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Abstract

WBGT (wet bulb globe temperature) equation is a heat stress index that gives information for the workers in the industrial areas. WBGT equation is described in ISO Standard 7243 [5]. WBGT is the result of the combined quantitative effects of the natural wet bulb temperature, dry bulb temperature, and air temperature. WBGT is a calculated parameter. WBGT uses input estimates, and heat stress monitor measures these quantities. In this study, the calibration method of a heat stress monitor is described, and the model function for measurement uncertainty is given. Sensitivity coefficients were derived according to GUM. Two pressure humidity generators were used to generate a controlled environment. Heat stress monitor was calibrated inside of the generator. Two pressure humidity generator, which is located in Turkish Standard Institution, was used as the reference device. This device is traceable to national standards. Two pressure humidity generator includes reference temperature Pt-100 sensors. The reference sensor was sheltered with a wet wick for the calibration of natural wet bulb thermometer. The reference sensor was centred into a black globe that has got 150 mm diameter for the calibration of the black globe thermometer.

Keywords: WBGT (wet bulb globe temperature), natural wet bulb temperature, black globe temperature, dry bulb temperature, calibration, measurement uncertainty

1. Introduction

A heat stress index includes the effects of relevant environmental and personal factors into a single meaning that says the degree of thermal strain on people. In industry, workers have been at risk from exposure to occupational hazards that would have adverse effects on their health. One of them is heat [1].

Heat stress occurs when an individual is exposed to a hot environment and dependent upon the production of heat inside the body as a result of physical activity and the characteristics of the environment governing heat transfer between the environment and the body [1].

Heat stress evaluation is determined using meteorological parameters that enable the estimation of the effect of environmental factors on thermal comfort [2]. Heat stress is caused by a negative balance between the net amount of energy flowing from the living things to its surrounding environment and the amount of heat energy produced by the living organism. This imbalance can be decreased by the changes in environmental parameters (sunlight, thermal radiation, etc.) [3]. Body heat balance is dependent on six fundamental factors. These are air temperature, radiant temperature, humidity, wind speed, clothing, and metabolic heat production [4]. The detailed information and tables about quantities used to describe the level of exposure to heat (metabolism, energy efficiency, insulation of clothing) can be found in ISO 7730 [15].

If cooling via convection is not enough, the metabolic heat production must be reduced. When physical activity is high in a hot environment, the worker's core body temperature may be at risk. Heat stress indices have been developed to protect workers from the effects of heat exposure [4]. One of these indices is WBGT (wet bulb globe temperature) index. WBGT is one of the empirical indices representing the heat stress. This index is easy to use in industrial environments. Evaluating the heat stress based on this index is precise and easy to use in industrial areas [5].

WBGT index is used in the estimation of heat stress on working people. Firstly, Effective Temperature Index was developed as an empirical index that was derived from a series of laboratory studies in the 1920s, and it was used to evaluate heat stress. Temperature, humidity, radiation and wind were combined into a single value in the index. Black globe temperature measurements of Effective Temperature Index were modified, and then WBGT index was established. WBGT index is explained in ISO

7243 [14]. This explanatory method of evaluating heat stress according to this index provides an easier usage. The method is depending on the heat exchange analysis between human and the environment [5].

Heat stress depends on the metabolic heat production and the ambient conditions that affect the heat transfer between the environment and the body. A complete estimation of heat stress effect can be done by measuring the parameters derived from air temperature, mean radiant temperature, air velocity and humidity [5].

WBGT index is the combination of three climate parameters; natural wet bulb temperature (T_{nw}), globe temperature (T_g), and air temperature (T_a). Mathematical expressions of WBGT index are given in ISO 7243. WBGT index for indoor environments is seen in Eq. 1, and for outdoor environments is given in Eq. 2 [5].

$$\mathrm{WBGT_{indoor}} = 0.7 * T_{\mathrm{nw}} + 0.3 * T_{\mathrm{g}} \quad (1)$$

$$\mathrm{WBGT_{outdoor}} = 0.7 * T_{\mathrm{nw}} + 0.2 * T_{\mathrm{g}} + 0.1 * T_{\mathrm{a}} \quad (2)$$

