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Durability assessment of products: analysis and testing of washing machines

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ABSTRACT

Designing more durable products is a key strategy of the Circular Economy to save materials and reduce the amount of waste to handle at the End of Life of the product. However, the design of more durable products needs to be supported by methods for assessing and verifying durability aspects. Although internal protocols are typically implemented by manufacturers, also depending on their business strategy, there is a lack of standardised methods allowing the comparison of products on the market.

The overall objective of this study is to improve the technical background related to the assessment and verification of the durability of products. General principles for the technical assessment of the durability of products have been developed and applied in this study to the analysis of household washing machines (referred to as washing machines):

1. Durability aspects associated to the use of washing machines and existing testing methods are reviewed;
2. A testing procedure for assessing and verifying the durability of washing machines is further developed;
3. The procedure is applied to two models of washing machines on the market, and the results analysed;
4. Lesson learnt and recommendations are provided for further improvement and application of assessment guidance and testing procedure.

The methodological steps applied in this study successfully allowed:

- Understanding the durability needs of the product, and identify technical problems which can disrupt the delivery of key functions;
- Analysing stress conditions, design aspects and misuses that could produce failures of key parts and loss of function(s)/sub-function(s) during the operation of the product;
- Identifying key aspects and/or correction measures to avoid / delay possible failures during the lifetime of the product and thus increasing its longevity;
- Developing further knowledge about how to assess and verify the durability of the product.

The approach could be tailored and applied to other products for which a durability assessment has to be carried out, for regulatory or research purposes. Moreover, this knowledge can also feed the ongoing discussion held at CEN/CENELEC JTC10 under Mandate 543 and which will lead to the development of a general method for the assessment of the durability of energy-related products.

The output of the analysis of washing machines was in particular oriented to the improvement of a procedure for testing the durability of the product. As lesson learnt it was recognised that the testing procedure should:

- Focus on the testing of the entire product under conditions closer to real life operations (the use of a fixed unbalance is avoided; stresses due to washing and rinsing cycles are integrated);
- Reduce the length of the testing (by applying Accelerating Life Testing);
- Cover mechanical and thermal stresses, as main cause of damages, as well as functionality aspects as loss of performance (washing performance parameters are monitored).

Moreover, a balance has to be sought between the desirable lifetime target for the testing procedure (e.g. the average lifetime of the product) and a practical length that can be applicable for verification purposes.

This complex task resulted in a series of test cycles which impose realistic thermal and mechanical stresses to washing machines and which are executed many times mimicking

a specific lifetime period of the device in a shorter period of time. The procedure was executed in a trial with two washing machines for a simulated usage period of two years. The coverage of the first two years of use of washing machines can allow identifying early failures, malfunctioning and loss of performance in worst performing products, as well as any potential sources of failures. This could be potentially suitable for Ecodesign purposes. The testing of a representative lifetime of 12 years could instead require about 6 times the time and resources required by the application of this procedure.

The procedure has appeared to be suitable for laboratory testing and to be realistic in the sense that the induced stresses caused thermal and mechanical wears and tears typically found in washing machines during their lifetime.

As follow-up of this study, it is recommended to apply the testing procedure to a larger sample of devices and for longer periods of time, to understand if and how the functional performance is decreasing after the first 2 years of use of washing machines, as well as if and when minor problems encountered during the operation of the device could become major failures. This would help understanding better what makes sense to monitor and how long in the procedure, especially if this is intended to be applied in the future for regulatory purposes. Further developments should address the monitoring of noises and of possible movements of the machine. Alignment with the final output of the ongoing revision of the Commission Regulation (EU) No 1015/2010 and of the Commission Regulation (EU) No 1061/2010 (and related standards) should be moreover sought.

However, it should be noted that, in practice, the testing procedure has already taken a considerable amount of time (in total 697 h for one person for two washing machines in parallel). If this were to be refined and applied for verification / monitoring purposes, this is deemed too long and ways to shorten the testing time would be needed. The saving of time could be alternatively invested to test the product for a duration representative of longer lifetimes and/or tracking the functional performance along different moments of the lifetime.

INTRODUCTION

Depletion of materials and production of waste tend to decrease when the lifetime of a product is increased[1]. Designing more durable products can thus be a key strategy to save materials and reduce the amount of waste to handle at the End of Life. However, the design of more durable products needs to be supported by methods for assessing and verifying durability aspects. Although internal protocols are typically implemented by manufacturers, also depending on their business strategy, there is a lack of standardised methods allowing the comparison of products on the market.

The lifetime of a product can be differentiated between (Alfieri et al. 2018):

- Technical lifetime, which is the time span or number of usage cycles for which a product is considered to function as required, under defined conditions of use, until a technical failure occurs.
- Functional lifetime, which is the time a product is used until the requirements of the user are no longer met due to the economics of operation, maintenance and repair or obsolescence.

Durability can be thus defined as the ability to function as required over time under defined conditions of use, maintenance and repair until a limiting state is reached. Differentiation between first and successive uses can also be made.

In this context, general principles for the technical assessment of the durability of Energy-related Products were developed by Alfieri et al. (2018) with the aim to:

1. Understand the durability needs of products, and identify technical problems which can disrupt the delivery of key functions;
2. Analyse stress conditions, design aspects and misuses that could produce failures of key parts and loss of function(s)/sub-function(s) during the normal and/or special conditions of operation of products;
3. Identify key aspects and/or correction measures to avoid / delay possible failures during the lifetime and thus increase the longevity of products and parts[2];
4. Develop further knowledge about how to assess and verify the durability of products.

The guidance has been applied in this study to the analysis of household washing machines (referred to as washing machines in the report). The study is structured in four parts:

1. Durability aspects associated to the use of washing machines and existing testing methods are reviewed;
2. A testing procedure for assessing and verifying the durability of washing machines is further developed;
3. The procedure is applied to two models of washing machines on the market, and the results analysed;
4. Lesson learnt and recommendations are provided for further improvement and application of assessment guidance and testing procedure.

The overall objective of this study is to improve the technical background related to the assessment and verification of the durability of products. It should be observed that the lifetime target is not fixed and that its definition can vary depending on the product and on the scope of the analysis (e.g. to demonstrate a satisfactorily long lifetime of the product; to verify the occurrence of early failures in worst-performing products on the

[1] This is generally the case when an increase of lifetime is not associated to design choices or repair/refurbishment operations requiring a significant addition of materials. Trade-offs among different material efficiency aspects could otherwise occur.

[2] Fixing a failure is instead the objective of what could be defined as reparability strategy

market). This requires the availability of appropriate testing procedures that can find use in practice.

The analysis of washing machines builds on a former study published in 2017 (Tecchio et al. 2017) and aims to gather additional learning about how the durability testing of the product should be carried out.

