 ℃

115.54 ± 0.04 ohms at + 40 ℃.

For the intercomparison, the probes will be selected to fall in these limits, equivalent to ± 0.1 ℃.

Technical diagram (all dimensions are in mm)



9.2 QUESTIONNAIRE 2

WORLD METEOROLOGICAL ORGANIZATION

QUESTIONNAIRE II

Addressed to Selected Participants of the

WMO Combined Intercomparison of Thermometer Screens/Shields,

in Conjunction with Humidity Measurements, in Various Climatic Regions,

Ghardaïa, Algeria, January - October 2007

Note: Please complete a separate questionnaire for each type of Sensor.
If necessary, attach additional pages.

Electronic version of the Questionnaire is available at:
http://www.wmo.int/web/www/IMOP/intercomparisons.html

1.	Member country

2.	Name of participating institution/company
	Address

3.	Person responsible for the intercomparison	
	Surname	First name
	Tel.:	Fax:
	E-mail:	Other:

4.	Alternative contact person	
	Surname	First name
	Tel.:	Fax:
	E-mail:	Other:

5.	Name of manufacturer *(if different from no above)* same ☐ different ☐
	Address

6.	**Shipment of participating instruments**	
	Approx. commercial value Euro	Total weight of consignment kg
	Number of boxes	Overall volume of boxes cm^3
	Overall dimension, in cm (i.e. for storage purposes) Length x Width x Height cm	
	Other information concerning shipping	

7.	**Instrument specifications** *Please enclose in a separate sheet a diagram showing, preferably, the different elements (photos are welcomed).* ***Please supply a technical documentation to allow the best evaluation by the organizer of all the constraints related to the installation, data acquisition and calibration.*** ***Please indicate a representative point of the sensor or screen/shield.***	
	Instrument name	Model/Type
	Number of sites where the instrument is in operational use or intended to be in your country:	Could you submit One ☐ or Two ☐ identical instruments? (Two identical instruments are preferred - one as backup.)
	Principle of operation:	

8.	**Information for field installation**	
	Notes on the power supply: Sensors should be able to operate on 220V AC, 50 Hz or unregulated 12V DC (if power supply is necessary); *For other voltages, converters must be provided.*	
	Overall dimensions of the instrument, in cm Length x Width x Height cm	Total weight kg
	Power supply/Voltage required	Maximum total power consumption (watts)

9.	**Sensor siting requirements**	
	Installation alignment required Yes ☐ No ☐	
	Maximum distance to the data logger m	Cable length m
	Will an expert from the Member country assist with the installation of the Sensor Yes ☐ No ☐	
	Will an installation tools kit accompany the shipment? Yes ☐ No ☐	
	Any special tools required for the installation? Yes ☐ No ☐ Please describe	

11.	**Calibration**
	Calibration reference
	Recommended calibration intervals
	Procedure

12.	**Sensor Output**			
	Analogue		Yes ☐ No ☐	Voltage or current
	Digital	RS232	Yes ☐ No ☐	
		Other	Yes ☐ No ☐	Please specify
	Or propose and clearly describe an interface for data acquisition			

13.	**Any other relevant information**

Date

Name of person who completed this form

Please return an electronic copy the completed questionnaire, as soon as possible, but not later than **14 July 2006** to:

Dr Miroslav Ondráš

Senior Scientific Officer, Observing System Division

World Weather Watch Department

P.O. Box 2300

1211 Geneva 2, Switzerland

Tel.: +(41 22) 730 8409

Fax: +(41 22) 730 8021

E-mail: mondras@wmo.int

9.3 LIST OF SELECTED INSTRUMENTS

Member country	Manufacturer	Type	Number	Acronym
Algeria	Socrima	Large Stevenson Screen	1	LSOC
Australia	BoM	Small Stevenson screen	1	LBOM
Austria	Lanser		2	LLAN
France	Socrima	BMO1195D	2	SSOC
Germany	Fischer	431411	2	VFIS
Germany	Vaisala	HMT337 & HMT 330 MIK	2	SVAI
Germany	Eigenbrodt / Vaisala	HMP45D / LAM630	2	VEIG UHMP
Germany	Testo	AG/63379742	2	UTES
Italy	CAE	TU20AS	2	SCAE
Sudan	Casella	Stevenson Screen	1	LCAS
Switzerland	Meteolabor	Thygan VTP37 Airport	1	VTHY
Switzerland	Meteolabor	Thygan VTP37 Thermohygrometer	1	
Switzerland	Rotronic	AG/RS12T & Hygroclip S3	2	VROT
UK/HMEI	Windspeed	T351-PX-D/3	2	SWIN
USA	Davis	PN7714	2	SDAV
USA	Davis		2	VDAV
USA/HMEI	Young	41003	2	SYOU
USA/HMEI	Young	43502	2	VYOU

9.4 CALIBRATION INFORMATION

9.4.1 Temperature calibrations by Meteo-France

Installed in screen	Serial Number of the probe	Calibration date	Temperature (°C)			
			-20	0	20	40
LCAS	T77	24-Jan-2006	0.0146	-0.0175	-0.0411	-0.0632
LLAN1	T79	24-Jan-2006	0.0227	-0.0032	-0.0263	-0.0408
LLAN2	T70	1-Feb-2006	0.0100	-0.0184	-0.0382	-0.0542
LSOC	T47	30-Jan-2006	0.0558	0.0286	0.0066	-0.0112
SDAV1	UT68	3-May-2004	0.0850	0.0450	0.0160	-0.0120
SDAV2	UT46	1-Apr-2004	0.0590	0.0200	-0.0080	-0.0380
SSOC1	T44	30-Jan-2006	0.0160	-0.0124	-0.0319	-0.0473
SSOC2	T45	9-Feb-2006	0.0337	0.0072	-0.0113	-0.0267
SYOU1	T53	3-Feb-2006	0.0246	-0.0032	0.0216	-0.0346
SYOU2	T51	7-Feb-2006	0.0304	0.0031	-0.0131	-0.0261
VDAV1	772	6-Jan-2006	0.0827	0.0544	0.0299	0.0087
VDAV2	728	10-Jan-2006	0.1022	0.0756	0.0522	0.0216
VEIG11	T49	9-Feb-2006	0.0273	-0.0022	-0.0230	-0.0383
VEIG12	T74	26-Jan-2006	0.0019	-0.0247	-0.0439	-0.0598
VEIG21	T64	3-Feb-2006	0.0520	0.0201	-0.0047	-0.0268
VEIG22	T73	26-Jan-2006	0.0230	-0.0057	-0.0297	-0.0477
VYOU1	T54	7-Feb-2006	0.0241	-0.0030	-0.0189	-0.0307
VYOU2	T55	1-Feb-2006	0.0157	-0.0128	-0.0294	-0.0435

Sensor	Calibration date	Calibration temperature (°C)			
		-20	0	20	40
Tground	27-Jul-2004	0.0520	0.0490	0.0540	0.0620
T@10cm	24-Jan-2006	-0.0262	-0.0520	-0.0695	-0.0839
T@50cm	24-Jan-2006	0.0207	-0.0110	-0.0343	-0.0541

9.4.2 Temperature calibrations by manufacturers

Screen	SN	Calibration date	Temperature (°C)				
			-20	0	20	22	40
SVAI1	B494000	4-Jan-2007				-0.04	

Screen	SN	Calibration date	Temperature (℃)				
			-20	0	20	22	40
	9						
SVAI2	B4940010	4-Jan-2007				-0.04	
SWIN1	1398	14-Mar-2007	0.0145	-0.0335	-0.0727		-0.1070
SWIN2	1397	14-Mar-2007	0.0148	-0.0381	-0.0825		-0.1232
VFIS1	188	19-Apr-2007			0.2		
VFIS2	189	19-Apr-2007			0.1		
VTHY1	338	1-Jun-2005				-0.03	
VTHY2	339	1-Jun-2005				-0.05	

9.4.3 Relative humidity laboratory calibrations by Météo-France

Sensor	Calibration date	T=23℃					T=40℃				
		10%	33%	55%	75%	90%	10%	33%	55%	75%	90%
SVAI1	12-Feb-2007	0.3	-0.7	-0.4	-1.1	-2.6	0.3	0.8	3.7	-2.3	2.2
SVAI2	12-Feb-2007	-0.2	0.3	-0.5	-0.9	-1.3	0.3	0.6	0.5	0.4	0.9
UHMP11	09-Jan-2007	0.0	1.8	0.9	0.9	2.0	0.5	2.3	1.0	0.9	1.5
UHMP12	09-Jan-2007	-0.3	1.4	0.3	0.5	1.7	0.0	2.3	1.6	2.1	3.1
UHMP21	09-Jan-2007	-0.1	1.7	1.0	1.0	2.1	0.5	2.8	2.2	2.7	3.5
UHMP22	09-Jan-2007	-0.3	1.7	0.6	0.6	1.8	0.2	2.4	1.6	1.8	2.8
UTES1	22-Dec-2006	-0.6	-0.4	-0.2	0.7	1.4	-0.8	-0.8	-1.1	0.0	1.2
UTES2	22-Dec-2006	-0.2	0.2	0.5	1.2	1.9	-0.4	-0.4	-0.5	0.6	1.4
VROT1	08-Mar-2007	-1.7	-0.1	0.7	0.7	1.3	-0.7	0.1	0.7	1.3	3.1
VROT2	08-Mar-2007	-1.4	0.0	0.6	0.9	1.2	-0.5	0.1	0.7	1.1	2.7

9.4.4 Relative humidity laboratory calibrations by manufacturers

Sensor	Calibration date	T=22℃	T=23℃		
		50%	33%	75%	90%
VFIS1	19-Apr-2007		0.3	0.8	-1.5
VFIS2	19-Apr-2007		0.0	-0.1	-1.8
VTHY1	Jun-2005	0.4			
VTHY2	Jun-2005	0.4			

9.4.5 Relative humidity on-site calibrations by Météo-France

This calibration was processed on the 5th of June, 2008.

Sensor	T=23℃				
	10%	33%	50%	80%	90%
UHMP11	0.1	1.6	2.3		1.7
UHMP12	-0.1	1.8	3.6		3.5
UHMP21	0.3	2.4	4.0		4.7
UHMP22	-0.2	1.6	0.7		0.6
UTES2		-2.7		-0.3	
VROT1	-0.7	0.6	0.6		0.1
VROT2	-0.3	0.7	-0.7		1.0

9.5 DETAILED ANALYSIS OF SCREENS HISTOGRAMS

The diagrams that show whether the distribution of the differences to normal are plotted in the following histograms. Almost all screens can be seen as having a normal distribution. This result is confirmed by the Q-Q plot (Quantile Quantile plot is a graphical technique for determining if two data sets come from populations with a common distribution). It is generally a more powerful approach than the common technique of comparing histograms.

The q-q plot is similar to a probability plot. For a probability plot, the quantiles for one of the data samples are replaced with the quantiles of a theoretical distribution.

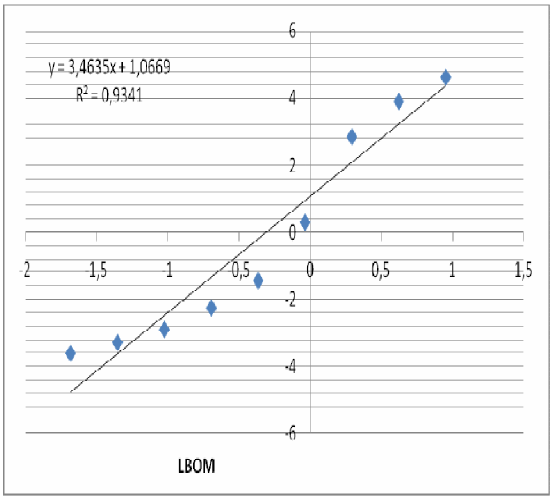


Figure 62. Q-Q plot for LBOM-VEIG22

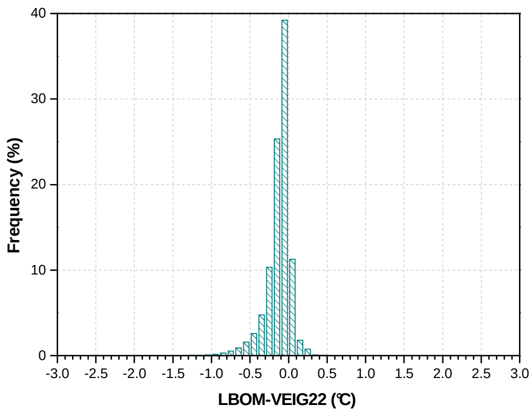


Figure 63. Histogram for LBOM-VEIG22

In terms of tail length, the histogram shown above would be characteristic of a "long-tailed" distribution and the majority of values (82%) are in the range [-0.2℃;+0.2℃] in figure 63. The same indication is found on figure 62: the points follow a strongly nonlinear pattern, suggesting that the data are non symmetric.

