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REPEATABILITY AND REPRODUCIBILITY OF DRY AND WET HEAT RESISTANCE TESTS ACCORDING TO EN 12721 AND EN 12722

The European Standards 12721 and 12722 specify a method for the assessment of the surface resistance to wet and dry heat of furniture respectively. The aim of the research is to establish data on the test precision of both tests in order that this precision is mentioned on the standards and test reports based on them. It is intended to measure the reproducibility and repeatability according to the standard ISO 5725-2 of data obtained in an international round-robin exercise carried out by eight participating laboratories expert in furniture surfaces. The results presented show that the repeatability variance is almost 0, while the between-laboratory variance is between 0 and 1, according to the order of increment of the assessment rating code.

Keywords: dry heat, wet heat, repeatability, reproducibility, round-robin test

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Introduction

A resistance-to-heat test is carried out to evaluate the effect produced by direct contact of a hot object on the surface under investigation (dry heat) or interposing a wet textile between the two surfaces (wet heat). It is a simulation of possible common actions happening frequently in a domestic environment [Bulian, Grayston 2009].

There are two European Standards regarding this subject, EN 12721 and EN 12722, which give the procedure, equipment and related information to assess the resistance of furniture surfaces to wet and dry heat. These methods permit the comparison of different finishes or may be used as quality control of the product. In the latest versions of these European Standards from 2009, there is no available data about their precision.

An international round-robin exercise to measure the reproducibility and repeatability of both tests was carried out. Five materials were used in the inter-comparison test in an attempt to represent those to which the test method is expected to be applied in normal use due to its implementation in the market. Furthermore, the influence of the light source, direct or diffuse, was studied. Each laboratory received a separate set of specimens from the same manufacturing batch, and instructions to be followed as closely as possible. The results obtained were sent to the inter-laboratory coordinators, AIDIMA and FCBA, in charge of the sample preparation and the statistical analysis of the raw data according to the standard ISO 5725-2. Data on the repeatability and reproducibility are presented.

For the assessment of the results, the test areas were evaluated according to a descriptive numerical rating scale with two lighting conditions, diffuse and direct light source. The analysis of these kinds of variables based on a numerical rating code creates challenges in the analysis and leads to an old controversy.

According to the "Theory of Scale Types" developed by Stevens [1946], there are four different rating scales depending on how the data are measured: nominal (also denoted as categorical), ordinal, interval and ratio variables.

On the nominal scale, any numbers used are mere labels, they express no mathematical properties. On the ordinal scale, numbers indicate the relative position of items, they describe order but not the magnitude of difference. On the interval scale, numbers indicate the magnitude of difference between items, but there is no absolute zero point; quantitative attributes are all measurable on interval scales. On the ratio scale, numbers indicate magnitude of difference and there is a fixed zero point.

Taking into account the theory developed by Stevens, he also classified the statistical analysis methods "permissible" according to each scale. It follows therefore that permissible statistics for determining the central tendency of a group of items with ordinal data could be described by using the mode or its median, and

the dispersion by means of the percentiles, or resorting to nonparametric methods, while when using interval data, the use of means and standard deviations are also allowed [Velleman, Wilkinson 1993].

Consequently, it would be not possible to apply the methodology detailed in the standard ISO 5725-2 to the results of the heat resistance tests, as they work on an ordinal scale. Nevertheless, there has been, and continues to be, debate on this subject. On the one hand, there is the view that the scale on which a set of measurements lies determines the type of statistical treatments that are suitable for application to the measurements. However, the opposite view is that there is no relation between the measurement scale and statistical procedures [Townsend J.T., Marín G. 1983].

Moreover, there is controversy about the merits of the classification made by Stevens due to the scale types not being precise categories, particularly in the cases of the nominal and ordinal classifications. This is often justified on the basis that ordinal scales are really somewhere between true ordinal and interval scales; although the interval difference between two ordinal ranks is not constant, it is often of the same order of magnitude.

On account of this, and considering the current of opinion of operational and classical theories, which justify for different reasons that there is no relationship between measurement scales and statistics, and therefore contradict Stevens's prescriptions (representational theory) [APA, 1986], in this research the data analysis will estimate the mean and the standard deviation of the results in order to obtain the repeatability and the reproducibility.

The European Committee for Standardization CEN/TC 207/WG7 "Surfaces and surface finishes of furniture" developed test methods for the assessment of surface resistance to wet and dry heat, but were unable to resolve the estimation of the reproducibility and repeatability. This study was carried out in response to this need. Consequently, the results of this round-robin exercise will not only provide information to be included in a future standards review, but will also inform laboratories, with the aim of disseminating this knowledge in client's reports.

Materials and methods

There were 8 participating laboratories (table 1) in the collaborative interlaboratory trial, which was set up in accordance with ISO 5725-2 (1994), with the aim of estimating the reproducibility and repeatability of EN 12721:2009 Furniture – Assessment of surface resistance to wet heat and EN 12722:2009 Furniture – Assessment of surface resistance to dry heat.

In essence, in both tests a standard aluminium alloy block at a specified test temperature (100ºC for dry heat, and 70º for wet heat) is placed on the surface of the test panel, which after a specified period of time (20 minutes) is removed. Then, the test area is wiped dry and the test panel is left undisturbed for

16 hours. Finally, it is examined under specified lighting conditions for signs of damage and evaluated according to a descriptive numerical rating code. In the wet heat resistance test, a damp cloth is placed between the alloy block and the test panel.

Table 1. Participating laboratories
Tabela 1. Uczestniczące laboratoria

Laboratory *Laboratorium*	Country *Kraj*
CATAS (A)	Italy *Włochy*
FIRA (B)	United Kingdom *Zjednoczone Królestwo*
ITD (C)	Poland *Polska*
IKEA (D)	Sweden *Szwecja*
LGA (E)	Germany *Niemcy*
IHD (F)	Germany *Niemcy*
FCBA (G)	France *Francja*
AIDIMA (H)	Spain *Hiszpania*

All participating laboratories were randomly labelled from A to H.

Five materials were used in the inter-comparison test in an attempt to represent those to which the test method is expected to be applied in normal use in the finished furniture.

