METHODOLOGY EMPLOYED IN A CALIBRATION APPARATUS FOR MEASURING AIR TEMPERATURE AND RELATIVE HUMIDITY SENSORS

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Abstract. *This article uses the analysis of variance (ANOVA) as a tool to validate a calibration apparatus for temperature and relative humidity sensors. The validation aims at showing apparatus operation ranges as to dry-bulb (tdb) and wet-bulb (twb) temperatures, and relative humidity of air (RH). Analyses were carried out testing twb as a function of air velocity ranging from 1.25 to 5.00 m/s, twb as a function of RH, and also comparing two environments to calibrate tdb: either in thermostatic bath, or in the airflow of a test section. The following sensors were used in the tests: thermocouples, thermoresistance, semiconductor, and mercury-in-glass thermometer.The results showed that air velocity on wet covering sensors within the tested range of 1.25 to 5.0 m/s does not change the measured twb, thus widening the range suggested in norm ASHRAE 41.1-1974. However, for relative humidity of air within the studied range, significant differences were found, and these are close to the 2-3% indicated range. The use of different calibrated sensors for tdb resulted in different calculated RH values in a controlled environment. Sensor calibrations either in airflow or water presented similar results.The validated tdb, twb and RH ranges were 30.50-44.50 ºC, 25.00-31.10 ºC, and 57.20-74.46%, respectively.*

Keywords: *psychrometry , psychrometer, relative humidity* of air*, calibration.*

1. Introduction

Data presented by the manufacturers of some electronic temperature sensors show that some of them have high thermal dissipation. The AD592 integrated system presents a power dissipation of approximately 4.4mW @ 15V (Analog Devices,____). The use of a sensor covered with a cotton sock to obtain relative humidity of air (RH), which provides the measure of the wet-bulb temperature, introduces a superficial thermal resistance in the sensor, and this may interfere in the process of heat transfer between the air and the sensor. This fact indicates that the sensor must be calibrated again. Therefore, it was found that a calibration apparatus should be build in order to test this conditions.

A calibration apparatus started to be built by Balestrin (1999) and latter by Gasparini (1999). Based on this first apparatus, this article proposes the building of a new one, based on ASHRAE 41.1-1974 standard, using the method of analysis of variance (ANOVA) as validation tool (Dias, 2001).

2. Calibration apparatus

The apparatus basically consists of three subsystems, as shown in Fig. (1). Subsystem [1] is the airflow circuit. Air temperature and humidity are controlled by a conditioning chamber [subsystem 2]. Subsystem [3] is the test section, where calibration by comparison is carried out.

2.1. Description of the apparatus subsystems

2.1.1. Closed ventilation circuit: subsystem [1]

Subsystem [1] consists of piping, a fan, and an airflow variator. Piping is made of conventional PVC plastic –used in buildings – and it is thermally isolated by a sheet of aluminum-coated polystyrene foam, which is commonly used to cover building roofs. The centrifugal fan is the same as those used in window-type air-conditioners, and the airlow variator was built with a plate restricting the flow cross area. The subsystem is provided with a micro-manometer with a Pitot tube, as shown in Fig. (2).

