Laboratory qualification for verification procedures – learning from ATLETE project

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Abstract
Verification of the compliance of products under the energy label and ecodesign regulation is essential to ensure a level playing field on the market and the achievement of the expected savings in energy and other resources. In Europe this is the national market surveillance authorities' (MSA) task, which will normally ask a competent testing laboratory to do the relevant measurements when it comes to verify any declared data. But doing those tests is not a simple task and errors may occur, even if the laboratory is accredited. How can MSAs reduce the risk of issuing false verdicts of wrong declaration, based on errors in the underlying measurements?

ATLETE (Appliance Testing for Energy Label & Evaluation) is a European funded project which organized the verification of washing machines (ATLETE II) on a European wide scale. In case of ATLETE II 50 washing machine models taken from the market were measured and assessed in six qualified laboratories. The following parameters were tested: energy consumption, water consumption, washing performance, spinning performance, spin speed, load capacity, power consumption and duration of off-mode and left-on mode, ecodesign minimum requirements, product specific requirements and information requirements In summary, the results of the testing campaign carried out on 50 washing machine models by 6 different EU laboratories, all selected through a well proved and transparent methodology, are a 100 % compliance rate with the energy efficiency class and energy consumption declarations for the Energy Label but only a 38 % compliance rate for the ecodesign-requested information to be provided in the booklet of instructions.

All in all, more 62 datasets of measurement data on 50 washing machine models (four machines were tested on four samples) are available from ATLETE II which is a unique chance to evaluate the process capability of the individual laboratory as well as the overall repeatability of the measurement system (together with the product variation) looking for statistical quality control measures. Knowing these measures, testing laboratories and MSAs may have to tool to check the quality of the measurements done and thus get confidence in the actions they are supposed to take. This paper describes the problem and discusses in detail a series of solutions.

Introduction
ATLETE (Appliance Testing for Energy Label & Evaluation)[1] is a European funded project which organized the verification of refrigerators and freezers (ATLETE I) and washing machines (ATLETE II) on a European wide scale. In case of ATLETE II 50 washing machine models taken from the market were measured and assessed in six qualified laboratories. All in all, 62 datasets of measurement data on 50 washing machine models are available from ATLETE II (four machines were tested on four samples) which is a unique chance to evaluate the process capability of the individual laboratory as well as the overall repeatability of the measurement system (together with the product variation) looking for statistical quality control measures.

The main objective of this EU funded project was to check the compliance of washing machines with the relevant provi-

1. Grant agreement no. IEE/11/022/SI2.615922 – Intelligent Energy – Europe (IEE): Energy Efficiency (SAVE) www.atlete.eu.

Table 1. Measured parameters and given verification tolerances.

Measured parameter	Relevant for		Unit	Verification tolerance
	ecodesign	labelling		
Annual energy consumption	✓	✓	kWh	+10 %
Energy consumption	✓	✓	kWh	Step 1: +10 % / Step 2: +6 %
Programme time	✓	✓	min	+10 %
Water consumption	✓	✓	litre	+10 %
Remaining moisture content		✓	%	+10 %
Spin speed		✓	rpm	-10 %
Power consumption in off-mode P0 and left-on mode Pl	✓	✓	W	if >1 W: +10 % if ≤1 W: +0,10 W
Duration of the left-on mode	✓	✓	min	+10 %
Airborne acoustical noise		✓	dB(A) re 1 pW	measured value shall meet the rated value
Washing efficiency index	✓			-4 %

The harmonized standard EN 60456: 2011 has been applied by the selected laboratories.

sions of EU energy labelling and ecodesign legislation. In order to do this, specific models were chosen for testing via a transparent selection process involving all known manufacturers and conducted by a notary. Appliances were selected on the basis of the company's market share and the product's availability in specific markets.

The following parameters were tested: energy consumption, water consumption, washing performance, spinning performance, spin speed, load capacity, power consumption and duration of off-mode and left-on mode, ecodesign minimum requirements, product specific requirements and information requirements (see below).

The laboratory tests were conducted on the parameters in Table 1 and showed if the differences between the declared product information and the measured information were within the authorised verification tolerances. Additionally following generic documentation requirements were checked.

Energy labelling (EU 1061/2010):

- presence of energy label in the washing machine unit(s) to be tested
- presence of the product fiche, in the unit(s) to be tested or delivered by the supplier upon request, and of the mandatory declarations & in the requested order.

Ecodesign generic requirements (2009/125/EC) (different deadlines).

Generic requirements about the washing machine:

- presence and identification of the 20 °C cycle
- identification of "standard programmes" on the machine front.

Information in the booklet of instructions:

- indication of the standard programmes and of their performance
- power consumption of the off-mode and left-on mode
- recommendations on detergents use
- indicative information for the main washing programmes (duration, moisture content, energy and water consumption).

