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A case study on how to maintain confidence of thermal properties test: Thermal conductivity of building insulation materials

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Abstract

This study discussed methods for improving confidence on results of measurement and test focusing thermal conductivity test of building insulation materials. The proposed methods in this study were: (1) maintenance of traceability by correction of test equipments; (2) performance evaluation by statistical analysis and control chart; (3) inter-tester comparative proficiency testing by outputting robust statistics and *Z*-scores.

Through confirmation of equipment maintenance condition, verification of test process, observation of variation factor and improvement, output of accuracy, retaining of researcher, improvement of proficiency, we will heighten precision and accuracy of test and improve confidence abroad.

Keywords: Confidence; Thermal conductivity test; Traceability; Proficiency test; Statistics

1. Introduction

1.1. Background and purpose of study

Recently, the efforts for improving confidence on results of test and measurement in order to deal with the expansion of conformity assessment for overcoming Technical Barrier of Trade (TBT) Agreement under the WTO system and Mutual Recognition Agreement (MRA), both internally and externally, for the test results on performance of industrial and commercial products are necessary not only in the industrial sector but also in the research sector.

At the current juncture with the measurement sector becoming internationalized, confidence on results of test and measurement in every field has become an important area of interest [1,2]. But how can confidence on test results be heightened and maintained?

The purpose of this study is on discussing methods for improving confidence on thermal conductivity test of building insulation materials.

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2. Maintenance of test traceability

2.1. Maintenance of traceability

Authorized measurement laboratories and research institutes must go forth, by correcting major devices related to the range of acknowledgement of test and measurement, to verify that results yielded from such devices are traceable in SI units of measurement and traceable to specific constants recommended by General Conference of Weights and Measures (GCWM) [3].

In other words, traceability can be preserved when procedures of each stage of comparing chain and such results are documented and continuously and repeatedly re-corrected in appropriate cycle as a method of securing accuracy of measurement by maintaining comparing chain that is not disconnecting but traceable to national or international standards in accordance with SI unit stipulated internationally.

2.2. Summary and purpose of calibration

Since errors tend to occur from various causes when devices and facilities are used or stored for a long period of time, calibration refers to a series of process that examines the distribution of such error range and corrects to conform to the standard value by finding the relational expression in case of large error distribution.

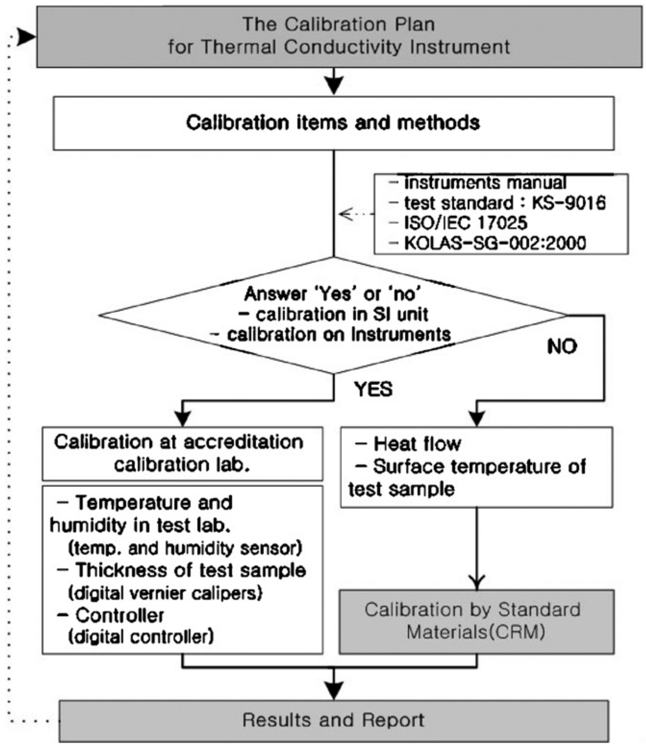

Fig. 1. Calibration procedure of thermal conductivity instrument.

The purpose of calibration is to continuously maintain the precision and accuracy of measuring device by repeatedly comparing and correcting to conform to the standard value. Therefore, homogeneity and precision of test results can be guaranteed and confidence can be secured abroad through calibration.

2.3. *Traceability of thermal conductivity test*

2.3.1. *Calibration procedures of test equipments*

In study for thermal conductivity test of building insulation materials, the applied standards are KSA test method KS L 9016:2005 [4,5] and ASTM test method C 518:2004 [6].

Specific calibration procedures must be established for the appropriate calibration on measuring devices. In this study, calibration procedures of thermal conductivity test were accomplished based on the specific calibration standard and plan shown below in Fig. 1.