Samples were prepared according to levels 1 to 5 as shown in the following table:

Table 2. Tested samples
Tabela 2. Badane próbki

Level *Poziom*	Description *Opis*
1	Paper-based decor finish foil Substrate: Particleboard *Dekoracyjna folia finish na bazie papierowej* *Podłoże: płyta wiórowa*
2	Monocomponent water based transparent coating Substrate: particleboard covered with beech veneer *Jednoskladnikowe przejrzyste pokrycie wodorozcieńczalne* *Podłoże: płyta wiórowa z okleiną bukową*

Table 2. Continued
Tabela 2. Ciąg dalszy

3	Bicomponent polyurethane Substrate: particleboard covered with beech veneer *Poliuretan dwuskładnikowy* *Podłoże: płyta wiórowa z okleiną bukową*
4	Pigmented coating based on polyester UV curing Substrate: MDF *Barwione pokrycie na bazie poliestru, utwardzane promieniami UV* *Podłoże: płyta MDF*
5	HPL, plain dark colour, high gloss Substrate: Particleboard *HPL, zwykły ciemny kolor, wysoki połysk*

Three replicates were carried out per material.

Table 3. Assessment code
Tabela 3. Kod oceny

Description *Opis*	Numerical rating *Ocena liczbowa*
• No change. Test area indistinguishable from adjacent surrounding area. • *Żadnych zmian.* *Powierzchnia badana nie daje się odróżnić od przyległej, otaczającej ją powierzchni*	5
• Minor change. Test area distinguishable from adjacent surrounding area, only when the light source is mirrored on the test surface and is reflected towards the observer's eye, e. g. discoloration, change in gloss and colour. No change in the surface structure, e.g. deformation, swelling, fibre raising, cracking, blistering. • *Niewielkie zmiany.* *Badana powierzchnia daje się odróżnić od przyległej, otaczającej ją powierzchni tylko wówczas, gdy źródło światła odbija się na powierzchni i jest odbijane w stronę oczu obserwatora, np. przebarwienie, zmiana połysku i koloru.* *Nie ma zmian w strukturze powierzchni, np. deformacji, pęcznienia, podnoszenia się włókien, pęknięć, pęcherzy*	4
• Moderate change. Test area distinguishable from adjacent surrounding area, visible in several viewing directions, e.g. discoloration, change in gloss and colour. No change in the surface structure, e.g. swelling, fibre raising, cracking, blistering. • *Umiarkowane zmiany.* *Badana powierzchnia daje się odróżnić od przyległej, otaczającej ją powierzchni, jest widoczna w kliku kierunkach obserwacji, np. przebarwienie, zmiana połysku i koloru.* *Nie ma zmian w strukturze powierzchni, np. pęcznienia, podnoszenia się włókien, pęknięć, pęcherzy*	3

Table 3. Continued
Tabela 3. Ciąg dalszy

• Significant change. Test area clearly distinguishable from adjacent surrounding area, visible in all viewing directions, e.g. discoloration, change in gloss and colour, and/or structure of the surface slightly changed, e.g. swelling, fibre raising, cracking, blistering. • *Znaczne zmiany.* *Badana powierzchnia wyraźnie daje się odróżnić od przyległej, otaczającej ją powierzchni, jest widoczna we wszystkich kierunkach obserwacji, np. przebarwienie, zmiana połysku i koloru, i/lub nieznacznie zmieniona struktura powierzchni, np. pęcznienie, podnoszenie się włókien, pęknięcia, pęcherze*	2
• Strong change. The structure of the surface distinctly changed and / or discoloration, change in gloss and colour, and/or the surface material totally or partially removed. • *Silne zmiany.* *Wyraźnie zmieniona struktura powierzchni i/lub przebarwienie, zmiana połysku i koloru i/lub materiał powierzchniowy całkowicie lub częściowo usunięty*	1

Statistical data analysis

Original test results

The interlaboratory study involved p laboratories called i (i = 1, 2, …, p), each testing q materials (levels) called j (j = 1, 2, …, q) with n replicates (each ij combination). All replicates of each ij are assigned to one cell (mainly 3 individual values).

The cell means and cell spread (standard deviation for each cell, combination of laboratory and level) were calculated as follows:

$$\bar{y}_{ij} = \frac{1}{n_{ij}} \sum_{k=1}^{n_{ij}} y_{ikj} \tag{1}$$

$$s_{ij} = \sqrt{\frac{1}{n_{ij} - 1} \sum_{k=1}^{n_{ij}} (y_{ikj} - \bar{y}_{ij})^2} \tag{2}$$

Where n_{ij} (number of replicates) is the number of test results in the cell for the laboratory i and material j, and y_{ikj} is any one of the test results (k = 1, 2,…, n_{ij}).

Scrutiny of results for consistency and outliers

During the first stage of the evaluation, the data were critically examined in order to identify outlier values and other inconsistencies. Both a graphical consistency technique and numerical outlier tests were applied.

Normally, the critical values in the consistency tests at the significance levels $\alpha = 1\%$ and $\alpha = 5\%$ are used as criteria for outliers and stragglers, respectively.

- If the statistic is greater than its 1% critical value, the item tested is called a statistical outlier.
- If the test statistic is greater than its 5% critical value but less than or equal to its 1% critical value, the item tested is called straggler.
- If the test statistic is less than or equal to its 5% critical value, the item tested is accepted as correct.

Graphical technique

Mandel's h-statistic is a "between-laboratory consistence statistic" which indicates a deviation of the cell mean measured from one laboratory when compared with the general mean obtained from the all laboratories in the round-robin test.

h-value is defined as:

$$h_{ij} = \frac{d}{s_{\bar{x}}} \qquad (3a)$$

$$h_{ij} = \frac{\bar{y}_{ij} - \bar{\bar{y}}_j}{\sqrt{\frac{1}{(p_j - 1)} \sum_{i=1}^{p_j} (\bar{y}_{ij} - \bar{\bar{y}}_j)^2}} \qquad (3b)$$

where: d = the deviation of the cell average from the average of the cell averages
$s_{\bar{x}}$ = the standard deviation of the cell averages
p_j = is the number of laboratories reporting at least one test result for material j.

Mandel's k-statistic is a "within-laboratory consistency statistic" which indicates a measurement deviation in one laboratory when compared within-cell standard deviation (repeatability standard deviation).