Results were communicated to the individual company responsible for each washing machine model, to market surveillance Authorities where the appliances were available, and were then made fully publicly available (http://www.atlete.eu/2/).

In summary, the results of the testing campaign carried out on 50 washing machine models by 6 different EU laboratories, all selected through a transparent methodology, are:

- 100 % compliance rate with the energy efficiency class and energy consumption declarations for the Energy Label;
- 100 % compliance rate with energy and water consumption ecodesign minimum requirements;
- 92 % overall compliance rate for functional performance class and parameters;
- 84 % overall compliance of the product fiche and ecodesign-requested information availability and proper format;
- 64 % compliance with the requirement to indicate the standard programme on the machine;
- 38 % compliance rate for the ecodesign-requested information to be provided in the booklet of instructions;

- 30 % overall compliance rate when including all individual parameters.

Additionally of testing these 50 models in qualified laboratories ATLETE II had the target to build up capacity of qualified testing laboratories in Europe. This was done by organising a round-robin test with five additional laboratories and analysing the results to see how consistent the testing of these laboratories was compared with those qualified laboratories. Analysing the statistical relative combined standard deviation of the measurement results provided by these laboratories allowed to use a new approach to assess the testing consistency. The task was then to see if this approach could be applied to the results of the main tests of the ATLETE II project and to elaborate how much this could contribute to testing quality and verification in general. Knowing these measures, testing laboratories and MSAs may have a tool to check the quality of the measurements done and thus get confidence in the actions they are supposed to take.

Material and Methods

The energy labelling[2] and ecodesign[3] requirements for household washing machines ask for testing of washing machines according to harmonised European measurement standards.

In brief, the testing procedure as laid out in this standard EN 60456:2011 defines a precise measurement procedure of how to load a washing machine using well-defined textiles (white cotton items only: sheets, pillow cases and towels; The partial load is half of the nominal load or rated capacity) under well-controlled conditions (ambient, water, voltage, frequency) together with well-specified test swatches with five different stain monitors and using a well-defined powder detergent. The amount of textiles, test swatches and detergent are depending on the rated capacity of the washing machine to be tested. For each washing machine tested, data from 7 test runs are available. They belong to three treatments:

- 2 × cotton 40 °C at half load (abbreviated as 40½)
- 2 × cotton 60 °C at half load (abbreviated as 60½)
- 3 × cotton 60 °C at full load (abbreviated as 60).

It is required that the results from these 7 test runs are then averaged to yield a single test result. No measurement of the real temperature in the load is done. After having done a washing process, the test monitors are evaluated by measuring the colour of remaining stains by a spectral photometer. The averaged sum of remaining stains values is then compared to the results achieved by a washing process done under similar conditions and in parallel to the machine under test in a reference washing system. This usage of a reference system allows to leverage uncontrollable factors of the whole test, like for example batch to batch variations of the stain monitors or the detergent. In parallel to the washing process all consumption values (water, energy, time) are recorded and the weighted average of all seven cycles is calculated. At the end of the spinning process the final humidity is determined by comparing the amount of water retained in the load with the conditioned weight of the load. Additionally the spinning speed is recorded during the spinning process and analysed afterwards to determine the maximum spin speed as the highest spin speed determined during a period of 60 s. Left-on mode power and energy consumption measurements shall be made for one run per treatment. The measurement shall be started after the end of the programme. Power measurements for the left-on and off-modes shall be in accordance with the requirements of EN 62301.

The following equation describes how the average value shall be calculated for each performance parameter. In addition a statistical analysis is carried out calculating the absolute and relative combined standard deviation of all 7 test runs for each measured value x.

The average value per treatment $\bar{x}$ is calculated as follows:

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

where
x_i is the value for each test run of the treatment;
n is the number of test runs per treatment.

The standard deviation per treatment s_x is calculated as follows:

$$s_x = \sqrt{\sum_{i=1}^{n} \frac{(x_i - \bar{x})^2}{n-1}} \tag{2}$$

where
$\bar{x}$ is the average value per treatment;
x_i is the value for each test run of the treatment;
n is the number of test runs per treatment.

The sum of squared residuals per treatment r_x is calculated as follows:

$$r_x = \sum_{i=1}^{n} (x_i - \bar{x})^2 \tag{3}$$

where
$\bar{x}$ is the average value per treatment;
x_i is the value for each test run of the treatment;
n is the number of test runs per treatment.

The weighted mean per test series Y_x is calculated as follows:

$$Y_x = (2 \times \bar{x}_{40½} + 2 \times \bar{x}_{60½} + 3 \times \bar{x}_{60}) / 7 \tag{4}$$

where
$x_{40½,60½,60}$ is the average value per treatment.
2,3,7 is the number of runs.

The standard deviation per test series Std_{yx} is calculated as follows:

$$Std_{y_x} = \sqrt{\frac{1}{4}(r_{40½} + r_{60½} + r_{60})} \tag{5}$$

where
$r_{40½,60½,60}$ is the sum of squared residuals per treatment;
4 is the degree of freedom (number of runs minus number of treatments).