2.3.2. *Calibration result of test equipments*

Calculation of calibration period must be determined so that calibration can be operated before any change occurs to the performance of test equipments.

The thermal conductivity test equipment in this study has been comprehensively selected by considering accuracy and allowable limit of error, safety of correction and equipment, frequency of use and method, environmental conditions, forms of equipment, assessment from previous calibration record and calibration objects and cycle presented by Korean Agency for Technology and Standards. Calibration period and such results are shown in Table 1.

Table 1
The period and result of calibration of thermal conductivity instrument

Calibration item	Calibration period	Calibration results
Temp. and humidity sensor (test environment condition)	12 months	(1) Temperature: °C (a) Reference value: 20.1 (b) Measurement value: 20.2 (c) Correction value: −0.1 (2) Humidity: % R.H. (a) Reference value: 59.1 (b) Measurement value: 57.0 (c) Correction values: 2.1
Digital vernier calipers	12 months	Measurement unit: mm (a) Reference value: 50 (b) Measurement value: 50 (c) Correction values: 0.0
Controller	12 months	Temperature: °C (a) Reference value: 25.0 (b) Measurement value: 25 (c) Uncertainty: ±0.61
Heat flow (Q) and surface temperature	6 months	Result of a measurement: W/(m K) (mean temp. = 20 °C) (a) Reference value: 0.0341 (b) Measurement value: 0.0342

The table was the period and result of calibration of thermal conductivity instrument.

3. Performance management

3.1. *Performance evaluation by general statistical analysis*

3.1.1. *Practical use of statistics*

Statistics, a set of theories and methods for making wise decisions under uncertainty, can be defined as a study that presents methods of making scientific judgment on uncertain facts based on data and numerical statement obtained from collecting, organizing and summarizing data on the object of interest [7]. The purpose of statistics is: (1) collecting and organizing data, (2) analyzing statistical relation between the factors that influence the result and (3) predicting and controlling the result by transforming the factors that influence the result.

3.1.2. *Mathematical measure calculation of thermal conductivity test*

Since, summary chart and simple listing of data can lead to subjective judgment and there is no way of knowing how close sample data (derived data result) is to population (data result measured infinitely), mathematical measure that can objectively represent the data is indispensable.

In this study, mathematical measure has been calculated through the data of thermal conductivity test result measured by tester A with standard qualification. The test piece is the 'glass fiber, a standard reference material of NIST' with 0.0341 (±1.6%, 95%) W/(m K) as the certified value of thermal conductivity at the average temperature of 20 °C [8]. The test result is summarized in Table 2.

Table 2
Thermal conductivity test result by A tester

$N = 10$ Thermal conductivity (W/(m K))	No. 1	No. 2	No. 3	No. 4	No. 5	No. 6	No. 7	No. 8	No. 9	No. 10
	0.03437	0.03430	0.03428	0.03430	0.03433	0.03426	0.03430	0.03427	0.03428	0.03431

The table was 10 data of tester A for thermal conductivity test.

Table 3
Mathematical measure of test data of A tester

Central tendency	Degree of freedom	Average (W/(m K))	Median (W/(m K))	Mode (W/(m K))
	9	0.03430	0.03430	0.03430
Disperse tendency	Variance	S.D.	QD	CV
	1.01×10^{-9}	3.18×10^{-5}	1.66×10^{-5}	0.00093

The table was mathematical measure of data on thermal conductivity test result of tester A: S.D. stands for the standard deviation, QD stands for the quartile deviation and CV stands for the coefficient of variation.

Mathematical measure has measure of central tendency and measure of dispersion tendency.

Measure of central tendency is the representative value of data and is also called measure of central tendency consisted of average, median and mode. Arithmetic mean, being the statistical result value of general data, represents the central data of population but may be greatly affected by abnormally large or small data, thus fail to show the characteristics of population. Median refers to the middle value when data is listed in order from smallest to the largest. It is also called medium and is not sensitive to abnormal data, thus bears a greater importance than average as the measure of central tendency when abnormality exists in the data. Mode refers to the value that appears most frequently among data.

Measure of distribution tendency is the measure that shows the extent of distribution by providing information on how closely bound or dispersed data are. It is consisted of variance, standard deviation, quartile deviation and coefficient of variation.

Variance and standard deviation are the most used terms among the concepts that display the degree of distribution. Variation is for obtaining the average by squaring the standard deviation of each measured value and its significance amplifies even greatly for the measured values that are further away from the average. Standard deviation is the square root of variation that it not only possesses all the characteristics of variation but also can be used in the same unit with data value and representative value; thus, it is widely used as the measure for the degree of distribution.