The k-value is defined as:

$$k_{ij} = \frac{s_{ij}}{s_{rj}} \qquad (4a)$$

$$k_{ij} = \frac{s_{ij}}{\sqrt{\frac{\sum_{i=1}^{p} s_{ij}^2}{p_j}}} \qquad (4b)$$

where: s_{ij} = the cell standard deviation for one laboratory
s_{rj} = the repeatability standard deviation of the material

Numerical technique

- Cochran's statistic C

  Cochran's statistic C is defined as:

$$C = \frac{s_{\max}^2}{\sum_{i=1}^{p} s_i^2} \tag{5}$$

Where s_{max} is the highest standard deviation in the set of standard deviations tested. Cochran's test is a one-sided outlier test because it examines only the highest value in a set of standard deviation.

– Grubbs' test

In Grubbs' test, the data to be tested should be arranged in ascending order, that is, for a set of xi values (i = 1, 2, …,p), where x_1 is the smallest and x_p is the largest. To examine the significance of the largest values, Grubbs' statistic G_p is:

$$G_p = \frac{(x_p - \bar{x})}{s} \tag{6}$$

where:

$$\bar{x} = \frac{1}{p} \sum_{i=1}^{p} x_i \tag{7}$$

and

$$s = \sqrt{\frac{1}{p-1} \sum_{i=1}^{p} (x_i - \bar{x})^2} \tag{8}$$

To examine the smallest value, Grubbs' statistic G_1 is:

$$G_1 = \frac{(\bar{x} - x_1)}{s} \tag{9}$$

Calculation of the general mean and variances

For level j, the general mean is:

$$\hat{m}_j = \bar{\bar{y}}_j = \frac{\sum_{i=1}^{p} n_{ij}\, \bar{y}_{ij}}{\sum_{i=1}^{p} n_{ij}} \tag{10}$$

Three variances are calculated for each material, i.e., the repeatability variance, the reproducibility variance, and the between-laboratory variance.

The repeatability variance is:

$$s_{rj}^2 = \frac{\sum_{i=1}^{p}(n_{ij}-1)\,s_{ij}^2}{\sum_{i=1}^{p}(n_{ij}-1)} \tag{11}$$

The between-laboratory variance (or inter-labs variance) is:

$$s_{Lj}^2 = \frac{s_{dj}^2 - s_{rj}^2}{\bar{\bar{n}}_j} \tag{12}$$

where:

$$s_{dj}^2 = \frac{1}{p-1}\sum_{i=1}^{p} n_{ij}\,(\bar{y}_{ij} - \bar{\bar{y}}_j)^2 \tag{13}$$

and

$$\bar{\bar{n}}_j = \frac{1}{p-1}\left[\sum_{i=1}^{p} n_{ij} - \frac{\sum_{i=1}^{p} n_{ij}^2}{\sum_{i=1}^{p} n_{ij}}\right] \tag{14}$$

The reproducibility variance is:

$$s_{Rj}^2 = s_{rj}^2 + s_{Lj}^2 \tag{15}$$

Results and discussion

Table 4. Collation of all test result data. EN 12722 (100ºC) Diffuse light source
Tabela 4. Porównanie wszystkich wyników badań. EN 12722 (100ºC) Źródło światła rozproszonego

Laboratory *Laboratorium*	Level *Poziom*				
	1	2	3	4	5
A	5 5 5	1 1 1	4 4 4	4 4 4	5 5 5
B	5 5 5	1 1 1	4 4 5	5 5 5	5 5 5
C	5 5 5	1 1 1	5 5 5	5 5 5	4 4 4
D	5 5 5	5 5 5	5 5 5	5 5 5	5 5 5
E	5 5 5	1 1 1	3 4 4	4 4 4	4 4 3
F	5 5 5	2 2 2	4 4 4	5 5 5	5 5 5
G	5 5 -	2 2 2	3 3 3	5 5 -	5 5 -
H	5 5 5	1 1 1	4 4 4	3 3 3	4 4 4

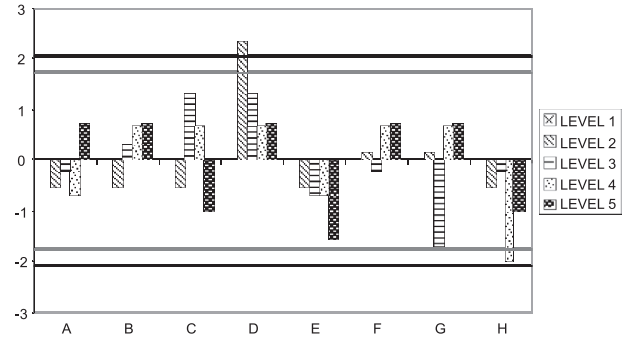

Fig. 1. Mandel's h plot EN 12722 Diffuse light
Rys. 1. Wykres h Mandela EN 12722 Światło rozproszone

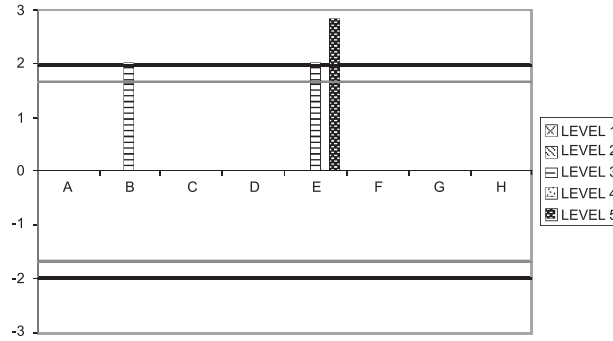

Fig. 2. Mandel's k plot EN 12722 Diffuse light
Rys. 2. Wykres k Mandela EN 12722 Światło rozproszone

Table 5. Application of Cochran's test
Tabela 5. Zastosowanie testu Cochrana

	Level *Poziom*				
	1	2	3	4	5
Cochran's C test statistics *Statystyki testu Cochrana*	–	–	0.500	–	1.000[b]
Cochran's critical values *Wartości krytyczne wg Cochrana*					
Number of laboratories (pj) *Liczba laboratoriów* (p_j)	8	8	8	8	8
Straggler values *Wartości wątpliwe*	0.516	0.516	0.516	0.516	0.516
Outlier values *Wartości nietypowe*	0.615	0.615	0.615	0.615	0.615
[a]Straggler; [b]Outlier *[a]Wątpliwe; [b]Nietypowe*					