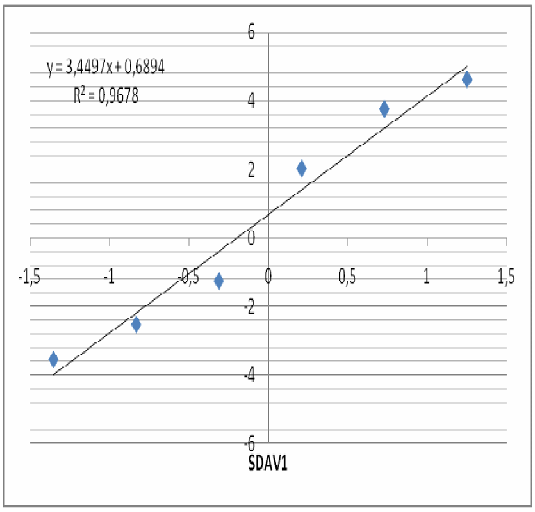


Figure 64. Q-Q plot for SDAV1-VEIG22

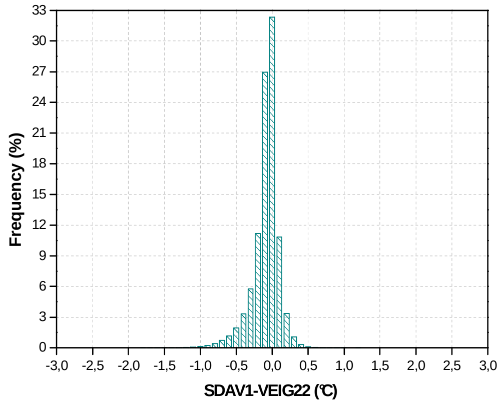


Figure 65. Histogram for SDAV1-VEIG22

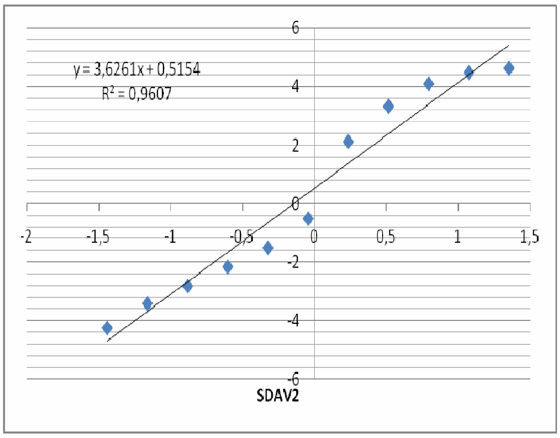


Figure 66. Q-Q plot for SDAV2-VEIG22

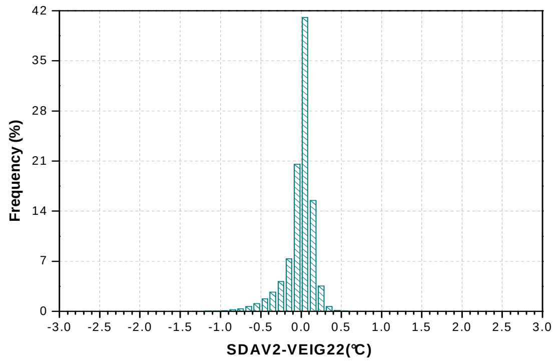


Figure 67. Histogram for SDAV2-VEIG22

Figure 66 and figure 64 show the linearity of the points suggesting that the data are normally distributed and figure 65 and figure 67 show that these two histograms are skewed to the left, suggesting that the data are not symmetric.

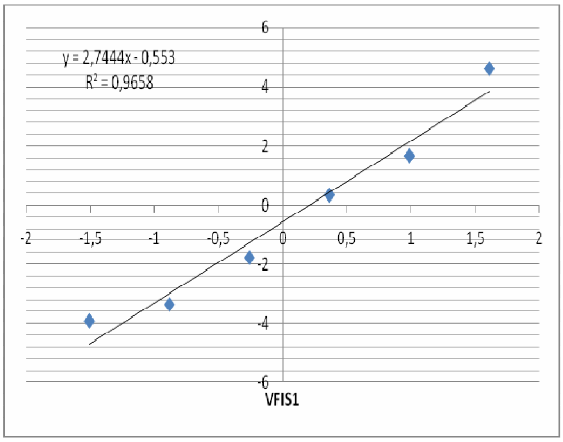


Figure 68. Q-Q plot for VFIS1-VEIG22

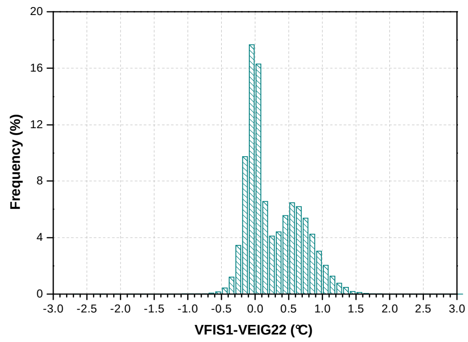


Figure 69. Histogram for VFIS1-VEIG22

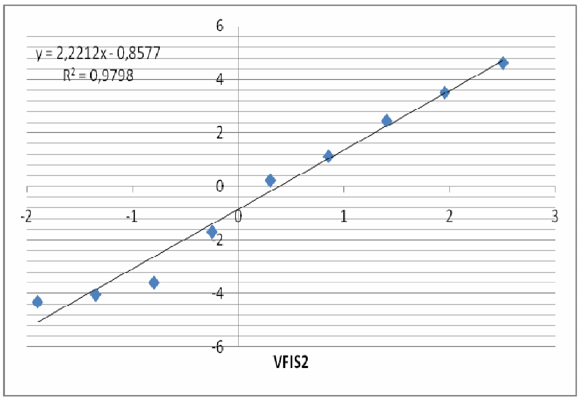


Figure 70. Q-Q plot for VFIS2-VEIG22

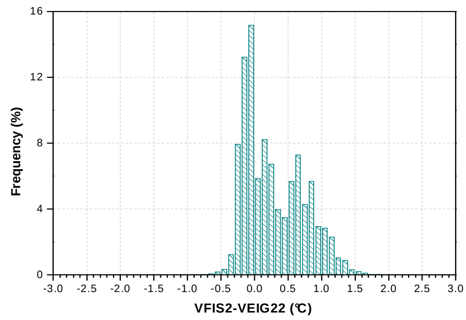


Figure 71. Histogram for VFIS2-VEIG22

This graph (Figure 69) illustrates bimodality due to a mixture of probability modes. In this case, each of the modes appears to have a roughly bell-shaped component. One could easily imagine the above histogram being generated by a process consisting of two normal distributions with the same standard deviation but with two different locations (one centred at 0 and the other centred at approximately 0.5).

Approximately 50% of the values are in the range [-0.2℃;+0.2℃]. The normal probability plot in figure 68 shows a reasonably linear pattern in the center of the data.

The figure 70 shows the linearity of the distribution but the graph of figure 71 shows that the histogram is non symmetric.

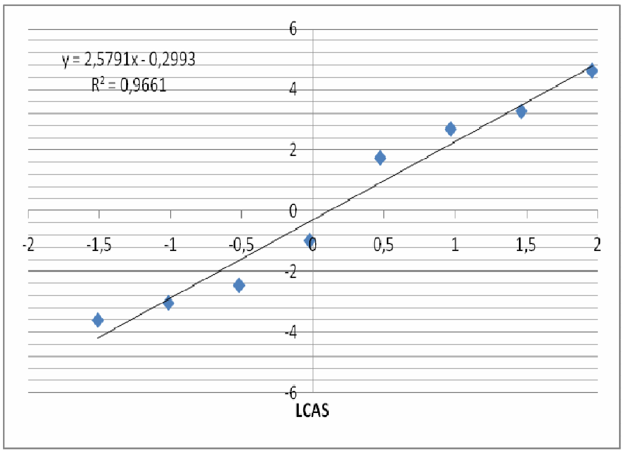


Figure 72. Q-Q plot for LCAS-VEIG22

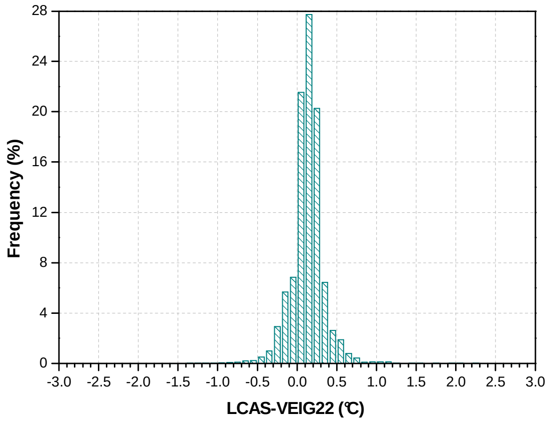


Figure 73. Histogram for LCAS-VEIG22

The graph in figure 72 shows the linearity of the points and suggests that the data are normally-distributed. This linearity is confirmed by the coefficient of adjustment R^2, equal to 0.97, very close to 1. A symmetric distribution is one in which the 2 "halves" of the histogram (Figure 73) appear as mirror-images of one another. The example in Figure 74 and Figure 75 is symmetric. And approximately 70% of values are in the range [-0.2℃; +0.2℃].

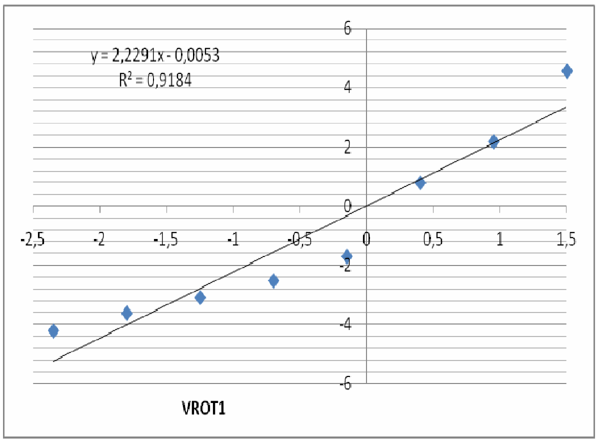


Figure 74. Q-Q plot for VROT1-VEIG22

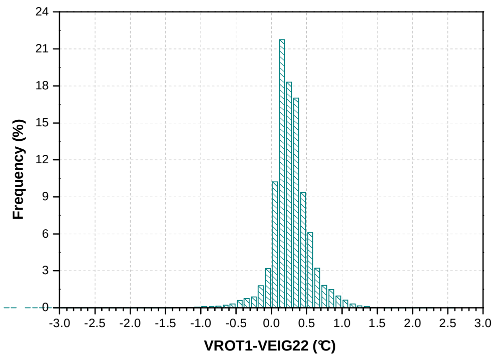


Figure 75. Histogram for VROT1-VEIG22

Figure 74 shows a reasonably linear pattern in the center of the data. However, the tails, particularly the upper tail, show departures from the fitted line and figure 75 shows that the histogram is skewed to the right, thus non symmetric.

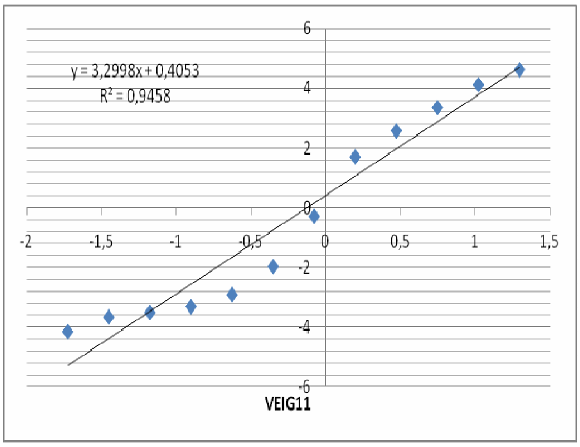


Figure 76. Q-Q plot for VEIG11-VEIG22

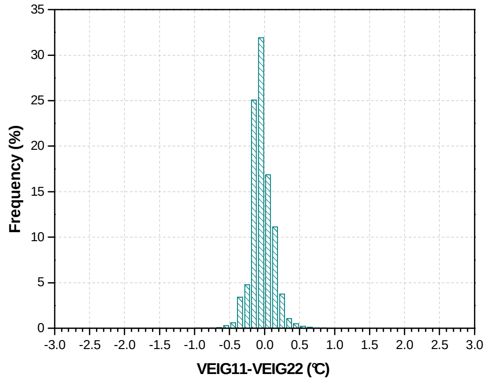


Figure 77. Histogram for VEIG11-VEIG22

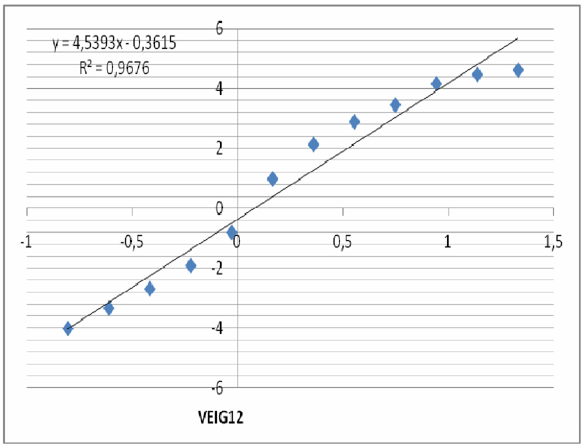


Figure 78. Q-Q plot for VEIG12-VEIG22

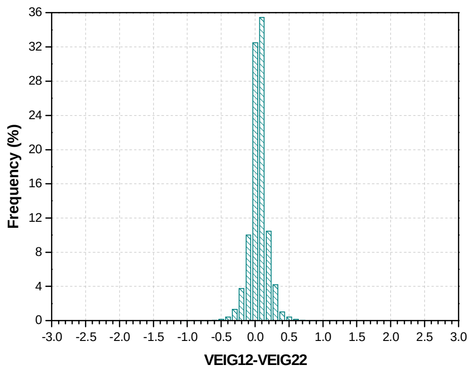


Figure 79. Histogram for VEIG12-VEIG22

Figure 76 shows the linearity of the points and approximately 86 % of values are in the range [-0.2℃;+0.2℃] , at first sight the distribu tion therefore appears symmetrical

Figure 78 shows a best linearity of the points in the center of the data. The upper tail, shows departures from the fitted line and 89% of values are in the range [-0.2℃;+0.2℃]. It confirms that this screen is symmetric.