Quartile deviation (QD) complements the weakness of range that displays only the difference between two extreme values. Quartile is a number resulting from dividing the data listed in the order of size into four. Such calculation results from dividing the quartile range (first quartile subtracted from third quartile) by 2.

$$Q_1 = (\text{number of data}\,(N)) \times 0.25 \leq N\text{th data of quantity}$$
$$Q_3 = (\text{number of data}\,(N)) \times 0.75 \leq N\text{th data of quantity} \quad (1)$$
$$\text{QD} = (Q_3 - Q_1)/2$$

Coefficient of variation (CV), a useful measure when comparing the distribution of two data, is defined as the relative ratio on the representative value of ultimate degree of distribution.

$$\text{CV} = s/x \quad (2)$$

where s is the standard deviation and x is the arithmetic mean.

Table 3 is the result of mathematical measure calculated on the data of test result. The representative value of the measurement is 0.03430 W/(m K) with the average, median and mode all being 0.03430 W/(m K), and variance, standard deviation and coefficient of variation, which are the distribution measures, showed lower values than the significant figure of the measurement. The above result is organized into a chart in Fig. 2.

As shown in Fig. 2, appropriate calibration procedure is indispensable for conforming to the certified value 0.0341 W/(m K) of test pieces.

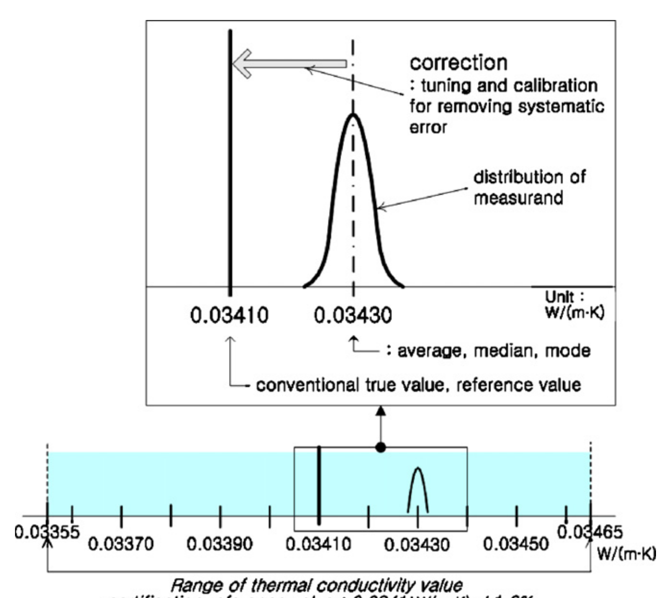

Fig. 2. Result of mathematical measure on measurement.

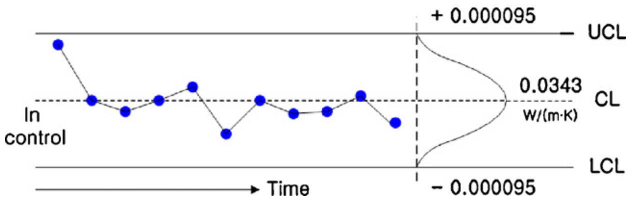

Fig. 3. Control chart on thermal conductivity test result of tester A.

3.2. *Performance evaluation by control chart*

Control chart, proposed by Schewhart in 1924, is a statistical procedure that rapidly detects the occurrence of special causes in the continuous production process [9]. This study has secured confidence on measurement by adopting the fundamental concept of control chart as the method for preserving confidence on measurement by distinguishing the fluctuation factor of test measurement and the existence or non-existence of error in management conditions.

The statistical concept used in control chart is similar to testing of statistical hypothesis that establishes hypothesis and examines such hypothesis with the sample (measured data) extracted from population. The difference is the continuous operation and the existence of follow up steps, such as confirmation of equipment maintenance condition, verification of test process and retaining of researcher for obtaining logical result value.

This study used the control chart of statistical procedures that indicates the measured result with the passage of time on the chart consisted of upper control limit (UCL) and lower control limit (LCL) centered on a control value (CL).

$$\begin{aligned} \mathrm{UCL} &= \mathrm{CL} + 3\sigma \\ \mathrm{LCL} &= \mathrm{CL} - 3\sigma \end{aligned} \quad (3)$$

where σ is the standard deviation of the measured value data set.

A case of measured values being over the value of upper control limit or below the value of lower control limit is considered an outlier and test data is managed through follow up steps. In other words, the measured value is said to be under suitable management condition when it exists within the range of LCL $\leq$ measured value data $\leq$ UCL. The control chart on data from Table 2 measured under the fixed interval of time is shown in the following Fig. 3.