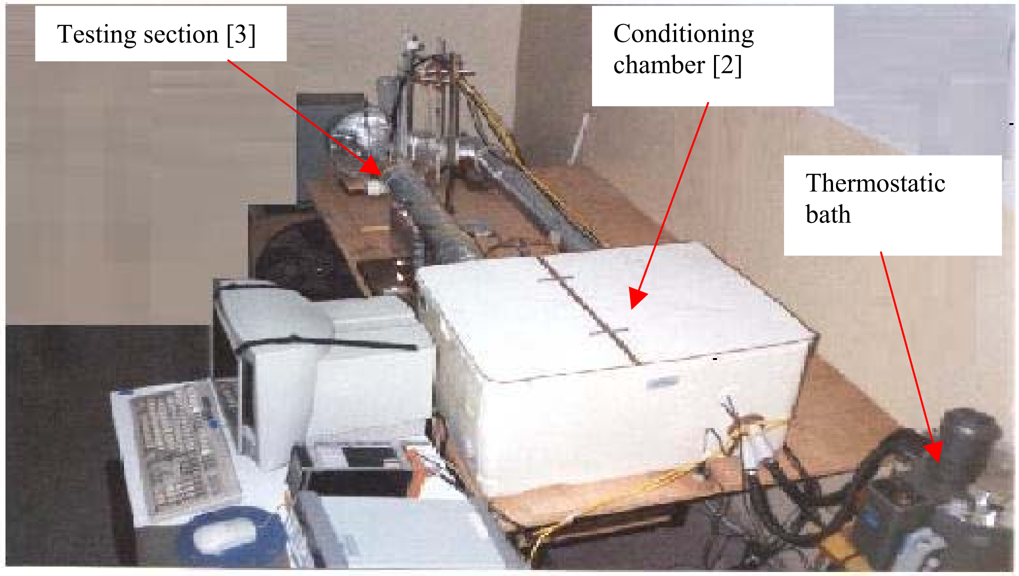

Figure 1- General vision of the calibration apparatus

2.1.2. Air conditioning chamber: subsystem [2]

The function of this subsystem is to supply air at controlled temperature and humidity in order to carry out the tests. The chamber consists of a sensitive heat exchange circuit, and a vaporizer. Air temperature control is obtained only by heating, depending on environmental conditions. The sensitive heat exchange device consists of an automatic thermostatic bath, which supplies heated water to a heat exchanger placed inside the chamber. The exchanger is a room air conditioner (RAC) evaporator with 2.2 kW capacity (7500 BTU/h). A water vaporizer is also placed inside the chamber. Vapor injection into the chamber is controlled by a PPC (Programmable Process Controller). The structure of the chamber consists of an expanded polystyrene box, internally covered with a galvanized steel plate aimed at protecting the chamber if it is exposed to high air temperature and humidity.

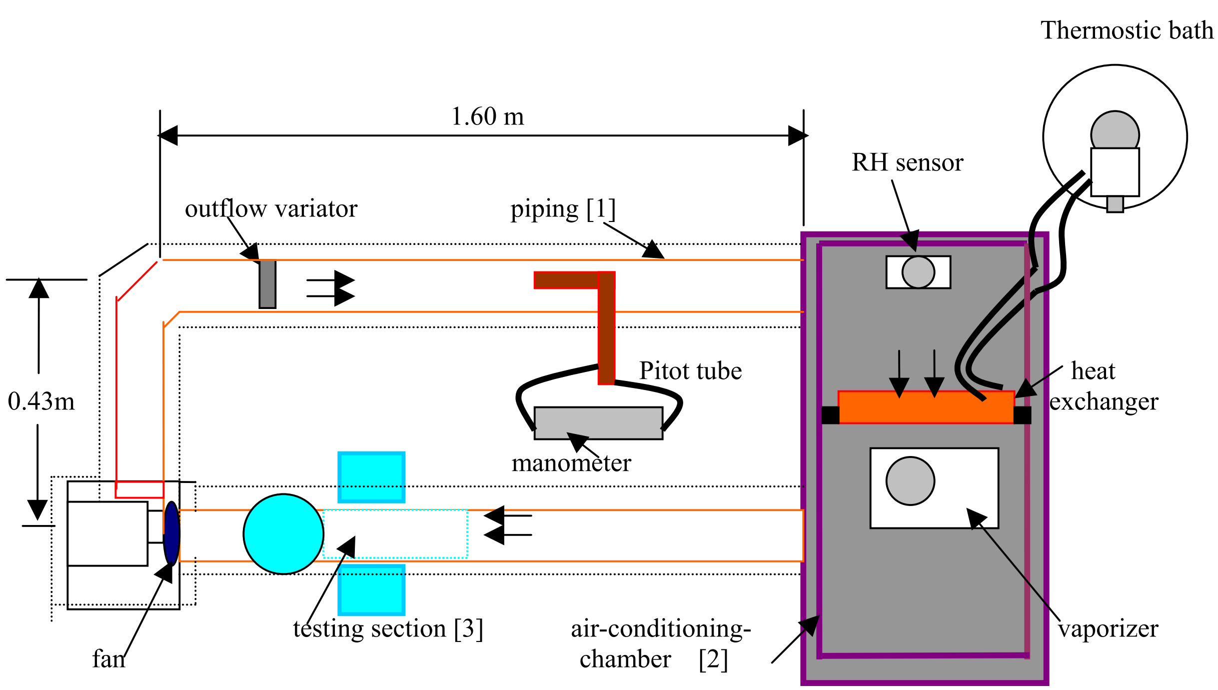

Figure 2. Design of the calibration apparatus

2.1.3. Seção de teste: subsistema [3]

The testing section shown in Fig. (3) is part of the piping where the sensor elements are placed for testing. It consists of reference and test temperature sensor elements, of a sock humidifier, by a distilled water reservoir, and other accessories. The sensor elements are placed on the testing section transverse to air outflow. The calibration procedure employs comparisons, where the different tested sensors are compared to a reference thermometer. The testing section ensures that the air that flows throughout the system is under the same conditions. The position of the reference and the test sensors follow the recommendations of norm ASHRAE 41.1-1974. Also according to this norm, the sensors must penetrate the piping up to its circumference center. The sensors for measuring wet-bulb temperature (twb) must have a cotton fabric sock or other hygroscopic material on the sensitive part. The sock must cover the sensor element, which must be at a minimal distance of 25.4 mm of the level of water of the sock humidifier, considering that the diameter of air outflow piping is 100mm.