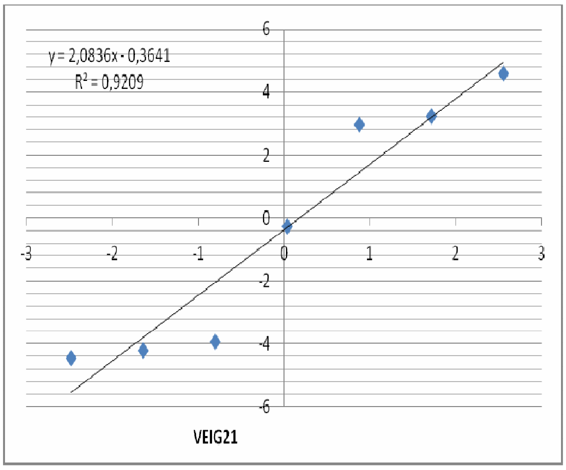


Figure 80. Q-Q plot for VEIG21-VEIG22

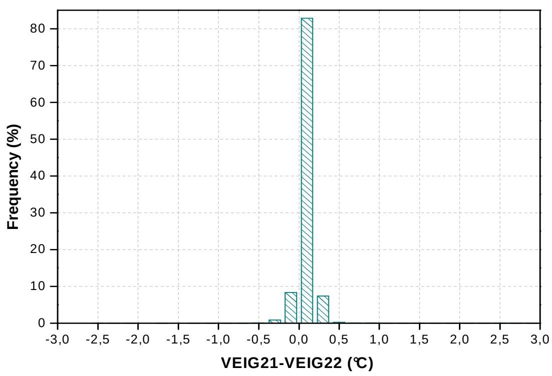


Figure 81. Histogram for VEIG21-VEIG22

The histogram in figure 81 shows that the majority of values approximately 95% are in the range [-0.2℃;+0.2℃]. The distribution appears sym metrical although it is not show in the curve of Q-Q plot (Figure 80) because of the high concentration of data in the range [0℃, +0.1℃].

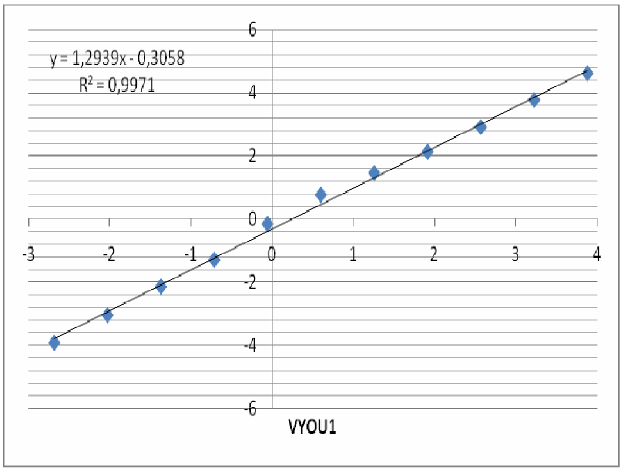


Figure 82. Q-Q plot for VYOU1-VEIG22

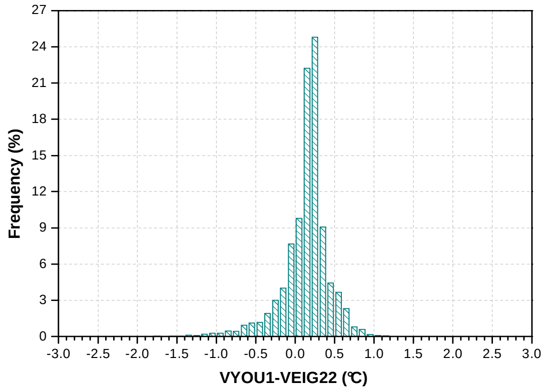


Figure 83. Histogram for VYOU1-VEIG22

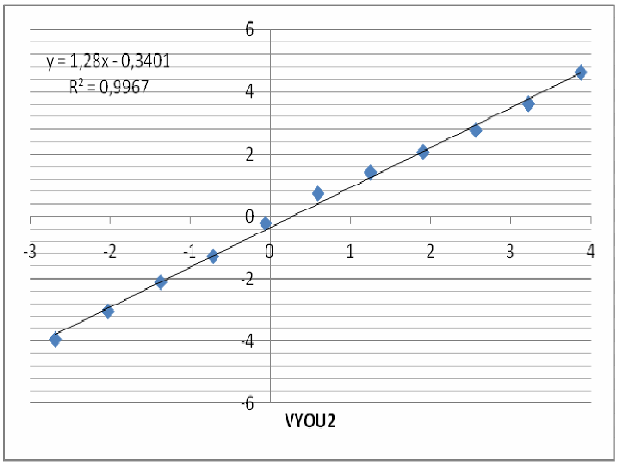


Figure 84. Q-Q plot for VYOU2-VEIG22

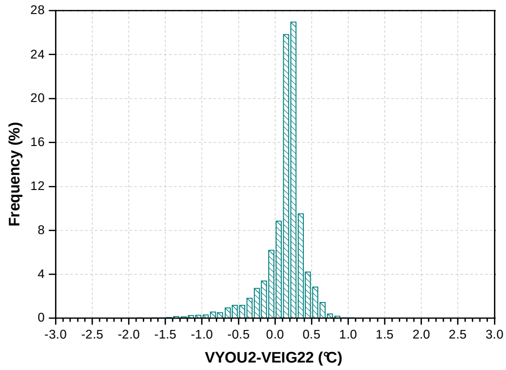


Figure 85. Histogram for VYOU2-VEIG22

The points are perfectly aligned on the graphs represented in the figure 82 and figure 84 and this linearity is confirmed by the coefficient of adjustment R^2, very close to 1. The two histograms in figure 83 and figure 85 show that two screens are approximately symmetrically distributed around the reference, and with a large dispersion around zero. The mode is centered at approximately 0.3 and 55% of values are in the interval [-0.2℃, +0.2℃]

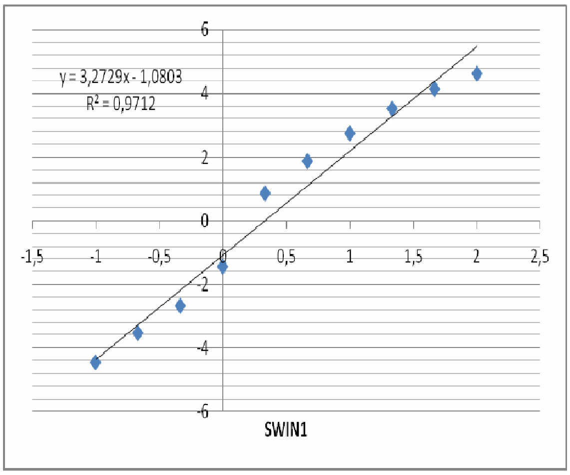


Figure 86. Q-Q plot for SWIN1-VEIG22

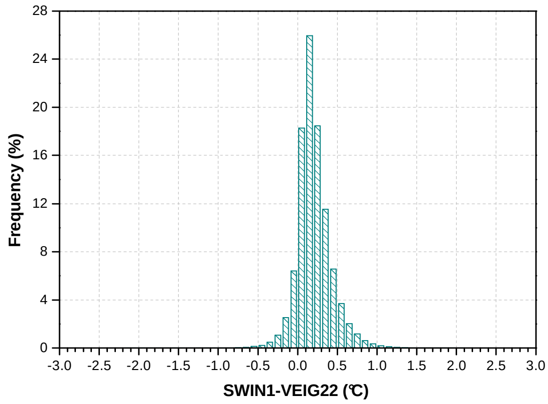


Figure 87. Histogram for SWIN1-VEIG22

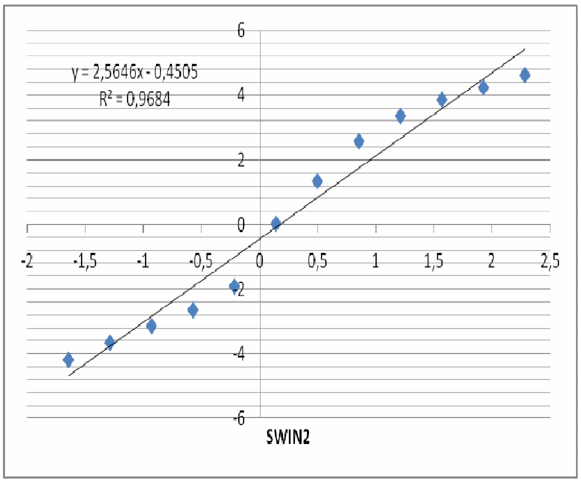


Figure 88. Q-Q plot for SWIN2-VEIG22

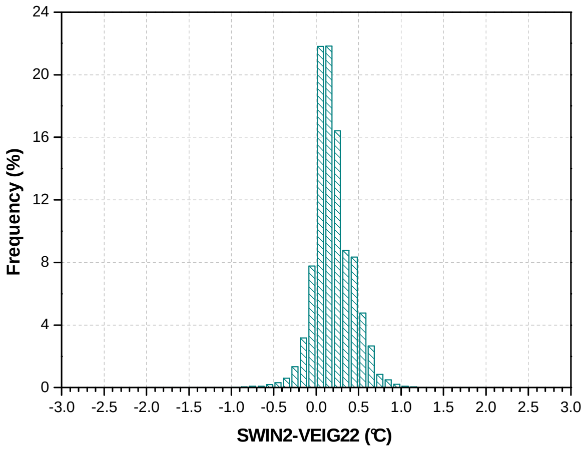


Figure 89. Histogram for SWIN2-VEIG22

Overall, for both SWIN screens the points are relatively aligned in the center of the data but skewed in the both extremities, as shown on the graphs represented in the figure 86 and figure 88, with the mode of the differences between 0℃ and 0.2℃, and symmetrical distributions about the modes being 0 and 0.1 respectively.

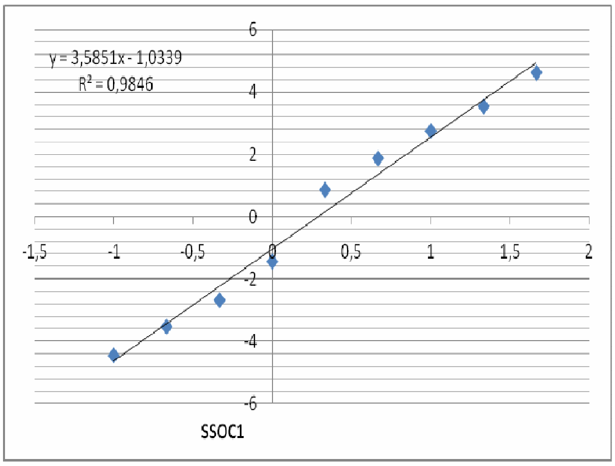


Figure 90. Q-Q plot for SSOC1-VEIG22

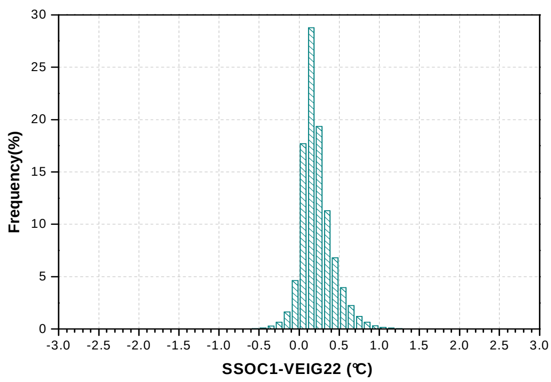


Figure 91. Histogram for SSOC1-VEIG22

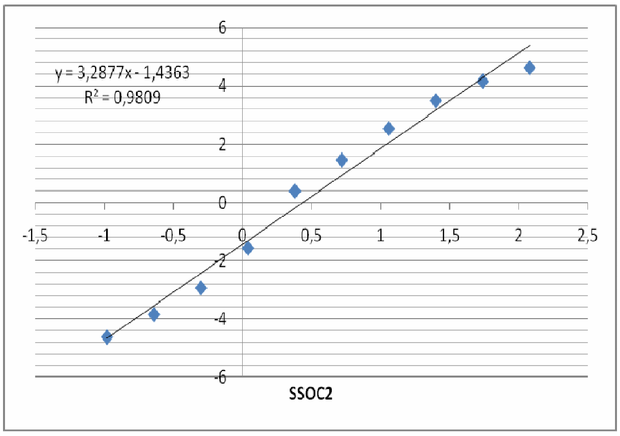


Figure 92. Q-Q plot for SSOC2-VEIG22

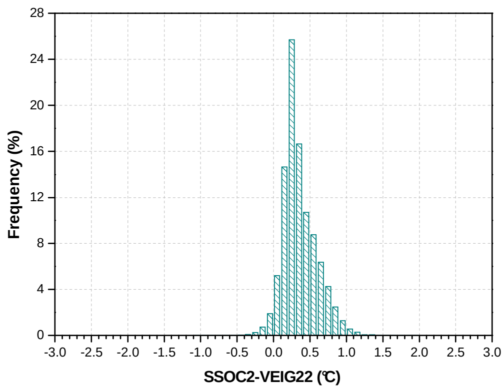


Figure 93. Histogram for SSOC2-VEIG22

For both SSOC screens the points are relatively aligned on the graphs represented in the figure 90 and figure 92, but the histogram in figure 91 and figure 93 shows they are skewed to the right then non symmetric.