4. Method of comparative proficiency

4.1. *Inter-tester comparative proficiency testing*

To decide and verify the precision of measured data, to find out the abilities of testing places and testers prior to any test or measurement as well as to secure confidence and quality guarantee on test and preserve competitiveness, and to verify problems and to improve such problems at the initial stage, evaluation by comparative proficiency testing that decides the test performance is conducted through the comparative method among testers or testing places.

Proficiency test techniques are used different based on the characteristics of test product, method of use and number of participating testing places (testers) but the similarity in the majority of techniques is that the comparison is made between the result obtained from one testing place (tester) and the result obtained from another or more testing place(s) or tester(s) [10].

The result of proficiency test can be displayed in various forms due to the types of data and the diversity of statistical distribution. The statistical technique used for result analyses must be appropriate for each situation; therefore, there are too many different types to explain in details.

In this study, evaluation by robust statistics and *Z*-scores was conducted for the statistical analysis of inter-tester proficiency testing [11,12]. The following Table 4 is the summary of thermal conductivity test result of ‘glass fiber’ tested by five testers (A–E) who possessed specific qualifications.

4.2. *Robust statistics*

Analysis on average and standard deviation has difficulties in yielding proper analysis on data since it is greatly influence by the existence of outlier within the data set. Robust statistics can be defined as summary statistics that is not greatly affected by the existence of such extreme result [11].

The countermeasure of robust statistics against average and standard deviation is the medium and the normalized interquartile range. Interquartile range (IQR) is the difference between first quartile (Q_1) and third quartile (Q_3), and the normalized interquartile range is the value yielded from multiplying IQR by 0.7413.

Here, the width of IQR of standard normal distribution with arithmetic mean of 0 and standard deviation of 1 is 1.34898 and 1/1.34898 is 0.7413. Accordingly, comparison with the standard deviation is possible by multiplying 0.7413 to IQR.

The result of robust statistics is summarized in Table 5. Comparing the results between robust statistics and the standard deviation, robust statistics is greatly reduced compared to the standard deviation in the test result, thus includes the result that could be judged as an outlier within the test data. Here, thermal conductivity data of tester C is 0.03414 W/(m K).

Table 4
Thermal conductivity test data for proficiency testing

Thermal conductivity (W/(m K))	A	B	C	D	E	Average	S.D.
	0.03448	0.03433	0.03414	0.03434	0.03440	0.03434	0.00013

The table was the thermal conductivity test result data for proficiency test among five testers. Average stands for arithmetic mean and S.D. stands for standard deviation.

Table 5
Results by robust statistical techniques

First quartile	Third quartile	IQR	QD	Normalized IQR
0.03433	0.03440	0.000070	0.000035	0.0000519

This table shows robust statistic results for inter-tester comparative proficiency testing: IQR is interquartile range. QD stands for quartile deviation.

Table 6
Z-scores results

Tester	A	B	C	D	E
Z-score	2.70	−0.19	−3.85	0.0	1.16
Judgment	Suspicious	Satisfying	Dissatisfying	Satisfying	Satisfying

4.3. *Z*-scores

Z-scores is frequently used in the world as the method of comparing testing places. *Z*-scores are the normalized values obtained from turning each data result on other values within the data into points. *Z*-score closer to 0 signifies that the results are very similar to the results of other testers (or testing places). If a measured value has a *Z*-score that is greater than 3 or less than −3, such can be considered dissatisfying, thus classified into an outlier [12].

As a result of calculating *Z*-scores (Table 6), the measured value of tester A resulted between 2 and 3 that it was judged suspicious, and the measured value of tester C was confirmed to be dissatisfying.

5. Conclusion

This study discussed the methods for improving confidence on results of measurement and test on the subject of thermal conductivity test of building insulation materials.

The methods presented in this study are: first, traceability maintenance of result with appropriate calibration of measuring device; second, performance evaluation by statistical analysis and control chart preparation on result data; third, inter-tester comparative proficiency testing by outputting robust statistics and *Z*-scores from the results of multiple numbers of testers.

The above methods presented in this study are not new methods but rather just some of the methods currently studied and used in science, such as statistics and industrial engineering, as well as in domestic/foreign test/inspection laboratory reform and international standardization.

By executing confirmation of equipment maintenance condition, verification of test process, observation and improvement of variation factors of test measurement, accuracy detection of test, retaining of researchers and proficiency improvement through such methods in relation to test and measurement, accuracy precision of test results can be heightened and confidence can be improved abroad.

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