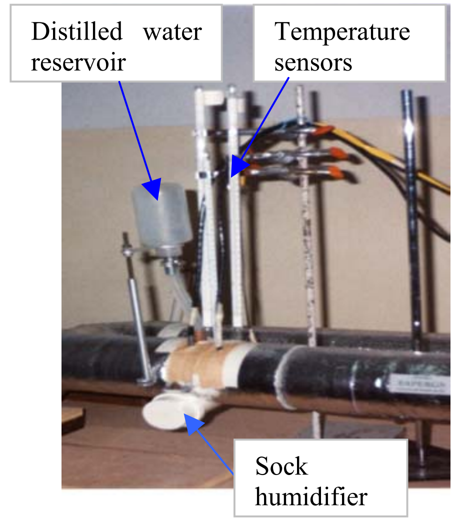

Figure 3. Testing section

Taking into consideration that minimum and maximum air velocity within the pipe is 1.25 m/s and 5.00 m/s, respectively, the number of Reynolds for outflow is between 8600 and 34400, assuming an air specific mass of ρ=1.225 kg/m^3, air absolute viscosity of μ=1.781 x 10^{-5} kg/ms, and temperature of 15 ºC. These results, which are higher than the critical number of Reynolds (Re=2300), indicate that outflow is turbulent. Therefore, the position of the sensors must be within a minimal distance of 10 diameters from any accessory, such as curves or restrictions (Hansen, 1974). The diameter of the piping used was 0.10 m, which leads to a minimal distance of 1.0m.

2.2. Equipment

Air fan: A motor-fan set operates at a rotation of 450 rpm (7.5Hz), and the rotor is of the centrifugal type.
Thermostatic bath: The temperature of the thermostatic bath is controlled by a PCC (Programmable Process Controller), and only functions under temperatures above the environmental temperature. The performance of tests under temperatures below the environmental temperature requires the addition of chopped ice to the bath, but this renders the tests labor-consuming and poorly controlled.
CPP- N8000 Controller: It is a controller with PID (Proportional, Integral, and Derivate) control action.
HP- 34970A: It is an instrument for data collection, which allows reading on the display itself, or via computer.

3. Basis

3.1. Psychrometry

A psychrometer is an instrument capable of determining relative air humidity from dry and wet-bulb temperatures. When a wet-bulb is exposed to an air current, water evaporates from the tissue, determining a temperature of equilibrium called twb. This process is not adiabatic saturation, which defined the thermodynamic twb, but rather simultaneous heat and mass transfers in the wet-bulb (ASHRAE, 1994). In order to avoid saturation of the environment surrounding the sensor, a small fan is added on the wet sensor to promote the aspiration of air flowing over the wet sensor.

Calculated relative humidity of air, RHc in [%] is defined by Eq. (1), obtained from the sequence of calculations of ASHRAE, (1997).

$$UHc = \frac{\mu}{1-(1-\mu)(pws_{(tdb)}/p)} x100\% \qquad (1)$$

where p is total atmospheric pressure in [Pa]; $pws_{(tdb)}$ is the partial pressure of water vapor in saturation at tdb in [Pa], and μ is the degree of saturation.

The ASHRAE 41.6-1994, norm proposed Eq. (2), known as the equation of the dry-bulb and wet-bulb psychrometer. In the present study, this equation was used to determine the coefficient of the psychrometer (A), in [K^{-1} or ºC^{-1}]

$$A = \frac{pws_{(twb)} - pw}{p(tdb - twb)} \quad (2)$$

where pw is the partial pressure of water vapor in the atmosphere [Pa], and $pws_{(twb)}$ is the partial pressure of water vapor in saturation at tdb in [Pa].

Deriving Eq. (2), as a function of tdb and twb, and replacing their derivates in the equation of Kleine and McClintock [Holman, 1996], we obtain Eq. (3), which determines the propagated uncertainty of measure relative humidity of air (*wrc)* in [%] in the testing section.

$$wrc = \left(\left(-Ax * wr_{tdb}\right)^2 + \left(Ax * wr_{twb}\right)^2 \right)^{1/2} x100\% \quad (3)$$

being $Ax = \frac{Ap}{pws_{(tdb)}}$, where $wr_{(tdb)}$ is the uncertainty of the measurement of tdb in ± [ºC], and $wr_{(twb)}$ is the uncertainty of the measurement of twb in ± [ºC].