Table 6. Application of Grubb's test
Tabela 6. Zastosowanie testu Grubba

	Level *Poziom*				
	1	2	3	4	5
Grubbs' test statistics (single low) *Statystyki testu Grubba (pojedyncze niskie)*	–	0.540	1.750	2.102	1.569
Grubbs' test statistics (single high) *Statystyki testu Grubba (pojedyncze wysokie)*	–	2.340[b]	1.250	0.625	0.713
Single Grubbs' critical values *Pojedyncze wartości krytyczne wg Grubba*					
Number of laboratories (p_j) *Liczba laboratoriów* (p_j)	8	8	8	8	8
Straggler values Wartości wątpliwe	2.126	2.126	2.126	2.126	2.126
Outlier values Wartości nietypowe	2.274	2.274	2.274	2.274	2.274
[a]Straggler; [b]Outlier *[a]Wątpliwe; [b]Nietypowe*					

Table 7. Collation of all test result data. EN 12722 (100ºC) Direct light source
Tabela 7. Porównanie wszystkich wyników badań. EN 12722 (100ºC) Źródło światła bezpośredniego

Laboratory *Laboratorium*	Level *Poziom*				
	1	2	3	4	5
A	5 5 5	1 1 1	5 5 5	4 4 4	5 5 5
B	5 5 5	1 1 1	5 5 5	5 5 5	5 5 5
C	5 5 5	1 1 1	5 5 5	5 5 5	5 5 5
D					
E					
F	5 5 5	2 2 2	4 4 4	5 5 5	5 5 5
G	5 5 -	2 2 2	4 4 4	5 5 -	5 5 -
H	5 5 5	1 1 1	4 4 4	3 3 3	5 5 5

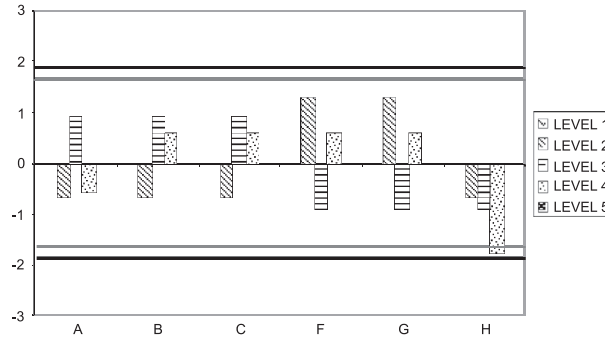

Fig. 3. Mandel's h plot EN 12722 Direct light
Rys. 3. Wykres h Mandela EN 12722 Światło bezpośrednie

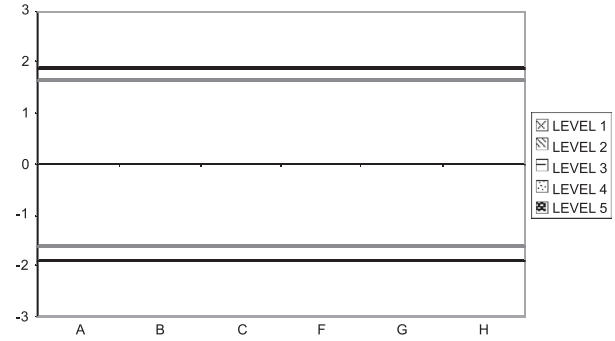

Fig. 4. Mandel's k plot EN 12722 Direct light
Rys. 4. Wykres k Mandela EN 12722 Światło bezpośrednie

Table 8. Application of Cochran's test
Tabela 8. Zastosowanie testu Cochrana

	Level *Poziom*				
	1	2	3	4	5
Cochran's C test statistics *Statystyki testu Cochana*	–	–	–	–	–
Cochran's critical values *Wartości krytyczne wg Cochrana*					
Number of laboratories (p_j) *Liczba laboratoriów* (p_j)	6	6	6	6	6
Straggler values *Wartości wątpliwe*	0.616	0.616	0.616	0.616	0.616
Outlier values *Wartości nietypowe*	0.722	0.722	0.722	0.722	0.722
[a]Straggler; [b]Outlier *[a]Wątpliwe; [b]Nietypowe*					

Table 9. Application of Grubb's test
Tabela 9. Zastosowanie testu Grubba

	Level *Poziom*				
	1	2	3	4	5
Grubbs' test statistics (single low) *Statystyki testu Grubba (pojedyncze niskie)*	–	0.645	0.913	1.927[a]	–
Grubbs' test statistics (single high) *Statystyki testu Grubba (pojedyncze wysokie)*	–	1.291	0.913	0.550	–
Single Grubbs' critical values *Pojedyncze wartości krytyczne wg Grubba*					
Number of laboratories (p_j) *Liczba laboratoriów* (p_j)	6	6	6	6	6
Straggler values *Wartości wątpliwe*	1.887	1.887	1.887	1.887	1.887
Outlier values *Wartości nietypowe*	1.973	1.973	1.973	1.973	1.973
[a]Straggler; [b]Outlier *[a]Wątpliwe; [b]Nietypowe*					

Table 10. Collation of all test result data. EN 12721 (70ºC) Diffuse light source
Tabela 10. Porównanie wszystkich wyników badań. EN 12721 (70ºC) Źródło światła rozproszonego

Laboratory *Laboratorium*	Level *Poziom*				
	1	2	3	4	5
A	2 2 2	2 2 2	4 4 4	3 3 3	5 5 5
B	1 1 1	2 2 2	4 4 4	4 4 4	5 5 5
C	1 1 1	2 2 2	4 4 4	3 3 3	5 5 5
D	4 4 4	4 4 4	4 4 4	5 5 5	5 5 5
E	1 1 1	2 2 2	5 4 4	3 3 3	5 5 5
F	2 2 2	1 1 -	4 4 4	5 4 4	5 5 5
G	1 1 -	2 2 2	4 4 4	5 5 -	5 5 -
H	2 2 2	2 2 2	3 3 3	3 3 3	5 5 5

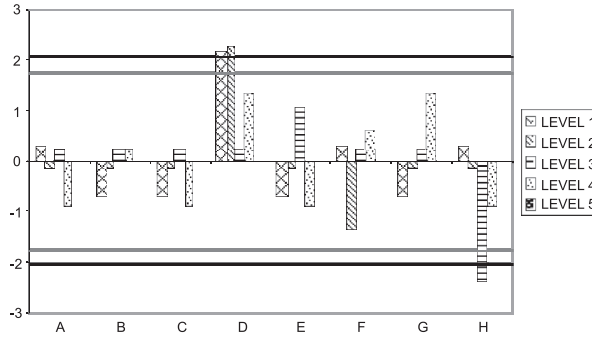

Fig. 5. Mandel's h plot EN 12721 Diffuse light
Rys. 5. Wykres h Mandela EN 12721 Światło rozproszone

