Report 2

Psychrometer construction for performance testing in temperature and humidity chambers, and the precision of humidity measurements
—Meeting the challenge of quality engineering—

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When measuring the performance of the temperature and humidity chamber, industrial standards have adopted the psychrometer (performance testing psychrometer) as the standard humidity sensor. However, the standards do not discuss the construction of the psychrometer itself, prescribing only the psychrometer equation and the psychrometer coefficient to be used. Due to the improvement of humidity measurement technology and the development of traceability systems in recent years, we have again taken up the challenge of verifying psychrometer construction and humidity measurement precision.

This report will also introduce quality engineering methods that we have applied experimentally, as well as the methods we have used.

1. *Introduction*

The Japan Testing Machinery Association has established standards (hereafter, JTM standards) for methods of indicating performance of temperature and humidity chambers. These standards are known as JTM K 01:1998 “Humidity chambers-Test and indication method for performance”. These standards prescribe only the psychrometer (described in detail in section 3-1) as a humidity sensor for finding the humidity fluctuation and the humidity uniformity in the chambers. However, the standards say nothing at all about the details of the construction of the psychrometer used. Only the wind speed and the psychrometer equation to be used are stipulated. In this report, the psychrometer used to measure the humidity performance of a chamber will be called a psychrometer for performance tests, or merely a psychrometer.

The construction of the psychrometer for performance tests used at Tabai Espec is illustrated in the article “Humidity measurement and psychrometers in environmental testing equipment”, in Espec Technology Report No. 7. That illustration is reproduced here as Fig. 1.

A plastic container (such as an empty 35 mm film canister) is used as a water pot, the thermocouple (type T) is covered by a wick, and the device detects the wet-bulb temperature. We consulted the BS standards[1), 2)] concerning this construction, and we found that this psychrometer obtains a roughly valid reproducibility. However, the use of cooled mirror dew-point meters (hereafter, dew-point meters) has led to the development of quite accurate humidity traceability systems for humidity measurements both internationally and domestically. These developments make it necessary once again to accurately confirm the humidity measurement precision of psychrometers for performance tests.

For this report, we have used quality engineering methods to run experiments probing the construction psychrometers for performance tests and humidity measurement precision. This report also includes an introduction to quality engineering, providing a detailed look at the subject.

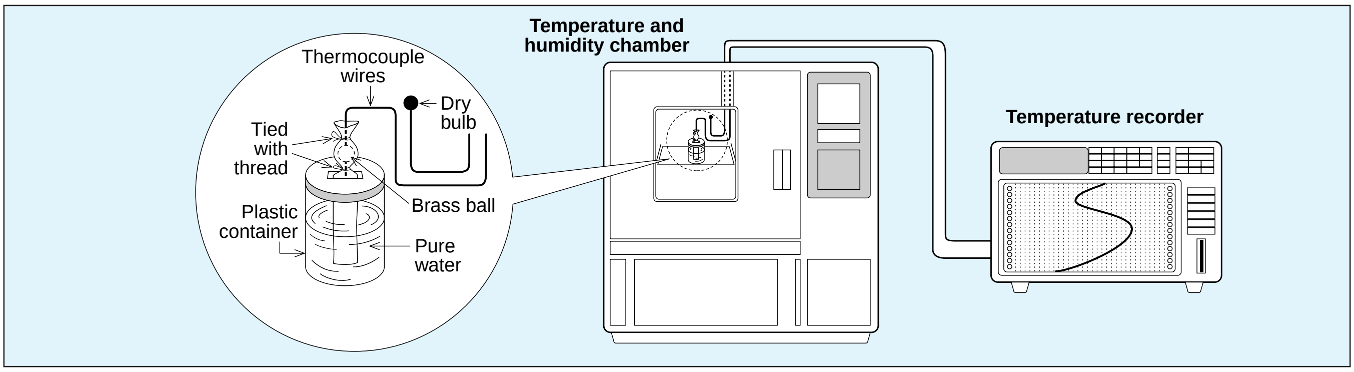

Fig. 1 Measuring temperature and humidity to evaluate equipment performance

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2. *Quality engineering approach*

2-1 Environmental testing and quality engineering

A quick way of learning something about quality engineering would be to do a keyword search on the internet for keywords such as “quality engineering” or “Taguchi methods”. Quality engineering is an evaluation method to determine the worth of specific technology. Doctor Genichi Taguchi advocated these methods, which are known as the “Taguchi methods” in the US.

The environmental testing equipment produced by Tabai Espec is widely used for testing production reliability. By exposing products to harsh environments in respect to such factors as temperature, humidity, pressure, and vibration, manufacturers can confirm whether products will operate normally in each environment, and are also able to estimate the life of the product.

When defects appear during final reliability testing of parts and products, making design changes as countermeasures at that time lengthens the development time frame. Should other defects appear as a result of the countermeasures, one can easily fall into an endless loop of design → prototype → performance confirmation. Furthermore, there are severe time constraints in testing long-term reliability. To speed development and obtain evaluation results quickly, composite environmental tests are used that combine all types of conditions. These are even harsher environmental tests such as the Highly Accelerated Stress Test (HAST) and the thermal shock test.

On the other hand, the quality engineering approach recommends using test pieces in environmental testing at the technical development stage. Test pieces are used to find design conditions, and so have less dispersion in characteristics, showing no change between characteristics in standard conditions and all types of environmental conditions and after test degradation. At this time, these are not the final product quality characteristics that will be listed in the catalog, but merely one index for evaluating the Signal-to-Noise Ratio (SN Ratio). This type of design method is called parameter design. Design conditions incorporating a high SN ratio have good reproducibility when manufactured as products, having a lower tendency to exhibit defects in the field. First of all, the design characteristics must have low dispersion, and then the characteristics must meet the required target values. This type of design method is called a two-stage design method.