Heat stress monitors include three sensors; black globe-bulb thermometer, wet-bulb thermometer and dry bulb thermometer [6]. Wet bulb thermometer is covered with a white wick and has a cylindrical shape (6 ± 1 mm diameter and 30 ± 5 mm long). This thermometer has a measuring range of 5 °C to 40 °C and its accuracy is ± 0.5 °C. The black globe thermometer measures temperature at the centre of a thin, matt black globe with emission coefficient of 0.95. Its measuring range is 20 °C to 120 °C with an accuracy ± 0.5°C up to 50°C and ± 1°C up to 120°C. The black globe should have 150 mm diameter. Dry-bulb thermometer's measuring range is 10 °C to 60 °C with an accuracy of ± 1 °C [5]. In this study, the calibration method of heat stress monitor will be explained. A heat stress monitor is given in Fig. 1.

It is recommended to read standards for detailed information about accuracy calculations of different instruments. The documents can be found in references section [17, 18].

WBGT reference values are given in Table 1, and these reference values are taken from ISO standard [5].

2. Method of calibration

A heat stress monitor includes wet bulb temperature sensor, dry bulb thermometer, and a black globe thermometer. Wet bulb temperature sensor is covered with a wet wick. The black globe thermometer comprises Pt-100 temperature sensor inside of a black coated globe and measures the temperature from the centre of the globe. Dry bulb thermometer measures air temperature. The main parameters to calculate WBGT are wet bulb temperature, black globe temperature, and dry- bulb temperature. The measuring device shall be calibrated for the accurate measurements. In this study, the calibration procedure of WBGT monitor is given.

Two-pressure humidity generator, which is sited in Turkish Standard Institution Gebze Calibration Laboratory, was used to generate controlled environments. The humidity generator is traceable to the national standards. Also, a traceable optical dew point transmitter was used in the calibration processes. The two-pressure method for generating environments that have known humidity involves saturating the air at high pressure with water vapour and then expanding the air to a lower pressure, and then the device generates high-accurate controlled environments [7]. The principle of the instrument was also proved by NIST [7, 8]. The two pressure humidity generator is supplied with constant humidity. These humidity values are known, and these values can be used for instrument calibration, verification and such as other processes. The set point values can be entered from the device’s front panel by an operator. Two pressure humidity generator calculates the relative humidity from the measurements of pressure and temperature. The operation of the humidity generator is based on the two-pressure method of producing known atmospheres of relative humidity and assumes that the water vapour pressure remains a fraction of the total pressure, known as Dalton's Law of Partial Pressure [19]. The two-pressure method contains saturating the air with water vapour at a given pressure and temperature. The saturated gas flows through an expansion valve where it is isothermally reduced to chamber pressure. If the temperature of the gas is held constant during pressure reduction, the humidity may be approximated as the ratio of two absolute pressures [20]. Two-pressure humidity generator is seen in Fig. 2.

Dry-bulb is commonly used as "air temperature." The dry-bulb temperature is a specific term for the temperature that is not influenced by evaporation or condensation [9]. Dry-bulb temperature sensor of the heat stress monitor was calibrated in the two-pressure humidity generator. Two-pressure humidity generator was using as the reference standard for the dry-bulb sensor. The sensor was calibrated in five temperature points; ambient temperature (23 °C), 30 °C, 40 °C, 50 °C and 5 °C. Calibration points were selected to test low and high-temperature responses of the device. WBGT reference values are given between 18 °C and 33 °C in the ISO standard 7243 (Table 1) [5]. It is though; calibration points shall be selected from this range.

Wet bulb temperature sensor is covered with a wet wick. When the wick is wet, evaporation will occur between moving air and the wet bulb temperature sensor in an amount depending upon the vapour pressure. The amount of cooling of the wet bulb when compared to the dry bulb temperature gives a reliable measure of the water vapour pressure and, consequently, the relative humidity and dew point temperature with using the psychrometric chart [10]. Psychrometric chart is a graph of the thermodynamic parameters of moist air. It gives the relationship between dew point and relative humidity [16]. Two pressure humidity generator was set to the various temperature points and humidity points to calibrate the natural wet-bulb thermometer. A precise dew point transmitter's Pt100 probe was used as the reference for the calibration. Reference Pt100 probe was sheltered in a wet wick and it was transformed to a wet bulb thermometer. The calibration was done in four temperature points between the range of 12 °C – 34 °C. It is hard to set exact values of wet-bulb temperature in the humidity generator. It is seen in the results with decimals.