1. REVIEW OF DURABILITY ASPECTS ASSOCIATED TO THE USE OF WASHING MACHINES AND EXISTING TESTING METHODS

The first part of the analysis consists in the review of durability aspects associated to the use of the product and on existing testing methods, and is based on the following steps:

1. Definition of main functions, sub-functions and conditions of use potentially affecting the durability of the product;
2. Description of typical lifetimes and durability expectations;
3. Analysis of the frequency of (single and multiple) failure modes and impacted parts/functions;
4. Discussion on stress conditions and degradation mechanisms potentially leading to failures of key parts and loss of functionalities;
5. Definition of key design aspects and maintenance needs to avoid or postpone faults and increase the longevity of products;
6. Review of existing practices for testing the durability of washing machines.

1.1 Main functions and sub-functions and conditions of use affecting the durability

The standard prEN 45552:2018 "General method for the assessment of the durability of energy-related products", under development by CEN/CENELEC TC10[3], emphasises the need to analyse the functions of a product as a basis for a durability assessment.

Functional analysis methodologies can be potentially applied in order to define the product system (EN 12973; EN 16271). Functional analysis enables the acquisition of a representative knowledge of the objective of the product under study with regard to user related functions. Main functions and sub-functions of the product are defined.

Functional aspects of washing machines are discussed in the Preparatory Study for the revision of "Ecodesign and Energy Label for household washing machines and household washer-dryers" (Boyano et al. 2017). The primary function of a washing machine is to clean, rinse and spin clothes. Terpstra (2001) defines the primary objective of cleaning as "…restoration of the fitness for use and the esthetical properties of the textiles, e.g. removal of soil, stains, odours and creases and regaining surface smoothness and thermal isolation".

1.1.1 General principles of functioning

1.1.1.1 Washing and drying process

Laundry washing can be defined as both the removal and the dissolution of water-soluble impurities (Boyano et al. 2017). This is a complex process involving the cooperative interaction of physical and chemical factors: washing temperature, chemistry (types, ingredients and amounts of detergent), time (length of washing cycles), and applied mechanical work. It is generally described by using a circle referred to as the "Sinner's Circle" (Sinner 1960), as presented in Figure 1. A fifth parameter, water (inner circle), has been added which represents the combining element of all factors.

[3] https://www.cenelec.eu/dyn/www/f?p=104:7:1299206399119101::::FSP_ORG_ID:2240017 (accessed on 1 October 2018)

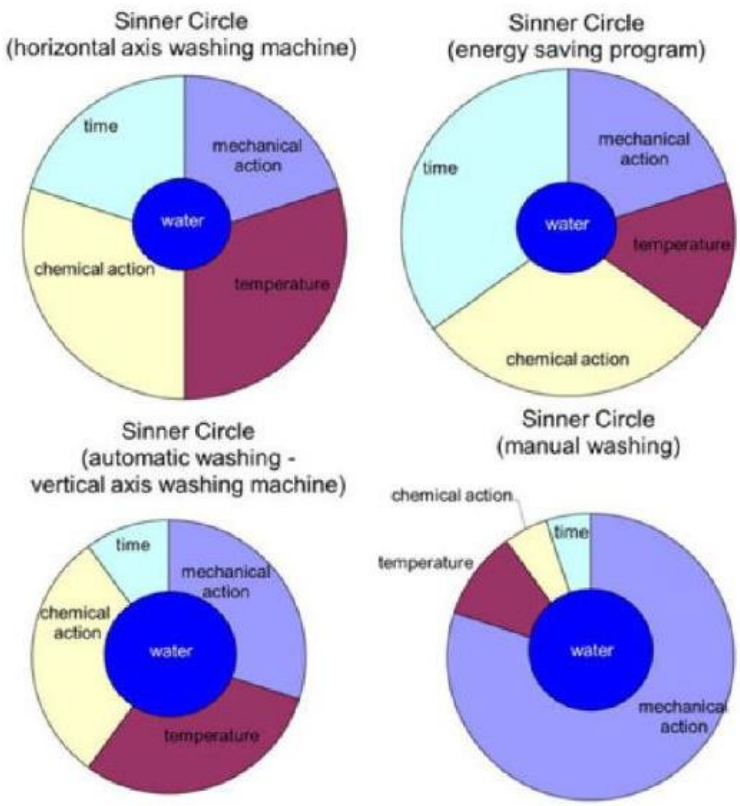

Figure 1: Sinner`s Circle; source: (Sinner 1960) cited in (A.I.S.E. 2013)

Factors depend on each other to achieve the same washing result (i.e. the same washing performance): a reduction in one factor has to be compensated by an increase in the others. The combination of different factors depends on the washing technique employed. For example, in the case of laundry washing by hand, the contribution of mechanics is much higher than that of time. The use of higher temperatures in washing machines can result in a more important contribution of temperature to the washing process.

After the washing process, clothes have to be dried. The washing process in a washing machine already includes the spin drying process, which mechanically reduces the residual moisture content. Depending on the spin-drying efficiency, different levels of residual moisture content remain in the clothes which afterwards have to be removed, essentially by evaporation. Clothes can be dried further either on a clothes line or in a dryer, which may require the forced transport of energy to evaporate water from the laundry (Boyano et al. 2017).

1.1.1.2 Phases of the washing cycle

The typical phases of a washing cycle are (Boyano et al. 2017):

- Pre-rinse: offered as additional option, it is carried out without detergents for taking out all kinds of loosely bound soils;
- Main wash: depending of the chosen programme, it is carried out with different water levels and wash rhythms (from sensitive or hand-wash to intensive)
- Main Rinses: 2 to 4 rinse phases and different water levels; an additional rinse is carried out when, for example, there is too much foam in the drum;
- Spinning: final spinning us applied in all programmes for water extraction; an interim spinning phase can be present additionally depending on the selected programme;

- Anti-crease: At the end of every programme, with exceptions like the wool programme, the drum usually continues to turn at intervals for up to 30 minutes to help prevent creasing (also known as wrinkling). The door can be opened to remove the laundry at any time during the anti-crease phase.

1.1.1.3 Washing programmes

The different programmes of a washing machine mainly differ in temperature cycle and maximum temperatures reached, levels of water and energy consumption, intensity of wash rhythms, number of rinses, length of different phases, number of spinning cycles and their speed. The panorama of washing programmes is broad and various; examples are: Cotton 20 °C / Cold wash; Cotton 30 °C; Cotton 40 °C; Cotton 60 °C; Cotton 90 °C; Synthetic / Easy care 30°C; Synthetic / Easy care 40°C; Standard cotton 40°C (Eco); Standard cotton 60°C (Eco); Quick wash / Short; Wool / Hand wash; Mix / automatic (all fabrics); Other wash programmes.

1.1.1.4 Dosage of detergents

The optimal dosing load depends on numerous factors such as water hardness, degree of soiling, type of textile, textile load and machine dimension. Both over and under-dosage may result in lower washing performance and a negative impact on the environment. In case of over-dosage both water and detergent are wasted; in case of under-dosage laundry washing has to be repeated.

Therefore, an easy and precise detergent dosing is needed. In this regard, for example, automatic detergent dosage technologies have been recently introduced on the market (Boyano et al. 2017).