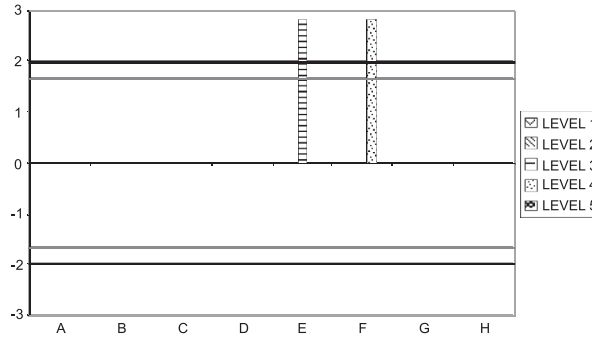

Fig. 6. Mandel's k plot EN 12721 Diffuse light
Rys. 6. Wykres k Mandela EN 12721 Światło rozproszone

Table 11. Application of Cochran's test
Tabela 11. Zastosowanie testu Cochrana

	Level *Poziom*				
	1	2	3	4	5
Cochran's C test statistics *Statystyki testu Cochrana*	–	–	1.000[b]	1.000[b]	–
Cochran's critical values *Wartości krytyczne wg Cochrana*					
Number of laboratories (p_j) *Liczba laboratoriów* (p_j)	8	8	8	8	8
Straggler values *Wartości wątpliwe*	0.516	0.516	0.516	0.516	0.516
Outlier values *Wartości nietypowe*	0.615	0.615	0.615	0.615	0.615
[a]Straggler; [b]Outlier *[a]Wątpliwe; [b]Nietypowe*					

Table 12. Application of Grubb's test
Tabela 12. Zastosowanie testu Grubba

	Level *Poziom*				
	1	2	3	4	5
Grubbs' test statistics (single low) *Statystyki testu Grubba (pojedyncze niskie)*	0.725	1.348	2.307[b]	0.955	–
Grubbs' test statistics (single high) *Statystyki testu Grubba (pojedyncze wysokie)*	2.174[a]	2.247[a]	0.903	1.337	–
Single Grubbs' critical values *Pojedyncze wartości krytyczne wg Grubba*					
Number of laboratories (p_j) *Liczba laboratoriów* (p_j)	8	8	8	8	8
Straggler values *Wartości wątpliwe*	2.126	2.126	2.126	2.126	2.126
Outlier values *Wartości nietypowe*	2.274	2.274	2.274	2.274	2.274
[a]Straggler; [b]Outlier *[a]Wątpliwe; [b]Nietypowe*					

Table 13. Collation of all test result data. EN 12721 (70°C) Direct light source
Tabela 13. Porównanie wszystkich wyników badań. EN 12721 (70°C) Źródło światła bezpośredniego

Laboratory *Laboratorium*	Level *Poziom*				
	1	2	3	4	5
A	2 2 2	3 3 3	5 5 5	3 3 3	5 5 5
B	1 1 1	2 2 2	3 3 3	3 3 3	5 5 5
C	1 1 1	2 2 2	4 4 4	4 4 4	5 5 5
D					
E					
F	2 2 2	1 1 –	4 4 4	5 5 5	5 5 5
G	1 1 –	2 2 2	4 4 4	5 5 –	5 5 –
H	2 2 2	2 2 2	3 3 3	3 3 3	5 5 5

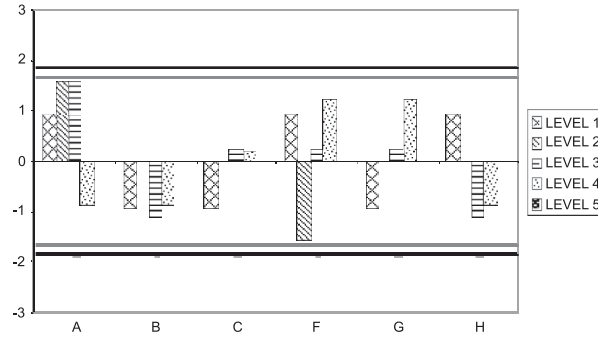

Fig. 7. Mandel's h plot EN 12721 Direct light
Rys. 7. Wykres h Mandela EN 12721 Światło bezpośrednie

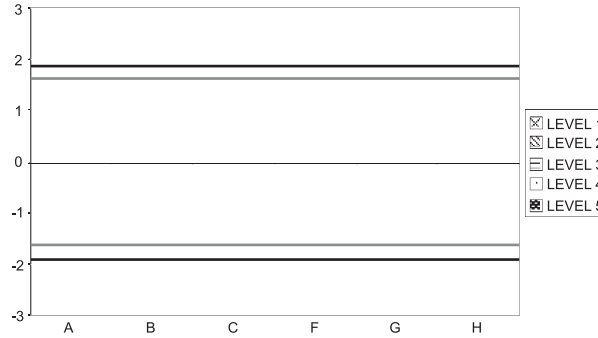

Fig. 8. Mandel's k plot EN 12721 Direct light
Rys. 8. Wykres k Mandela EN 12721 Światło bezpośrednie

Table 14. Application of Cochran's test
Tabela 14. Zastosowanie testu Cochrana

	Level *Poziom*				
	1	2	3	4	5
Cochran's C test statistics *Statystyki testu Cochrana*	–	–	–	–	–
Cochran's critical values *Wartości krytyczne wg Cochrana*					
Number of laboratories (p_j) *Liczba laboratoriów* (p_j)	6	6	6	6	6
Straggler values *Wartości wątpliwe*	0.616	0.616	0.616	0.616	0.616
Outlier values *Wartości nietypowe*	0.722	0.722	0.722	0.722	0.722
[a]Straggler; [b]Outlier *[a]Wątpliwe; [b]Nietypowe*					