2-2 SN ratio and ideal functions

The SN ratio compares the amount of signal to the amount of noise. With measuring instruments, changes in the object of measurement (input signal) as far as possible are output as linear reactions. Designs that are unaffected by all types of noise factors (noise) are said to have a high SN ratio and exhibit good performance. At present, there are no measuring instruments that are completely unaffected by noise, and so this remains an ideal, and is called ideal function.

With the psychrometer, the relationship between input and output as a measuring instrument can be conceptualized as shown in Fig. 2. This input/output relationship attains ideal form, and so consists of ideal function.

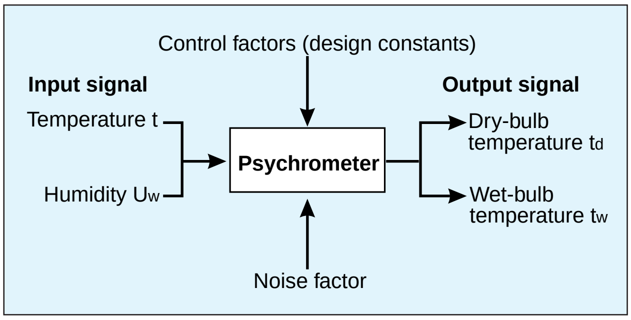


Fig. 2 Relationship between input and output in the psychrometer

Ambient temperature t and humidity U_w are the signal for the psychrometer. (This type of factor that serves as the input signal is called the “signal factor”.) Wet- and dry-bulb temperatures t_d and t_w are proportional to changes in the input signal, and can be output as characteristics values of the psychrometer. In other words, these can be indicated as follows.

$$t_d = t \qquad (1)$$

$$t_w = f\,(t, U_w) \qquad (2)$$

Design constants that can be set by the designer are called control factors. For example, wind speed can be set in the design, and so is a control factor for chamber control psychrometers. However, wind speed becomes a noise factor for psychrometers for performance tests, as it changes depending on the surrounding conditions. Wind speed that is measured and revised, though, is no longer a noise factor. Whether it is an noise factor or a control factor depends on the purpose of the experiment.

3. *Setting experiment conditions*

3-1 Psychrometer basics

The psychrometer is an instrument that uses two thermometers to simultaneously measure air temperature and humidity.

One thermometer is covered with a cloth called a wick, and is kept moist with water. This thermometer is called the wet-bulb thermometer in this report. The other thermometer is called the dry-bulb thermometer, and it measures ambient atmospheric temperature. In environmental testing equipment, the sensor probe of the dry-bulb thermometer is called the dry-bulb temperature sensor, and the sensor probe of the wet-bulb thermometer is called the wet-bulb temperature sensor.

When the ambient atmosphere is dry, moisture evaporates from the wick of the psychrometer, and so the temperature of the wet-bulb temperature sensor drops and reaches a certain equilibrium temperature. This temperature is called the wet-bulb temperature. The temperature of the ambient atmosphere at that time is called the dry-bulb temperature.

The basics of the input/output relationship of the psychrometer are expressed in the following formula.

$$t_d - t_w \infty e_{sw} - e \qquad (3)$$

Where: t_d represents the dry-bulb temperature, t_w represents the wet-bulb temperature, e_{sw} represents the saturation water vapor pressure, and
e represents the partial pressure of water vapor in air.

The relationship found by Formula (3) is the psychrometer equation, and the coefficient for that equation is called the psychrometer coefficient. The most commonly used of the psychrometer formulas is the following Sprung formula.[3)]

$$e = e_{sw} - A \cdot p\,(t_d - t_w) \qquad (4)$$

Where: p represents atmospheric pressure, A represents the psychrometer coefficient, and $A = 0.000662$ (K^{-1}) when the wet-bulb is not frozen.

The wind speed must be at least 2.5 m/s (there is some variation in the literature). Any pressure units can be used as long as they are unified, but the unit currently used is the Pascal (Pa).

Using the wet-bulb temperature and the dry-bulb temperature, the water vapor partial pressure in the atmosphere is found according to the psychrometer equation, and the relative humidity is calculated. Relative humidity U_w (%RH) is defined by the following formula.

$$U_w = (e/e_s) \times 100 \qquad (5)$$

Where e_s represents the saturation water vapor pressure at dry-bulb temperature.

In the JTM standards, when a minimum 2.5 m/s wind speed cannot be maintained, the following Pernter formula is used. Table 1 shows the coefficients for that formula.

$$e = e_{sw} - a \cdot p\,(t_d - t_w)\,(1 + t_w/b) \qquad (6)$$

Table 1 Coefficients for the Pernter formula

Wet-bulb vicinity wind speed (m/s)	When the wet-bulb is not frozen	
	a	b
Calm 0 to 0.5	0.0012	610
Weak breeze 1.0 to 1.5	0.0008	610
Strong breeze Min. 2.5	0.000656	610

3-2 Signal factor

The input signal for the psychrometer consists of the ambient temperature and humidity for the psychrometer. The psychrometer equation can be thought of as a calibration formula for humidity, and so here instead of scrutinizing that equation, we will use the Sprung formula.

The temperature and humidity measured on a standard thermometer and hygrometer is taken as the standard temperature and humidity that should naturally be shown on a psychrometer. First of all, the atmospheric temperature as measured on a standard thermometer is set as standard dry-bulb temperature T_d. Next, the standard wet-bulb temperature T_w that should be shown on the psychrometer is calculated from aforementioned standard dry-bulb temperature T_d and dew-point D_p measured on a standard hygrometer with the dew-point calibrated. Then, the standard wet- and dry-bulb temperature differential ($T_d - T_w$) is found. The same ambience is simultaneously measured with psychrometers of various types of construction, and the wet- and dry-bulb temperature differential ($t_d - t_w$) is found. The optimum psychrometers for performance tests will have little dispersion of ($t_d - t_w$) relative to ($T_d - T_w$), having good straight-line characteristics even in the presence of all types of noise. A psychrometer with a systematic deviation can be corrected afterwards.