Pt100 was using as the reference device in the calibration of heat stress monitor's black globe temperature sensor. Pt100 probe was combined with a black coated matt globe. This globe has got 150 mm diameter. The reference sensor was measured the radiation temperature from the centre of the globe. Humidity generator was set to the ambient temperature, 30 °C, 40 °C, and 60 °C during the calibration of the black globe thermometer.

Measurement results and uncertainty analysis will be given in the results section.

3. Results

It was defined; the heat stress monitor has got three main sensors; a dry-bulb temperature sensor, a wet bulb temperature sensor, and a black globe thermometer. All of these sensors shall be calibrated. The calibration methods were given in the previous section.

The results are given in the tables. Reference value means; "the value that is known" or "the true value." The reference value is read from a device that had been calibrated. The test value is the value of the device under calibration; the test value is indicated in the heat stress monitor's screen. Uncertainty is a parameter associated with the result of a measurement that characterizes the dispersion of the values be reasonably attributed to the measurand [11]. Measurement uncertainties were calculated according to the GUM [11]. The error is the difference between the test value and the reference value (Error = Test - Reference).

Dry bulb sensor of the heat stress monitor was calibrated in a range of 5 °C to 50 °C. The calibration points are 5 °C, 23 °C (ambient temperature), 30 °C, 40 °C, and 50 °C. Ten reference and test values were recorded for each calibration point. Values were taken periodically in every 5 minutes after the stability. Calibration results of the heat stress monitor's dry bulb temperature sensor are given in Table 2. Expanded measurement uncertainties are given in the table. The combined uncertainties were multiplied by a coverage factor to obtain an overall uncertainty, it is named as expanded uncertainty, and the coverage factor was taken as 2 and it gives 95% level of confidence [11]. Hysteresis measurements were also taken and their effects were added to the uncertainty budget. The accuracy of the sensor shall be ± 1 °C [5]. The errors of the measurements are not out of the tolerance.

The two pressure humidity generator was set to 15 °C and 60 % rh, 23 °C and 70 % rh, 30 °C and 70 % rh and 40 °C and 70 % rh for the calibration of wet bulb temperature sensor. These set values gave reference wet-bulb temperature results as 12.8 °C, 20.0 °C, 26.2 °C, and 33.7 °C in the reference Pt100 device's indicator. Ten temperature values were recorded periodically for each temperature point. Calibration results for the wet bulb temperature probe are given in Table 3. Combined expanded uncertainties are also given in the table. The effects of the hysteresis were added to uncertainty budget. In ISO standard [5], the accuracy of the sensor must be ± 0.5 °C. All of the wet bulb temperature values are seen intolerance.

A Pt100 sensor was used in the calibration of black globe thermometer. The sensor was centered into a black globe. The globe has 150 mm diameter. The chamber was set to 20 °C, 30 °C, 40 °C, 50 °C and 60 °C temperatures. Tolerance for the black globe thermometer is given as ± 1 °C in the ISO standard [5]. Measurement errors are seen acceptable in Table 4.

All of the measurement uncertainties is given in the tables for the calibration points. The uncertainty budget of WBGT equation will be modelled, sensitivity coefficients will be derived according to GUM. Partial derivations give the sensitivity coefficients, and they are indicated with the letter *C* [11].

WBGT equation for indoor environments is seen in Eq. 1. Sensitivity coefficient of the natural wet bulb temperature that effects directly to $\mathrm{WBGT_{indoor}}$ is given in Eq. 3. Sensitivity coefficient of the black globe thermometer is given in Eq. 4.

$$C_{\mathrm{WBGT_{indoor}},T_{\mathrm{nw}}} = \frac{\partial \mathrm{WBGT_{indoor}}}{\partial T_{\mathrm{nw}}} = 0.7 \qquad (3)$$

$$C_{\mathrm{WBGT_{indoor}},T_{\mathrm{g}}} = \frac{\partial \mathrm{WBGT_{indoor}}}{\partial T_{\mathrm{g}}} = 0.3 \qquad (4)$$

WBGT equation that is used for outdoor environments is seen in Eq. 2. There are three parameters in the equation; natural wet bulb temperature, black globe temperature, and dry bulb temperature. The sensitivity coefficient of natural wet bulb temperature that effects to $\mathrm{WBGT_{outdoor}}$ is given in Eq. 5, the sensitivity coefficient for black globe temperature is given in Eq. 6, and the sensitivity coefficient for dry bulb temperature is shown in Eq. 7.