2. Commission Delegated Regulation (EU) No 1061/2010.

3. Commission Regulation (EU) No 1015/2010.

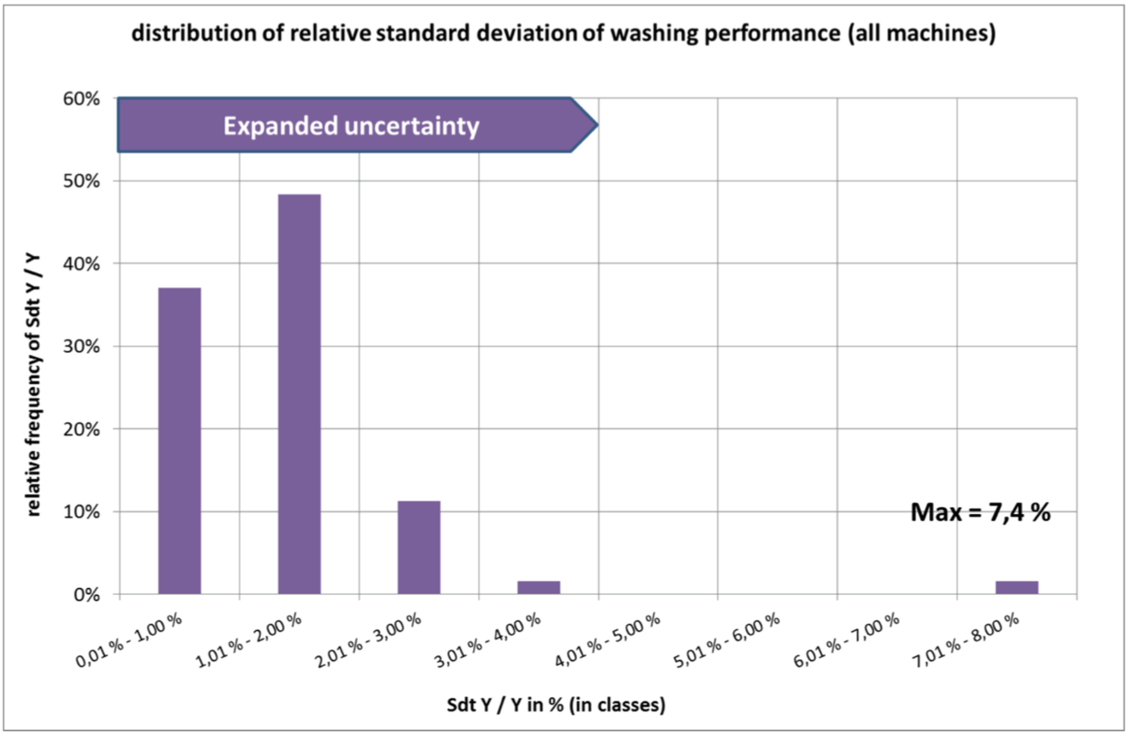

Figure 1. Relative standard deviation of the washing performance of all tested 62 washing machines compared to the expanded uncertainty as given in TR 62617. The value given as 'Max =' is the maximum found.

The relative standard deviation y_x is calculated as

$$y_x = Std_{y_x} / Y_x \qquad (6)$$

and expressed in per cent (%).

This calculation allows to compare the relative uncertainty of the measured result independent of the absolute size of the result and thus to compare the results from different machines on the same scale.

This relative standard deviation depends on the repeatability of the machine itself in performing the 7 test runs at three different testing conditions (treatments), but also on the accuracy and repeatability of the testing as done in the individual laboratory and the reproducibility of the measurement standard in different laboratories. Concerning the latter factor, IEC SC 59D has published in the technical report TR 62617 values for the reproducibility of the measurement standard IEC 60456 4th ed. in terms of 'expanded uncertainties'[4]. These 'expanded uncertainties' define the range (at a 95 % confidence interval) where the average measured result of a test may be found when the measurement is re-done on the same machine at any other laboratory following the defined measurement standard. So comparing the relative standard deviation of the test of each of those 62 washing machines with the expanded uncertainty of a specific measurement result allows assessing the repeatability of the machine cycle itself and the accuracy and repeatability of the testing in the specific laboratory. However it is not possible to find out which of those factors may have caused a too high relative uncertainty. One will need to look on each individual test result to track down where inconsistencies are coming from.

4. There are many books and articles about statistics of measurement uncertainty. For example: https://www.wmo.int/pages/prog/gcos/documents/gruanmanuals/UK_NPL/mgpg11.pdf

Results

The result of our analysis is presented for washing performance, metered electrical energy, program time, water consumption and spinning efficiency.