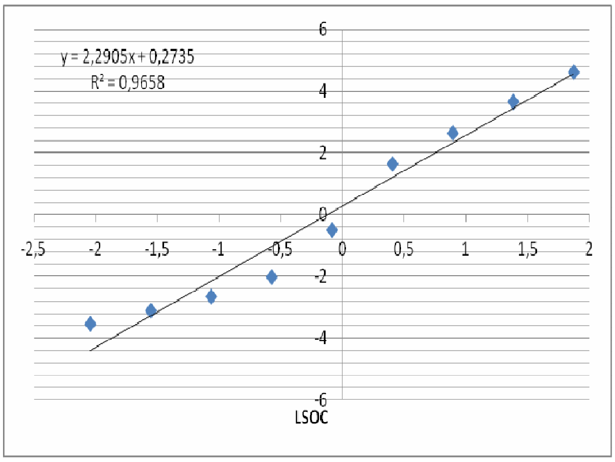


Figure 94. Q-Q plot for LSOC-VEIG22

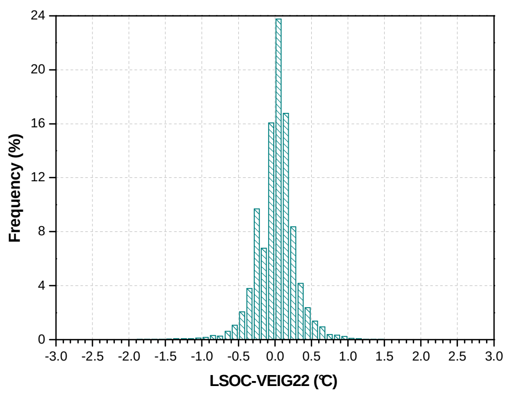


Figure 95. Histogram for LSOC-VEIG22

Figure 94 shows the linearity of the points and approximately 70 % of values are in the range [-0.2℃;+0.2℃. The mode and the mean are cen tred around zero and at first sight the distribution therefore appears symmetrical.

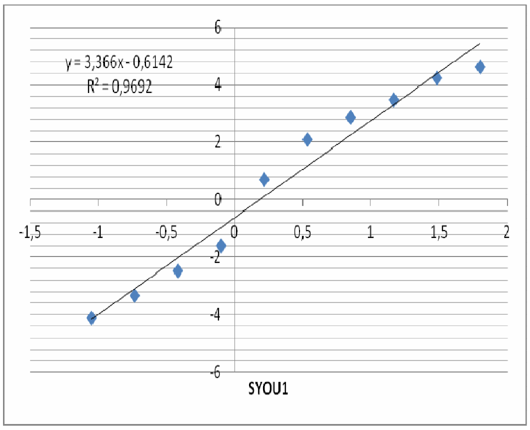


Figure 96. Q-Q plot for SYOU1-VEIG22

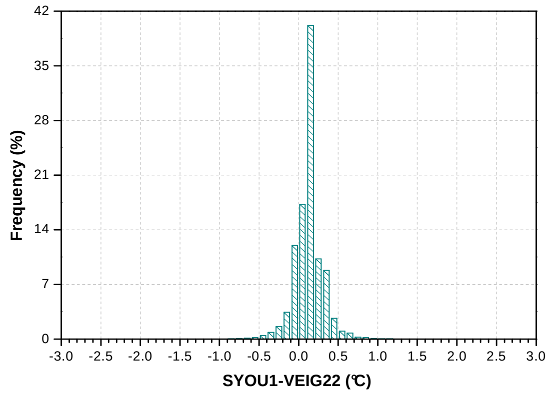


Figure 97. Histogram for SYOU1-VEIG22

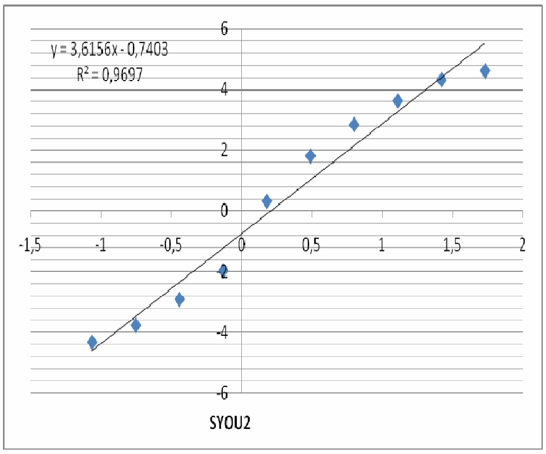


Figure 98. Q-Q plot for SYOU2-VEIG22

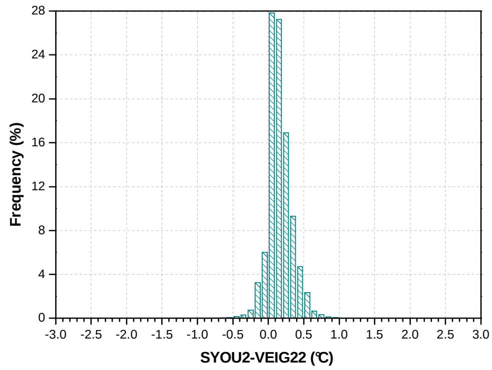


Figure 99. Histogram for SYOU2-VEIG22

For both SYOU screens the points are relatively aligned on the graph represented in the figure 96 and figure 98. Relative to the reference, approximately 70% of the data points being in the range [-0.2℃;+0.2℃]. For both screen s, the distribution of the differences is symmetrical around the highest frequency at 0.1°C and 0.2°C.

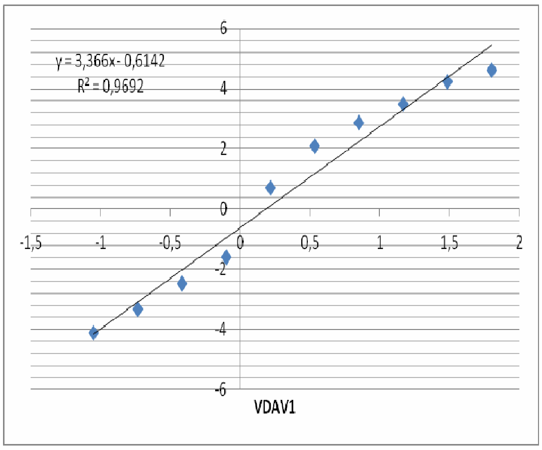


Figure 100. Q-Q plot for VDAV1-VEIG22

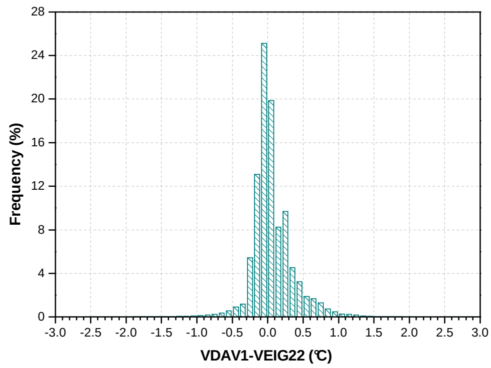


Figure 101. Histogram for VDAV1-VEIG22

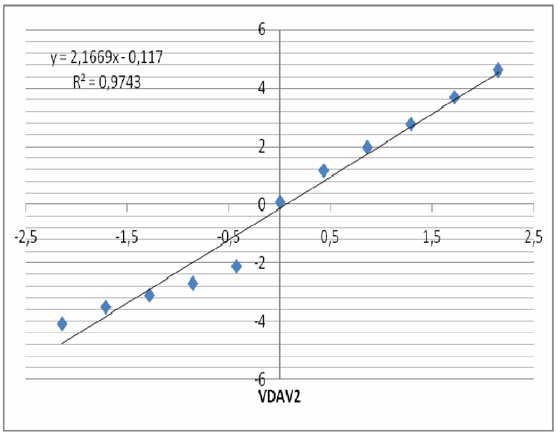


Figure 102. Q-Q plot for VDAV2-VEIG22

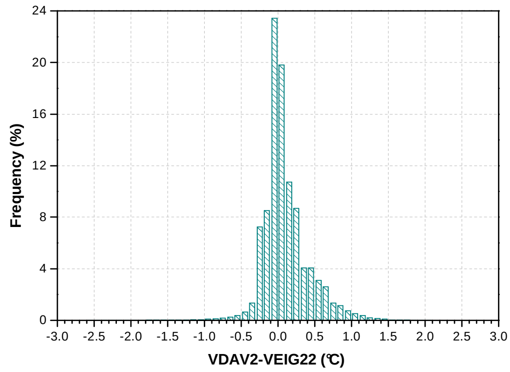


Figure 103. Histogram for VDAV2-VEIG22

The figure 100 and figure 102 show the linearity of the distribution but the graphs in figure 101 and figure 103 show that these two histograms are skewed to the right. Therefore the distributions of the differences are non symmetric.

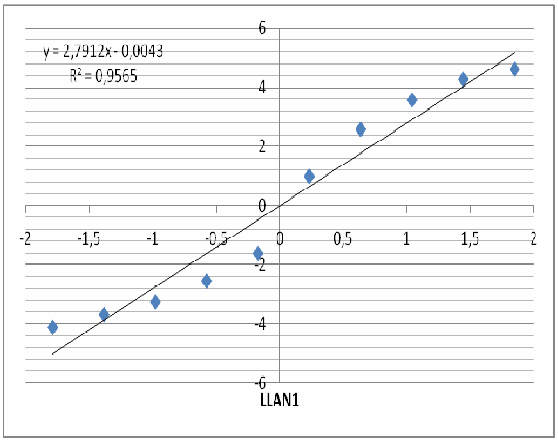


Figure 104. Q-Q plot for LLAN1-VEIG22

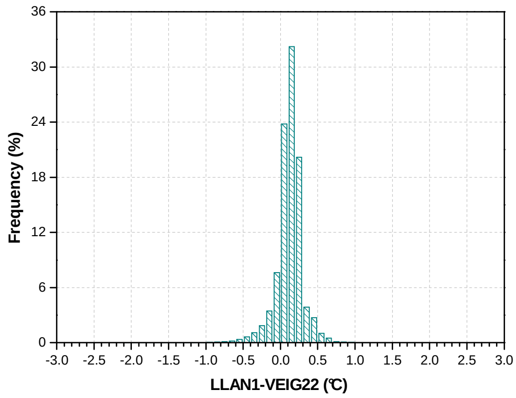


Figure 105. Histogram for LLAN1-VEIG22

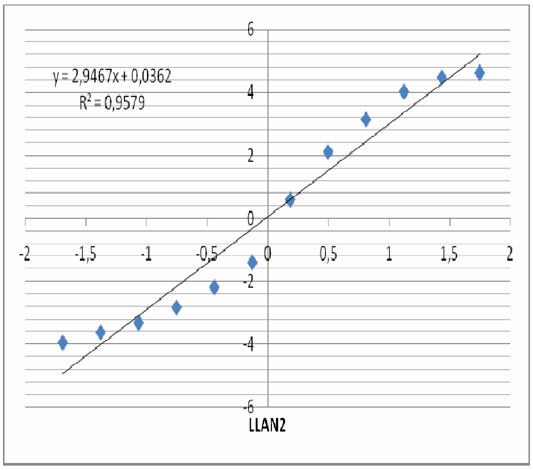


Figure 106. Q-Q plot for LLAN2-VEIG22

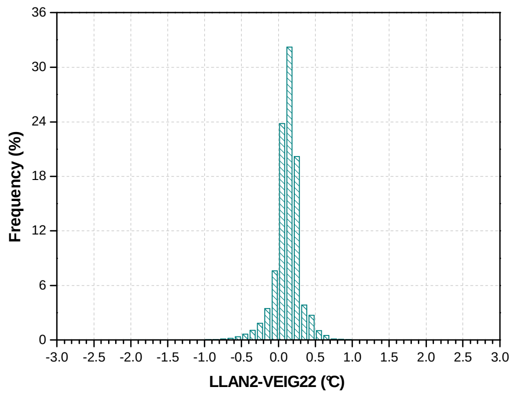


Figure 107. Histogram for LLAN2-VEIG22

For both LLAN screens the points are relatively aligned on the graphs represented in the figure 104 and figure 106, with approximately 75% of the data points in the range [-0.2℃;+0.2℃]. For both screens, the distribution o f the differences is symmetrical around the highest frequency at 0.1°C and 0.2°C.