1.1.1.5 Temperature and hygiene

The temperatures indicated in care labels of clothes are maximum temperatures at which textiles can be washed. However, it is not necessary to reach these temperatures to remove soiling (Boyano et al. 2017).

The application of high washing temperatures for a certain minimum time (e.g. 60 °C for 40 minutes according to A.I.S.E (2013)), and the use of a heavy duty powder detergent with bleach, would be recommendable for hygiene reasons in the treatment of clothes which can come into contact with elderly people and persons with a vulnerable health condition, or of clothes soiled with faeces, vomit, blood, body fluids, or by pets.

In general, the use of low temperature programmes would demand high temperature maintenance cycles from time to time to avoid contamination of appliances with biofilms causing malodours, e.g. 60 °C washes using a general-purpose powder detergent every month (A.I.S.E 2013).

Some manufacturers already offer special programmes (e.g. anti-mite option, anti-allergy options, and hygiene or machine cleaning programmes) that promise to effectively reduce microbes and allergens in the laundry and/or biofilms in the machine (Boyano et al. 2017)

1.1.1.6 Definition of key functions

Based on the information described in this section, the main functions and sub-functions of a washing machine have been classified by the authors of this report in different categories:

1. Primary functions: to clean, rinse and spin clothes (declared as "washable") without damaging textiles from an aesthetic and hygienic point of view[4]
2. Secondary functions[5]:

[4] And in alignment with existing legislation and measurement standards (EN 60456)

- Efficient use of resources (water, energy, detergent, time);
- Ensure longevity of textiles and durability of washing machine;
- User-friendliness.

To fulfil these functions, washing machines consist of several parts which work together in so called "programmes", usually defined by a garment/textile type and a maximum permitted temperature (as indicated by the care label). Programmes and/or options are also available which provide specific actions (e.g. spinning, extra rinsing).

In Europe, main parts included in almost any type of washing machine to fulfil primary and secondary functions are: drum & tub, motor, tachogenerator, drive belt/pulley, heater & thermostats, pressure chamber, level control, shock absorbers, bearings, hose (inlet/outlet), aquastop system, valves, detergent drawer, door (handle/hinge/lock/seal), gasket, drain pump and electronics (control/engine/IO).

[5] Secondary functions are defined in prEN 45552 as a breakdown of aspects that contribute to enable, supplement or enhance this process. In this context, functions that are needed to enable the process are considered implicitly in the definition of primary function (e.g. water pumping, water heating, detergent loading, drum spinning, water sealing)

1.2 Lifetimes and durability expectations

The assessment of the durability of a product needs the preliminary understanding of how relevant is to extend its lifetime. This can be based on technical and behavioural aspects (e.g. time of use, consumer's expectations), as well as on other environmental and economic aspects (e.g. life cycle impacts, cost of products (Alfieri et al. 2018).

1.2.1 Time of occurrence of failures

It is generally possible to identify different phases during which failures can occur (Wilker 2010):

- Phase I: Early failures, which can be caused by construction and production errors, faulty software, material defects, or defective components received from suppliers. Frequent early failures are an indication of inadequate quality control.
- Phase II: Random failures, which occur during the characteristic useful life and are attributable to maintenance and operational errors, or to mechanical effects, e.g. vibrations.
- Phase III: Wear-out failures, which occur in the late life of a product and are attributable to material ageing and fatigue. The maximum period of use of a product is determined by the shortest-lived component.

These phases are represented in a so-called bath tub curve (see Figure 2). The x-axis shows the lifespan and the y-axis shows the failure rate. The bath-tub curve describes the failure rate for the entire product population, so that it is not possible to use the graph to predict the failure behaviour of an individual product.

When designing product for a theoretically optimised duration, the aim would be to concentrate failures of parts in Phase III. Strategies to extend the duration of a product target this transition point by delaying the occurrence of wear-out failures, but focus also on measures to enable and enhance repair and upgrade operations.

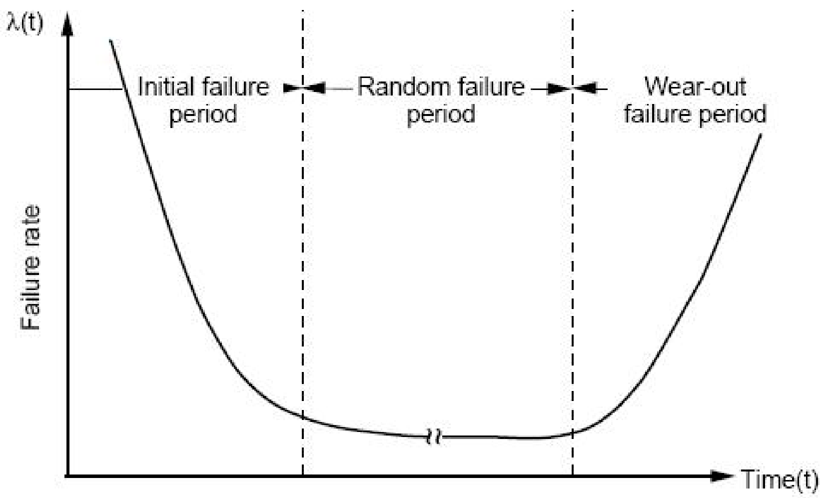

Figure 2: Bath-tub curve of failures (Weibull distribution)[6]

1.2.2 Typical lifetime

The lifetime of a product is a parameter, typically expressed as number of years (or using different units of measure as the number of cycles or the hours of operation), and which

[6] Source: http://www.sdram-technology.info/SEMICONDUCTOR-RELIABILITY.html (Accessed on 1 October 2018)

can serve to orient designers, researchers and policy makers. This depends on many factors, such as stress, abrasion stock, maintenance, technological change, fashion, shift in values and other external environmental influences (Prakash et al., 2016).

Typical lifetimes and durability expectations for washing machines have been investigated and discussed recently in the literature. Key findings are described hereafter.

Information about lifetime and durability of products can be obtained from different sources (Prakash et al. 2016):

- Internet forums and social media: the subjective experience of each individual reflects the different conditions under which they use a product, potentially leading to spread results regarding the lifespan of appliances.
- Consumer portals and campaigns: attempts are made with advertising and commercial marketing activities to stimulate purchase impulses and to serve real or perceived needs; consumer information portals and awareness-raising campaigns (e.g. by NGOs) attempt to introduce more transparency.
- Product tests: product tests are regularly carried out by manufacturers and consumer testing organisations. In the latter case, durability assessment is not carried out systematically for all product groups. When endurance tests are carried out, consumer testing organisations usually assess "only" whether appliances work for a specified minimum period (and not how much longer appliances would continue to function).
- Official depreciation tables: in company accounting, it is important to know the expected lifetime of products in order to calculate the mean annual rate of depreciation of investment assets.
- Waste management sector: in the waste management sector, knowing the lifetime of products plays an important role when assessing future amounts of waste and providing suitable waste disposal capacity. For example, lifetimes can be quantified by means of the Distribution Delay Method. Sales of products are linked to the probability of their becoming unusable over the years after the product first came onto the market. The probability of failure over time is estimated using a Weibull distribution function.