Table 15. Application of Grubbs' test
Tabela 15. Zastosowanie testu Grubba

	Level *Poziom*				
	1	2	3	4	5
Grubbs' test statistics (single low) *Statystyki testu Grubba (pojedyncze niskie)*	0.913	1.581	1.107	1.044	–
Grubbs' test statistics (single high) *Statystyki testu Grubba (pojedyncze wysokie)*	0.913	1.581	1.550	1.167	–
Single Grubbs' critical values *Pojedyncze wartości krytyczne wg Grubba*					
Number of laboratories (p_j) *Liczba laboratoriów* (p_j)	6	6	6	6	6
Straggler values *Wartości wątpliwe*	1.887	1.887	1.887	1.887	1.887
Outlier values *Wartości nietypowe*	1.973	1.973	1.973	1.973	1.973
[a]Straggler; [b]Outlier *[a]Wątpliwe; [b]Nietypowe*					

Calculation of the general mean and variances

An outlier can be considered as a result which is sufficiently different from all other results to warrant further investigation. The ISO 5725-2 standard recommends confidence levels of 95% for outliers termed "stragglers" and 99% for outliers termed "statistical outliers".

When carrying out the outlier tests, it should be understood that outliers should not be discarded or rejected purely from a statistical point of view. In this round robin test it should be noticed that the Cochran's test and the Mandel's k test (used as a measure of within-laboratory consistency) reported some cell standard deviations as exceptionally large, when they only show one point of difference in the assessment of the three replicates tested by the same laboratory. Generally this is due to the different labs not exhibiting any difference in their results.

Taking into account that the measurements in both methods (EN 12721 and 12722) are calculated according to a categorization or a sorting scheme and divided into five categories. These consistency and outlier test results are not considered potential outliers.

When applying Mandel's h statistic or Grubbs' test (used to measure the between-laboratory consistency), any result which appeared to be an outlier is not included in the calculation of the overall mean and variances. Straggler values were retained in these calculations.

Dry heat resistance 100ºC Diffuse light source (EN 12722)

Table 16. Computed values of general mean and variances
Tabela 16. Obliczone wartości ogólnej średniej i wariancji

		Level *Poziom*					
		1	2*	2	3	4	5
Number of laboratories *Liczba laboratoriów*	p_j	8	8	7	8	8	8
General mean *Ogólna średnia*	$\hat{m}_j$	5.0	1.8	1.3	4.1	4.5	4.6
Repeatability variance *Wariancja powtarzalności*	s^2_{rj}	0.0	0.0	0.0	0.1	0.0	0.0
Between-laboratory variance *Wariancja pomiędzy laboratoriami*	s^2_{Lj}	0.0	1.9	0.2	0.4	0.6	0.3
Reproducibility variance *Wariancja odtwarzalności*	s^2_{Rj}	0.0	1.9	0.2	0.5	0.6	0.4
Repeatability std. dev. *Odchyl. stand. powtarzalności*	s_{rj}	0.0	0.0	0.0	0.3	0.0	0.2
Reproducibility std. dev. *Odchyl. stand. odtwarzalności*	s_{Rj}	0.0	1.4	0.5	0.7	0.8	0.6
Number of excluded outliers *Liczba wykluczonych wartości nietypowch*		0	0	1	0	0	0
Outlier laboratories *Laboratoria nietypowe*		–	–	Lab D	–	–	-

*Without discarding the statistical outlier values
**Bez odrzucania statystycznych wartości nietypowych*

The straggler values were retained as correct items and the statistical outliers were discarded. After the exclusion of outlier observations, the consistency and outlier tests were repeated on the remaining values, and no more outliers were detected. The remaining data were used for the calculation of the general mean and variances.

Dry heat resistance 100ºC Direct light source (EN 12722)

Table 17.Computed values of general mean and variances
Tabela 17. Obliczone wartości ogólnej średniej i wariancji

		Level *Poziom*				
		1	2	3	4	5
Number of laboratories *Liczba laboratoriów*	p_j	6	6	6	6	6
General mean *Ogólna średnia*	$\widehat{m}_j$	5.0	1.3	4.5	4.5	5
Repeatability variance *Wariancja powtarzalności*	s_{rj}^2	0.0	0.0	0.0	0.0	0.0
Between-laboratory variance *Wariancja pomiędzy laboratoriami*	s_{Lj}^2	0.0	0.3	0.3	0.7	0.0
Reproducibility variance *Wariancja odtwarzalności*	s_{Rj}^2	0.0	0.3	0.3	0.7	0.0
Repeatability std. dev. *Odchyl. stand. powtarzalności*	s_{rj}	0.0	0.0	0.0	0.0	0.0
Reproducibility std. dev. *Odchyl. stand. odtwarzalności*	s_{Rj}	0.0	0.5	0.5	0.9	0.0
Number of excluded outliers *Liczba wykluczonych wartości nietypowch*		0	0	0	0	0
Outlier laboratories *Laboratoria nietypowe*		–	–	–	–	–

Wet heat resistance 70ºC Diffuse light source (EN 12721)

Table 18.Computed values of general mean and variances
Tabela 18. Obliczone wartości ogólnej średniej i wariancji

		Level *Poziom*						
Laboratory *Laboratorium*		1*	1	2*	2	3**	4	5
Number of laboratories *Liczba laboratoriów*	p_j	8	7	8	7	8	8	8
General mean *Ogólna średnia*	$\widehat{m}_j$	1.8	1.5	2.2	1.9	3.9	3.7	5.0
Repeatability variance *Wariancja powtarzalności*	s_{rj}^2	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Between-laboratory variance *Wariancja pomiędzy laboratoriami*	s_{Lj}^2	1.1	0.3	0.7	0.1	0.1	0.8	0.0

Table 18.Continued
Tabela 18. Ciąg dalszy

Reproducibility variance *Wariancja odtwarzalności*	s^2_{Rj}	1.0	0.3	0.7	0.1	0.2	0.8	0.0
Repeatability std. dev. *Odchyl. stand. powtarzalności*	s_{rj}	0.0	0.0	0.0	0.0	0.2	0.2	0.0
Reproducibility std. dev. *Odchyl. stand. odtwarzalności*	s_{Rj}	1.0	0.5	0.8	0.3	0.4	0.9	0.0
Number of excluded outliers *Liczba wykluczonych wartości nietypowch*		0	1	0	1	0	0	0
Outlier laboratories *Laboratoria nietypowe*		–	Lab D	–	Lab D	–	–	–

*Without discarding the statistical outlier values
**Bez odrzucania statystycznych wartości nietypowych*
** The reason mentioned in the preceding paragraph is also used for not discarding any value in the case of the level 3, where in the first stage the tests indicated as outlier the results from laboratory H which differed only one point from the results from the rest of the laboratories
*** Powód wspomniany w poprzedzającym akapicie jest również powodem nie odrzucania żadnej wartości w przypadku poziomu 3., gdzie w pierwszym etapie testy wskazywały, że wyniki z laboratorium H odstawały od innych, chociaż różniły się one zaledwie jednym punktem od wyników z reszty laboratoriów*

The straggler values were retained as correct items and the statistical outliers were discarded. After exclusion of outlier observations shown in the wet heat resistance results, the consistency and outlier tests were repeated on the remaining values.

