

## **Project T-Hygro.S. Thermo Hygrometers sensors in different Screens.**

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### **Abstract**

The project T-Hygro.S., aims to investigate the screen influence on temperature and humidity measures, in order to gain useful information for the choice of an appropriate instruments screen able to replace the traditional Stevenson Screen of manned weather stations. Technology changes and improvements for meteorological instrumentation, as well as the necessity of replacing mercury thermometers with other electronic devices with a lower environmental impact, require an instrumentation renewal. At this point, the homogeneity of measurements historical series, as well as the maintenance costs evaluation, becomes a very important issues in the passage from manned weather stations to the (semi-)automatic contest.

In this framework, an experiment has been carried out at the Centre of Meteorological Experimentation (RESMA) of Vigna di Valle (42°04'49" N; 12°12'41" E; 266 m a.s.l.), using three thermo-hygrometers of the same kind and model, calibrated and adjusted both in humidity and in temperature against certificated references.

Sensors have been installed in the field in the same environmental conditions in order to enlighten only the screen influence. One sensor took place in the Stevenson screen of the local weather station, and its measurements have been taken as reference.

### **Text**

The structural measurement and monitoring systems of the Italian meteorological observation network are interested by an automation development through the implementation of automatic standard weather station (SWS) in many sites. This modernization will concern the replacement of existing equipment and measuring instruments (often mechanical/analog) by electronic components with digital output. In this context, it must be verified to have no difference in measurements with respect to the historical series. Actually, the introduction of new instruments should not affect the homogeneity of the historical series and technological solutions should be able to reproduce the measurement conditions used till now. In particular, with respect to the instruments, currently protected from direct solar radiation by the Stevenson screen, we should be sure that the new screening facilities, defined as equivalent in reason of environment context and protection, don't introduce errors due to their constructive characteristics, in the measurements provided by the new generation sensors.

The task of this study is to process temperature and relative humidity data, collected by three thermo-hygrometers with equivalent characteristics and previously calibrated, comparing their synchronized measurements with the one of them placed in the Stevenson screen of the official

weather station. The comparison should highlight the difference in behavior of the three environmental conditions in which the individual sensors are operating.

The purpose of experimentation, we will call T-HYGRO.S. (Thermo-Hygrometer measurements in different Screens) aims to understand if there are and what are the conditions of measurement, among those offered by new technologies, which could reproduce an equivalent environment and ensure the uniformity of measurements of the historically and internationally adopted "Stevenson screen". In particular, it will be highlighted the influences on the measures of temperature and relative humidity due to two types of screens, one actively ventilated and the other naturally ventilated. It will be showed any deviation from measurements taken from the third thermo-hygrometer located inside the local standard Stevenson screen.

The experimentation T-HYGRO.S. was organized into the following four steps:

1. Calibration of the sensors used for experimentation;
2. Installation of the sensors in the field using the different screens available:
  - Stevenson screen (considered as the reference screen);
  - Active ventilated screen (or aspirated);
  - Natural ventilated screen.
3. Data acquisition.
4. Processing and analysis of data.

This experiment continued for a period of about three months. The first step, involving the use of instrumentation for calibration, lasted one month. The second step, concerning in field installation of the three sensors, took two weeks. The duration of step 3 was 17 days, from 15 to 31 May 2012. The 4<sup>th</sup> step, regarding processing and data analysis, lasted about 1 month.

### 1. Description of Step 1.

The Department has recently acquired three temperature-humidity sensors, model HygroClip2 (Rotronic), with self-diagnostic function and calibration capability by dedicated software. Such sensors have also excellent performance in terms of reproducibility and accuracy. The capacitive sensor used for measuring humidity is Higromer IN-1, while for the temperature measurement is a PT100 1/3 DIN class B.

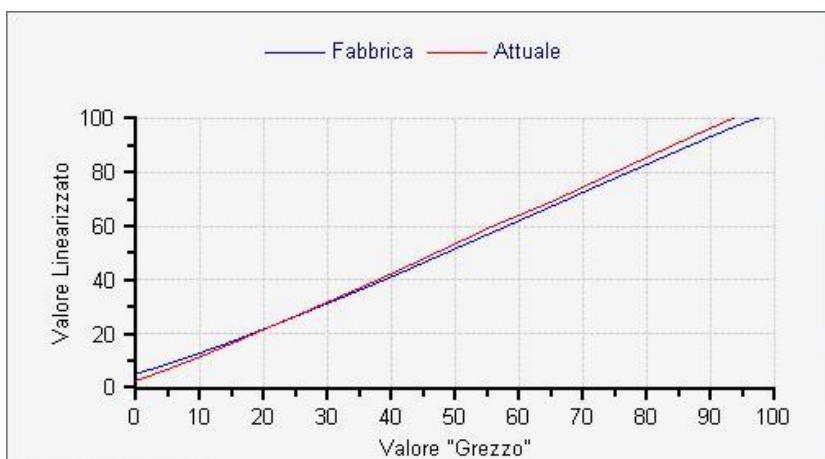


*Fig. 5.1  
Measures on different set points to adjust sensors' output (Michell HG-1 "chilled mirror").*

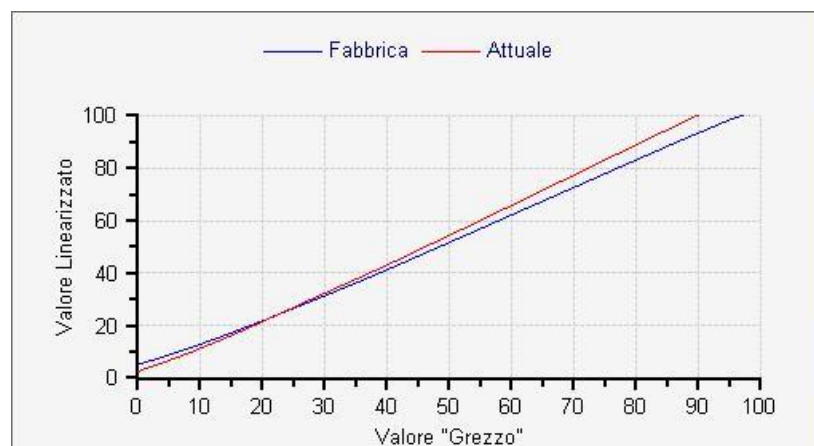
As a preliminary phase, we wanted to ensure that the three instruments had comparable performances in various temperature-humidity conditions. Therefore we proceeded to calibrate the instruments with respect to a large relative humidity range (15%, 85%) reporting their performance to certified reference (chilled mirror) installed in the Calibration and Adjustment Laboratory of ReSMA (Figure 5.1). Figures 5.2, 5.3, 5.4 show the calibration curves of the three sensors, renamed with the abbreviations R1, R2, and R3.