For washing performance, the relative standard deviations of all machines tested (Figure 1) is mainly concentrated in the range of up to 2 %. The expanded uncertainty for the measured washing performance if done following IEC 60456 4th ed. is at 4 %. As the measurement of the washing performance according to EN60456 is different (three different treatments for the test machine in EN60456 compared to one treatment with five repetitions in IEC 60456) a higher uncertainty would have been no surprise. The highest relative standard deviation is found to be at 7.4 %.

Regarding total electrical energy consumption metered (Figure 2) during the test, the expanded uncertainty is at 10 %. Within this range almost all machines are found. Just two machines were found to have a higher relative standard deviation during the tests. Programme duration is found to be accurately measured within 4 % relative standard deviations (Figure 3), but a few are found to be outside with the maximum at 17,9 %.

For total water consumption again most machines are measured within a relative standard deviation of just 5 % as the expanded uncertainty suggests, but there are eight machines measured which exceed the expanded uncertainty with a maximum deviation of 26.3 %.

The question may be raised if these extreme values of the relative standard deviations are perhaps correlated and occur on only a few (bad) washing machines or incompetent laboratories.

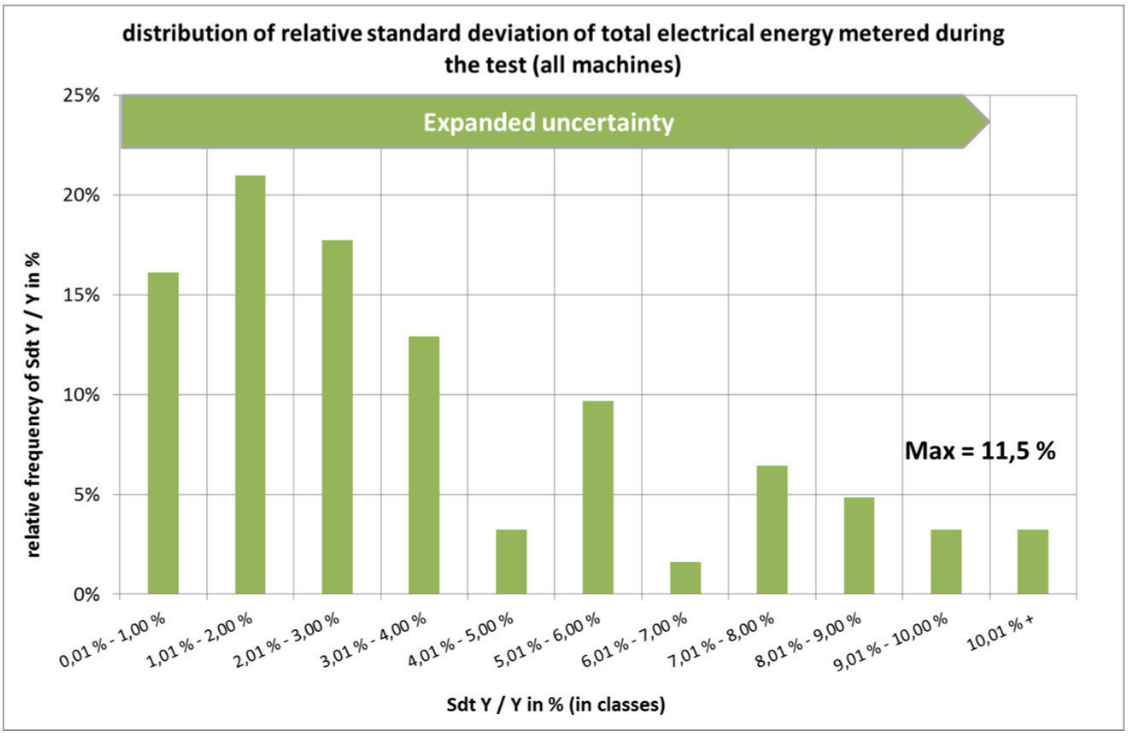

Figure 2. Relative standard deviation of the total energy consumption of all tested 62 washing machines compared to the expanded uncertainty as given in TR 62617. The value given as 'Max =' is the maximum found.