After repeating the consistency and outlier tests, no more statistical outliers were detected in the level 1. When repeating the tests with level 2, the results from laboratory F turned out to be outlier, but they were not considered nor rejected because they were the result of a difference of one point in the assessment scale.

Wet heat resistance 70ºC Direct light source (EN 12721)

Table 19. Computed values of general mean and variances
Tabela 19. Obliczone wartości ogólnej średniej i wariancji

		Level *Poziom*				
Laboratory *Laboratorium*		1	2	3	4	5
Number of laboratories *Liczba laboratoriów*	p_j	6	6	6	6	6
General mean *Ogólna średnia*	$\widehat{m}_j$	1.5	2.0	3.8	3.8	5.0

Table 19.Continued
Tabela 19. Ciąg dalszy

Repeatability variance *Wariancja powtarzalności*	s_{rj}^2	0.0	0.0	0.0	0.0	0.0
Between-laboratory variance *Wariancja pomiędzy laboratoriami*	s_{Lj}^2	0.3	0.4	0.6	0.9	0.0
Reproducibility variance *Wariancja odtwarzalności*	s_{Rj}^2	0.3	0.4	0.6	0.9	0.0
Repeatability std. dev. *Odchyl. stand. powtarzalności*	s_{rj}	0.0	0.0	0.0	0.0	0.0
Reproducibility std. dev. *Odchyl. stand. odtwarzalności*	s_{Rj}	0.5	0.6	0.8	1.0	0.0
Number of excluded outliers *Liczba wykluczonych wartości nietypowch*		0	0	0	0	0
Outlier laboratories *Laboratoria nietypowe*		–	–	–	–	–

According to the standard, there should be one observer, and in case of doubt, three. Due to the nature of this study and the problems which arise from having a number of observers at several of the centres, the number of observers involved in each laboratory was determined by each centre.

Diffuse/Direct light comparison

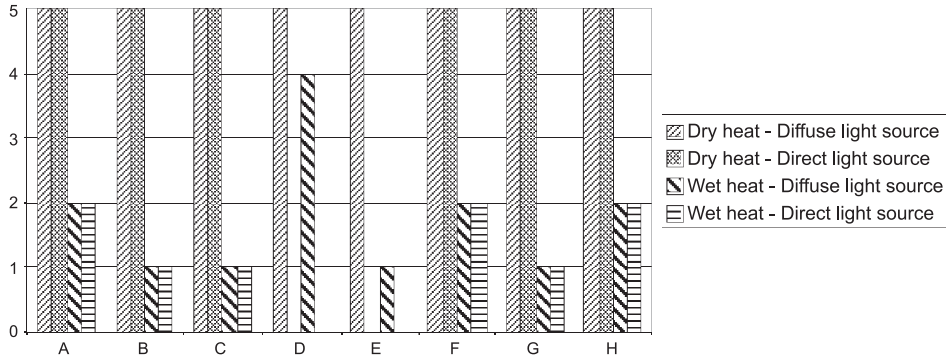

Fig. 9. Diffuse/Direct light comparison for level 1
Rys. 9. Porównanie światła rozproszonego/bezpośredniego dla poziomu 1

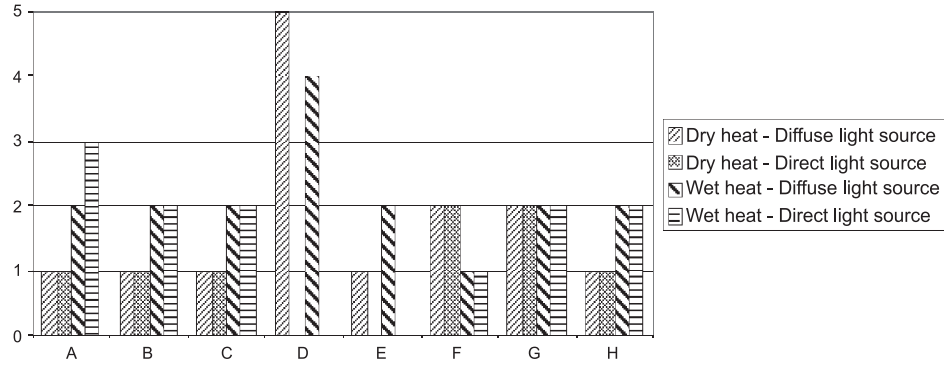

Fig. 10. Diffuse/Direct light comparison for level 2
Rys. 10. Porównanie światła rozproszonego/bezpośredniego dla poziomu 2

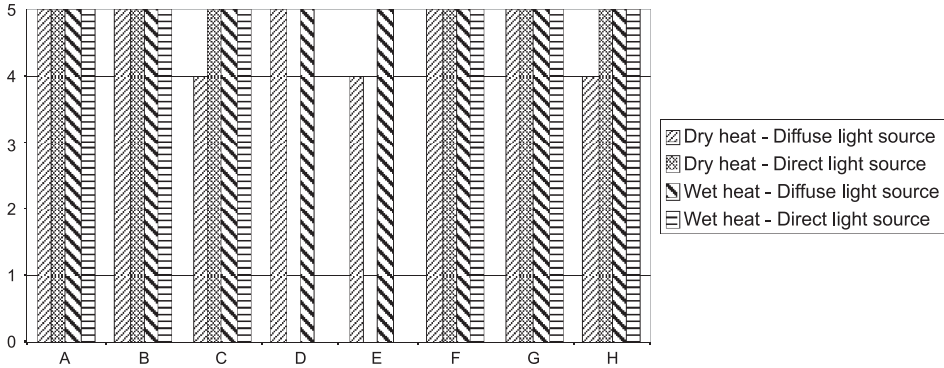

Fig. 11. Diffuse/Direct light comparison for level 3
Rys. 11. Porównanie światła rozproszonego/bezpośredniego dla poziomu 3