*Fig. 5.2 – Adjustment curve of sensor R1.*



*Fig. 5.3 – Adjustment curve of sensor R2.*



*Fig. 5.4 – Adjustment curve of sensor R3.*



Fig. 5.5 – Sensors calibration in temperature.

About temperature at first it was carried out the relative calibration of the instruments by pushing them simultaneously to variations of temperature between 12 °C and 45 °C and changing in relative humidity between 15% and 85%.

Figure 5.5 shows the calibration phase into the thermo-hygrometric chamber and Fig. 5.6 shows results and comparability. It shows, from the thermal point of view, the measures of the three instruments under test with respect to the reference S904, that is the sensor installed inside the calibration chamber.

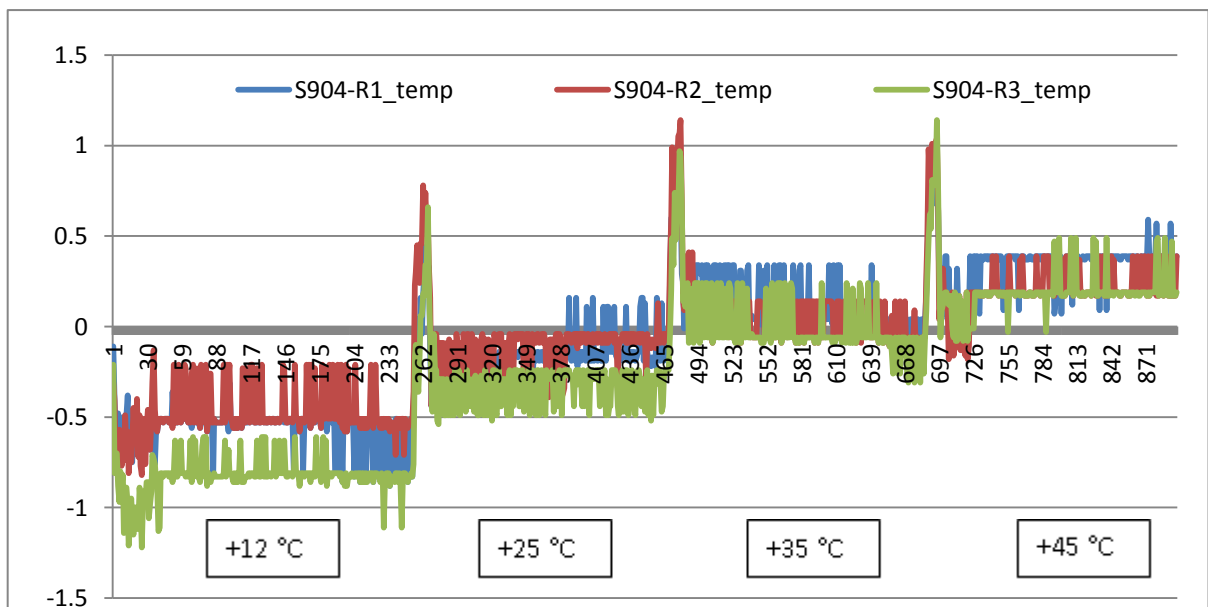


Figure 5.6 - Sensors response in temperature (measuring instrument, called "S904", placed inside the chamber) to the temperature-humidity stress. For each set of temperature (12 °C, 25 °C, 35 °C, 45 °C) was performed a variation cycle of relative humidity with the following values: 15%, 30%, 45%, 60% 75%, 85%.

Checked the constant behavior of the temperature sensors with respect to humidity changes, their calibration curves were calculated and applied to the three sensors under test (Fig. 5.7), obtaining in this way that their performances were homogeneous to the reference sensor of the thermo-hygrometer chamber (fig. 5.8), even if the performance of the chamber do not cover the whole meteorological temperature range.

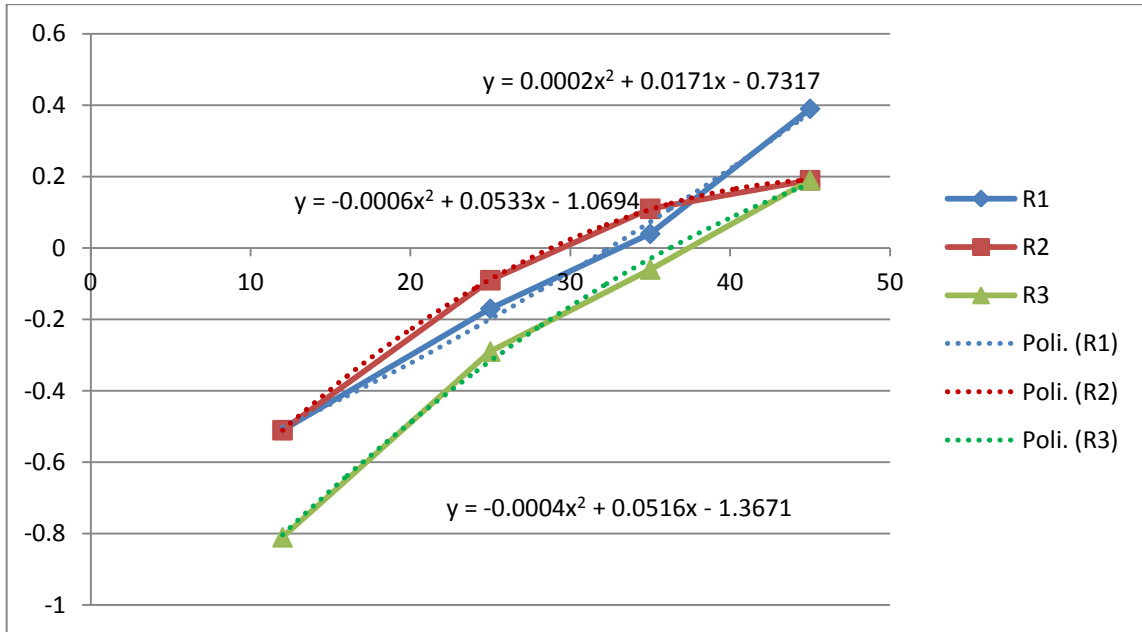


Figure 5.7: Calibration curves of the three temperature sensors R1, R2, and R3 with their 2<sup>nd</sup> order polynomial interpolation.