3.2. ANOVA

The method of analysis of variance (ANOVA) (Box et al., 1978, and Barros et al., 1995) for multiple groups was employed in a situation of a single variable (one-way ANOVA). The experiment always involves one variable of response and a controllable factor in several levels. The aim is to identify if there differences among the means or the variances of a variable of response, measured at various levels. The tested hypotheses are:

Ho: there are no significant differences among groups;
H1: there are significant differences among groups.

The test compares the value of factor F, calculated by the method with the Fc value (critical value) found in tables of F distribution. If the value calculated by the method is higher than the value found in the table, the Ho hypothesis is rejected and hypothesis H1 is accepted, that is, there are significant differences among group means.

4. Validation of the calibration apparatus

The method of analysis of variance (ANOVA) was used to validate the tests. Validation aims at determining the operation ranges of the apparatus as to dry-bulb temperature (tdb), wet-bulb temperature (twb), and relative humidity of air (RH). Tests of twb as a function of air velocity within the range of 1.25 to 5.00 m/s, of twb as a function of RH, of the comparison between two calibration environments (in the water of a thermostatic bath or in the air – testing section) were analyzed. Type-k thermocouple, PT100 thermoresistance, AD592 semiconductor, and mercury-in-glass sensors were used in four assay categories, as follows:

4.1. Apparatus stability in terms of temperature and relative air humidity

It is important and necessary to check a system in order to understand the limitations of the equipment and the stability in terms of temperature and relative humidity of air. It is also necessary to check the behavior of sensors submitted to an environment with variable temperature, relative humidity and air velocity. Fig. (4) illustrates the stability curves of tdb, twb, and air temperature (tamb) as a function of time (t).

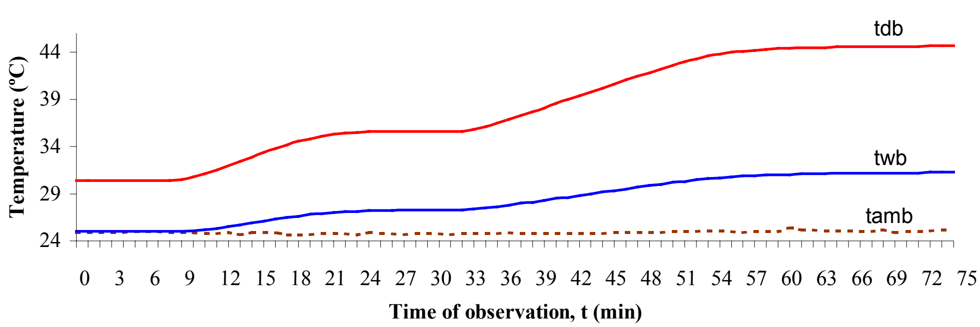

Figure 4. Stability curves of tdb and twb in the testing section, and tamb, as a function of time (t)

Stability was pursued with tdb as control variable. Fig. (4) shows three stabilization plateaus for tdb: 30.50 ºC, 35.60 ºC, and 44.40 ºC. Following the same time intervals in the stability curve of tdb, twb shows similar behaviors, with three stabilization plateaus at 25.00 ºC, 27.20 ºC, and 31.10 ºC. Tamb also remained virtually constant throughout the test, at approximately 25 ºC with a 0.40 ºC variation during 75 min of observation. Data indicated that the apparatus is capable of ensuring stable conditions for the test. Fig. (5) presents the stability curves of calculated relative humidity of air (RHc) in the testing section, and environmental relative humidity of air (RHamb) as a function of time (t).

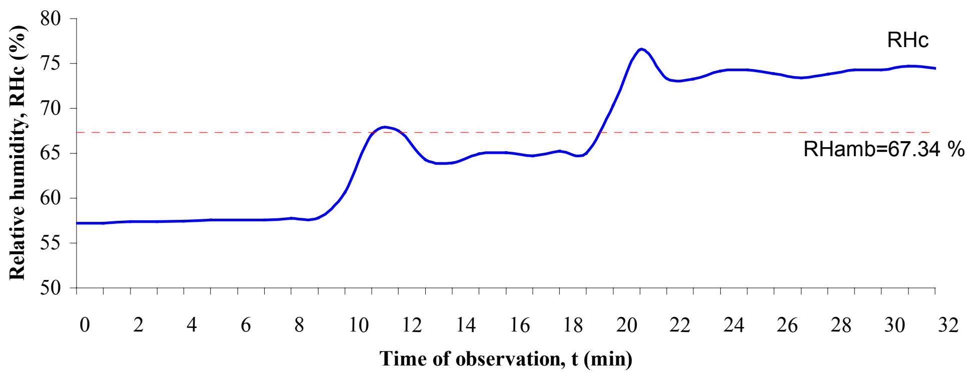

Figure 5. Stability curves of calculated relative humidity - RHc in the testing section, and of environmental relative humidity of air - RHamb as a function of time (t)