Estimations about the lifetime of electrical and electronic equipment vary considerably. This is due to different surveying and calculation methods, but also geographical, socio-economic and cultural aspects can play a role, as well as the considered years. Table 1 presents an overview of lifetime data for washing machines from different sources (Prakash et al. 2016).

Table 1: Average lifetime of washing machines from different studies and surveys; Source: Prakash et al. (2016)

Lifetime (years)	Country	Method of data survey	Source (*)
9	UK	Survey in households	Cooper 2005
9	China	Annual figures based on official statistical data from China	Yang et al. 2008
12	China	Based on sales figures for 2005	Eugster et al. 2007
12.1 (2000) 11.7 (2005)	Netherlands	Weibull distribution	Wang et al. 2013 Bakker et al. 2014
12 (CAMA) 14 (USDOE) 16-20 (SHEU)	Canada	Supply data, market information and consumer studies, survey in households	Young 2008
14	Greece	Survey in households and electrical retailers	Karagiannidis et al. 2005

(*) Full references reported in Prakash et al. (2016)

1.2.3 Reasons and time of disposal

Hennies and Stamminger (2016) carried out a survey in Germany to investigate the reasons of consumer behind the replacement of different appliances. For washing machines, it was found that 69% of the interviewed consumers discarded the products because of a defect. 10% of consumers instead considered that the resource efficiency was not satisfying, while 2% were not satisfied with the number of functions. The washing machine was no longer liked by another 1%.

Moreover, it was found that the age of discarded washing-machines varied from 1 to 40 years, with an average of 12 years. However, an arithmetic mean over 40 years is probably biased by outliers. The analysis of percentiles can be instructive: 50% of discarded washing machines were less than 10 years old. Nevertheless, there are many washing-machines which do not reach a lifespan of 5 years (almost 20%); whilst about 5% of washing machines were older than 25 years. The lifetime was observed to increase with the cost of the appliance. Interestingly, 56% of consumers seemed satisfied with the lifetime of their washing machines (corresponding to an average lifetime of 13 years or more). Another 12% were partially satisfied, having experienced an average lifetime of 11 years.

Based on the results of a market study conducted by GfK in Germany (Prakash et al. 2016), the average first use of large household washing machines has apparently declined slightly between 2004 and 2012 from 12.7 years to 11.9 years. However, consumers seem on average willing to use their washing machines for a longer period (about 13 years) (see Table 2).

Table 2: Average time of first use of washing machines and large household appliances; Source: Prakash et al. (2016)

Appliance	**Survey period (pool of interviewed users)**	**Mean first use in years depending on reason for replacement**			
		All reasons (the old appliance broke / was faulty or unreliable / wanted a better appliance)	**The old appliance broke**	**The old appliance was faulty / unreliable**	**The old appliance still worked, but I/we wanted a better one**
All large household appliances	2004 (n= 2712)	14.1	13.5	14.6	15.0
	2008 (n= 3380)	14.4	13.9	13.9	16.2
	2012/2013 (n=5664)	13.0	12.5	13.8	13.6
Washing machines	2004 (n=882)	12.7	12.5	13.2	13.1
	2008 (n=1077)	12.4	12.6	10.8	13.3
	2012/2013 (n=1600)	11.9	11.6	13.2	13.2

1.2.4 Influence of product price on durability

As indicated in Hennies and Stamminger (2016), the lifetime of washing machines in Germany increase with the cost of the appliance. This affirmation is supported by the analysis of information about the durability of washing machines provide by Stiftung Warentest (2013). Stiftung Warentest published data for washing machines for the period 2003-2012. Washing machines costing less than 550 € were three times more prone to fail than the appliances costing 700 € or more. The gap could be still greater since washing machines of less than 350 € were not included in the analysis.

Figure 3: Correlation of lifespan and price for washing machines; Source: Stiftung Warentest (2013)

Note:

1. y-axis: Cumulative failures (%)
2. x-axis: time of use (years)
3. Kaufpreis = Purchase price (< 550 €; 550–700 €, > 700 €)
4. Period of study: 2003-2012

1.2.5 Environmental implications

Tecchio et al. (2016) have conducted a parametric LCA of a washing machine to analyse the environmental consequences (impacts or benefits) resulting from an extension of the lifetime of a device beyond an average lifetime expectancy of 12.5 years.

Three impact categories were assessed:

1. Freshwater eutrophication: limited environmental benefits (about 0.2%) were calculated in case of prolonging the lifetime of the analysed washing machine. Freshwater eutrophication is in fact influenced mainly by the impacts due to the detergent used during the use phase.
2. Climate change (measured as GWP): prolonging the lifetime of the analysed washing machines was found to be environmentally beneficial in the large majority of the considered scenarios. However, this would not be the case if the energy efficiency of new products on the market were significantly higher.
3. Abiotic depletion of elements (mainly influenced by materials used during the production phase): prolonging the lifetime of the analysed washing machines was always beneficial and considerable.

1.2.6 Summary

About 70% of replacements of washing machines are due to a fault or defect in the existing appliance.

The average first use of washing machines in Germany has apparently declined slightly between 2004 and 2012 from 12.7 years to 11.9 years. However, it was found that 50% of replaced washing machines are less than 10 years old and that 20% are less than 5 years. The average consumer could be instead willing to use a washing machine for a longer period (about 13 years).

The lifetime of washing machines increase with the purchase price of the appliance: low-end products seem to be more prone to failure than high-end products.

An increase of the durability of washing machines could also be beneficial for the environment.

The background information gathered shows that durability of washing machines is an important issue, especially to avoid premature replacements of the product.

1.3 Frequency of failure modes, impacted functions and parts

Functions and parts of a product can be subject to failures, which can compromise the functioning of the overall product and limiting its lifetime. An analysis of the frequency of failure modes is needed to understand which are the impacted functions and parts, and which limiting states should be removed or delayed (EN 60812).

The frequency of failure modes and the impacted parts/functions have been investigated in several studies, as summarised by Tecchio et al. (2017).

Most recurring failure modes affected: electronics (including control electronics, control panels, program selectors, relays, line filters, etc.), shock absorbers and bearings, doors (including seals, handles, hinges and locks) and motor (carbon brushes).