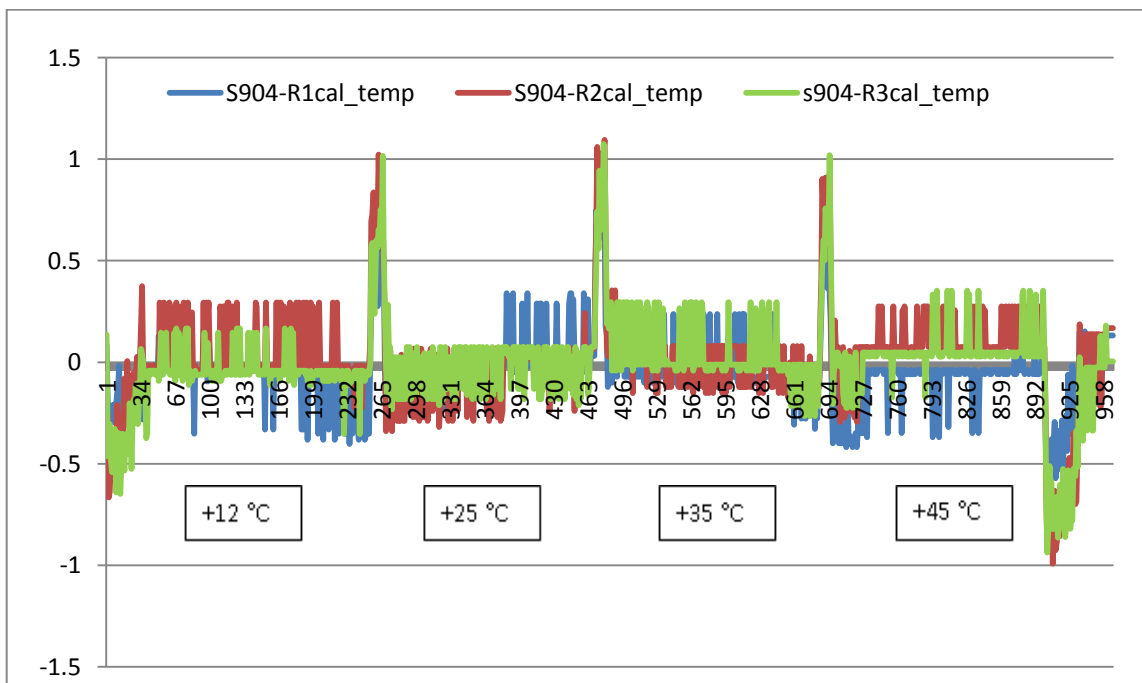


Figure 5.8: Responses of temperature sensors with respect to the reference S904 after applying the calibration curves in Fig. 5.7.

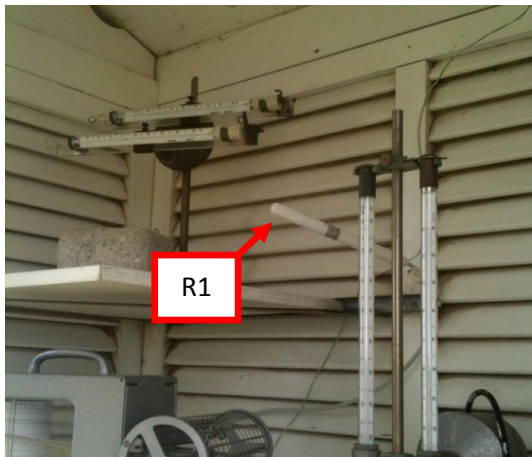


## 2. Description of step 2.

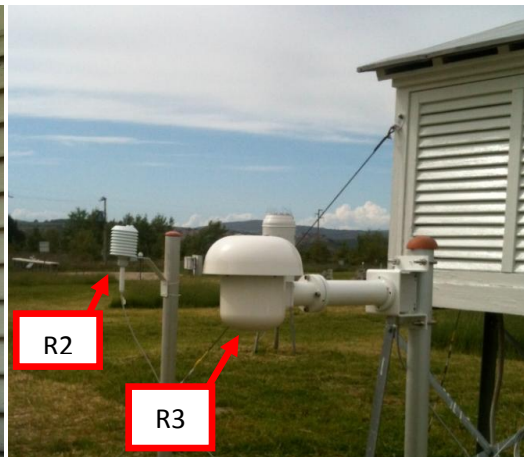
### - Installation

The three sensors have been installed in the field in the following way:

- ✓ R1 has been installed inside the Stevenson screen (Fig. 2.1);
- ✓ R2 was installed outside the Stevenson screen with a protective screen with natural ventilation (9 discs), model Rotronic AC1000;
- ✓ R3 was installed outside the Stevenson screen with a protective screen with active ventilation, Rotronic RS12T/RS24T model;



*Fig. 2.1 - R1 sensor inside the Stevenson screen.*



*Fig. 2.2 - The nearest screen active ventilated (sensor R3) and the background screen natural ventilated (sensor R2).*

R2 and R3 sensors were installed on a shaft at the south side of the Stevenson screen, at the same height, at a distance of about 1.5 meters from it, to avoid possible interference in the measurement (Fig. 2.2).

## 3. Description of step 3.

### - Connections and signal conversion

This installation phase required the passage of cables for the control and the remote acquisition of measurements, and many tests needed to obtain the synchronization of communication. Considering that the output of the instruments is a UART digital signal and that it can transmit information with a cable not longer than 5 meters, it needed to connect them by a converter ADAM 4017 (placed in the Stevenson screen) that captures the 6-channel digital input (3 channels for humidity and 3 channels for temperature) returning as output a single digital signal (string with the six measures) every second.

### - Methods of data acquisition by the SWS prototype Standard Weather Station.

The output of the converter ADAM 4017 is 422 digital signal, that has a distance transmission of kilometers. Trough the instrumental equipped emplacement "PS-6", near the Stevenson screen,

signal is controlled / stored by the prototype SWS, already being tested at RESMA. Power to the actively ventilated screen has been provided by 12V transformer.

#### 4. Description of step 4.

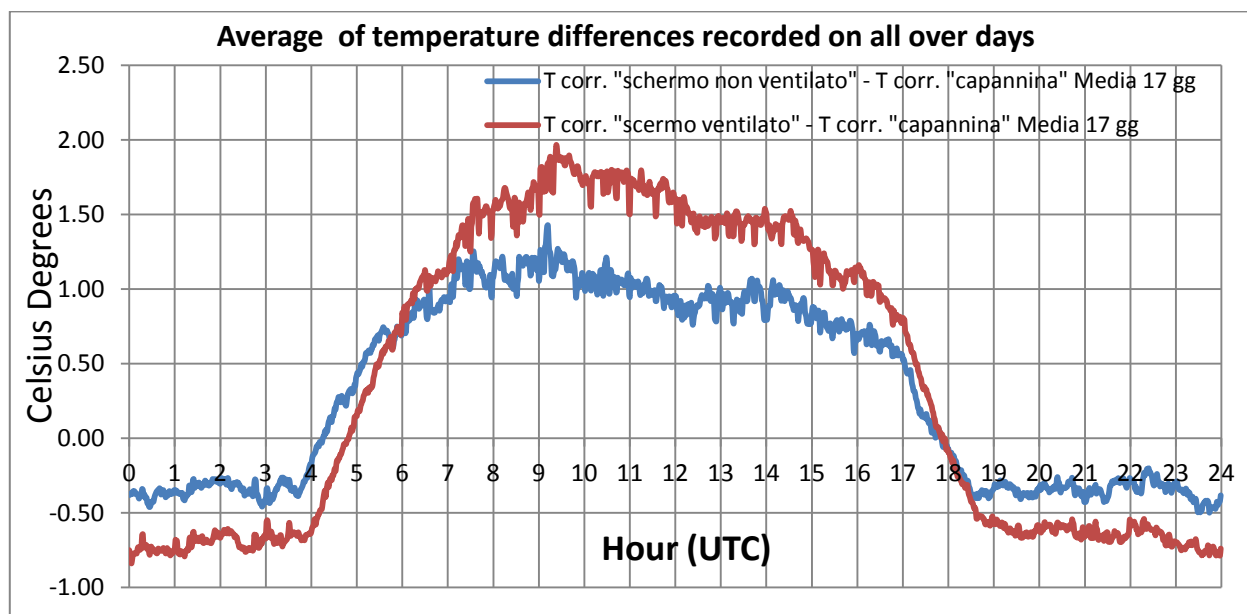
##### - Analysis and processing of temperature per minute data relative to external sensors and the one inside the Stevenson screen.