Stability was pursued with twb as control variable. Three stabilization plateaus of RHc of 57.20, 65.06, and 74.46 % were observed. In Tab. (1), we observe that the uncertainty of propagated measurement of relative humidity of air (wrc) was within the range of ± (0.26 - 0.32) %, which was below the expected of ± (2-3) % (ASHRAE, 1994). Data indicated that the apparatus is capable of ensuring stable conditions for the tests. Tab. (1) shows the values determined for RHc, the coefficient of the psychrometer (*A*), and propagated uncertainty of measure of wrc, calculated by Equations (1), (2), and (3), respectively.

Table 1. Results of RHc, wrc, and coefficient of psychrometer (*A*), determined in the testing section as a function of time (t)

t (min)	RHc (%)	wrc ±(%)	A (ºC^{-1})	t (min)	RHc (%)	wrc ± (%)	A (ºC^{-1})
0	57.19	0.32	6.399 x 10^{-4}	17	64.72	0.29	6.391 x 10^{-4}
1	57.22	0.32	6.399 x 10^{-4}	18	65.24	0.30	6.390 x 10^{-4}
2	57.35	0.32	6.399 x 10^{-4}	19	65.01	0.30	6.390 x 10^{-4}
3	57.35	0.32	6.399 x 10^{-4}	20	70.36	0.27	6.384 x 10^{-4}
4	57.45	0.32	6.399 x 10^{-4}	21	76.56	0.27	6.377 x 10^{-4}
5	57.56	0.32	6.399 x 10^{-4}	22	73.31	0.27	6.381 x 10^{-4}
6	57.55	0.32	6.399 x 10^{-4}	23	73.27	0.27	6.381 x 10^{-4}
7	57.59	0.32	6.399 x 10^{-4}	24	74.15	0.27	6.380 x 10^{-4}
8	57.71	0.32	6.399 x 10^{-4}	25	74.29	0.27	6.379 x 10^{-4}
9	57.80	0.31	6.399 x 10^{-4}	26	73.89	0.27	6.379 x 10^{-4}
10	60.65	0.29	6.396 x 10^{-4}	27	73.37	0.27	6.378 x 10^{-4}
11	67.06	0.29	6.390 x 10^{-4}	28	73.84	0.27	6.379 x 10^{-4}
12	67.53	0.30	6.389 x 10^{-4}	29	74.29	0.27	6.378 x 10^{-4}
13	64.30	0.30	6.392 x 10^{-4}	30	74.29	0.21	6.378 x 10^{-4}
14	63.94	0.30	6.392 x 10^{-4}	31	74.69	0.26	6.377 x 10^{-4}
15	64.93	0.29	6.391 x 10^{-4}	32	74.46	0.26	6.377 x 10^{-4}
16	65.06	0.30	6.391 x 10^{-4}				

Tab. (1) shows the mean value of *A* (6.381 x 10^{-4}) C $^{-1}$, which is close to the values suggested by ASHRAE (1994) that are (6.5 x 10^{-4}, 6.7 x 10^{-4}, e 6.9 x 10^{-4}) C $^{-1}$. Temperature and relative humidity of air were ensured within the following ranges: tdb of 30.50 - 44.40 ºC with uncertainty of measure of temperature (wr) within the range of ± (0.11-0.19) ºC, and RHc of 57.20 - 74.46 % with wrc within the range of ± (0.26 - 0.32) %, which were the ranges assayed in the present study.

4.2. Variation of air velocity during outflow

All norms for relative humidity of air measurement assign values for the outflow of the air that passes through sensor elements. The (twb x vm) test aimed at verifying if the values of wet-bulb temperature (twb) as measured in the testing section were different if air velocity (vm) varied. In order to do so, Hg sensors were placed in the testing section of the apparatus. The velocity range during outflow for this test was 1.25 to 5.00 m/s, whereas the velocity range recommended by ASHRAE (1994) is 3.0 to 5.0 m/s. In test 1, (Tab. (2)), a sequence of four twb and one tdb stabilization plateau collections were carried out for each velocity. Test 2 followed the same procedure, but of a different tdb stabilization plateau. Tab. (3) presents the results of factor F of ANOVA.