Fig. 3 shows this relationship as a zero-point proportional formula.

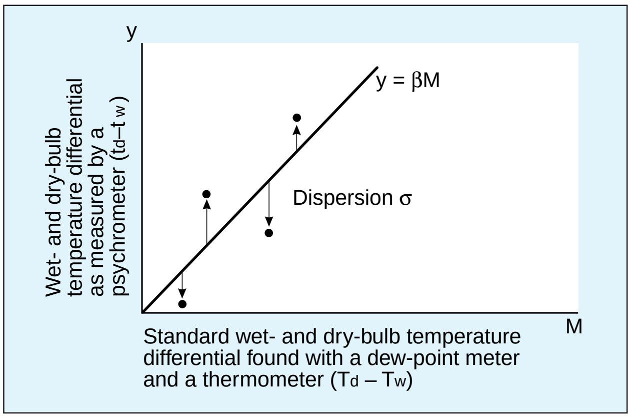


Fig. 3 The relationship between signal factor M and output y

Quality engineering takes the input signal M on the horizontal axis and the output signal y on the vertical axis and displays the signal as the proportional coefficient β.

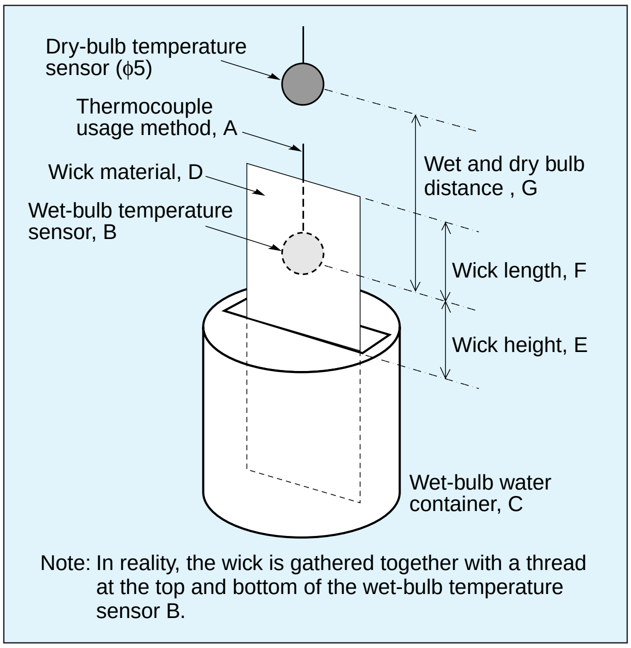
The signal factors are the 4 temperature and humidity conditions shown in Table 2. These four conditions are taken as the temperature and humidity settings for the chamber, and the amount (the calculated value) of moisture in the air at that time is shown on the instruments. Performance limitations of the dew-point meter make it difficult to measure the dew-point in high-temperature, high-humidity regions, and so the upper bound was set at 85°C and 90 %rh.

Table 2 Signal factors and conditions (calculated values)

Temperature and humidity settings		Air moisture levels		
Dry-bulb temperature	Relative humidity	Dew-point	Wet-bulb temperature	Wet- and dry-bulb temperature differential
t_d (°C)	U_w (%rh)	D_p (°C)	T_w (°C)	$T_d - T_w$ (°C)
10	50	0.1	5.6	4.4
	90	8.4	9.2	0.8
85	20	48.7	52.2	32.8
	90	82.3	82.4	2.6

3-3 Control factors

Fig. 4 shows the wet-bulb construction of psychrometers for performance tests. Seven control factors were taken up. These are shown in Table 3. As Table 5 shows, the control factors were apportioned as in the inside orthogonal array L_{18}.



Note: In reality, the wick is gathered together with a thread at the top and bottom of the wet-bulb temperature sensor B.

Fig. 4 Design and control factors for psychrometers for performance tests

Table 3 Control factors and their levels

Symbols	Control factors	Levels		
A	Thermocouple usage method	A1: Usual formula	A2: Differential method	—
B	Wet-bulb temperature sensor	B1: Bare wire only	B2: ϕ3 mm brass ball attached	B3: ϕ5 mm brass ball attached
C	Wet-bulb water container	C1: Lactic acid bacterium beverage container	C2: 35 mm film canister	C3: Sample bottle*
D	Wick material	D1: Non-woven nylon fabric	D2: Bleached cotton	D3: Gauze
E	Wick height	E1: 10 mm	E2: 20 mm	E3: 30 mm
F	Wick length	F1: 10 mm	F2: 30 mm	F3: 50 mm
G	Wet and dry bulb distance	G1: Wet- and dry-bulb coordinated positions	G2: Dry-bulb 25 mm upwind	G3: Dry-bulb 50 mm upwind

* Plastic cylindrical container, diameter 30 mm, height 50 mm

3-4 Noise factors and signal factors

We have taken up the following 3 items as noise factors: wind speed, wind direction, and sampling position of the dew-point meter. These are shown in Table 4.

Table 4 Noise factors and their standards

Symbols	Noise factor	Levels	
H	Wind speed (m/s)	H1: 1.0 to 1.5	H2: ≧ 2.5
I	Wind direction	I1: Straight up	I2: Facing
J	Sampling position of dew-point meter	J1: Fixed	J2: Equidistant

Temperature and humidity (refer to Table 2) are combined as signal factors, and were apportioned as in the outside orthogonal array L_8 in Table 5.