The period we refer in this study concerns seventeen days, starting from 15 until 31 May 2012. The measurements in temperature (equivalently for those in relative humidity) performed by the three sensors, have been sampled at intervals of one second. The processing and data analysis were performed on one minute averaged values (the average is considered valid / present, only if at least 40 second data per minute are available) on all over the reporting period.

Among data, it has been taken into account every absence, always considering the exact correspondent empty time, to cover the entire period analyzed unambiguously. Since the three sensors transmit their measurements simultaneously with a single string by the analog / digital converter "ADAM 4017", data presence are always temporally coincident and any absences are common at any moment they happened.

Initially it was investigated any difference in measurements recorded by sensors in the new generation screens, naturally ventilated concentric discs (internal sensor "R2") and actively ventilated (internal sensor "R3"), with respect of the screen offered by the traditional Stevenson screen in which has been placed the sensor "R1".

In particular it has been prepared data in column values: the T2c (minute average temperature of sensor "R2") and the T1c (minute average temperature of sensor "R1") from 00:00 to 23:59 minutes (1440 records) for everyone of the seventeen days. In a new column, it was calculated the values, averaged on the seventeen days, of the differences "T2c-T1c". Equivalently it was made for T3c temperature (minute average temperature of sensor "R3") versus T1c.



*Fig.8.1 Average of temperature differences between the thermo-hygrometer into the naturally ventilated screen (blue curve) and the second one into the actively ventilated screen (red curve) both with respect to the one into the Stevenson screen.*

The graph of such differences (Fig. 8.1) shows clearly a behavior dictated by the diurnal cycle. In the first case ( $T2c-T1c$ ), during nighttime we can suppose to be a greater cooling of the air in the naturally ventilated screen than into the Stevenson screen, of about less than half degree. During daytime the difference is clearly in favor of the sensor with the naturally ventilated screen, measuring an air temperature of about 1 °C higher than the one measured by the equivalent sensor closed in the Stevenson screen. In the second case ( $T3c-T1c$ ) differences confirm the same diurnal cycle of the previous case, but they are more pronounced:  $(T3c-T1c) > -0.5$  °C during the night and  $(T3c-T1c) > 1.5$  °C during the day.

Figure 8.2 is a graphical representation of temperatures measured at the same time on one day (2012/05/15) with the three different screens. It may be noted that, besides the difference on measures already discussed, there is a different thermal inertia of the Stevenson screen with respect to external screens that can also reach shifts of one hour during the heating phase of the day, but no more recorded in the declining phase of the sun and at night.

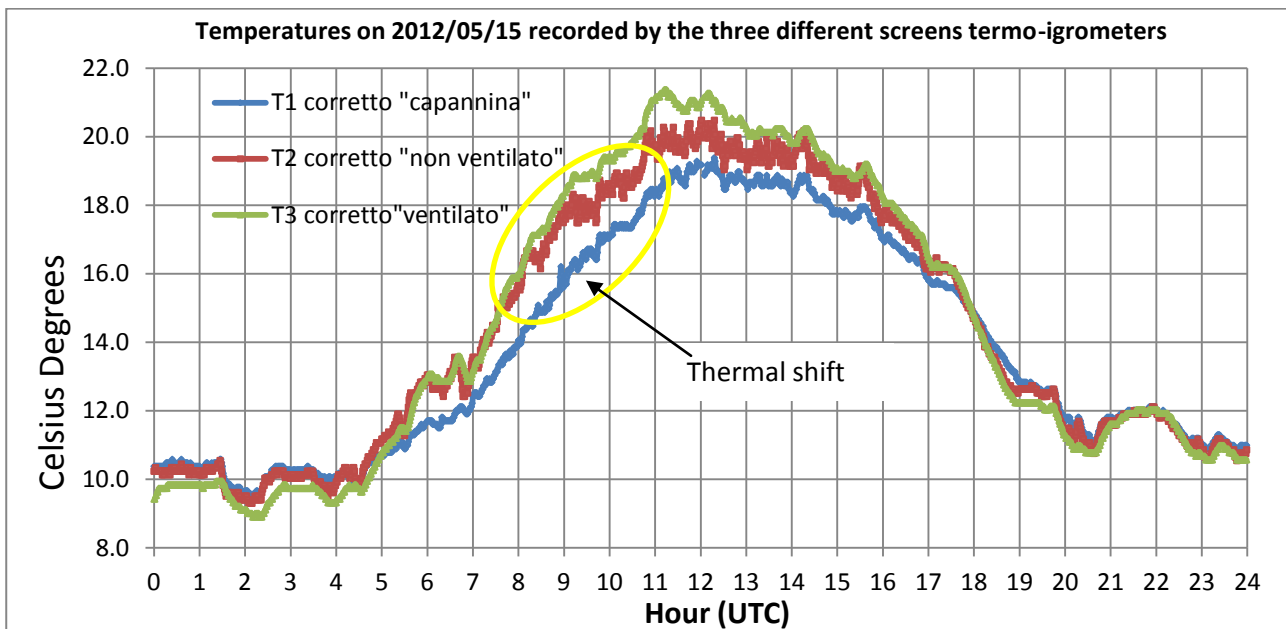


Figure 8.2 Temperatures measured on 2012/05/15 by the thermo-hygrometer in the Stevenson screen (blue curve), the thermo-hygrometer with a naturally ventilated screen (red curve) and the third one with the actively ventilated screen (green curve).

The data analysis continued ordering data in term of increasing values of the temperatures simultaneously measured by the three thermo-hygrometers with different screens. They were made two scatter plots which show the relation between measurements recorded by thermo-hygrometer in naturally ventilated screen and those of the one in the Stevenson screen (Fig. 8.3) Similarly it was done with the measurements recorded by thermo-hygrometer in the actively ventilated screen (Figure 8.4). As can be seen in the two cases there is a temperature overestimation which is more pronounced when increasing the temperature and an underestimation for low values. The values that mark this reversal are between 11 °C and 14 °C.