Table 2. Data referring to the test: (twb x vm)

Test 1	**Wet-bulb temperature twb (ºC)**				**tdb (ºC)**	**vm (m/s)**
sequence 1	29.3	29.3	29.3	29.3	37.3	1.25
sequence 2	29.2	29.2	29.2	29.2	37.4	2.50
sequence 3	29.1	29.1	29.1	29.1	37.4	3.75
sequence 4	29.0	29.0	29.0	29.0	37.4	5.00
Test 2	**Wet-bulb temperature twb (ºC)**				**tdb (ºC)**	**vm (m/s)**
sequence 1	33.4	33.4	33.3	33.3	48.1	1.25
sequence 2	33.5	33.5	33.5	33.5	48.8	2.50
sequence 3	33.6	33.6	33.6	33.6	49.1	3.75
sequence 4	33.4	33.4	33.4	33.4	49.1	5.00

Table 3. Results of ANOVA F-test: (twb x vm)

Tests	F (calculated)	Fc (critical
1	0	3.4902996
2	0.064516129	3.4902996

In Tab. (3), it is observed that the F-value (calculated) < Fc (critical), and hence, the Ho hypothesis is considered as true, i.e., there were no significant differences among the twb means within the tested velocity range. This means that twb did not significantly change with velocities within the range of 1.25 to 5.00 m/s. However, for the calculation of relative humidity of air within the mentioned velocity range, significant difference were found, and these were close to the 2-3% range indicated by ASHRAE 41.1-1974. Tables (4) and (5) show the results of calculated relative humidity of air (RHc) and ANOVA F-test, respectively

Table 4. Results of tests (RHc x vm) within the range of 1.25 to 5.00 m/s

vm (m/s)	**1.25**	**2.50**	**3.75**	**5.00**
Test 1 RHc (%)	55.79	54.92	54.46	53.99
	55.79	54.92	54.46	53.99
	55.79	54.92	54.46	53.99
	55.79	54.92	54.46	53.99
Test 2 RHc (%)	37.44	36.07	35.67	35.07
	37.44	36.07	35.67	35.07
	37.13	36.07	35.67	35.07
	37.13	36.07	35.67	35.07

Table 5. Results ANOVA F-test: (RHc x vm) within the range of 1.25 to 5.00 m/s

Tests t	F (calculated)	Fc (critical)
1	65.535	3.4903
2	425.493	3.4903

It is observed in Tab. (5) that the F-value (calculated) > Fc (critical), and hence H1 hypothesis is considered as true, i.e., there are significant differences among the means of RHc within the tested velocity range.

4.3. Variation of relative humidity of air obtained with different sensors

Among the available temperature sensors, we chose for this study the PT100 sensor, the type-k thermocouple sensor, the AD592 semiconductor sensor, and the mercury-in-glass sensor. However, do these sensor present the same behavior as that shown at calibration when measuring wet-bulb temperature (twb)? To answer this, the sensors were submitted to three different levels of calculated relative humidity of the air (RH) at each tdb plateau (Tests 1, 2 e 3) in the testing section. Fig. (6) presents the results of twb readings of each sensor and an analysis using ANOVA F-test. This comparison aimed at verifying if the twb values read in the passive sensors, such as PT100 and AD592, were different from those read in the type-k sensor and in the mercury-in-glass sensor.

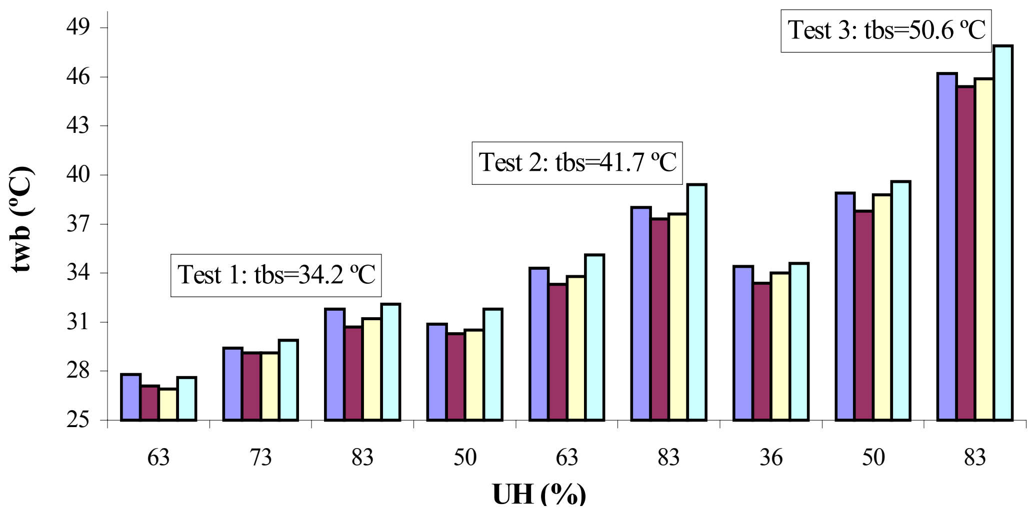

Figure 6. Comparison of sock sensors measuring twb at three different RH levels at each tdb plateaus (tests 1, 2, 3)

Tab. (6) shows the values of calculated relative humidity of air (RHc), as determined by twb in each sensor corrected by calibration equations.