These experiments use complex noise factor combinations, which required longer times for running the experiments. The aim was narrowed down to the crucial noise factor of wind speed, and this was thought to have satisfactorily speeded up the experiments.

3-5 Experiment combinations

Table 5 shows the experiment combinations. In other words, the 18 different types of psychrometer construction were each measured with 8 sets of conditions, resulting in the experiment being run 144 times (18 × 8).

Table 5 Assignment of experiment factors

Outside orthogonal array L8

Row	Factor	No. 1	2	3	4	5	6	7	8
1	**Temperature**	10°C	10°C	10°C	10°C	85°C	85°C	85°C	85°C
2	**Humidity**	50%rh	50%rh	90%rh	90%rh	20%rh	20%rh	90%rh	90%rh
3	—	—	—	—	—	—	—	—	—
4	**Wind speed**	1.0 to 1.5	≧ 2.5	1.0 to 1.5	≧ 2.5	1.0 to 1.5	≧ 2.5	1.0 to 1.5	≧ 2.5
5	**Wind direction**	Straight up	Facing	Straight up	Facing	Facing	Straight up	Facing	Straight up
6	**Sampling position**	Fixed	Equidistant	Equidistant	Fixed	Fixed	Equidistant	Equidistant	Fixed
7	—	—	—	—	—	—	—	—	—

Inside orthogonal array L18

Row	1	2	3	4	5	6	7	8	No. 1	2	3	4	5	6	7	8
Control factors	**Thermocouple usage method**	**Wet-bulb sensor**	**Wet-bulb water container**	**Wick material**	**Wick height**	**Wick length**	**Wet and dry bulb distance**	**Experient margin of error**								
Symbols	**A**	**B**	**C**	**D**	**E**	**F**	**G**	**e**								
Experiment No.1	Common method	Bare wire only	Lactic acid bacterium beverage container	Non-woven nylon fabric	10mm	10mm	0mm	1	y11	y12	y13	y14	y15	y16	y17	y18
2	Common method	Bare wire only	35 mm film canister	Bleached cotton	20mm	30mm	25mm	2	y21	...	...	...	...	...	...	y28
3	Common method	Bare wire only	Sampling bottle	Gauze	30mm	50mm	50mm	3	y31	...					...	y38
4	Common method	ϕ3 brass ball	Lactic acid bacterium beverage container	Non-woven nylon fabric	20mm	30mm	50mm	3	y41	...					...	y48
5	Common method	ϕ3 brass ball	35 mm film canister	Bleached cotton	30mm	50mm	0mm	1	y51	...					...	y58
6	Common method	ϕ3 brass ball	Sampling bottle	Gauze	10mm	10mm	25mm	2	y61	...					...	y68
7	Common method	ϕ5 brass ball	Lactic acid bacterium beverage container	Bleached cotton	10mm	50mm	25mm	3	y71	...					...	y78
8	Common method	ϕ5 brass ball	35 mm film canister	Gauze	20mm	10mm	50mm	1	y81	...					...	y88
9	Common method	ϕ5 brass ball	Sampling bottle	Non-woven nylon fabric	30mm	30mm	0mm	2	y91	...		yij			...	y98
10	Differential method	Bare wire only	Lactic acid bacterium beverage container	Gauze	30mm	30mm	25mm	1	y101	...					...	y108
11	Differential method	Bare wire only	35 mm film canister	Non-woven nylon fabric	10mm	50mm	50mm	2	y111	...					...	y118
12	Differential method	Bare wire only	Sampling bottle	Bleached cotton	20mm	10mm	0mm	3	y121	...					...	y128
13	Differential method	ϕ3 brass ball	Lactic acid bacterium beverage container	Bleached cotton	30mm	10mm	50mm	2	y131	...					...	y138
14	Differential method	ϕ3 brass ball	35 mm film canister	Gauze	10mm	30mm	0mm	3	y141	...					...	y148
15	Differential method	ϕ3 brass ball	Sampling bottle	Non-woven nylon fabric	20mm	50mm	25mm		y151	...					...	y158
16	Differential method	ϕ5 brass ball	Lactic acid bacterium beverage container	Gauze	20mm	50mm	0mm	2	y161	...					...	y168
17	Differential method	ϕ5 brass ball	35 mm film canister	Non-woven nylon fabric	30mm	10mm	25mm	3	y171	...	...	...	...	...	...	y178
18	Differential method	ϕ5 brass ball	35 mm film canister	Bleached cotton	10mm	30mm	50mm	1	y181	y182	y183	y184	y185	y186	y187	y188

3-6 Experiment equipment

Fig. 5 shows an outline of the equipment used in these experiments. An air duct (arc-shaped) is installed inside the chamber with controlled temperature and humidity settings, and the type of psychrometer corresponding to each experiment number is installed inside the air duct. A standard thermometer and dew-point meter are also installed to simultaneously measure the temperature and humidity inside the air duct.

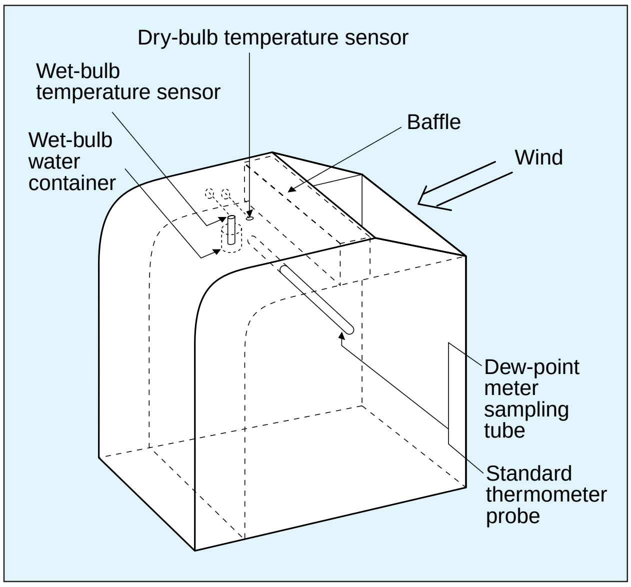


Fig. 5 Outline of experiment equipment

3-7 Experiment results

3-7-1 Measured temperature and humidity versus standard temperature and humidity

Table 6 shows a portion of the measurement data collected using psychrometers for performance tests along with standard thermometers and dew-point meters. The data in Table 6 was collected using the inside orthogonal array No.1 psychrometer and measured using the conditions in outside orthogonal array No.2, both shown in Table 5.