$$C_{\mathrm{WBGT_{outdoor}},T_{\mathrm{nw}}} = \frac{\partial \mathrm{WBGT_{outdoor}}}{\partial T_{\mathrm{nw}}} = 0.7 \qquad (5)$$

$$C_{\mathrm{WBGT_{outdoor}},T_{\mathrm{g}}} = \frac{\partial \mathrm{WBGT_{outdoor}}}{\partial T_{\mathrm{g}}} = 0.2 \qquad (6)$$

$$C_{\mathrm{WBGT_{outdoor}},T_{\mathrm{a}}} = \frac{\partial \mathrm{WBGT_{outdoor}}}{\partial T_{\mathrm{a}}} = 0.1 \qquad (7)$$

The standard uncertainty of a function is obtained by appropriately combining the standard uncertainties of the input estimates. This combined standard uncertainty is noted by $u_c(y)$. The positive square root of the combined standard uncertainty of a function is given in Eq. 8 [11].

$$u_c^2(y) = \sum_{i=1}^{N} \left(\frac{\partial f}{\partial x_i}\right)^2 u^2(x_i) = \sum_{i=1}^{N} [C_i u(x_i)]^2 \tag{8}$$

The combined uncertainty of $\text{WBGT}_{\text{indoor}}$ is calculated as below according to GUM. Modelling of expanded uncertainty of $\text{WBGT}_{\text{indoor}}$ is seen in Eq. 10 (k=2).

$$u_{\text{WBGT}_{\text{indoor}}} = \sqrt{\left(C_{\text{WBGT}_{\text{indoor}},T_{\text{nw}}} * u_{T_{\text{nw}}}\right)^2 + \left(C_{\text{WBGT}_{\text{indoor}},T_{\text{g}}} * u_{T_{\text{g}}}\right)^2} \tag{9}$$

$$U_{\text{WBGT}_{\text{indoor}}} = k * u_{\text{WBGT}_{\text{indoor}}} \tag{10}$$

The combined uncertainty of $WBGT_{\text{outdoor}}$ is given in Eq. 11, and the expanded uncertainty is seen in Eq. 12 (k=2).

$$u_{\text{WBGT}_{\text{outdoor}}} = \sqrt{\begin{matrix}\left(C_{\text{WBGT}_{\text{outdoor}},T_{\text{nw}}} * u_{T_{\text{nw}}}\right)^2 + \\ \left(C_{\text{WBGT}_{\text{outdoor}},T_{\text{g}}} * u_{T_{\text{g}}}\right)^2 + \left(C_{\text{WBGT}_{\text{outdoor}},T_{\text{a}}} * u_{T_{\text{a}}}\right)^2\end{matrix}} \tag{11}$$

$$U_{\text{WBGT}_{\text{outdoor}}} = k * u_{\text{WBGT}_{\text{outdoor}}} \tag{12}$$

3.1 An example to calculate the uncertainty of WBGT measurement

When a physical quantity cannot be measured directly, it can be determined from other measurable quantities with a functional relationship [11]; such as WBGT equation.

Model functions of WBGT equations were given in the main section. An example calculation will be given in this section. In the example, the dry bulb temperature is 23.0 °C, natural wet bulb temperature is 20.1 °C. The measurements were taken for an outdoor environment. The black globe temperature was measured as 30.5 °C. The temperature values are given below:

T_a= 23.0 °C, T_{nw}= 20.1 °C, T_g= 30.5 °C

WBGT calculation for this example is given below:

$$\mathrm{WBGT_{outdoor}} = 0.7 * 20.1 + 0.2 * 30.5 + 0.1 * 23.0 = 22.47\ ^\circ\mathrm{C} \quad (13)$$

Measurement uncertainties of the given temperature points (k=2):

$$U_{T_\mathrm{a}} = 0.21\ ^\circ C$$

$$U_{T_\mathrm{nw}} = 0.21\ ^\circ C$$

$$U_{T_\mathrm{g}} = 0.53\ ^\circ C$$

The combined measurement uncertainty was calculated as seen in Eq. 14. And, expanded uncertainty (k=2) is seen Eq. 15.

$$u_{\mathrm{WBGT_{outdoor}}} = \sqrt{(0.7 * 0.105)^2 + (0.2 * 0.265)^2 + (0.1 * 0.105)^2} = 0.15\ ^\circ\mathrm{C} \quad (14)$$

$$U_{\mathrm{WBGT_{indoor}}} = 2 * 0.15 = 0.30 \quad (15)$$

WBGT result that is combined with measurement uncertainty is seen below:

$$\mathrm{WBGT_{outdoor}} = (22.47 \pm 0.30)\ ^\circ\mathrm{C}$$

Uncertainty budget of this example is given in Table 5.