Table 6. Values of calculated relative humidity of air (RHc) as a function of twb for three tdb plateaus

Tests	**Hg thermometer**		**PT 100**		**k thermocouple**		**AD 592**		**Sensor**
tdb (ºC)	RHc(%)	twb (ºC)	RHc (%)	twb (ºC)	RHc (%)	twb (ºC)	RHc (%)	twb (ºC)	RH (%)
Test 1 34.2	61.75	27.8	58.12	27.1	57.09	26.9	60.70	27.6	**63**
	70.44	29.4	68.77	29.1	68.77	29.1	73.26	29.9	**73**
	84.52	31.8	77.90	30.7	80.88	31.2	86.38	32.1	**83**
Test 2 41.7	46.72	30.9	44.37	30.3	45.14	30.5	50.35	31.8	50
	61.13	34.3	57.13	33.3	58.89	33.8	64.81	35.1	63
	79.16	38.0	75.55	37.3	77.09	37.6	86.70	39.4	83
Test 3 50.6	34.63	34.4	31.79	33.4	33.48	34.0	35.21	34.6	**36**
	48.88	38.9	45.16	37.8	48.54	38.8	51.33	39.6	**50**
	78.04	46.2	74.43	45.4	76.67	45.9	86.09	47.9	**83**

The analysis of data on Tab. (6) indicated that the RHc values varied with a small variation in twb. Using two twb values as examples (27.1 and 27.8 ºC) at a tdb of 34.2 ºC, the respective determined RHc values were: 58.12 and 61.75%. For a difference of 0.7 ºC in twb, there is a 3.63 % difference in RHc. It was also verified that the RHc values with the twb of the AD592 sensor are higher than the RHc values of the other tested sensors. The ANOVA F-test was used to verify if these differences in the results were different or not. The results for each test are presented in Tab. (7).

Table 7. Results of ANOVA F-test: (twb x RHc)

Tests	F (calculated)	Fc (critical)
1	67.58355	4.256492
2	77.49752	4.256492
3	183.4362	4.256492

As the F-value (calculated) > Fc (critical), H1 hypothesis was considered as true, i.e., there were significant differences among the RHc means in the tests. Therefore, the tested sensors behave differently when measuring twb.

4.4. Calibration of temperature sensors

The calibration of the testing section was carried out using dry-bulb air temperature (tdb). Each calibrated sensor has its own fitting equation, with its respective correction term b (tk) (ISO, 1995."Guide to the Expression of Uncertainty in Measurement," Switzerland), obtained by the method of least squares with uncertainty of measure (wr) in the linear case. This step aimed at the calibration of the sensors and the comparison between two calibration environments: either in water of a thermostatic bath, or in air at the testing section. The sensor elements used were the PT100, the AD592, the type-k thermocouple, and the mercury-in-glass thermometer. The calibration was carried out using a third mercury-in-glass thermometer as reference. Air velocity during air outflow for this calibration was 3.75 m/s. Data of the mercury sensors were read directly on their scales, at the same time that data of the PT100 and type-k thermocouples, obtained by HP-3970A, were collected via computer. Fig. (7) shows only the adjustment curves of the type-k thermocouples.

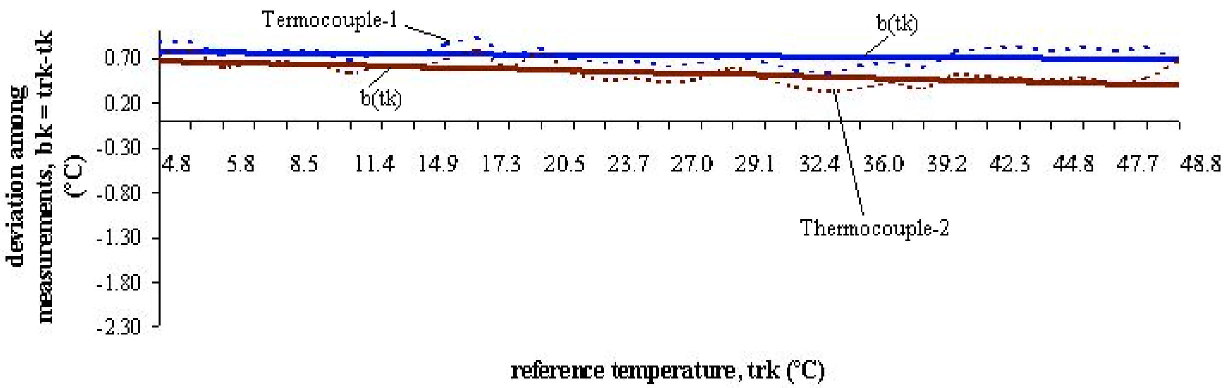

Figure 7. Fitting curves of the type-k thermocouples

In Fig. (7), it is observed that the fitting curves, b(tk) of thermocouples 1 and 2, respectively, present a slight angular variation as to the axis of the reference temperatures. This indicates that that thermocouples have essentially the same deviation (bk), which is of approximately 0.7ºC.