Table 6 Measurement data examples: Experiments No. 1-2

Time	Standards inside the air duct		Psychrometers for performance tests	
	Dry-bulb temperature	Dew-point	Dry-bulb temperature	Wet-bulb temperature
(min)	Td (°C)	Dp (°C)	Td (°C)	Tw (°C)
0	9.8	–0.62	9.6	5.7
1	9.7	–0.07	9.5	5.6
...	...	...	...	...
11	9.7	–0.57	9.6	5.8

The air duct is placed inside the chamber, and after the temperature and humidity are stabilized inside the air duct, 11 measurements are taken at intervals of one minute each, and this data is used to calculate the SN ratio.

3-7-2 Calculating the SN ratio

For each of the experiments No.1 through 18 in orthogonal array L_{18}, the input signal is defined as the standard wet- and dry-bulb temperature differential ($T_d – T_w$), and the output signal is defined as the wet- and dry-bulb temperature differential ($t_d – t_w$) as measured on the psychrometer. The SN ratio is found using the zero-point proportional formula. Let's look now at the calculation sequence used to find the SN ratio in experiment No.1.

Total fluctuation S_T

S_T = the sum of squares of the individual data

$$= y_{111}^2 +...+ t_{1111}^2 + y_{121}^2 +...+ y_{1211}^2 +...+y_{181}^2+... +y_{1811}^2$$

Where y_{ijk} is the wet- and dry-bulb temperature differential ($t_d – t_w$) of the psychrometer for performance tests. In other words, i represents the 18 types of psychrometers, j represents which of the 8 times the experiment was performed with each psychrometer, and k represents the measurement repetition number (1 to 11) in each experiment. In experiment No.1, i = 1, j = 1 to 8, and k = 1 to 11.

Primary fluctuation S_β

$$S_\beta = (y_{111}\cdot M_{111} + y_{112}\cdot M_{112} +... + y_{1111}\cdot M_{1111}+y_{121}\cdot M_{21} + y_{122}\cdot M_{122} +...+ y_{1211}\cdot M_{1211} +...+y_{181}\cdot M_{181} + y_{182}\cdot M_{182} +...+ y_{1811}\cdot M_{1811})^2/r$$

Where M_{ijk} is the standard wet- and dry-bulb temperature differential ($T_d – T_w$), and is calculated from dew-point D_p measured with a dew-point meter and the dry-bulb temperature T_d measured with a standard thermometer. Temperature and humidity settings include 4 sets of conditions, but the number of experiments is j = 8.

Effective divisor r

$$r = M_{111}^2 +...+M_{1111}^2 + M_{121}^2 +...+ M_{1211}^2 +...+M_{181}^2 +...+M_{1811}^2$$

Error fluctuation S

$$S_e = S_T – S_\beta$$

Error variance V_e

$$V_e = S_e/f_e$$

Where f_e is the degree of freedom, and since there are 88 individual bits of data, f_e here is 87.

Sensitivity β^2

$$\beta^2 = (S_\beta – V_e) /r$$

Dispersion σ^2

$$\sigma^2 = V_e$$

SN ratio η

$$\eta = \beta^2/\sigma^2 = (S_\beta – V_e) / (r\cdot V_e)$$

Normally, SN ratio η is expressed in decibel (db) units as in the following.

$$\text{SN ratio } \eta \text{ [db]} = 10\text{Log } \eta = 10\text{Log}\{(S_\beta – V_e)/(r\cdot V_e)\}$$

The above calculation was repeated for each of the 18 types of psychrometer construction.

Displaying the SN ratio in decibels is done to express the additiveness of the factorial effect. For detailed meanings, refer to the drawings.[5)]

3-7-3 SN ratio effects

Table 7 shows the SN ratio for each experiment number. Table 8 shows the SN ratio calculated from Table 7 for each factor level. The SN ratio is averaged for the 18 psychrometer types which include the factor levels found.

Table 7 SN ratio

Experiment No.	SN (db) η
No. 1	7.379
No. 2	2.608
No. 3	9.725
No. 4	15.699
No. 5	6.727
No. 6	7.238
No. 7	14.040
No. 8	6.299
No. 9	13.948
No. 10	3.861
No. 11	11.757
No. 12	–2.410
No. 13	0.343
No. 14	5.895
No. 15	10.120
No. 16	10.131
No. 17	9.683
No. 18	10.795
Average	7.991

Table 8 SN ratio for each factor level

Sym-bols	Control factors	Level symbols	Level details	Total SN ratio for each level	SN ratio (db) for each level
A	Thermocouple usage method	A1	Common method	83.663	9.296
		A2	Differential method	60.173	6.686
B	Wet-bulb temperature sensor	B1	Bare wire only	32.919	5.487
		B2	ϕ3 mm brass ball	46.022	7.670
		B3	ϕ3 mm brass ball	64.896	10.816
C	Wet-bulb water container	C1	Lactic acid bacterium beverage container	51.453	8.576
		C2	35 mm film canister	42.969	7.161
		C3	Sample bottle	49.415	8.236
D	Wick material	D1	Non-woven nylon fabric	68.586	11.431
		D2	Bleached cotton	32.102	5.350
		D3	Gauze	43.149	7.191
E	Wick height	E1	10mm	57.104	9.517
		E2	20mm	42.446	7.074
		E3	30mm	44.287	7.381
F	Wick length	F1	10mm	28.531	4.755
		F2	30mm	52.806	8.801
		F3	50mm	62.499	10.416
G	Wet and dry bulb distance	G1	Wet- and dry-bulbs in same position	41.670	6.945
		G2	Dry-bulb 25 mm upwind	47.549	7.925
		G3	Dry-bulb 50 mm upwind	54.617	9.103
				Average	7.991

Fig. 6 shows the SN ratio for each control factor level.