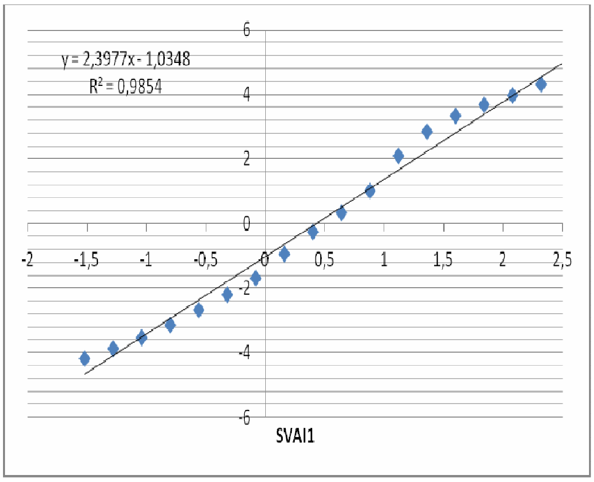


Figure 108. Q-Q plot for SVAI1-VEIG22

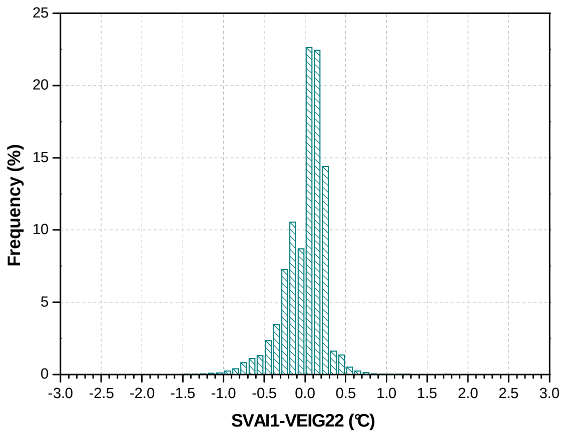


Figure 109. Histogram for SVAI1-VEIG22

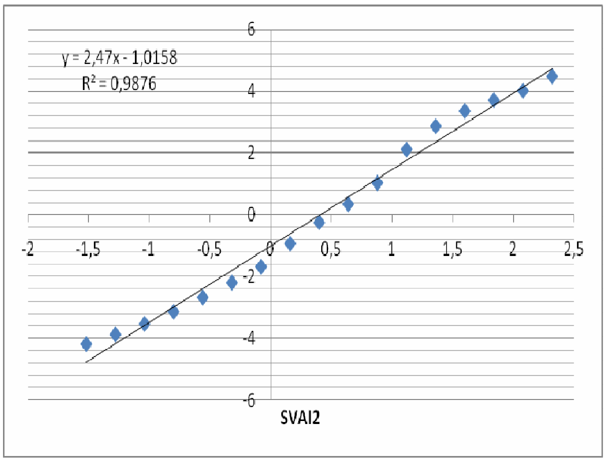


Figure 110. Q-Q plot for SVAI2-VEIG22

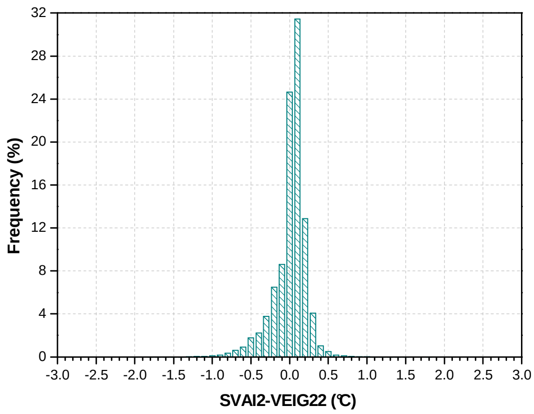


Figure 111. Histogram for SVAI2-VEIG22

Figure 108 and figure 110 show the linearity of the points and figure 109 and figure 111 show that these two histograms are skewed to the left, suggesting that the distribution of the differences is non symmetric.

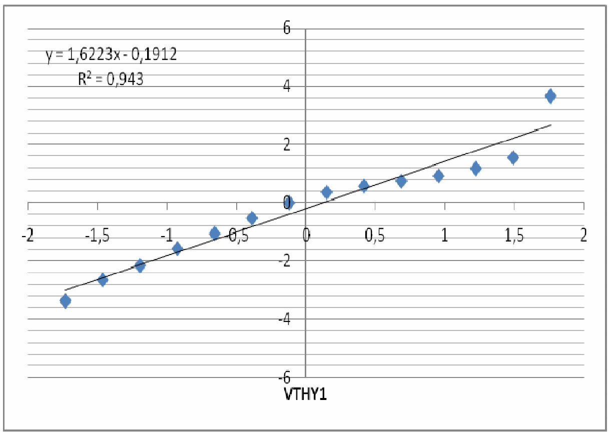


Figure 112. Q-Q plot for VTHY1-VEIG22

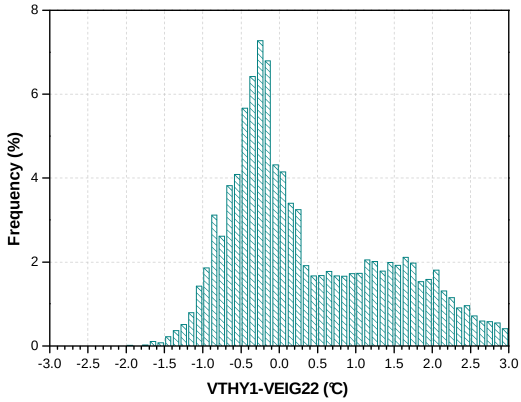


Figure 113. Histogram for VTHY1-VEIG22

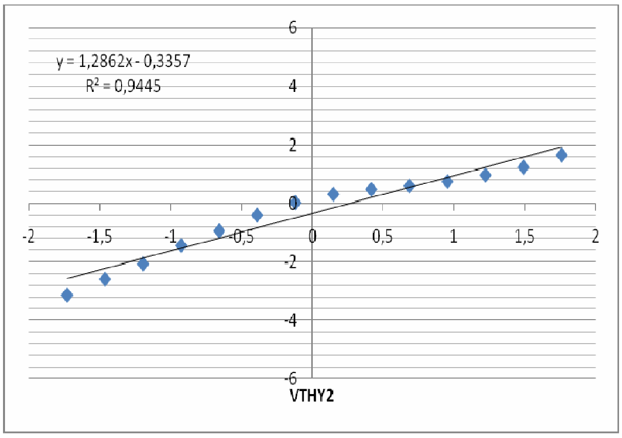


Figure 114. Q-Q plot for VTHY2-VEIG22

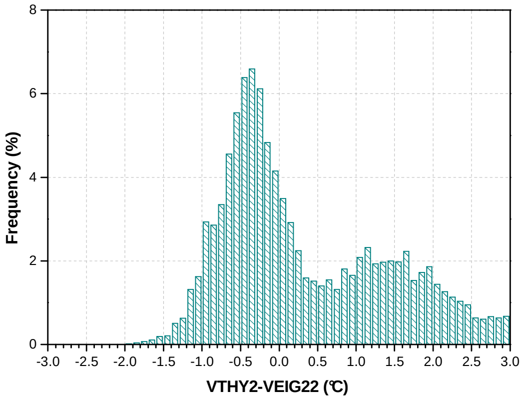


Figure 115. Histogram for VTHY1-VEIG22

Figure 112 and figure 114 show the linearity of the points although the tails, particularly the upper tail, show departures from the fitted line in figure 55. The two histograms in figure 113 and figure 115 show that they are skewed to the right, suggesting that the distribution of the differences are non symmetric.

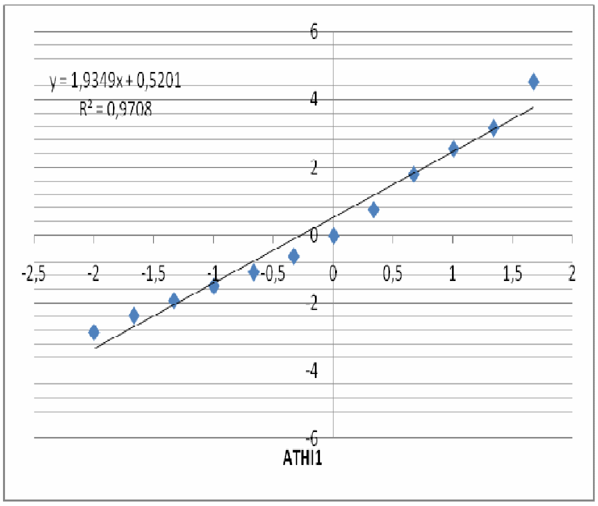


Figure 116. Q-Q plot for ATHY1-VEIG22

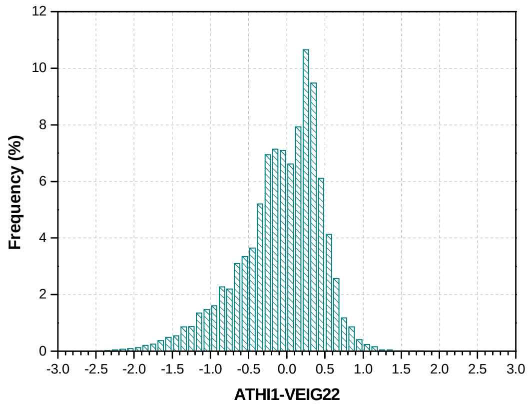


Figure 117. Histogram for ATHY1-VEIG22

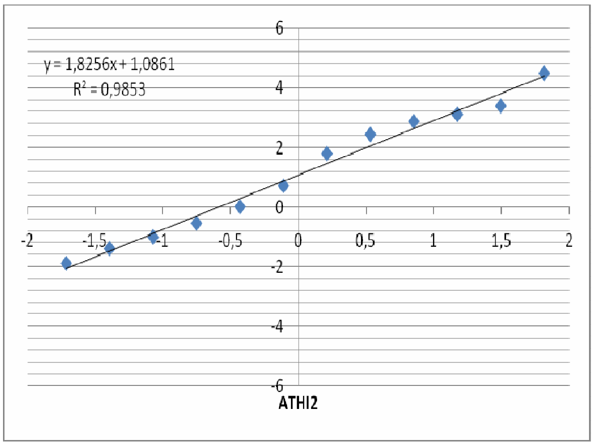


Figure 118. Q-Q plot for ATHY2-VEIG22

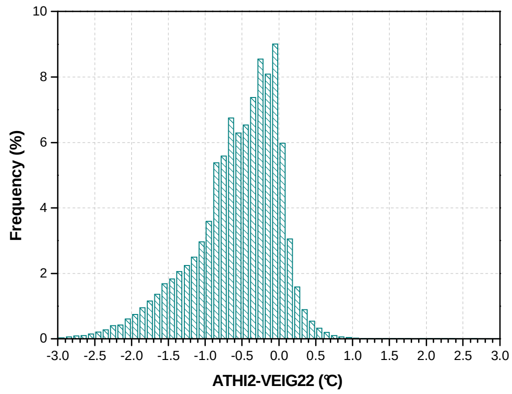


Figure 119. Histogram for ATHY2-VEIG22

Figure 116 shows the linearity of the points and figure 117 and figure 119 show that these two histograms are skewed to the left, suggesting that the distribution of the differences is non symmetric.

9.6 EFFECT OF NON-WORKING ARTIFICIAL VENTILATION

The two VYOU screens show a pronounced radiation error of about 1.8 K at low wind speeds and high irradiance during the period when the ventilation was not working.

In order to see the effect of the ventilation, the figure 120 shows on the top the evolution of temperature of both VYOU screens and the reference VEIG22, during 2 days before the operation of maintenance (when the power supply was repaired), and two days after. The chart in the middle is the global radiation, the one in the bottom is the 2-meter wind speed (2-minute average). The improvement due to the ventilation is clearly seen.