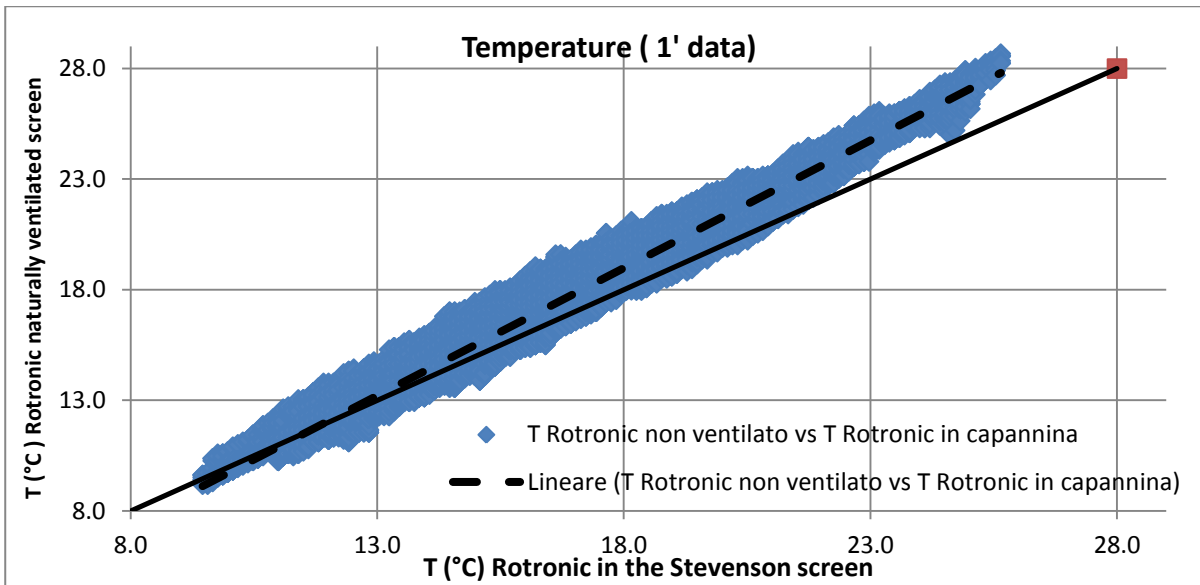


Figure 8.3 Temperature measurements  $T_{2c}$  detected by thermo-hygrometer with naturally ventilated screen  $T_{1c}$  vs those of thermo-hygrometer in the Stevenson screen.

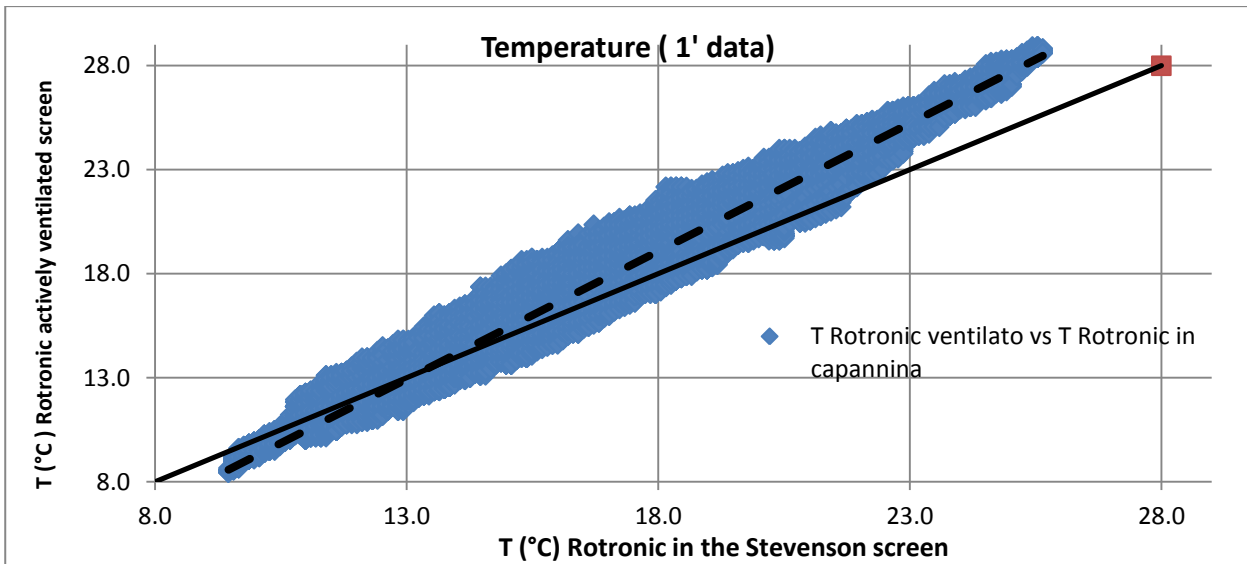


Figure 8.4 Temperature measurements  $T_{3c}$  detected by thermo-hygrometer with active ventilated screen  $T_{1c}$  vs those of thermo-hygrometer in the Stevenson screen.

To confirm what has been shown, grouping data in cluster of values of 1 °C gap and considering as reference the intervals of measures in the Stevenson screen, it was possible to analyze with more detail the behavior of screens when stressed by different thermal conditions. They were calculated the averages, on the 17 days available, of the differences between the temperatures detected by the sensor with the naturally ventilated screen and from the sensor in the Stevenson screen and the corresponding standard deviations. The same was done for the other sensor with the actively ventilated screen. As it can be seen looking at the graphs (Figs. 8.5 and 8.6), as the temperature increases the average of differences between  $T_{2c}$  and  $T_{1c}$  and between  $T_{3c}$  e  $T_{1c}$ , respectively increases too. In particular, this difference exceeds the value of 1.5 °C in the first case and the value of 2 °C in the second one.