ISO 7726:1985 gives the recommendations about environmental measurements. The accuracy limits in the standard may be taken as uncertainty limits of the devices. ISO 7726 recommends ± 0.5 °C limits for thermometers [12, 13]. So, the uncertainty limits of WBGT values can be calculated with these values with uncertainty calculation methods that were given in the study. Uncertainty tolerance of $\mathrm{WBGT_{outdoor}}$ and $\mathrm{WBGTin_{door}}$ were calculated in Equation 16 and 17.

$$Tolerance\ (u_{\mathrm{WBGT_{outdoor}}}) = \sqrt{(0.7 * 0.5/2)^2 + (0.2 * 0.5/2)^2 + (0.1 * 0.5/2)^2} = 0.37\ ^\circ\mathrm{C} \quad (16)$$

$$Tolerance\ (u_{\mathrm{WBGT_{indoor}}}) = \sqrt{(0.7 * 0.5)^2 + (0.3 * 0.5)^2} = 0.38\ ^\circ\mathrm{C} \quad (17)$$

Uncertainty value that is calculated in example is seen within tolerance.

4. Discussion

The wet bulb globe temperature index gives a result according to the combined quantitative effects of the air temperature, black globe temperature, and natural wet bulb temperature. Heat stress monitors are used to measure WBGT parameter. Heat stress monitor has got natural wet bulb temperature sensor, black globe thermometer, and dry-bulb temperature sensor. In this study, a heat stress monitor was calibrated, and the results were given. Conditioned environments were generated by two pressure humidity generator. The generator and a Pt100 probe were used as the reference device. The devices were calibrated and traceable. Pt100 probe was combined with a wet wick in natural wet bulb thermometer calibration. The black globe was used with the reference device for black globe temperature sensor’s calibration. Dry bulb thermometer was calibrated with Pt100 reference directly in the environment that was controlled by two pressure humidity generator.

Sensitivity coefficients were derived from the uncertainty calculations of WBGT indoor and outdoor equations. The most dominant uncertainty component is natural wet bulb temperature in uncertainty budget.

An example was given in the previous section. In the example, WBGT equation for an outdoor environment was calculated, and the uncertainty calculation was given. It was seen; the highest uncertainty source is globe temperature measurement. Black globe’s certificate uncertainty is higher. But the sensitivity coefficient of the natural wet bulb temperature is bigger than the black globe thermometer’s sensitivity coefficient. The most dominant uncertainty component is natural wet bulb temperature.

5. Conclusions

1. Workers and occupants are exposed to thermal stressful environments in industrial working places. WBGT index is useful to detect heat

stress in working areas. This index can be measured indirectly by a heat stress monitor. WBGT value is a calculated parameter using the input estimates. These input estimates are natural wet bulb temperature, black globe temperature, and air temperature. Heat stress monitors measure these parameters. A measuring device shall be calibrated for more accurate measurements.

2. In ISO standard 7243 [5], methods of WBGT measurements are described, and the tolerances for the temperature sensors are given. It is thought; these tolerances cannot be evaluated appropriately without a calibration process.

3. All temperature sensors, which exist in heat stress monitor (natural wet bulb temperature, dry bulb temperature, and black globe temperature), were calibrated in the study. A two pressure humidity generator was used to generate controlled environments, and the heat stress monitor was calibrated inside of it. A Pt100 probe that is traceable to national standards was used as the reference device. In the calibration of natural wet bulb sensor, Pt100 reference was sheltered with a wet wick. The sensor was centred to a black globe for the calibration of black globe thermometer. With these combinations, same conditions were constituted for test and reference devices.

4. Estimated usage range of the heat stress monitor was taken into account to assess the calibration points. Calibration of the sensors was done at least four measurement points. These points were selected between the maximum and minimum points of the estimated usage

range of the device. It is thought; calibrations of the minimum and maximum measuring points are important.