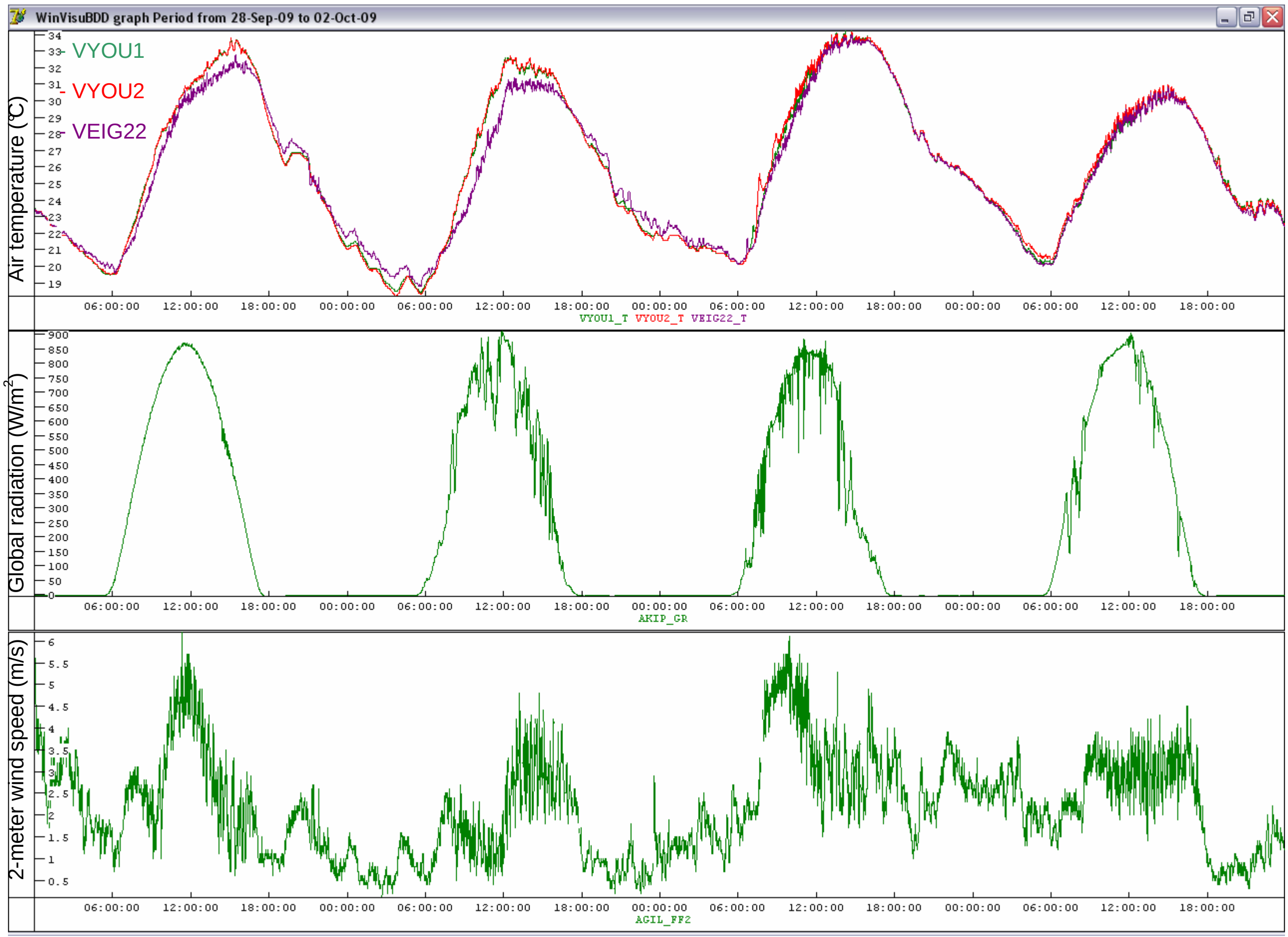


Figure 120. Situation of the 28th of September to the 1st of October, 2009

It is difficult to establish when the ventilation was shut off. Indeed, even in the beginning of the intercomparison period, VYOU screens showed radiation effect during day and during night. The figure 121 shows the same parameters as before, during the first days of the intercomparison period. So it was considered that the ventilation was not on during the first eleven months of the intercomparison.

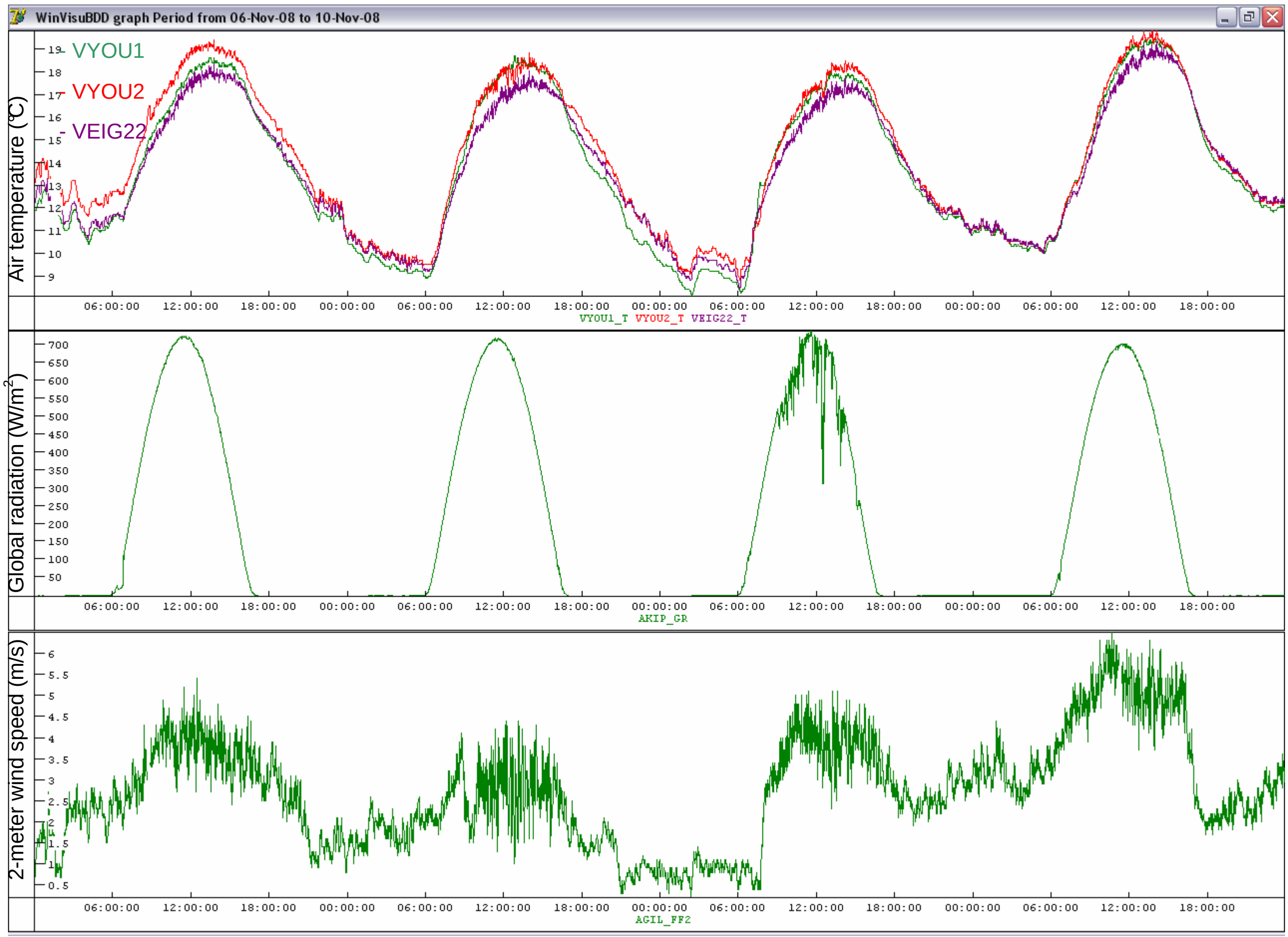


Figure 121. Situation at the beginning of the intercomparison period

The figure 122 and figure 123 show the histograms of differences with the reference before and after the cleaning operation. Both histograms after this operation are much less dispersed than histograms before it. For both screens the maximum frequency is obtained for the class of 0.2℃. For both screens the median s of the distributions after the cleaning is 0.18℃.

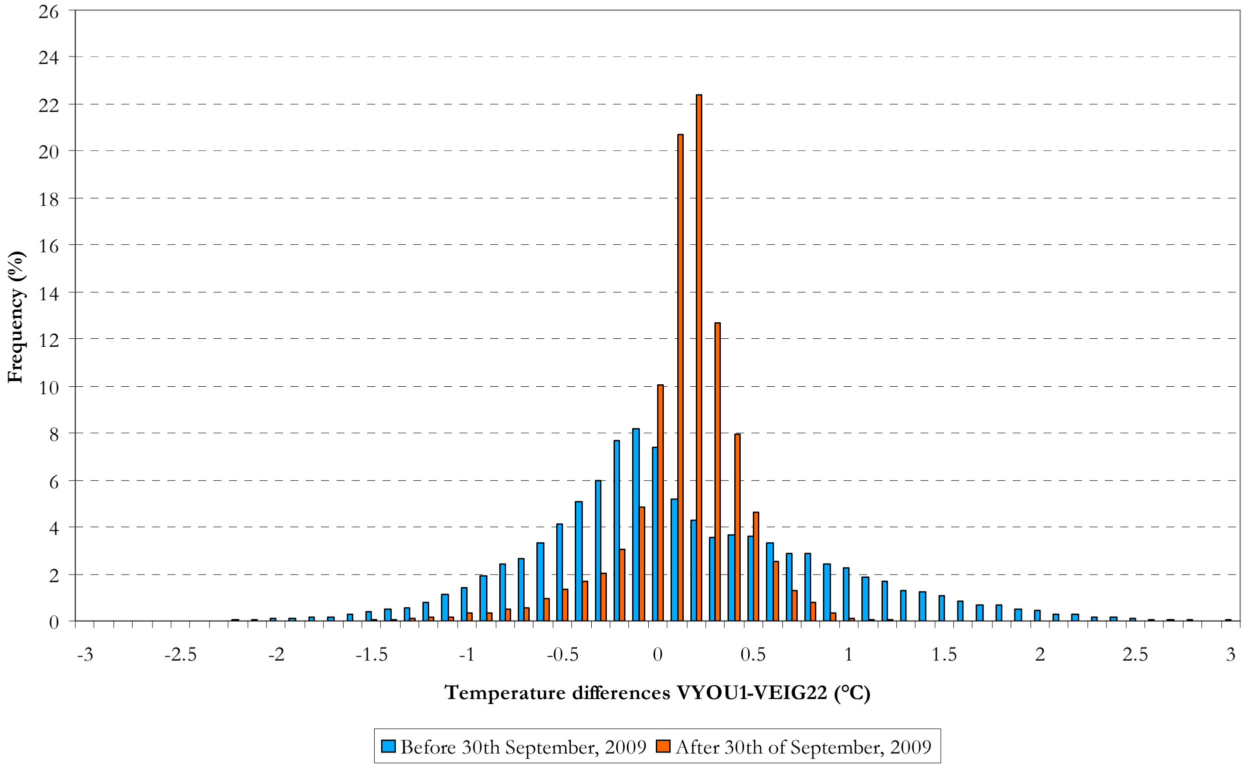


Figure 122. Comparison before and after the maintenance operation for VYOU1 screen

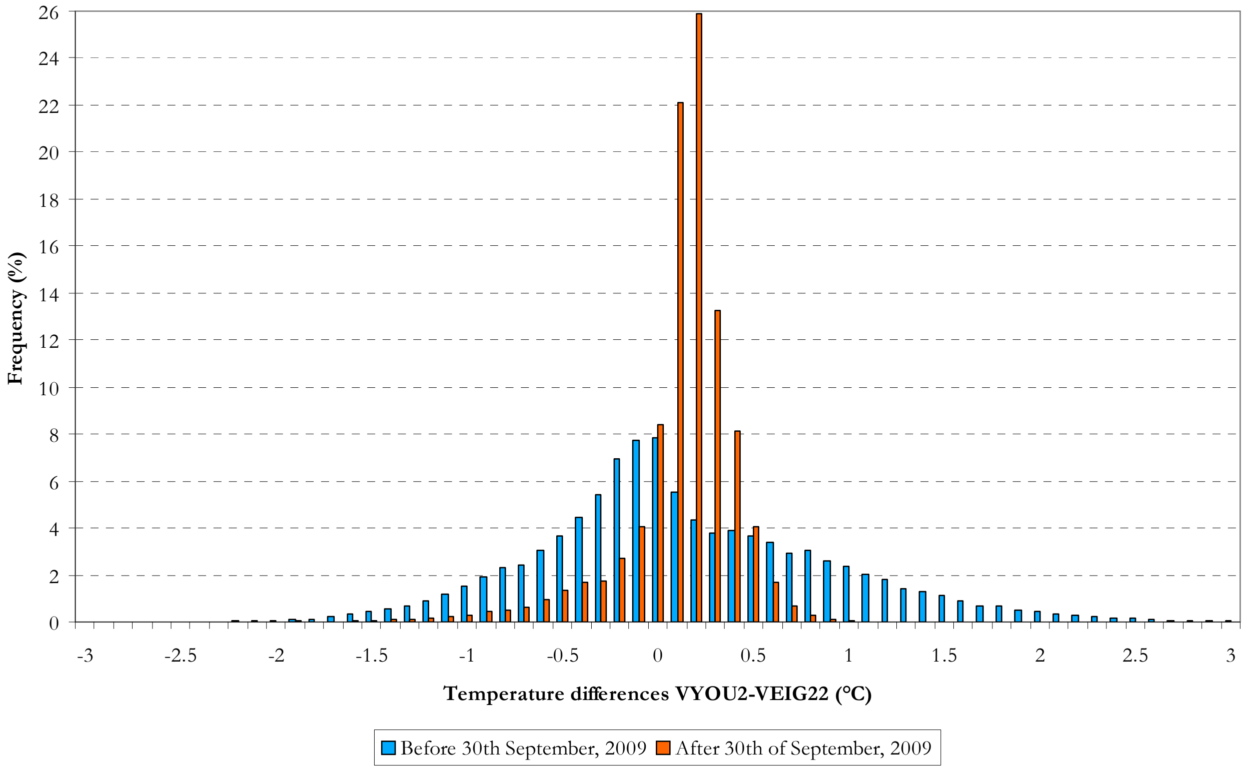


Figure 123. Comparison before and after the maintenance operation for VYOU2 screen

The table 9 gives numerical values of data that differ by less than 0.2°C (and 0.5°C) from the reference, before and after the cleaning.