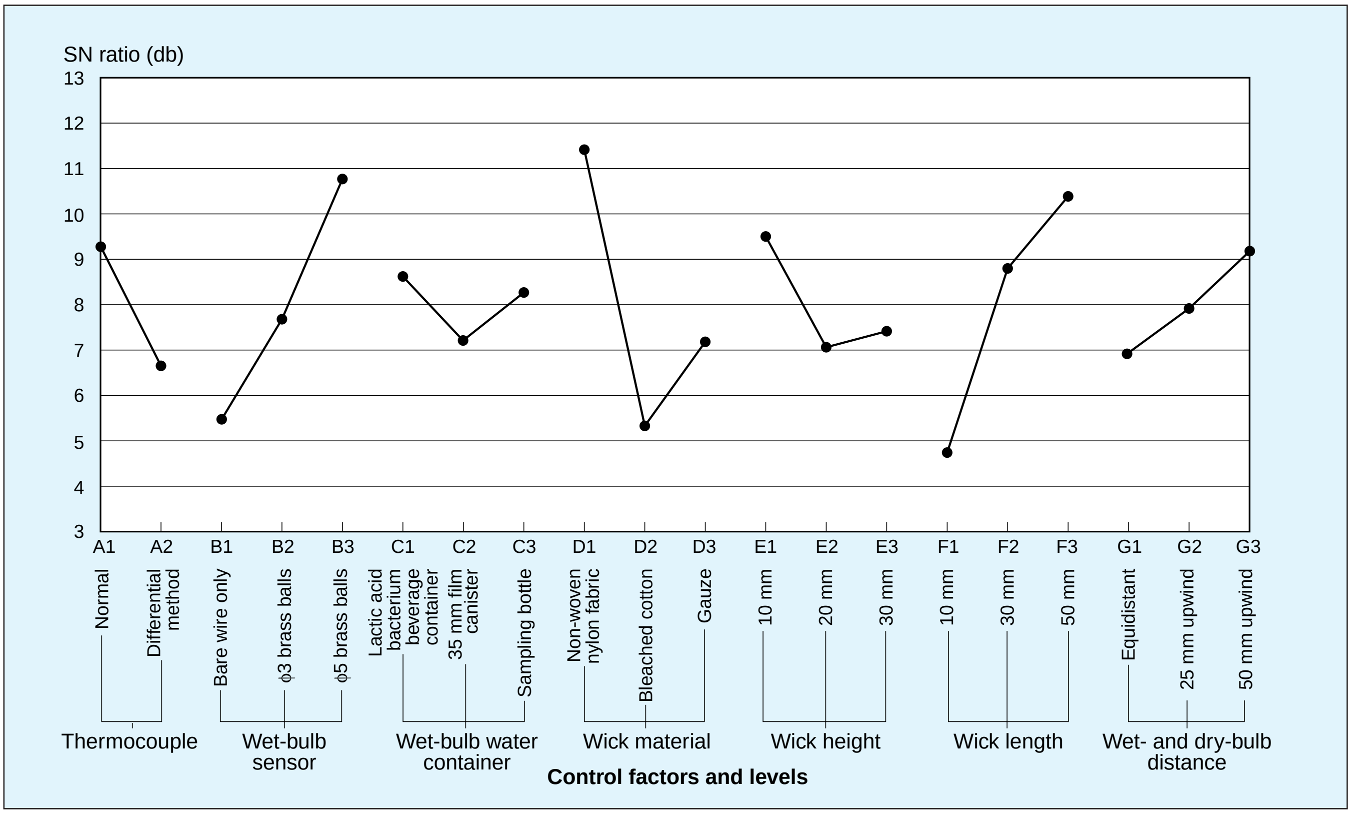


Fig. 6 SN ratios for each control factor and level

3-7-4 Analysis of variance for SN ratios

Table 9 shows analyses of variance for SN ratios. When factors with relatively small variance are pooled (here, C, E, and G), the results become as shown in Table 10. The factorial effect of A, B, C, and D is large.

Table 9 Analysis of variance for SN ratios

Factor	Degree of freedom f	Fluctuation S	Variance V
A: Thermocouple	1	30.6545	30.6545
B: Wet-bulb sensor	2	86.1346	43.0673
C: Wet-bulb water container	2	6.5382	3.2691
D: Wick material	2	116.6722	58.3361
E: Wick height	2	21.2519	10.6259
F: Wick length	2	102.0557	51.0278
G: Wet- and dry-bulb distance	2	14.0080	7.0040
Error e	4	13.7100	3.4275
Total	17	391.0251	

Table 10 Variance analysis table after pooling

Factor	Degree of freedom f	Fluctuation S	Variance V	Variance ratio F*o*	Contribution ratio *p* (%)
A: Thermocouple	1	30.6545	30.6545	5.52	6.4
B: Wet-bulb sensor	2	86.1346	43.0673	7.76	19.2
D: Wick material	2	116.6722	58.3361	10.51	27.0
F: Wick length	2	102.0557	51.0278	9.19	23.3
Error e	10	55.5081	5.5508		24.1
Total	17	391.0251			100

3-8 Confirmation experiments

3-8-1 Confirming the SN ratio

The size of the SN ratio was considered along with other factors, and confirmation experiments were run with current conditions and with combinations of the best and worst conditions as shown in Table 11. The current conditions used in these experiments refers to the psychrometer for performance tests seen in Fig.1, used by Tabai Espec.