5. An example calculation is given in the study. The model function of the measurement uncertainty is given. Sensitivity coefficients of WBGT equation for indoor and outdoor environments were derived according to GUM. Natural wet bulb temperature has got the highest sensitivity coefficient.

Abbreviations

WBGT	Wet bulb globe temperature
T_{nw}	Natural wet bulb temperature, units of °C
T_a	Air temperature, units of °C
T_g	Black globe temperature, units of °C

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Figures

Fig. 1 A heat stress monitor

Fig. 2 Two pressure humidity generator (Thunder Scientific Model 2500)

Tables

Table 1 WBGT reference values

Metabolic rate (W/m^2)	***WBGT Reference Value***			
	Acclimatized person (°C)		***Not acclimatized person*** (°C)	
0 *Resting* *M < 65*	33		32	
1 *65 < M < 130*	30		29	
2 *130 < M < 200*	28		26	
3 *200 < M < 260*	25	26 *(for sensible air movement)*	22	23 *(for sensible air movement)*
4 *M > 260*	23	25 *(for sensible air movement)*	18	20 *(for sensible air movement)*

Table 2 Calibration results for the dry-bulb temperature sensor

Set value	*Mean reference value*	*Mean test value*	*Error*	*Expanded Measurement uncertainty (k=2)*
5 ºC	5.9 ºC	6.3 ºC	0.4 ºC	0.31 ºC
23 ºC	22.9 ºC	23.0 ºC	0.1 ºC	0.21 ºC
30 ºC	29.7 ºC	29.8 ºC	0.1 ºC	0.21 ºC
40 ºC	39.3 ºC	39.2 ºC	- 0.1 ºC	0.24 ºC
50 ºC	48.9 ºC	48.9 ºC	0.0 ºC	0.21 ºC

Tolerance: ± 1.0 ºC

Table 3 Calibration results for the natural wet-bulb temperature sensor

Set value	*Mean reference value*	*Mean test value*	*Error*	*Expanded Measurement uncertainty (k=2)*
15 ºC, 60% rh	12.8 ºC	12.4 ºC	- 0.4 ºC	0.21 ºC
23 ºC, 70% rh	20.0 ºC	20.1 ºC	0.1 ºC	0.21 ºC
30 ºC, 70% rh	26.2 ºC	26.4 ºC	0.2 ºC	0.24 ºC
40 ºC, 60% rh	33.7 ºC	33.3 ºC	- 0.4 ºC	0.21 ºC

Tolerance: ± 0.5 ºC

Table 4 Calibration results for the black globe thermometer

Set value	*Mean reference value*	*Mean test value*	*Error*	*Expanded Measurement uncertainty (k=2)*
20 ºC	20.5 ºC	20.4 ºC	- 0.1 ºC	0.51 ºC
30 ºC	30.7 ºC	30.5 ºC	- 0.2 ºC	0.53 ºC
40 ºC	40.7 ºC	40.5 ºC	- 0.2 ºC	0.54 ºC
50 ºC	50.9 ºC	50.7 ºC	- 0.2 ºC	0.58 ºC
60 ºC	61.0 ºC	60.8 ºC	- 0.2 ºC	0.61 ºC

Tolerance: ± 1.0 ºC

Table 5 Calculation of the combined uncertainty of WBGT for example

Quantity	***Expanded Uncertainty Value***	***Probability Distribution***	***Divisor***	***Standard Uncertainty of Measurement***	***Sensitivity Coefficient***	***Contribution to the Uncertainty***
Air temperature	$U\ (T_a) =$ 0.21 ºC	*Normal*	2	0.105 ºC	0.1	0.0105
Black globe temperature	$U\ (T_g) =$ 0.53 ºC	*Normal*	2	0.265 ºC	0.2	0.053
Natural wet bulb temperature	$U\ (T_{nw}) =$ 0.21 ºC	*Normal*	2	0.105 ºC	0.7	0.0735
u_{Tcl} *Total Standard Measurement Uncertainty (k=1)*					$\sqrt{}(0.0105^2+0.053^2+0.0735^2)$	
U_{Tcl} *Expanded Measurement Uncertainty (k=2)*					$2*\sqrt{}(0.0105^2+0.053^2+0.0735^2)$	