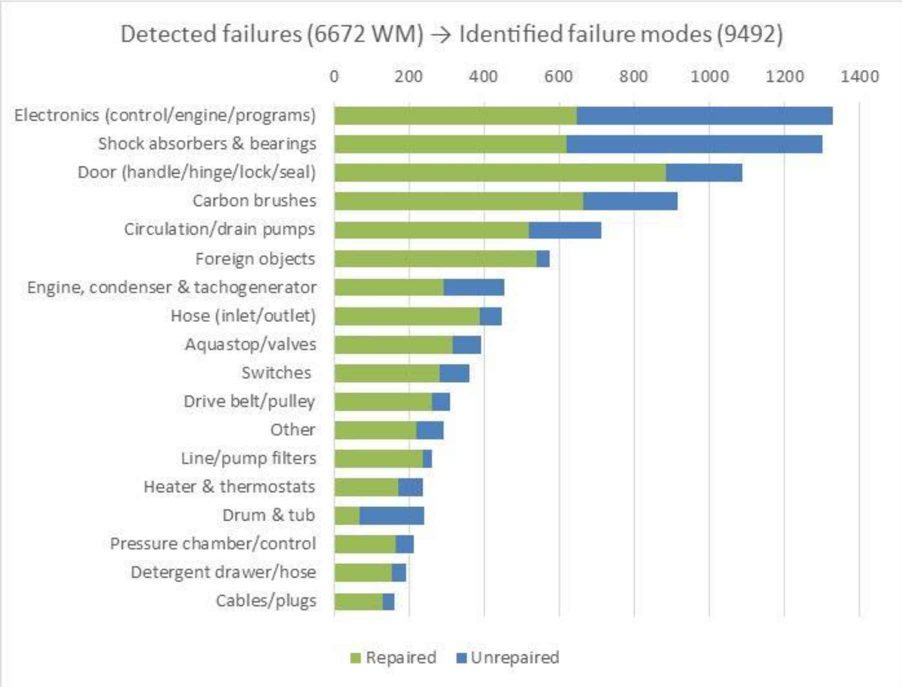

Figure 4: Analysis of failures for washing machines based on data from R.U.S.Z.; Source: Tecchio et al. (2016)

Apart from electronics, bearings and shock absorbers are the parts most affected by failure modes (multiple failure modes in 69% of cases). Tecchio et al. (2016) highlighted how the majority of bearing-related failures are not repaired because of the high cost (Figure 5), while shock absorbers are repaired in almost 58% of cases (Figure 6).

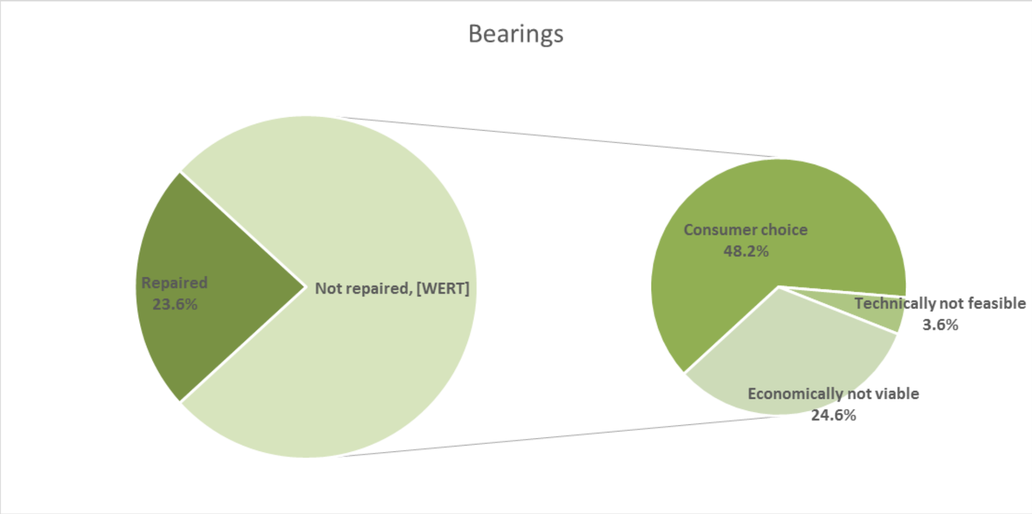

Figure 5: Frequency of repairs for bearings of washing machines; Source: Tecchio et al. (2016)

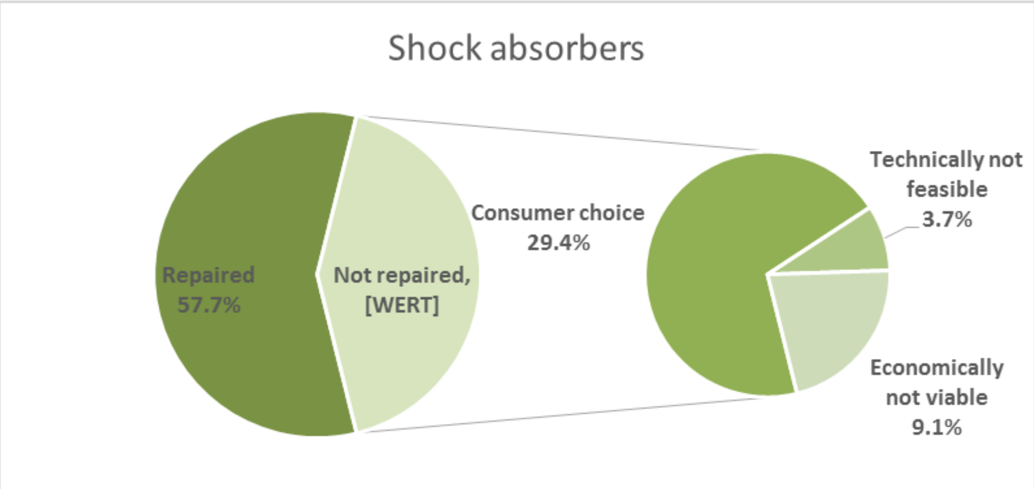

Figure 6: Frequency of repair for shock absorbers of washing machines; Source: Tecchio et al. (2016)

Even though problems with electronics, shock absorbers and bearings were the most recurring failure modes, they did not represent the most-repaired parts. The largest number of positive repairs was registered for doors and carbon brushes: 69% in total (Tecchio et al. 2016).

Additional analyses on failures reported in Tecchio et al. (2017) are summarised in Table 3, which confirm to a large extent the findings shown described above.

A detailed analysis of causes of failures for washing machines in Germany, as published in the test magazine "Stiftung Warentest" from 2000 to 2014, hardly showed any recurrent failures (see Table 4). Practically, all elements of a washing machine can lead to failure. In particular, the components that are most exposed to vibrations (all parts attached to the suds container (tub) such as springs and shock absorbers) seem to fail more often than other parts.

Manufacturers' views about likelihood of failures in washing machines and costs associated with the repair of parts were described by Prakash et al. (2016), as reported in (*) Three machines per model were always tested

Table 5 and in Table 6. With the exception of suds pump, manufacturers consider that likelihood of failure of parts is rare or very rare. However, repair of failures could imply high costs to consumers, in most of cases due to cost of manpower.

Failures have been described as binary parameter (working / failure). However, as conclusive remark, it should be also noted that failures can also include a loss of performance, which sometimes is difficult to be identified by the users.