Table 11 shows the SN ratios estimated from the results in section 3-7, compared to the SN ratio measured in confirmation experiments with these conditions.

The reasons for the combinations of factors and levels are as follows.

A precision digital voltmeter is deemed suitable for use with a level A2 differential thermocouple. However, a differential thermocouple is not generally used for measuring temperature. Therefore, A1 was done in the same way. The lactic acid bacterium beverage container in level C1 does not have good heat resistance and deforms at 85°C, and so it was excluded. Wick height E and wick length F are often limited by the total length of the wick, and so the combinations given above were set.

Table 11 Control factor combinations and estimated vs. measured SN ratios

Control factor combinations		Estimated value		Measured value	
		SN ratio	Gain	SN ratio	Gain
1. Current conditions:	A1B3C2D1E1F1G2	12.3	—	17.7	—
2. Best conditions:	A1B3C3D1E1F3G3	18.0	5.7	17.8	0.1
3. Worst conditions:	A1B1C2D2E1F1G2	0.9	–11.4	–7.1	–24.8

The average value of SN ratio $\overline{T}$ in Table 8 was set for the estimated value of the SN ratio, and was included in the SN ratio for each of the factors with a large factorial effect (A, B, D, and F) and the totals were calculated. The estimated values of the SN ratios with the current conditions were calculated in the following way.

Current conditions:

$$A1 + B3 + D1 + F1 - 3 \times \overline{T}$$
$$= 9.296 + 10.816 + 11.431 + 4.755 - 3 \times 7.991$$
$$= 12.3 \text{ (db)}$$

Calculations for the best and worst conditions were done in the same way.

As you can see in Table 11, the SN ratio was high at the best conditions, but there was little difference in results at best conditions and current conditions. The results from the worst conditions were clearly bad. However, the SN ratios estimated from the orthogonal array experiments were not fully reproduced in the confirmation experiments. Further study is needed in the method of conducting the experiments in regard to such matters as whether to handle standard humidity as a signal factor. For signal M in Fig. 3, it would be possible to use the difference between standard wet-bulb temperature T_d and standard dew-point D_p ($T_d - D_p$), but that doesn't yield a linear proportional equation. It can also be considered as a difference in water vapor pressure. Also, it would probably be better to use a wider range for the wind speed as a noise factor, from a natural convection current to a strong wind.

The fundamental factors in humidity measurements with the psychrometer are thermal conduction and evaporation of water on the wet bulb. In B1, the thermocouple bare wire only serving as the wet-bulb sensor is thought to provide insufficient thermal conductivity with the wick. Also, with the non-woven nylon fabric in D1, the fiber has no unevenness and is thought to be more likely to provide even evaporation.

Wick length F requires a certain length to prevent thermal conductivity from the thermocouple wire to the wet bulb. The length should be from 30 to 50 mm, longer than the currently used conditions (F1 = 10).

For wet and dry bulb distance G, better results are obtained by placing the dry bulb upwind, but this doesn't really make much difference since the wind direction is not fixed inside the actual chamber.

3-8-2 Confirmations with relative humidity

Table 12 shows the deviation from standard relative humidity. The standard relative humidity is found by converting from values measured with a dew-point meter and a standard thermometer. To arrive at the deviation, these results are compared with the relative humidity (%rh) derived from the wet- and dry-bulb temperature t_w and t_d measured with the psychrometer.

The wind speed in the Sprung formula was handled as a noise factor, and the psychrometer coefficient A = 0.000662 (K^{-1}) was used for all cases. For reference, calculations were also made with the Pernter formula using a separate value for the psychrometer coefficient for each wind speed.

4. Conclusion

When calculating the psychrometer for performance tests with current conditions using the Pernter formula, and handling the wind speed as a noise factor, measured values shift higher in the low-temperature, low-humidity region with low wind speed. However, when the wind speed is measured and calculated with the Pernter formula even at low wind speeds accurate measurements can be made in all temperature and humidity regions.

When calculating the psychrometer for performance tests with best conditions using the Sprung formula, and handling wind speed as a noise factor, even with low wind speed accurate measurements can be made in all temperature and humidity regions. We were able to improve only slightly on the current conditions for the construction of the psychrometer.

When using psychrometers with unsuitable construction, error can exceed 10 %rh, and the standard deviation becomes rather large, reaching 1.0 %rh.

When using either current conditions or best conditions, the standard deviation shows little change and remains within 0.8 %rh. Even with current conditions, valid reproducibility was obtained, backing up the results.

These experiments handled wind speed as a noise factor, using the Sprung formula even with low wind speeds from 1 to 1.5 m/s. While the Pernter formula was

Table 12 Relative humidity deviation (%rh) from standard humidity

	Psychrometer construction											
	Current conditions				Best conditions				Worst conditions			
Experi-ment No.	Sprung formula		Pernter formula		Sprung formula		Pernter formula		Sprung formula		Pernter formula	
	m	σ n-1	m	σ n-1	m	σ n-1	m	σ n-1	m	σ n-1	m	σ n-1
1	6.6	0.55	2.1	0.59	2.7	0.56	–2.3	0.60	15.0	0.90	10.9	0.96
2	2.7	0.49	2.7	0.49	–0.6	0.71	–0.6	0.71	9.3	0.67	9.3	0.67
3	2.1	0.56	0.9	0.60	1.2	0.60	0.0	0.65	4.8	0.68	3.9	0.70
4	1.1	0.76	1.0	0.76	–0.7	0.68	–0.8	0.68	4.1	0.40	4.0	0.40
5	1.2	0.03	0.1	0.06	0.2	0.07	–1.0	0.07	5.8	0.06	4.8	0.06
6	1.4	0.07	1.2	0.07	0.3	0.06	0.0	0.06	5.4	0.09	5.2	0.09
7	0.4	0.25	0.2	0.25	–0.4	0.27	–0.5	0.27	0.7	0.40	0.5	0.40
8	0.7	0.19	0.6	0.19	0.2	0.18	0.2	0.18	0.7	0.19	0.6	0.19