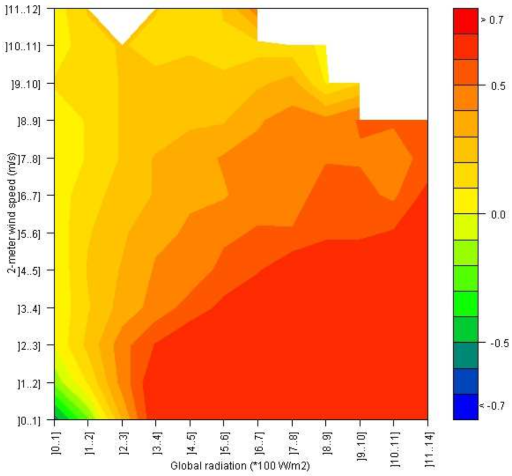
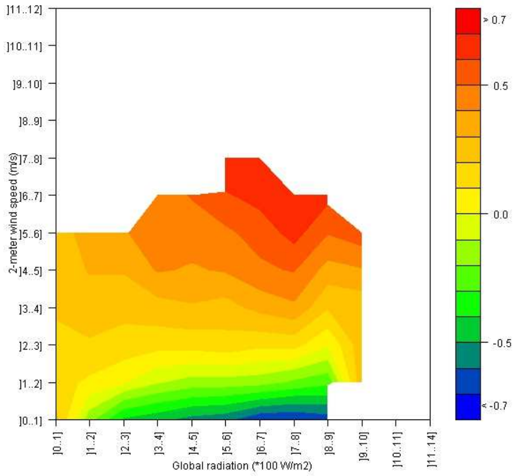
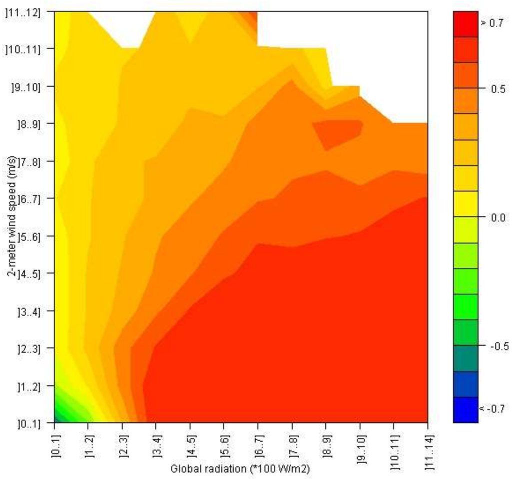
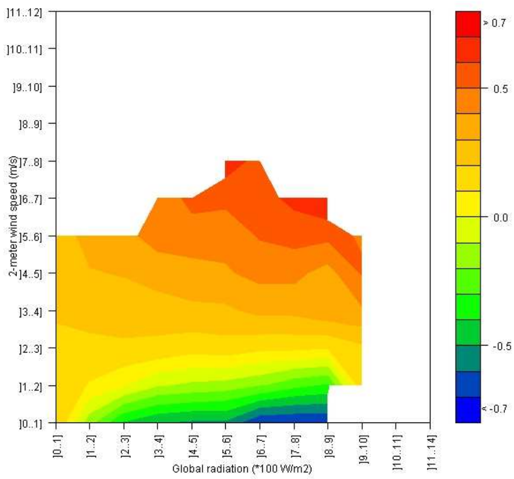
Table 9. Numerical values of histograms

	[-0.2°..0.2°]	[-0.5°..0.5°]

		[-0.2°..0.2°]	[-0.5°..0.5°]
VYOU1	before	32.7	58.7
	after	61.0	91.4
VYOU2	before	32.4	57.3
	after	63.2	93.4

The table 10 shows the contour plots obtained for both sensors before and after the maintenance operation. Charts after the operation are processed with less than one month of data, which may be not enough: most points represent less than 1000 data.

Table 10. Contour plots for VYOU screens before and after maintenance operation

	Before operation	After operation
VYOU1		
VYOU2		

9.7 SAND BLOWING EVENT: BEHAVIOUR OF SCREENS

Many sand blowing events occurred from the 4th to the 7th of March, 2009. From the global meteorological point of view, the situation is very dynamic in the upper atmosphere: the North-Westerly jet stream is above Ghardaïa during the whole period. It brings cold air in higher altitudes and generates instable conditions at the ground level.

During this period, many fast variations of temperature and relative humidity occurred, as seen on figure 124. These events may be useful for a better understanding of the behaviour of screens/shields and relative humidity sensors in dynamic conditions.

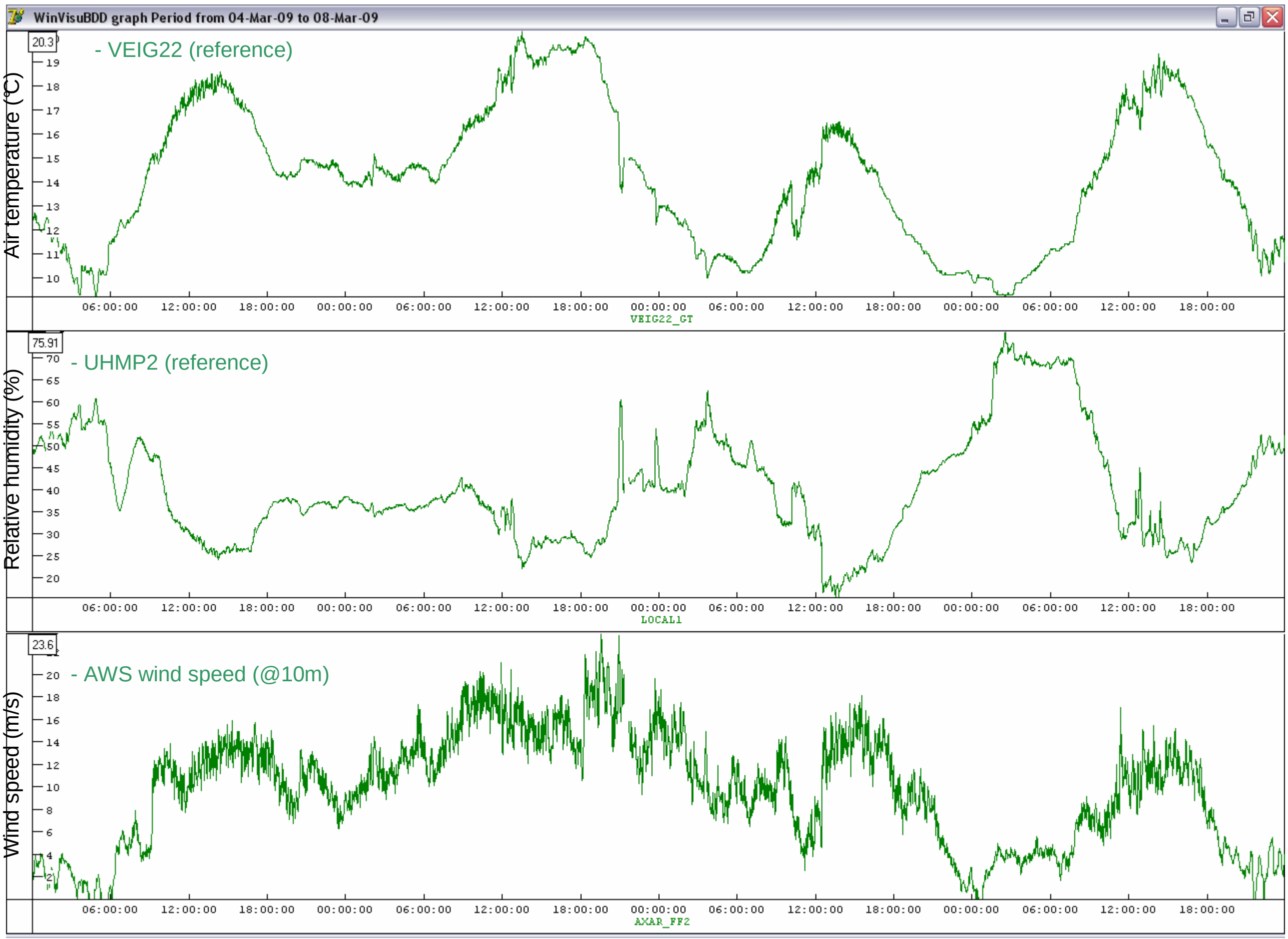


Figure 124. Temperature, relative humidity and wind speed from the 4th to the 7th of March, 2009

9.7.1 Large naturally-ventilated screens

LBOM gives very close results with the reference. LCAS and LSOC show an inertia: they show some delay regarding the reference and maxima (respectively minima) are underestimated (resp. overestimated), as shown on figure 125.

Figure 125. Behaviour of LBOM, LCAS and LSOC screens

9.7.2 Large artificially-ventilated screens

Like LCAS and LSOC in the section above, LLAN screens show an inertia versus the reference, cf figure 126.

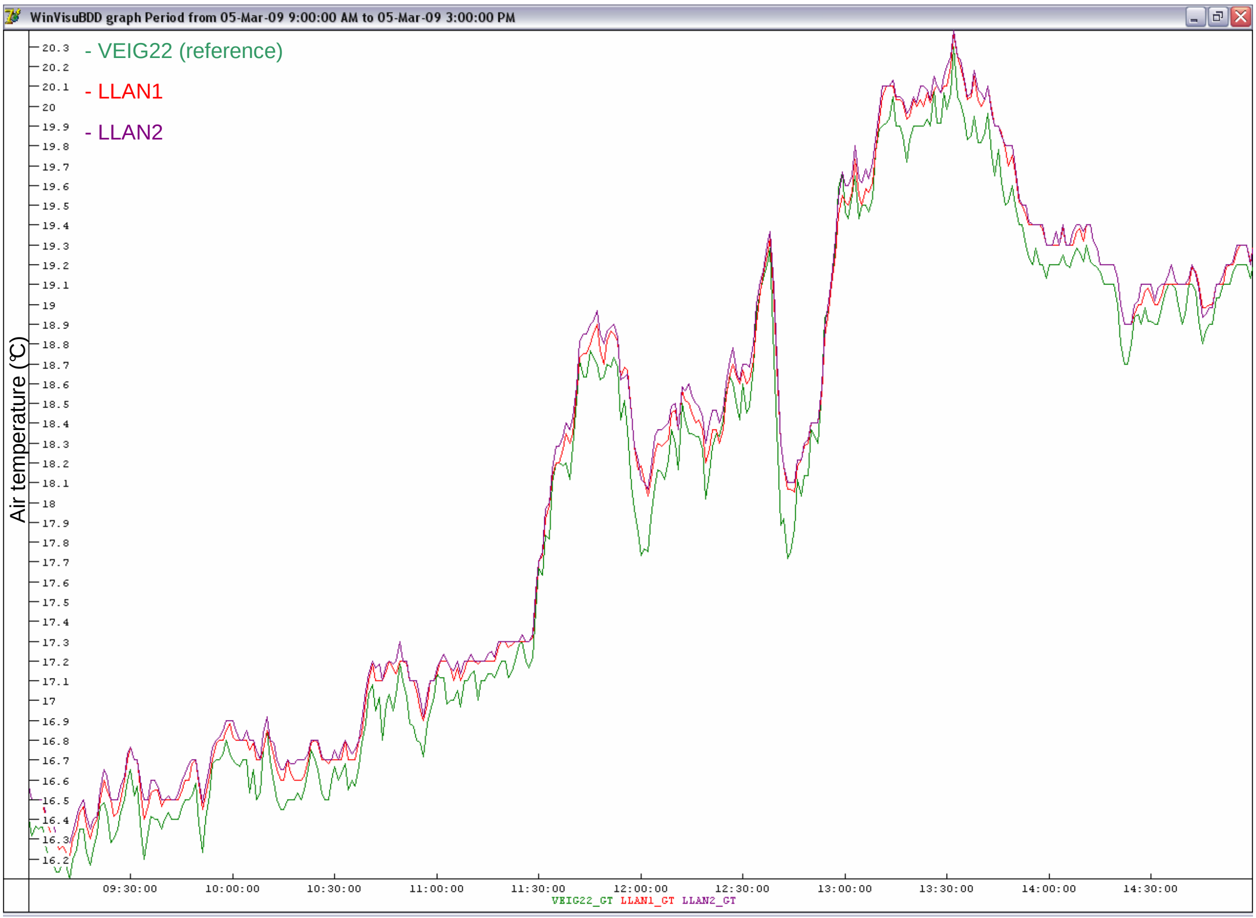


Figure 126. Behaviour of LLAN screens

9.7.3 Small naturally-ventilated screens

Nearly all small naturally-ventilated screens are in relative good agreement with the reference during these days. As an example the figure 127 shows the SYOU measurements.