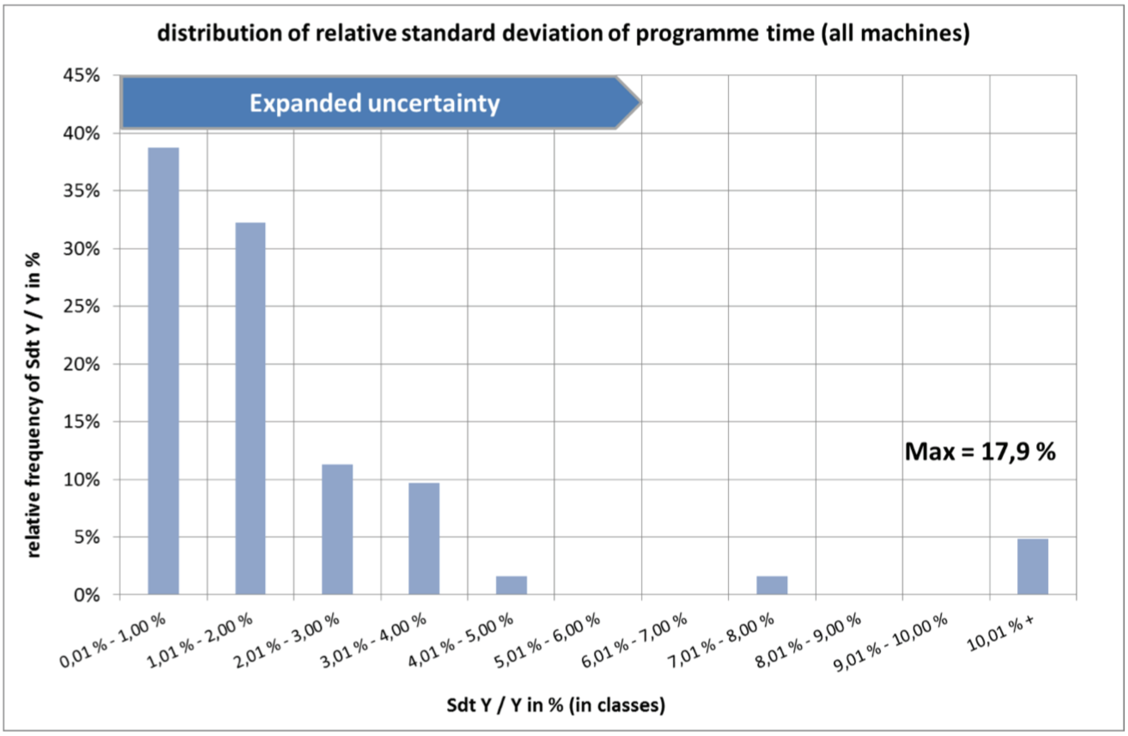

Figure 3. Relative standard deviation of the programme time of all tested 62 washing machines compared to the expanded uncertainty as given in TR 62617. The value given as 'Max =' is the maximum found.

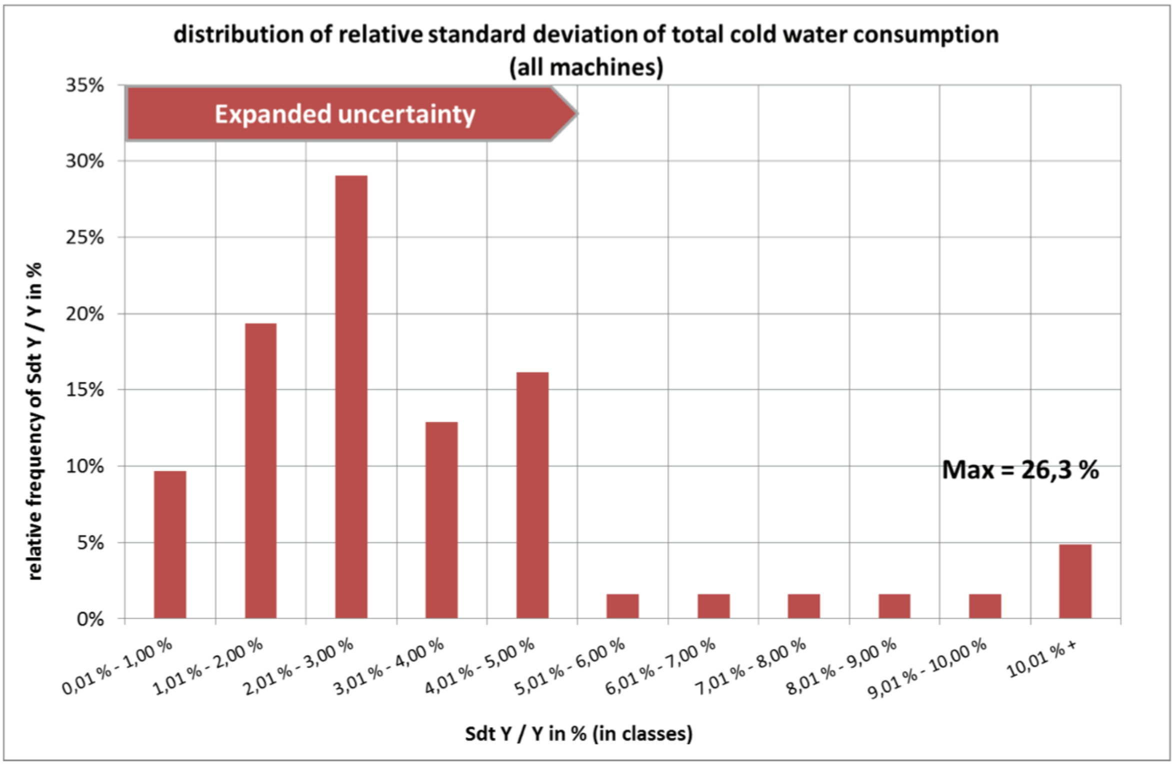

Figure 4. Relative standard deviation of the total water consumption of all tested 62 washing machines compared to the expanded uncertainty as given in TR 62617. The value given as 'Max =' is the maximum found.