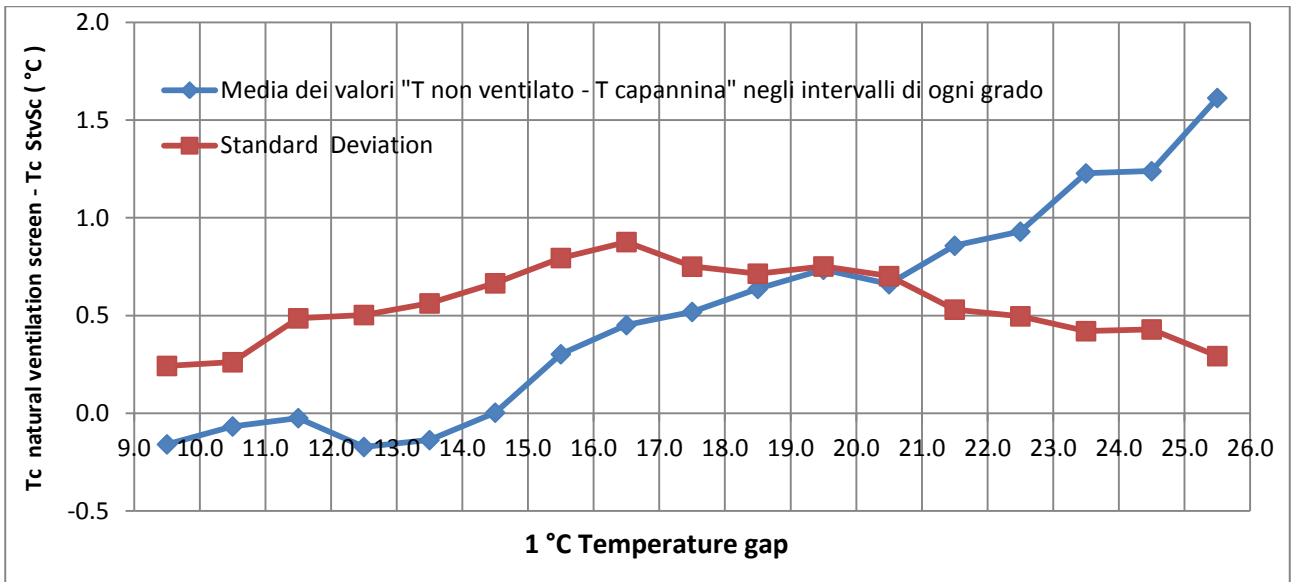


Figure 8.5 Average, on 17 days, of the differences ( $T_{1c}-T_{2c}$ ) between temperatures measured by thermo-hygrometers in the natural ventilation screen and in the Stevenson screen, considering groups of measures contained in the intervals of 1 °C. The blue curve is the mean, the red curve is the standard deviation.

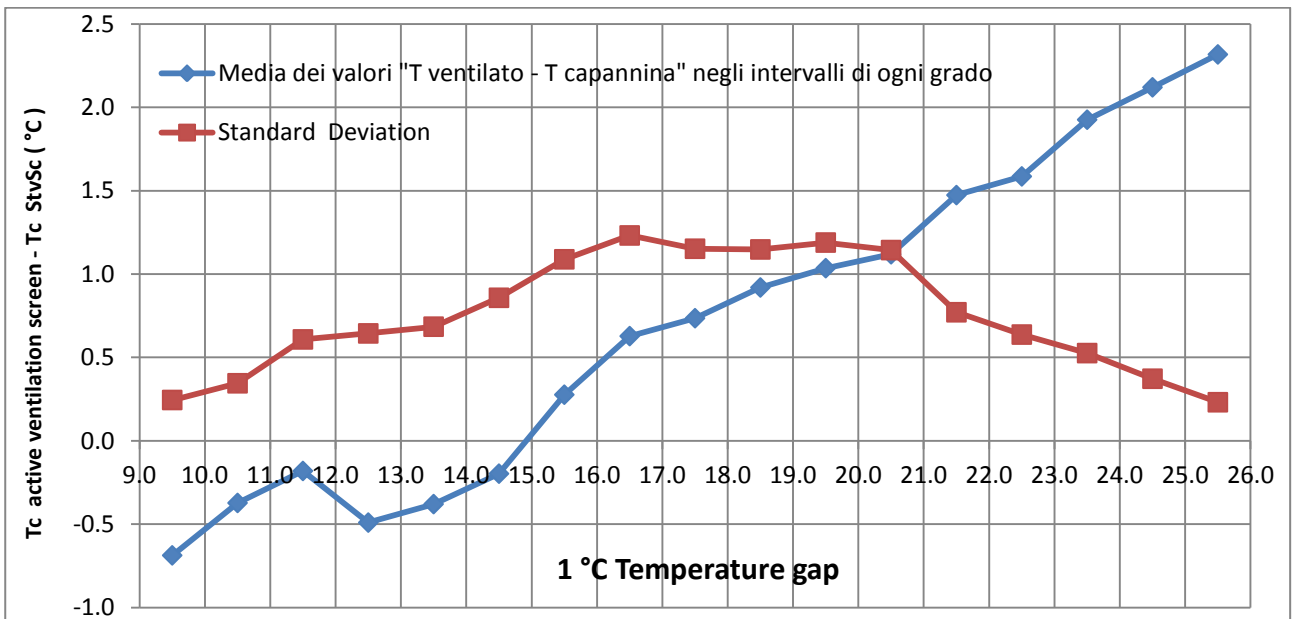


Figure 8.6 Average, on 17 days, of the differences ( $T_{3c}-T_{1c}$ ) between temperatures measured by thermo-hygrometers in the active ventilation screen and in the Stevenson screen, considering groups of measures contained in the intervals of 1 °C. The blue curve is the mean, the red curve is the standard deviation.

- Analysis and data per minute processing of relative humidity detected by external and in Stevenson screen sensors.

The time interval is anyway referred to the seventeen days from 15<sup>th</sup> to 31<sup>st</sup> of June. Measurements of relative humidity of the three sensors have been sampled at intervals of one second. The processing and data analysis was, also in this case, performed on the averaged

values for every minute of the whole period. Data have been processed as already described at the beginning of this paragraph.

Data processing, also in this case, had the aim to investigate any difference in the behavior of the new generation screens, in concentric discs with natural ventilation (internal sensor "R2") and active ventilation (internal sensor "R3"), relatively to the screen offered by traditional Stevenson screen inside which was placed the sensor "R1".

As for temperature, relative humidity data were placed in side by side column, RH2 (relative humidity per minute of the sensor "R2") and RH1 (relative humidity per minute of the sensor "R1") values from 00:00 to 23:59 minutes (1440 records) for everyone of the seventeen days. Then in a new column was wrote the value, averaged over all seventeen days, of the differences "RH2-RH1". Equivalently it was done for the relative humidity RH3 (relative humidity per minute of the sensor "R3") with respect to RH1.

The graph of these differences (Fig. 8.7) shows, also in this case, a clear behavior dictated by the diurnal cycle. In the first case (RH1-RH2) the natural ventilated sensor estimates, during the night, at least 4 percentage points in relative humidity higher than the measurements recorded by the sensor into the Stevenson screen, while, during daytime, RH2 measured up to 3 percentage points less with respect to the sensor RH1 into the Stevenson screen. In the second case the mean differences (RH1-RH3), behaving differently as for temperature, are less marked in the daytime and not much than 2%.