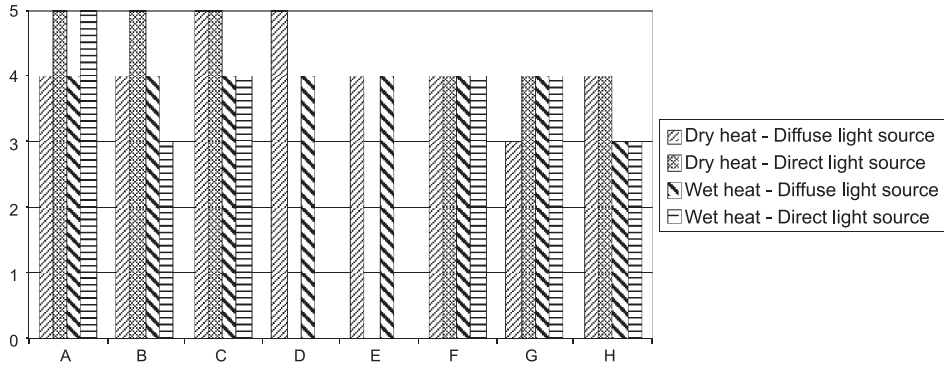

Fig. 12. Diffuse/Direct light comparison for level 4
Rys. 12. Porównanie światła rozproszonego/bezpośredniego dla poziomu 4

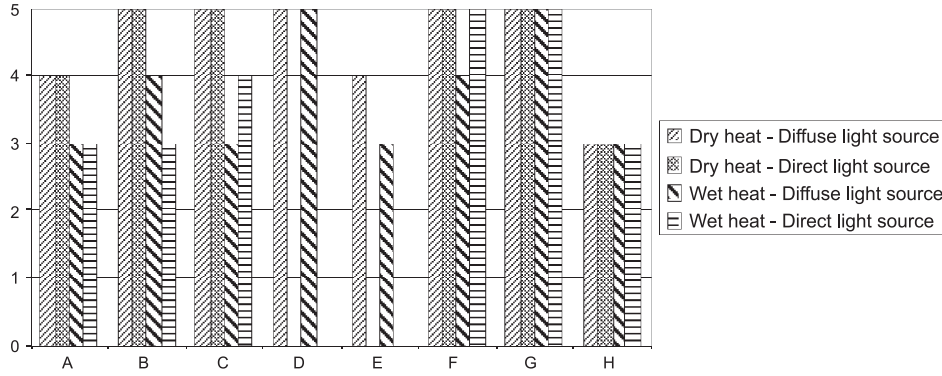

Fig. 13. Diffuse/Direct light comparison for level 5
Rys. 13. Porównanie światła rozproszonego/bezpośredniego dla poziomu 5

Conclusions

With reference to the source light used in the assessment, it could be observed that the effects on the test surfaces were more easily appreciated when the diffuse light was used, except for one laboratory. This is shown in fig. 10 to 14.

In Mandel's h graphs the respective hij values are plotted for each cell grouped for all levels and examined by each laboratory. The horizontal lines on the plots are an indicator for Mandel's h at the 5% (black line) and 1% (grey line) significance level. These indicator lines serve as guides when examining patterns in the data.

As could be observed, all the laboratories have both positive and negative values at different levels of the experiments, but laboratory D exhibits a pattern of results that are markedly different form the other laboratories in the study. Their results stands out on the h plot as always having positive values in the assessment of the dry and wet heat resistance of the surfaces. Therefore it means that its results are usually higher than the average values. Moreover, individual extreme values are reported by laboratory D with the EN 12722 (level 2) and with EN 12721 (levels 1 and 2).

Some precautions have to be taken when the statistical outlier tests are carried out. When the within-laboratory variability is analysed, sometimes a cell standard deviation, that only shows one point of difference in the assessment of the three replicates tested by the same laboratory. is shown in the tests to be a statistical outlier due to the fact that generally the labs do not exhibit any difference in their own results.

In the same way, when scrutinizing between-laboratory variability, when all the laboratories present the same cell average except one, which differs only by one point it appears also as a statistical outlier. In these cases, and bearing in mind that the measurements in both methods (EN 12721 and 12722) are made accor-

ding to a rating code divided into five categories with one point as an increment of the assessment. These consistency and outlier test results are not considered.

From the calculation of variances, it could be concluded that the repeatability variance is nearly 0, while the between-laboratory variance is between 0 and 1. Subsequently, the reproducibility variance also has values from 0 to 1 depending on the level tested.

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List of standards

EN 12721:2009 Furniture Assessment of surface resistance to wet heat

EN 12722:2009 Furniture Assessment of surface resistance to dry heat

ISO 5725-2:1994 Accuracy (trueness and precision) of measurement methods and results. Part 2: Basic method for the determination of repeatability and reproducibility of a standard measurement method

ASTM E 691-99. Standard Practice for Conducting an Interlaboratory Study to Determine the Precision of a Test Method

POWTARZALNOŚĆ I ODTWARZALNOŚĆ BADAŃ ODPORNOŚCI NA CIEPŁO SUCHE I MOKRE WEDŁUG NORM EN 12721 AND EN 12722

Streszczenie

Normy europejskie 12721 i 12722 określają metodę oceny odporności powierzchni meblowych na mokre i suche ciepło. Celem badań jest ustalenie danych dotyczących precyzji oby rodzajów badań w celu umieszczenia tych informacji w normach i sprawozdaniach z badań opartych na tych normach. Zamierza się dokonać pomiarów powtarzalności i odtwarzalności wyników międzynarodowego badania round-robin przeprowadzonego

przez osiem laboratoriów, które specjalizują się w badaniu powierzchni, zgodnie z normą ISO 5725-2. Zaprezentowane wyniki wskazują, że wariancja powtarzalności jest bliska 0, natomiast wariancja pomiędzy laboratoriami mieści się w przedziale 0 i 1, zgodnie z porządkiem wzrostu kodów oceny.

Słowa kluczowe: suche ciepło, mokre ciepło, powtarzalność, odtwarzalność, test roun-robin