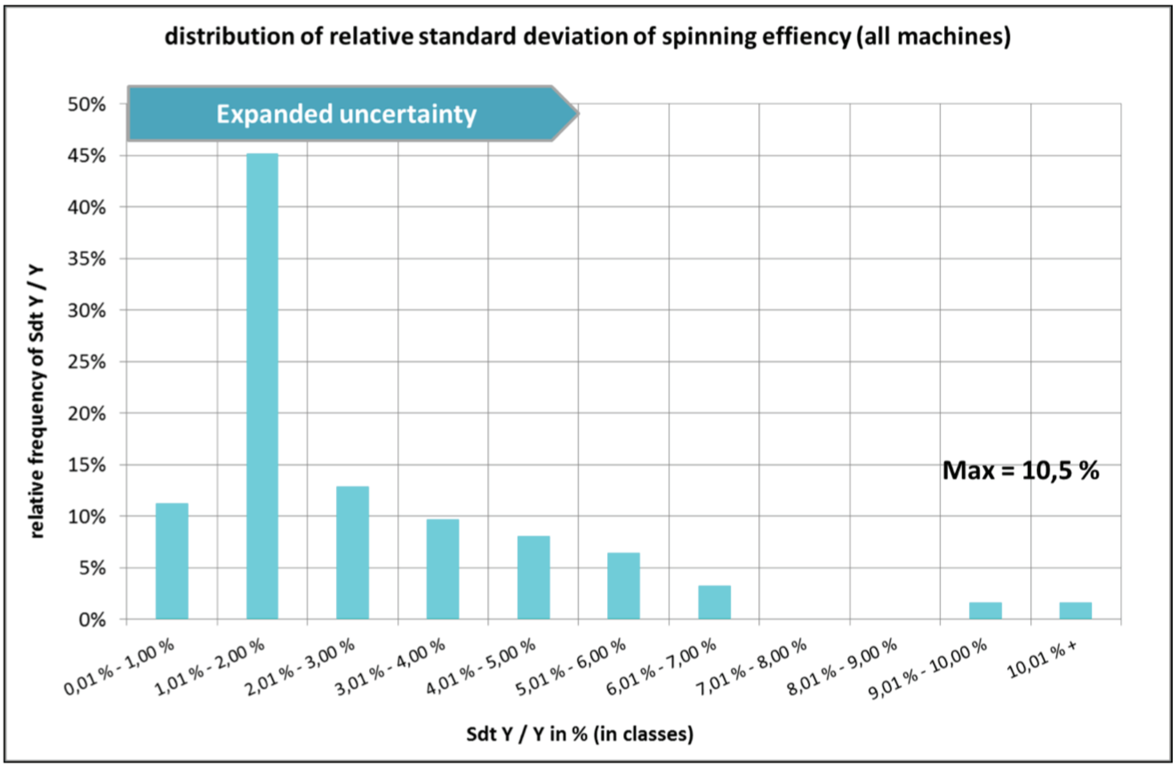

Figure 5. Relative standard deviation of the spinning efficiency (remaining moisture content) of all tested 62 washing machines compared to the expanded uncertainty as given in TR 62617. The value given as 'Max =' is the maximum found.

Table 2. List of all relative standard deviations for all 62 tested washing machines sorted per laboratory performing the test with highlighting of large standard deviations.