Notes: m = average value, σ n-1 = standard deviation, n = 11

No.2, 4, 6, 8: Wind speed > 2.5 m/s, No.1,3,5,7: Wind speed = 1.0 to 1.5 m/s No.1,2: 10°C, 50% rh; No.3,4: 10°C, 90% rh; No.5,6: 85°C, 20% rh; No.7,8: 85°C, 90% rh able to provide the coefficients for each wind speed, the wind speeds were scattered over a wide range, and so the question arose as to how to handle that gap.

Realistically, the Sprung formula can be applied as is when the wind speed rises above 1.5 m/s. When the wind speed is in the range of 0.5 to 1.5 m/s, the Pernter formula weak wind coefficient can be used. However, the psychrometer construction, as shown in these experiments, needs to be optimized.

5. A final word

Follow-up experiments on performance evaluation humidity sensors for temperature and humidity chambers need to consider results using not only psychrometers, but also other types of hygrometers such as electronic humidity sensors. So-called humidity sensors have some reliability concerns due to changes over long periods of time and due to problems with environmental resistance, but these effects can be considered slight when the devices are used for short periods. In such cases, calibration becomes problematic, but calibration methods using quality engineering have become standardized even at JIS.

Recently, quality engineering has become widely applied in a number of fields as a method of reducing the development period and lowering costs for new products as well as reducing the number of customer complaints.

Within this trend, environmental testing is an extremely important factor. If the product functions do not suffer changes in a variety of environmental conditions, deterioration of functions should not be expected from the usage conditions in the field. We at Tabai Espec will continue to offer the best environmental testing methods available.

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Topics

Applications of the Fast Cycle Chamber

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1. Introduction

The market for cellular phones, mobile information equipment, and car electronics is continuing to show explosive growth. Competition is heating up as manufacturers invest major efforts in the research and development race for new parts and materials to create new products. The intensity of this competition has led to dramatic increases in such needs as improving reliability of devices and products, increasing mounting density, expanding the range of product application, utilizing new materials, improving safety, reducing development time, and lowering testing costs. To meet these needs, Tabai Espec has developed a new environmental test chamber called the Fast Cycle Chamber.

2. Appearance and specifications

Photo 1 shows the new unit, and Table 1 gives the main specifications.

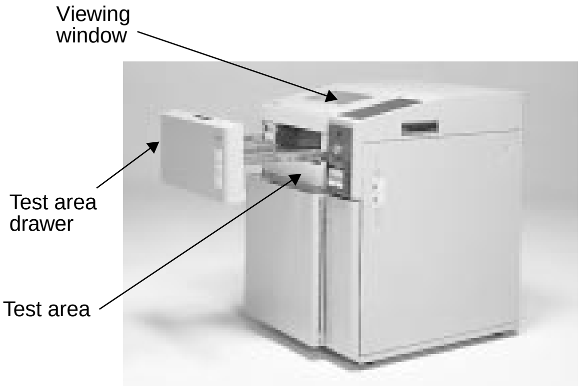

Photo 1 Fast Cycle Chamber

Table 1 Main specifications

Item	Specification
Temperature range	–60°C to +150°C
Outer dimensions	W800 × H1115 × D1000 mm
Inner dimensions	W380 × H100 × D320 mm
Capacity	12 L
Temperature heat-up rate	From –40°C to +100°C, within 10 min (no load, refrigerator off)
Temperature pull-down rate	From +20°C to –40°C, within 10 min (no load)
Permissible heat load	Max.800W (at –40°C) *refrigerator control: HIGH setting
Instrumentation	Language:English, Program instrumentation (touch panel type)
Refrigerator	Hermetically sealed compressor
Refrigerant	Low temp. side:R508A (HFC), High temp. side:R404A (HFC)
Components	• Casters (with adjustor foot) • Cable clamp • Viewing window (on top)
Main options	• Temperature recorder • Communication function (RS-232C, GP-IB)

3. Features

Higher temperature change rate

This model achieves a much higher rate of temperature change than conventional temperature chambers. This makes it possible to reduce temperature conversion time, thus reducing total test time.

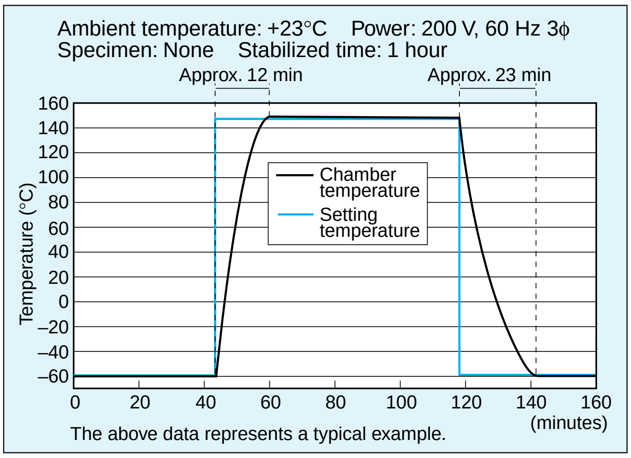

Fig. 1 Temperature characteristics from –60°C to +150°C

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