Figure 127. Behaviour of SYOU screens

9.7.4 Small artificially-ventilated screens

Artificially-ventilated Davis screens showed some delay during these days, as shown in the figure 128.

Figure 128. Behaviour of VDAV screens

The four temperature probes in the VEIG screens showed very good agreement.

The figure 129 and the figure 130 respectively show the measurements from the VFIS and VROT sensors. On both figures, a delay in the temperature signal can be seen, but there is no delay on the relative humidity signal.

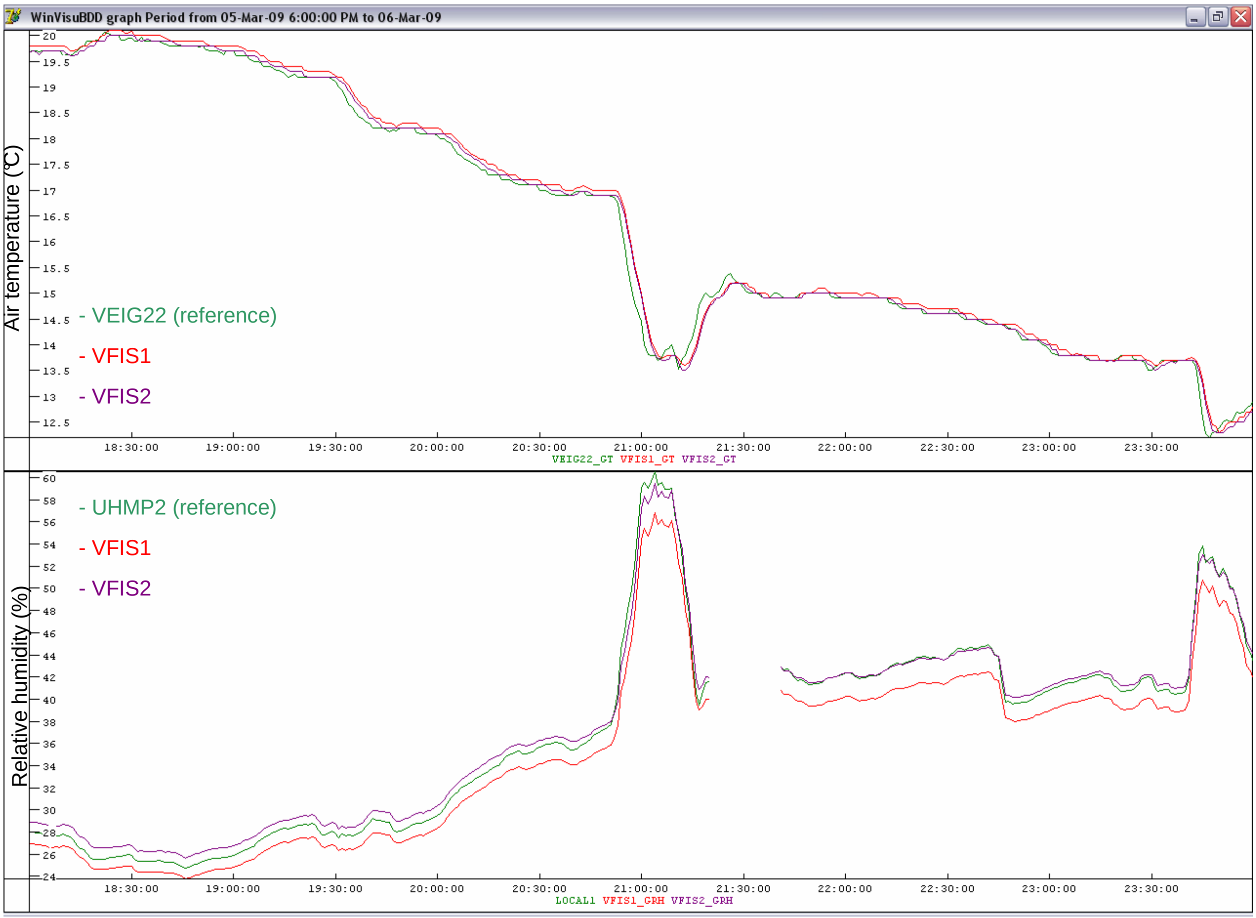


Figure 129. Behaviour of VFIS screens

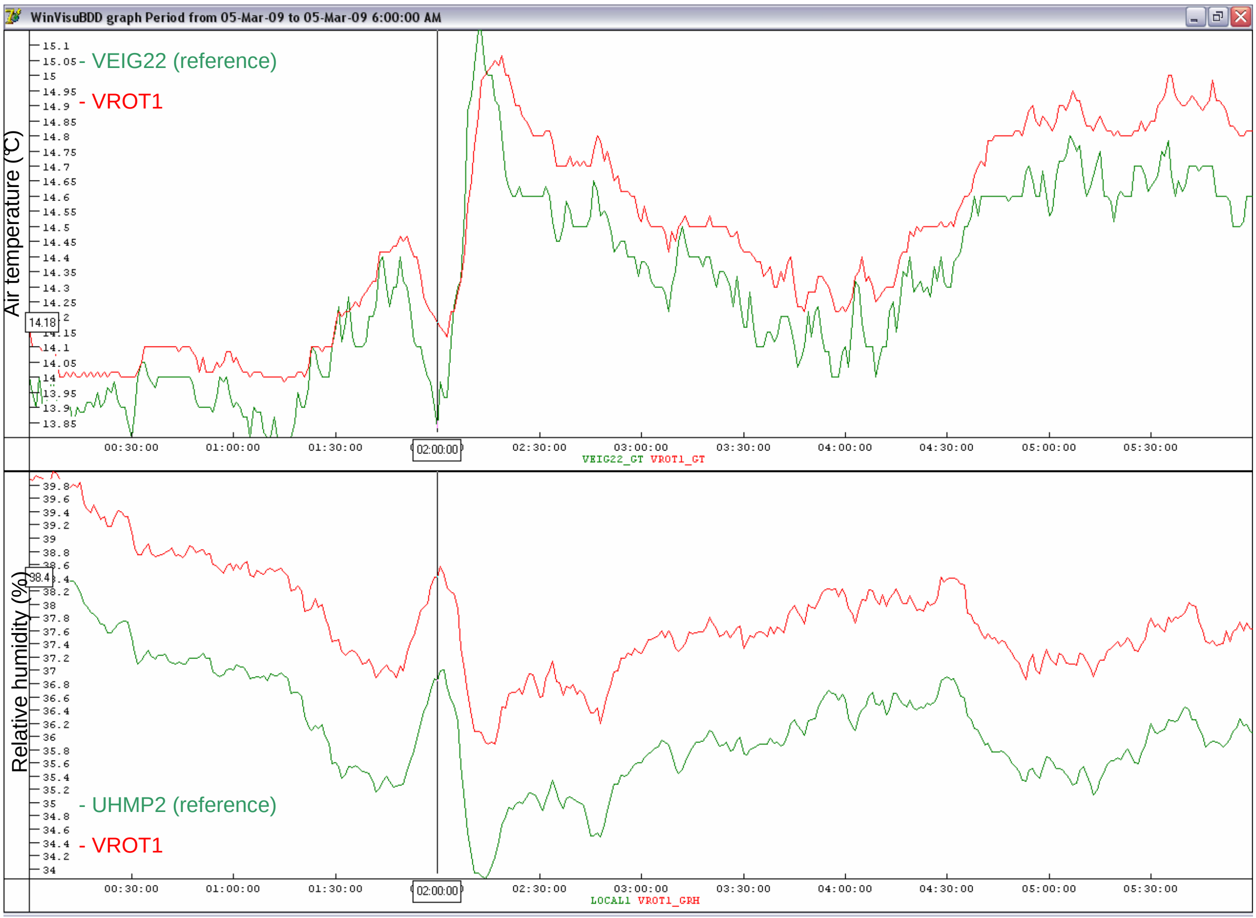


Figure 130. Behaviour of VROT1 screen

9.7.5 Thies ultrasonic wind sensors

Unfortunately these sensors did not work during these days.

9.7.6 Thygan sensors

Unfortunately these sensors did not work during these days.

9.8 RULES FOR RATINGS

9.8.1 Rules for rating the screens

A rating is proposed, based on the following conventions:

- The consistency between two identical screens is taken into account. If the absolute value of the limits contains 90% of the differences and is equal or lower than 0.1℃, 4 points are counted; 3 points for 0.2℃; 2 points for 0.3℃; 1 point for 0.5℃; 0 point above.
- The solar radiation error is evaluated from the datasheets. If for high solar radiation and low wind speed, the screen is colder than the reference, it gets 4 points; 3 points if warmer up to 0.2℃; 2 points if warmer up to 0.5℃; 1 point if warmer up to 1℃; 0 point for larger differences.
- The percentage of the differences of the minutely temperatures between the screen and the reference lying between –0.5℃ and +0.5℃ i s calculated (see datasheets). If this percentage is higher than 98%, the screen gets 4 points; 3 points if the percentage is higher than 95%; 2 points for 90%; 1 point for 80%; 0 point below.
- The same calculation is made for the percentage of the daily max temperatures (Tx) and for the daily min. temperature (Tn).
- If only one screen was present, the consistency is not taken into account. The total number of points is therefore multiplied by 5/4, to compensate the missing points from consistency section.
- If the total number of points is greater than 16, 5 stars are allocated (*****); if the total is greater than 12, 4 stars are allocated (****); greater than 8, 3 stars (***); greater than 4, 2 stars (**); less, 1 star (*).
- To take into account the imperfect characteristics of the working reference screen itself, one star is also added or removed in the last column of the table to get a more “absolute” rating.

The table 11 gives the raw rating for each screen.

Table 11. Ratings of the screens

Screen acronym	Rating
LSOC	11/16 → 13.75/20
LBOM	14/16 → 17.5/20
LLAN	17/20
LCAS	13/16 → 16.25/20
SSOC	10/20
SVAI	9/20
SWIN	10/20
SDAV	17/20
SYOU	15/20
VFIS	7/20
VEIG	18/20

Screen acronym	Rating
VTHY	4/20
VROT	6/15
VDAV	11/20
VYOU	12/20
ATHI	4/20

9.8.2 Rules for rating the hygrometers

A rating is proposed, based on the following conventions:

- The consistency between two identical hygrometers is taken into account. If the absolute value of the limits contain 90% of the differences and is equal or lower than 1%, 3 points are counted; 2 points for 2%; 1 point for 3%; 0 point above.
- The annual drift is evaluated from the datasheets. If the drift is evaluated to be less than 0.5% (or non significant), the hygrometer gets 3 points; 2 points for a drift less than 1.5%; 1 point for a drift less than 2.5%; 0 point for a larger drift.
- The maximum influence of temperature on the relative humidity is evaluated from the datasheets, for a range of temperature between 5 and 45℃. This maximum influence generally occurred close to 50% of RH, either due to the characteristics of the hygrometer itself or due to the range of temperature and RH experienced during the test period. If the influence of temperature over this 40℃ range is lower than 1%, the hygrometer gets 3 points. 2 points if the influence is lower 2%; 1 point if the influence is lower than 4%; 0 point above.
- The maximum influence of RH itself on the relative humidity measured by a hygrometer itself is evaluated from the datasheets, for a range of RH between 5 and 100%. This maximum influence generally occurred close to a temperature of 10℃, either due to the characteristics of the hygr ometer itself or due to the range of temperature and RH experienced during the test period. If the influence of RH over this 95% RH range is lower than 1%, the hygrometer gets 3 points. 2 points if the influence is lower than 2%; 1 point if the influence is lower than 4%; 0 point above.
- The percentage of the differences of the minutely RH between the hygrometer and the reference lying between –3% and +3% of RH is calculated (see datasheets). If this percentage is higher than 98%, the hygrometer gets 3 points; 2 points if the percentage is higher than 95%; 1 point for 90%; 0 point below.
- If only one screen was present, the consistency is not taken into account. The total number of points is therefore multiplied by 5/4, to compensate the missing points from consistency section.
- If the total number of points is greater then 12, 5 stars are allocated (*****); if the total is greater than 9, 4 stars are allocated (****); greater than 6, 3 stars (***); greater than 3, 2 stars (**); less, 1 star (*).

The table 12 gives the raw rating for each hygrometer.

Table 12. Ratings of hygrometers

Hygrometer acronym	Rating
LBOM	12/12
VFIS	6/15
SVAI	12/15
UHMP	15/15
UTES	5/12
VTHY	12/12
VROT	9/12