Machines	Laboratory	no.	Cold water consumption during main wash	Total cold water consumption	Total electrical energy metered during the test	Main wash duration	Programme time	Spin speed	Spinning efficiency	Washing Performance
1	Lab F	1	1,4%	1,8%	2,3%	0,3%	0,2%	0,1%	3,2%	1,3%
2	Lab F	2	1,2%	3,0%	0,8%	0,0%	0,4%	0,2%	1,3%	0,9%
3	Lab F	3	0,7%	1,2%	1,6%	2,4%	2,8%	0,1%	1,5%	0,7%
4	Lab F	4	4,4%	2,8%	1,3%	1,6%	2,5%	0,0%	1,4%	0,9%
5	Lab F	5	3,7%	1,2%	2,5%	1,8%	1,3%	0,0%	1,4%	0,9%
6	Lab F	6	0,4%	0,2%	1,0%	0,2%	0,3%	1,0%	3,3%	1,9%
7	Lab F	7	4,7%	2,8%	1,6%	0,4%	0,6%	0,0%	1,5%	1,3%
8	Lab F	8	5,0%	3,2%	2,2%	0,9%	1,8%	0,1%	1,8%	0,8%
9	Lab F	9	1,4%	26,3%	7,8%	3,0%	3,5%	0,9%	2,0%	0,7%
10	Lab F	10	5,7%	5,7%	9,6%	0,4%	0,5%	0,1%	2,8%	0,9%
11	Lab G	1	1,3%	1,2%	1,7%	0,6%	0,5%	0,7%	1,4%	1,7%
12	Lab G	2	3,0%	2,5%	8,2%	0,6%	0,3%	1,6%	2,7%	1,3%
13	Lab G	3	3,5%	4,5%	3,2%	1,2%	1,0%	9,1%	4,2%	0,6%
14	Lab G	4	1,5%	2,2%	0,9%	0,4%	0,3%	9,8%	4,2%	1,1%
15	Lab G	5	1,3%	2,5%	0,7%	0,2%	0,3%	1,4%	1,8%	1,5%
16	Lab G	6	1,0%	1,8%	0,2%	0,3%	0,1%	0,1%	1,1%	0,4%
17	Lab G	7	2,4%	4,3%	2,2%	0,4%	2,2%	9,0%	5,2%	1,4%
18	Lab G	8	2,4%	1,5%	2,5%	0,8%	1,5%	1,2%	1,6%	1,5%
19	Lab G	9	2,7%	9,1%	1,5%	1,0%	1,1%	0,2%	1,1%	1,2%
20	Lab G	10	3,2%	1,6%	3,4%	0,5%	0,7%	1,7%	3,9%	1,7%
21	Lab G	11	2,5%	1,6%	5,7%	2,8%	4,0%	19,6%	9,8%	0,6%
22	Lab G	12	3,5%	2,8%	0,5%	0,2%	0,4%	0,0%	1,2%	0,9%
23	Lab G	13	4,1%	1,1%	3,2%	0,4%	1,1%	0,1%	1,1%	1,2%
24	Lab H	1	6,2%	2,1%	8,8%	2,2%	2,9%	5,4%	6,1%	1,3%
25	Lab H	2	3,4%	1,9%	1,6%	0,3%	0,8%	0,0%	1,0%	1,0%
26	Lab H	3	2,8%	2,7%	3,9%	1,6%	1,5%	3,6%	2,3%	1,9%
27	Lab H	4	3,8%	3,2%	4,0%	2,7%	1,7%	0,4%	1,4%	2,6%
28	Lab H	5	7,4%	4,5%	5,6%	2,0%	3,9%	8,4%	3,8%	2,1%
29	Lab H	6	5,4%	0,8%	5,7%	1,4%	1,7%	0,0%	1,6%	2,8%
30	Lab H	7	4,3%	2,6%	4,0%	0,0%	0,5%	1,8%	5,4%	1,5%
31	Lab H	8	0,3%	1,0%	2,0%	0,4%	0,4%	0,1%	3,0%	1,2%
32	Lab H	9	3,6%	2,5%	0,8%	0,9%	1,2%	0,0%	0,9%	1,2%
33	Lab H	10	5,0%	2,3%	6,1%	2,1%	1,7%	0,2%	1,8%	1,9%
34	Lab H	11	1,4%	3,2%	2,3%	1,7%	2,0%	0,1%	1,2%	1,4%
35	Lab H	12	2,9%	3,6%	2,7%	0,7%	2,1%	1,7%	1,5%	1,0%
36	Lab H	13	3,4%	4,0%	5,8%	1,2%	1,2%	0,1%	0,8%	1,7%
37	Lab H	14	3,2%	2,6%	7,8%	2,1%	1,4%	11,2%	4,8%	3,1%
38	Lab H	15	2,5%	3,9%	8,0%	1,9%	1,3%	0,1%	0,5%	1,9%
39	Lab H	16	2,4%	2,1%	0,7%	0,7%	1,0%	0,0%	2,8%	2,2%
40	Lab I	1	1,0%	2,5%	4,4%	1,0%	0,7%	0,3%	0,8%	0,6%
41	Lab I	2	2,7%	17,2%	1,5%	1,4%	17,9%	0,2%	3,5%	0,7%
42	Lab I	3	7,3%	4,2%	5,8%	2,0%	2,8%	0,5%	10,5%	1,1%
43	Lab I	4	7,8%	7,3%	11,0%	16,6%	15,2%	0,6%	4,3%	2,9%
44	Lab I	5	1,1%	2,9%	1,3%	4,5%	4,1%	1,3%	5,5%	1,1%
45	Lab I	6	4,9%	4,7%	1,6%	4,4%	3,9%	0,2%	1,5%	0,8%
46	Lab I	7	3,4%	1,1%	3,5%	4,7%	1,9%	0,4%	0,4%	1,0%
47	Lab J	1	0,5%	0,3%	1,6%	0,0%	0,2%	0,1%	1,0%	0,9%
48	Lab J	2	2,7%	1,7%	4,3%	0,6%	1,1%	2,3%	6,9%	0,8%
49	Lab J	3	4,5%	4,4%	1,1%	0,6%	0,9%	0,1%	3,0%	1,2%
50	Lab J	4	1,8%	0,8%	0,3%	0,4%	1,0%	2,6%	1,6%	0,9%
51	Lab J	5	1,8%	4,9%	2,2%	0,4%	0,7%	1,4%	1,1%	0,9%
52	Lab J	6	4,1%	10,2%	2,1%	0,0%	0,3%	1,8%	2,1%	0,7%
53	Lab J	7	3,3%	2,3%	2,5%	1,7%	1,8%	0,1%	1,4%	1,1%
54	Lab K	1	6,6%	8,1%	11,5%	15,7%	10,1%	0,1%	4,1%	7,4%
55	Lab K	2	10,3%	2,3%	9,2%	2,2%	1,4%	0,2%	1,8%	1,9%
56	Lab K	3	1,2%	3,8%	1,9%	1,8%	2,8%	0,1%	1,8%	1,3%
57	Lab K	4	4,4%	6,7%	5,7%	0,6%	0,7%	0,1%	2,7%	1,0%
58	Lab K	5	2,5%	4,6%	7,1%	1,4%	8,0%	0,7%	5,8%	2,9%
59	Lab K	6	2,4%	4,0%	1,8%	3,5%	3,9%	0,0%	1,6%	2,3%
60	Lab K	7	7,3%	4,1%	7,6%	0,0%	0,5%	0,6%	2,4%	1,0%
61	Lab K	8	3,4%	4,5%	1,0%	0,4%	0,4%	1,5%	0,8%	1,0%
62	Lab K	9	0,3%	0,2%	3,6%	1,3%	3,2%	5,3%	1,2%	1,5%