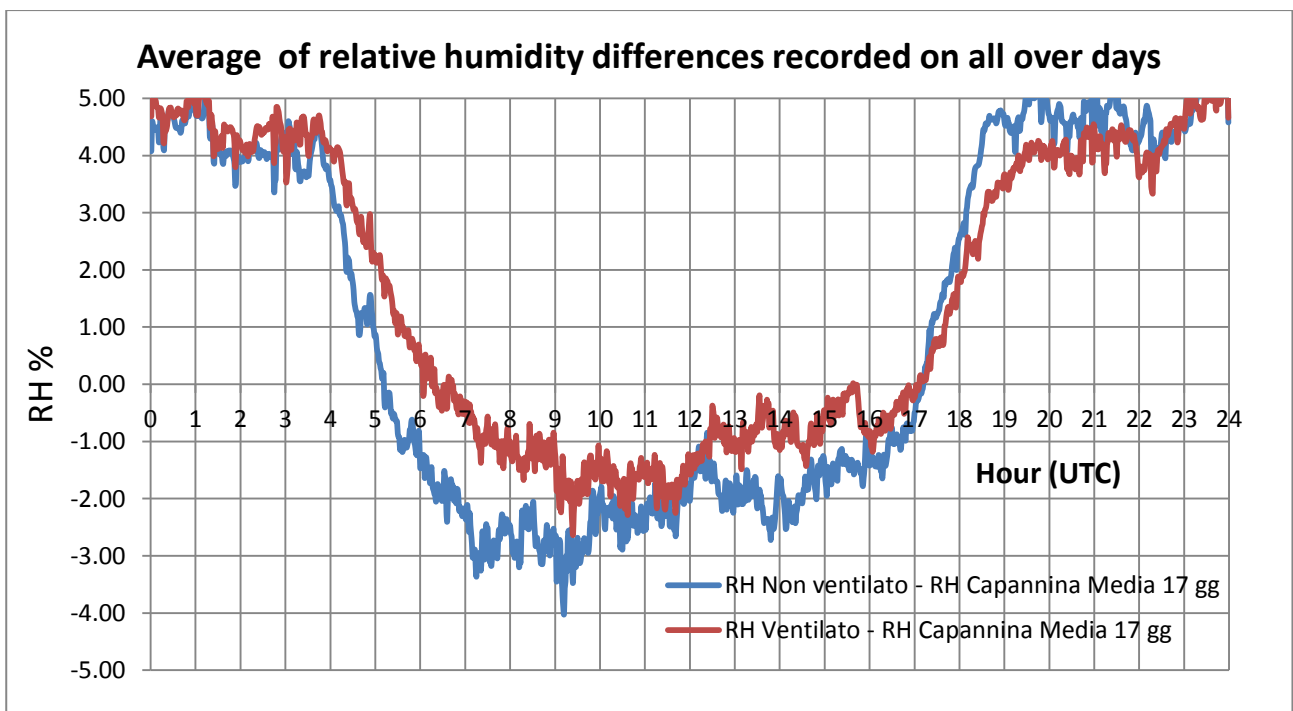


Figure 8.7 Average of relative humidity differences between the thermo-hygrometer with the natural ventilated screen and the one in the Stevenson screen (blue curve) and between the thermo-hygrometer in the active ventilated screen and the one in the Stevenson screen (red curve).

Figure 8.8 is a graphical representation of the relative humidity detected in one of the experimentation day by the three sensors with different screens. Unlike as one can see for temperature measurements, there is no evidence of inertia in the hygrometer measures inside the Stevenson screen compared to external displays.

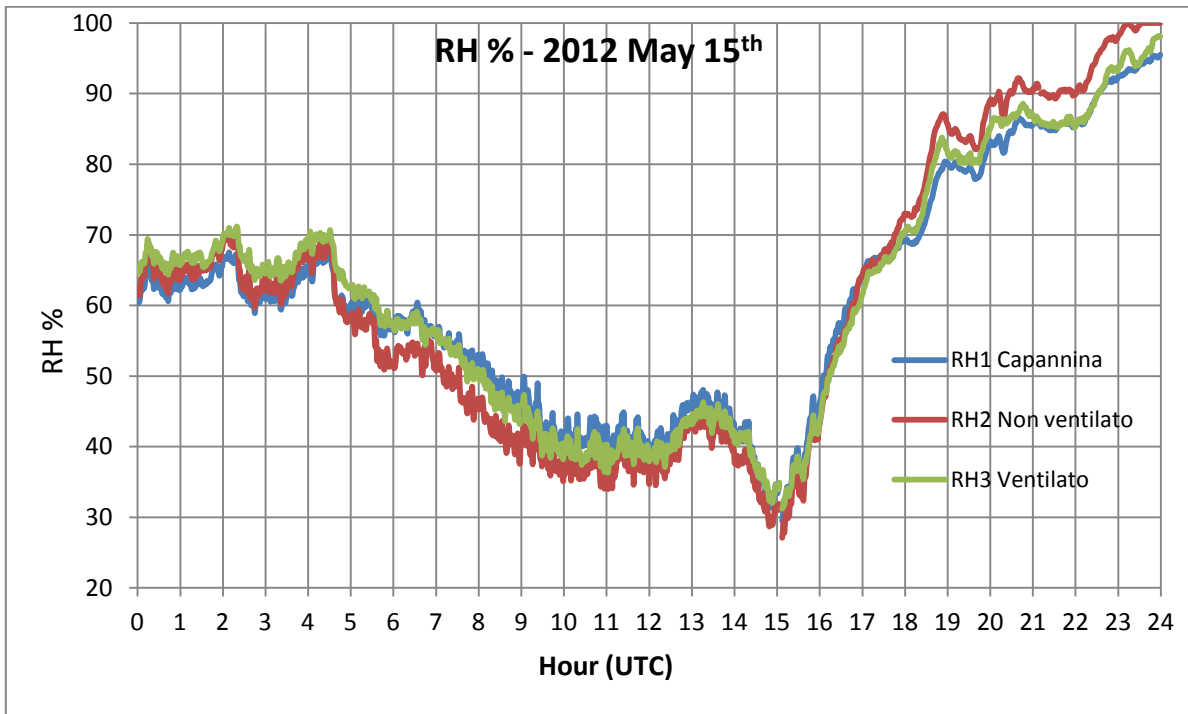


Figure 8.8 Relative humidity detected (15/05/2012) by the thermo-hygrometer in the Stevenson screen (blue curve), the thermo-hygrometer in the natural ventilated screen (red curve) and the one in the active ventilated screen (green curve).

By grouping data in cluster of values with a gap of 5% in relative humidity, considering as interval reference the ones of the measures in the Stevenson screen, it was possible to analyze the behavior of the different screens when stressed by different humidity conditions. Also for these kind of measures, we calculated, considering the average on the 17 days available, the differences between the relative humidity detected by the sensor in the naturally ventilated screen and the sensor in the Stevenson screen and the corresponding standard deviations. The same calculation was done with the sensor in the active ventilation screen. As one can see from the graph (Figure 8.9), with increasing of relative humidity from 35% to 85%, the differences between the two measurements increase more and more moving from negative values under 65% to positive ones for higher values. In particular, the relative humidity detected by the thermo-hygrometer in the natural ventilated screen, for values of humidity between 25% and 40%, is sometimes less than 3.5 percentage points with respect to the one measured by the sensor in the Stevenson screen. For humidity values between 85 and 95% of the same sensor measures between 5% and 6% more with respect of the sensor in the Stevenson screen. In the extremes of the range of measurement differences fade remaining around 2 percentage points.