Table 3: Comparative analysis of failures for parts/functions of washing machines (results are expressed as a percentage in case of surveys, or by a mark where no detail is available); Source: Tecchio et al. (2017)

Part/Function affected by failure modes	Tecchio et al. (2016)	RREUSE (2013)	WRAP (2011)	OCU (2015)	Altroconsumo (2015)	American Insurance Institute for Business Home and Safety(IIBHS, n.d.)
Electronics (control/engine/programs)	14 %	X	X			
Shock absorbers & bearings	14 %	X	X			
Door (handle/hinge/lock/seal)	11 %	X	X	12 %	7 %	
Carbon brushes	10 %					
Circulation/drain pumps	8 %	X	X	9 %	8 %	10 %
Foreign objects	6 %					
Engine, condenser & tachogenerator	5 %	X	X			
Hose (inlet/outlet)	5 %		X			55 %
Aquastop/valves	4 %					18 %
Switches	4 %	X	X			
Drive belt/pulley	3 %					
Other	3 %					13 %
Line/pump filters	3 %		X	11 %		
Heater & thermostats	3 %	X	X			
Drum & tub	3 %		X			
Pressure chamber/control	2 %					
Detergent drawer/hose	2 %					
Cables/plugs	2 %					
Spinning function				10 %	7 %	
Water leakage				9 %		4 %
Corrosion					6 %	

Table 4: Results of endurance tests conducted on washing machines by the test magazine "Stiftung Warentest" (2000-2014); own-elaboration

Year of publication	Number of models tested (*)	Name of appliance	Main problems
2014	13	LG F 14A8QDA	Rubber parts leaked
		Gorenje W 8544 T	Two machines failed in the first half of the duration test due to loose insulation material
		Beko WBB 71443 LE	Half way through the duration test, 2 machines failed with electronics damage
		Bauknecht WA Plus 784 DA	3 x Start button broken
2013	12	Haier HW80-B1486	1 of 3 failed due to bearings damage and other problems
		Gorenje W7543 T	Water inlet hose showed friction wear
2013	13	Gorenje WA 72149	Unknown
		Candy EWO 1483DW	Water leak
2011	14	Gorenje WA 72147 AL	2 of 3 failed with motor problems
		Haier HW70-BW140	2 of 3 failed with a hole in the hose connecting detergent draw and suds container
2010	14	Candy GO 1460D	Drum casing opened and destroyed the entire machine
2009	10	Bauknecht WA pure XL	Hole in door seal
		LG F1403 TD	Loose fan + defective heating element
2008	13	Bauknecht WA Pure XL 12 BW	Electronic problems
		Blomberg	Electronic problems
		AEG-Electrolux Lavamat 72850	Leak from suds container
2007	11	LG WD-14370 FD	Programme stopped
		Bauknecht WA Pure 14 Di	Fault in switch
		Samsung WF-B146 NV	Door spring broken
2006	15	EBD WA 3112	Electronic problems
		Indesit WIE 127	Ballast weight fixture loose

Year of publication	Number of models tested (*)	Name of appliance	Main problems
		Samsung B 1245 AV	Drum casing opened
2005	11	Bauknecht WAK 8788	Heating element worn by drum
			Contact broken on heating element
		Blomberg WAF 1340 A	Carbon brushes faulty
		Ariston AWD 149	Temperature sensor broken and contact problems
2004	10	Bauknecht Dynamic Sense WAL 10988	Minor problems with control
		Blomberg WA 54611	Minor problems
		Candy Tempo Logic CBL 160 PDE	Minor problems
		LG intellowasher WD 16220 FD	Minor problems
2003	12	Foron WF 1596 A	Heating charred
2002	15	AEG 84740	Connection element charred
		Bauknecht WAP	Motor faulty
		Brandt	Plastic parts broken
2001	16	Bauknecht WAT 9565 WP	Water damage and other problems (motor, crack in cement weight)
		EBT TL 2247	Water damage and other problems
		Hoover T225E/1	Bearing damage and other problems
		Candy ActivaCTA125 DE	Leaks and bearing problems
		Foron Vitatop WN 1243 N	Leaks in 2 machines, cement weight broken
		Zanker FR 2921	Vibrations, Baffles broken (1 appliance)
2000	17	Constructa Viva 1000	Drum cross piece broken (1) – Belt fell off (1)
		Bauknecht WA 7575 W	Heating element defective (2) – bearing (1) – Drum cracked (1) – suds container leaked (1) – Weight cracked (1)

(*) Three machines per model were always tested

Table 5: Likelihood of failure according to manufacturers of washing machines; Source: Prakash et al. (2016)

Part/component (multiple responses from different manufacturers)	**Likelihood of failure**			
	Very rare	**Rare**	**Frequent**	**Very frequent**
Inlet/outlet hose	X	X		
Suds pump (pump motor)		X	X	
Pump casing	X			
Springs	X			
Shock absorbers		X		
Bearings	X			
Seals		X		
Suds container		X		
Interference suppression	X			
Pressure sensor		X		
Heating		X		
Thermostat		X		
Control electronics (Platine)	X	X		
Input / output electronics (buttons, display)	X	X		
Programme switch/Microswitch		X		
Tacho-generator	X	X		
Door lock (electronics)		X		
Door handle, catch (mechanical)	X	X		
Temperature sensor		X		
Motor (carbon pins)	X			
Aqua Stop system	X			

Table 6: Repair costs according to manufacturers (net prices); Source: Prakash et al. (2016)

Part	**Labour costs (€)**	**Cost of parts (€)**	**Time for repair**
Inlet/outlet hose	ca. 103	ca. 60 / 23	ca. 30 min.
Suds pump (pump motor)	ca. 125	ca. 53	ca. 45 min.
Pump casing	ca. 125	ca. 16	ca. 45 min.
Springs	ca. 103	ca. 9	ca. 30 min.
Shock absorbers	ca. 146	ca. 30	ca. 60 min.
Bearings	ca. 233	ca. 29	ca. 120 min.
Seals	ca. 125	ca. 20	ca. 45 min.
Suds container	ca. 233	ca. 40 plus 170	ca. 120 min.
Interference suppression	ca. 103	ca. 17	ca. 30 min.
Pressure sensor	ca. 103	ca. 33	ca. 30 min.
Heating	ca. 103	ca. 46	ca. 30 min.
Thermostat	ca. 103	ca. 27	ca. 30 min.
Control electronics (Platine)	ca. 125	ca. 158	ca. 45 min.
Input / output electronics (buttons, display)	ca. 125	ca. 147	ca. 45 min.
Programme switch/Microswitch	-	-	-
Tacho-generator	ca. 125	ca. 23	ca. 45 min.
Door lock (electronics)	ca. 125	ca. 45	ca. 45 min.
Door handle, catch (mechanical)	ca. 103	ca. 47	ca. 30 min.
Temperature sensor	ca. 103	ca. 46	ca. 30 min.
Motor (carbon pins)	ca. 125	ca. 262	ca. 45 min.
Aqua stop system	ca. 125	ca. 11	ca. 45 min.