Looking on all individual results (Table 2) it is clear that 16 out of 62 tested machines are tested with high relative standard deviations. In only 4 of those cases more than one of the measured parameters is found to be critical outside standard values. Not shown is the fact that those conspicuous machines are not those machines which had been tested in four units as the first sample was found to be outside of the tolerance given by the regulation.

Discussion and recommendations

There are many possible reasons why the relative standard deviation of a test is higher than expected or as given by the reproducibility (expanded uncertainty) figure:

- The washing machine operation is not the same from one to the other cycle, although the operating conditions are the same. This may come from imprecise sensors, like thermostats or water level controls. Also software modifying program structures based on fuzzy signals may cause a variable program execution.
- Operation conditions may be variable, like ambient conditions (mainly temperature of the inlet water and the machine itself), testing conditions (mainly conditions of the textile load), etc. … If all these parameters are within the conditions as specified in the measurement standard, their influence should be not more than the one given in the expanded uncertainty. If they are outside, the testing is not done according to the conditions as defined by the measurement standard.
- Mistakes in the measurement itself. There are many possibilities to do something wrong. Some of them are:
  - Chose a wrong program (e.g. cotton 40 °C instead of cotton 60 °C or a regular program).
  - Use a wrong amount of detergent or leave one of the three detergent components out. Note that for each rated capacity of the machine and for full and half load operation, a different amount of detergent needs to be prepared out of three basis components.
  - Mismatch the textile load, which needs to be well treated to have a specific age and needs to be split following a defined allocation for the half load cycles.
- Mistakes in the analysis or allocation of the measurement results to the specific treatment.
- Typing errors.

For some of those deviations it may be possible to find explanations when looking at the gathered data in more detail. For example a mistake in the detergent may be assumed if all the program parameters are the same, but just the washing performance is lower or higher. If the program data are different for one of the cycles of a treatment, but match very well to the data of the other treatments, it may be assumed that the wrong cycle was chosen.

Overall, this exercise on this unique set of data yields to our following recommendations for further discussion:

- The relative standard deviations as calculated according to EN60456 are additional values which can be easily calculated from each test of a washing machine.
- High relative standard deviations may indicate that something was wrong – either with the machine or the testing or just a typo!
- Laboratories should indicate the relative standard deviation and compare to the expanded uncertainties given in the standards for internal control of their measurements.
- When relative standard deviations are found to be as high as the expanded uncertainty all of the testing shall be carefully checked and – when no obvious reasons is found – a warning shall be added to the test report.
- Market Surveillance Authorities should request the calculation of the relative standard deviations and comparison to the expanded uncertainties when ordering tests from test laboratories.
- Market Surveillance Authorities should be careful when trusting results even from qualified laboratories.
- Standardisation should include the calculation of relative standard deviations and provide the expanded uncertainty value in their measurement standards.
- Standardisation should work on updating their measurement standards towards reducing uncertainties where deemed necessary and appropriate. This is valid for all product groups.
- Legislation should respect the uncertainty of the measurement when setting verification tolerances.

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