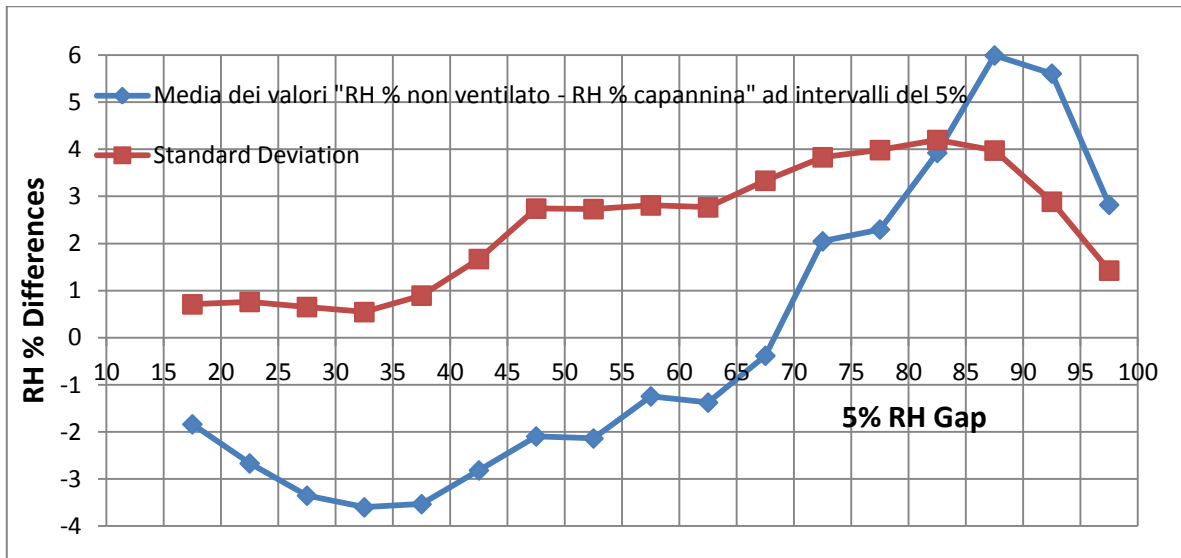


Figure 8.9 Average on 17 days of the difference between the relative humidity measured by thermo-hygrometers in the natural ventilation screen and in the Stevenson screen, considering groups of measures contained in intervals of 5%. The blue curve is the mean, the red curve is the standard deviation.

The data analysis carried out from the comparison between the sensor in the actively ventilated screen and the one in the Stevenson screen (Fig 8.10), shows that between 20% and 70%, the differences between the two measurements don't exceed 1%. The relative humidity detected by the thermo-hygrometer in the actively ventilated screen, for values of humidity between 70% and 95% increases more and more reaching, between 80% and 90%, differences around 5% compared to the sensor in the Stevenson screen. Also in this case, in the extremes of the measurement range the differences decrease towards values of 2%.

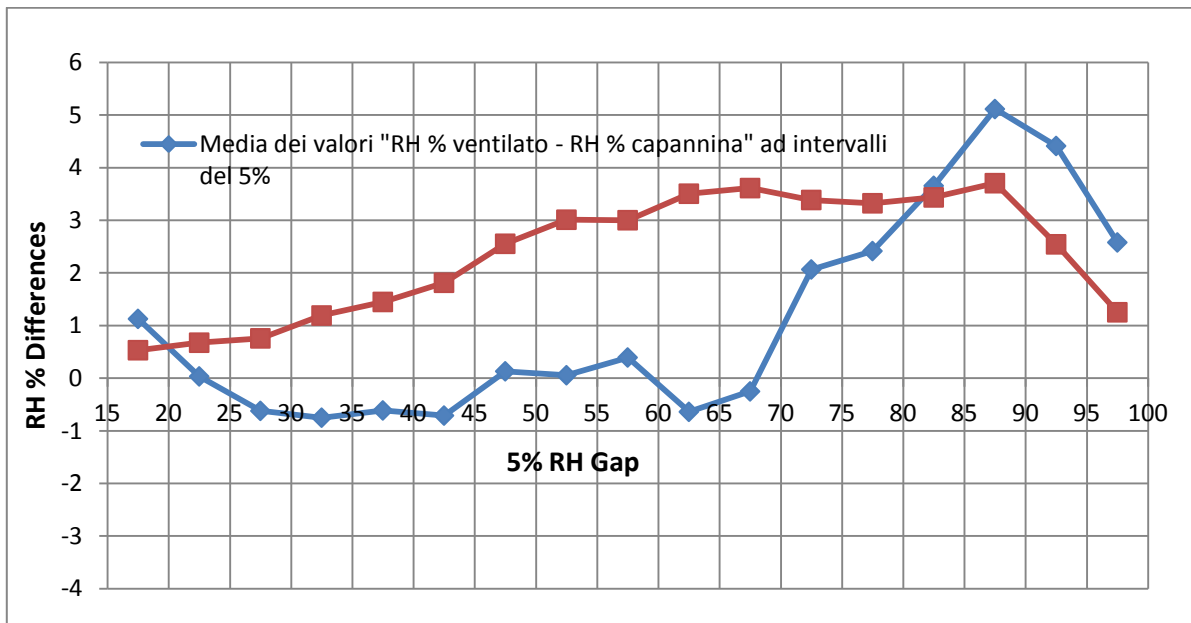


Figure 8.10 Average of 17 days of the difference between the relative humidity measured by the thermo-hygrometers in the natural ventilation screen and in the Stevenson screen, considering groups of measures contained in intervals of 5%. The blue curve is the mean, the red curve is the standard deviation.

## 9. Conclusions and evaluation

The data analysis performed on the comparison of thermo-hygrometers in the natural ventilation screen and the sensor in the Stevenson screen showed marked differences in measurements for relative humidity but especially for temperatures.

The differences between measurements in the Stevenson screen and those recorded by the other two types of screens, in the thermometric field, show a clear trend dictated by the diurnal cycle, much more pronounced as higher is the air temperature. A slight thermal inertia has also been highlighted between measures with small screens and measures in the Stevenson screen.

In humidity field the differences between measurements in naturally or actively ventilated screen and the Stevenson screen showed maximum deviations around 5% - 6% in the measuring range between 85% and 95% of relative humidity.

The measures in the screen with natural ventilation showed also negative differences in humidity between 25% and 40% which however don't exceed 3,5%. There is no evidence of inertia in relative humidity measurements related to the type of screen.

The acquisition of the measures will continue at least until the end of this year and this will allow us to realize an extension of the study reported here.