1.4 Stress conditions and degradation mechanisms leading to failures and/or loss of functions

Limiting states can be due to stress factors (e.g. mechanical, thermal) and/or to the capability of products to achieve and maintain a required performance. Stress factors are linked to specific environmental conditions (e.g. ambient temperature and humidity, mechanical vibration due to the transportation) and operating profiles (e.g. electrical stresses due to the function of the equipment, temperature variation during the turning on/off, shocks, vibration, drops, and mechanical impacts) (Alfieri et al. 2018). The study of stress conditions and degradation mechanisms (EN 60812) is fundamental to understand how the durability of a product can be improved. By defining the durability of a product as its ability to function as required over time […] (see the Introduction), also loss of functions can be considered a limiting state when performance requirements are not met anymore.

From an engineering point of view, washing machines are subject to several types of stress, including thermal, hydraulic, extreme vibration, and other mechanical and chemical stress to materials during use. It is essential that machines are designed to withstand these stresses. Vibration and mechanical stresses during use were considered to represent main sources of stress for the whole washing machine, especially in case of low quality shock absorbers and ball bearings (Tecchio et al. 2017).

1.4.1 Key parts

A detailed analysis of failed parts revealed that many failures are associated with the tub/drum system (Prakash et al. 2016). These are failures of the tub and drum itself, but also failures of the motor or the transmission belt or the fixation of the inertia weight. This could be in some way expected as the highest mechanical stress occurs on those parts during the washing operation and, especially, the spinning phase.

A detailed investigation of the life-time of washing machines has also shown a clear correlation between the actual life-time of washing machines in Germany with the frequency of use (Hennies and Stamminger 2016). This indicates that the actual operation of the appliance is the major factor limiting its lifetime.

To understand where this high mechanical stress originates, a more detailed look on the general construction of a (horizontal axis) washing machine is needed.

1.4.2 Dynamic behaviour of a horizontal axis washing machine

The dynamic behaviour of a horizontal axis washing machine is discussed by Tecchio et al. (2017). As depicted in Figure 7, horizontal axis washing machines can be seen as a vibrating system where the tub (including the drum) is fixed with two (sometimes three) springs on the top of the housing. The description of such system can be simplified by the physics of free oscillation. This oscillator is energized by the movement of the drum, which is rotating with an angular velocity of ω. When ω is greater than $\sqrt{\mathrm{g/r}}$ (r = radius of the drum; g = gravitational acceleration), laundry sticks to the inner wall of the drum without falling to the bottom. This is the case for spinning speeds above 60-70 rpm for the typical dimensions of household washing machines. As the laundry may not distribute uniformly on the wall of the drum, some unbalancing may occur. For simplification purposes, it can be assumed that the unbalance can be mimicked by just one mass. The force of the movement of the oscillator now depends on the mass m_U of the unbalance which is rotating and which will cause the total drum to displace. Such kind of forced oscillation is well-known due to its resonance behaviour. At the resonance frequency, defined by $\omega_R = \sqrt{K/m}$ (K = spring constant; m = total mass of tub and drum), this would lead to a theoretically infinite amplitude. This frequency is typically between 200 and 400 rpm for horizontal axis washing machine designs, thus, between the frequency for washing (about 50 rpm) and spinning (1000 rpm and more). Additional dampers are installed (Figure 7) to limit the amplitude which can be afforded by the space between the tub and the housing of the machine.

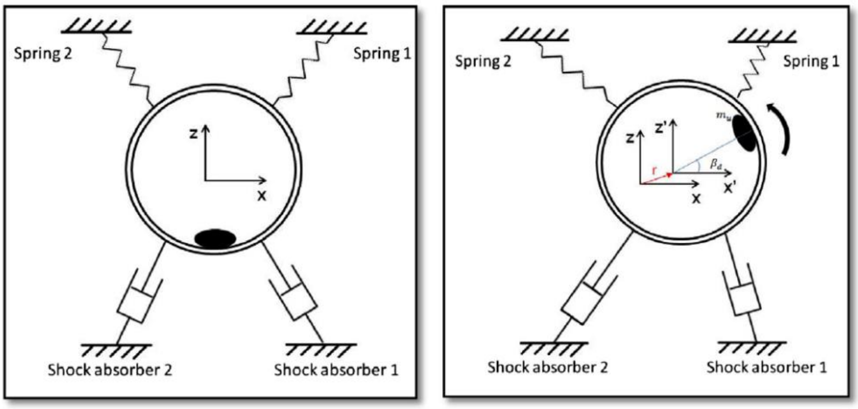

Figure 7: **Two-dimensional sketch of a washing drum as an oscillating system without (left) and with (right) unbalanced mass; Source: Boyraz and Gunduz (2013)**

This kind of system is known in physics as forced oscillation with damping and described in the one-dimensional case by a simple differential equation (1):

$$m\frac{d^2x}{dt^2} = F_0 \sin \omega t - c\frac{dx}{dt} - Kx \quad (1)$$

Where,

- *m* is the accelerated mass,
- F_0 is the oscillating force,
- *c* is the damping factor, and
- *K* the spring constant.

At frequencies much below the resonance (see Figure 8), the solutions of this equation show that the amplitude *A* (equal to the ratio of the accelerating force F_0 divided by the spring constant *K* of the movement) is equal to 1. The phase φ is close to 0, which means that the displacement and the force are in phase. When the frequency of the force applied is much greater than the resonance frequency, the amplitude decreases inversely as the square of the frequency of the applied force increases. It is also proportional to the magnitude of the force. At very high frequencies, the displacement and force are out of phase by 180°, meaning the oscillation of the tub has the opposite direction to the force originating from the unbalanced mass. In between, when the frequency of the applied force is close to the natural resonance frequency of the oscillator, the amplitude of the movement depends very much on the quality function *Q*, which comprises especially the damping characteristics. At this frequency, there is also the point where the phase changes from being in phase with the agitating force to being in the opposite direction.

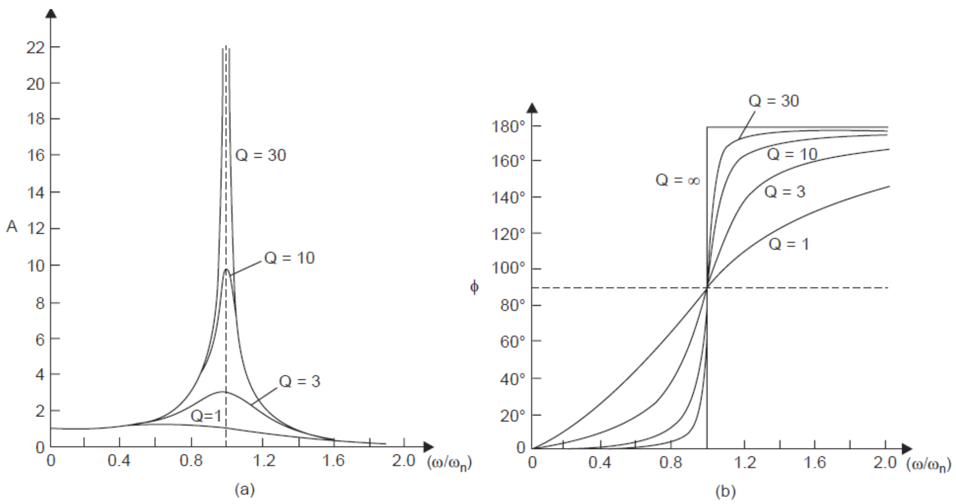

Figure 8: Frequency dependence of amplitude (a) and phase (b); Source: Srinivasan (2009)

Such an oscillator driven by an external force causes intensive vibration but also absorbs energy. The energy absorbed by the oscillator is equal to the energy dissipated due to damping. The absorbed energy equals the product between viscous force and velocity (see Figure 9).