Tab. (8) presents the fitting curves of the calibrated sensors, with the respective ranges of uncertainty of measure wr, where t_{cor} is the corrected temperature, and tk is the temperature read in the sensor in [ºC].

Table 8. Fitting curves of the air-calibrated sensors and the respective ranges of uncertainty of measure

Sensors	**Fitting curves**	**wr ± (ºC) wthin tested range**
thermometer-1	t_{cor} = tk - 0.2035723 + 0.0003286 (tk - 3)	0.02 to 0.05
thermometer -2	t_{cor} = tk - 0.1056936 - 0.00002742 (tk - 3)	0.02 to 0.05
PT100-1	t_{cor} = tk - 0.7650357 - 0.005246 (tk - 3)	0.10 to 0.22
PT100-2	t_{cor} = tk -1.2801292 + 0.0156482 (tk - 3)	0.10 to 0.22
thermocouple-1	t_{cor} = tk + 0.775365 - 0.00167 (tk - 3)	0.02 to 0.03
thermocouple-2	t_{cor} = tk + 0.6746113 - 0.0057067 (tk - 3)	0.02 to 0.03
AD592-1	t_{cor} = tk - 1.7490207 + 0.033431 (tk - 3)	0.01 to 0.02
AD592-2	t_{cor} = tk - 2.522744 + 0.0722953 (tk - 3)	0.01 to 0.03

4.4.1. Comparison between calibrations in water or air

The objective of this comparison was to identify if there were differences in the responses of the mercury-in-glass sensors (thermometer-1 and thermometer-2) and thermoresistant sensors (PT100-1 and PT100-2) when they were submitted to different calibration environments, either in water or air. This comparison was made applying tdb values obtained in air to the calibration equations obtained for water. When corrected tdb values were obtained, ANOVA F-test was applied in order to verify if the differences between reading were significant or not. Tab. (9) shows the results of this test.

Table 9. Results ANOVA F-test of Hg and PT100 sensors, calibrates either in water or air

Calibration environment	F (calculated)	Fc (critical)
water (bath) and air (testing section)	0.072836	2.429999

As F-value (calculated) < Fc (critical) for the obtained temperature values, the Ho hypothesis is considered as true, i.e., there were no significant differences among the calibrated sensors as to the calibration environment.

5. Conclusions

The validation tests of the apparatus by the method of analysis of variance (ANOVA) were the main focus of this study. Based on the experiments that were carried out, temperature and relative humidity of air are ensured within the testes range, with an uncertainty of measure of relative humidity of air below that expected by ASHRAE (1994). It was demonstrated that the calibration apparatus was able to maintain stable dry-bulb (tdb) and wet-bulb (twb) temperatures, and relative humidity of air (RH).

The verification test of twb as a function of air velocity (vm) showed that there was a small difference among the values obtained for twb. However, this difference was not significant by the ANOVA F-test. Therefore, it is possible to use the air velocity range of (1.25 to 5.00) m/s in twb measurements. Nevertheless, significant differences were obtained when relative humidity of air was calculated within that air velocity range. These differences were close to the 2-3% variation indicated by ASHRAE 41.1-1974.

The behavior of twb as a function of RH was similar to the behavior of twb under the same environmental conditions. The sensor AD592 presented the highest deviation as compared to the other sensors. As to RHc, as determined with twb and tdb values, the ANOVA F-test found a significant difference among the calculated values. Therefore, it is possible to assert that the tested sensors behaved differently as to the calculation of this property within the tested range.

The comparison between two calibration environments, either water of a thermostatic bath, or air in the testing section, and between PT100 sensors and mercury-in-glass thermometers calibrated in both environments, there were slight differences in the responses of the sensors when submitted to the two different environments. However, these differences in tdb were not significant by the ANOVA F-test. Therefore, we conclude that both calibration environments provide similar results.

The average coefficient de psychrometer determined for the apparatus is 6.383×10^{-4} C^{-}, which is similar to the valued suggested by ASHRAE (1994) of (6.5×10^{-4}, 6.7×10^{-4}, e 6.9×10^{-4}) C^{-1}.

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