To reduce the undesirable effects of vibration isolation techniques are applied. The design of a vibration isolation system is based on the theory of forced vibration. The vibration isolation system can be active or passive depending on whether the external power is required for the isolator to perform its function or not. A passive isolator consists of a resilient member (stiffener or spring) and an energy dissipater (dampener). Examples of passive isolators include metal springs, cork, felt, pneumatic springs and elastomer (rubber) springs. An active isolator is composed of a servomechanism with a sensor, signal processor and an actuator.

Washing machines system kinematics is studied by scientists and applied research in industry to find the ideal compromise between the unbalance occurring during spinning of the load, spring dimensioning, damper characteristics and the gravimetric weight of the whole oscillating system. The lower the maximum unbalanced mass to be expected, the less the gravity mass of the whole "swinging" system needs to be or the lower the space between tub and housing must be.

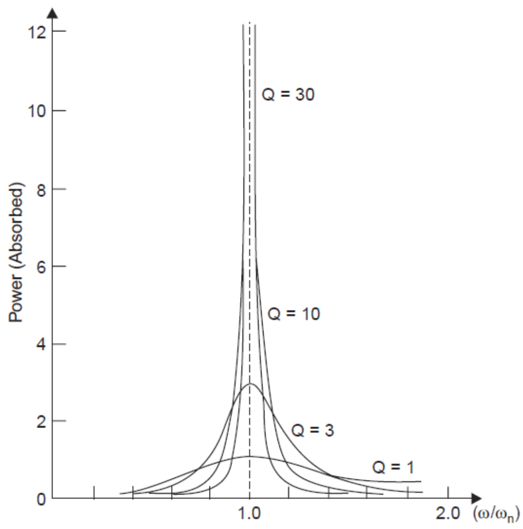

Figure 9: Frequency dependence of mean power absorbed by an oscillator for various values of Q; Source: Srinivasan (2009)

But, also the lifetime of relevant parts of a washing machine are affected heavily by the unbalance mass, like the lifetime of ball bearings. The nominal lifetime L_h of ball bearings in hours is given by equation 2 (INA-FAG)

$$L_h = \frac{16666}{n}\left(\frac{C}{P}\right)^p \qquad (2)$$

Where:

- C is the basic dynamic load rating in N
- P is the dynamic equivalent bearing load in N
- n is the rotation speed in rpm and
- p is the lifetime exponent, for ball bearing p = 3.

As P is proportional to the centrifugal force ($m \cdot \omega^2 \cdot r$) and ω is proportional to n, the expected lifetime L_h is inversely proportional to the spinning speed to the power of five and inversely proportional to the unbalanced mass to the power of three. This explains why it is so important to know and to restrict the unbalanced mass strictly in relation to the design of the ball bearings to avoid lifetime failures.

The implications due to the unbalance of the textile load during the spinning can be managed also by applying a balancing weight directly opposite to the unbalanced mass. This is relatively easy, as any flexible mass above the resonance frequency will automatically take a position opposite to the unbalanced mass due to the phase difference of close to 180° between the mass and the deflection of the tub. Two distinct groups of dynamic balancers can be separated: liquid-filled systems and mechanical systems (Chen et al. 2015; Conrad and Soedel 1995; Son et al. 2012). A hydraulic balancer belongs to the liquid-filled systems. Inside the hydraulic balancer obstacles are included to control the liquid's movement. In alternative designs, "hollow spaces" inside the drum are filled by a liquid (water) according to the amount of balance needed (patent DE 19616985). Ring-, pendulum- or ball- balancers belong to the mechanical systems. The mechanical systems have an advantage over the liquid-filled systems since they are capable of more precise balancing. Both types of unbalancing system require additional active or passive elements which are costly and, therefore, not found in many washing machines on the market (e.g. LG Washer – TrueBalance anti-vibration system).

1.5 Key design and behavioural aspects to increase the longevity

1.5.1 Key design aspects

Measures for extending the lifetime of a washing machine are described by WRAP (2011), which assessed the Bosch Avantixx 6 VarioPerfect and the Siemens IQ-700. Both machines had an "A" energy rating. The Siemens model was guaranteed leak-proof and had a 5 year guarantee for parts and labour. The Bosch model has a 2 year guarantee. The Siemens IQ-700 costed about EUR 800, about the double of the Bosch Avantixx 6 VarioPerfect.

The study found that both machines were robust, durable, and offered easy access to key parts for repairs and replacements. Clear step-by-step instructions to replace parts such as the motor or drum were available for qualified repairers. Other parts such as the door and seal could be replaced by the user through online manuals.

Motor, concrete block and dampers are bolted securely in both models, preventing damages due to vibrations. The Siemens model had additional damping material to reduce vibration during the use. In both models it was relatively easy to replace circuit boards, hoses, and drive belts. Repairs were made easier by using only the necessary types and numbers of fasteners and connectors (screws, bolts, cable routing systems, snap fits).

Based on the observation of such examples, a list of features is made in this report which could be replicated to improve the durability of washing machines:

1. Access to information to avoid faults and to diagnose them in case of occurrence;
2. Good-quality design, oriented to the avoidance of mechanical and electrical damages:

   - Robust and corrosion-resistant housing;

   - Damping to reduce the effects of vibrations during operation;

   - Well-secured internal components, with a combination of bolts and lugs;

   - Sensors and electronic controls to reduce vibrations and wear;

   - Low-maintenance, brushless motors;

   - Leak protection for vulnerable parts such as circuit boards;

   - Wiring held in place by clips;

   - Shorter leads to minimise risks of breakage;

   - Parts well protected against potential internal leaks.
3. Ease of access and availability of spare parts for repairs:

   - Large rear and top covers affording easy access;

   - Fixing with a minimum number of standard screws and bolts;

   - Internal clips and connections that are easy to operate;

   - Availability of spare parts at reasonable prices, so that repairs can be carried out beyond the warranty period.

Quality of materials and parts is in particular a critical factor to reduce the risk of failure of washing machines (Tecchio et al. 2017). Low quality shock absorbers and ball bearings for example can fail prematurely if exposed to high spin speeds. In many cases, the replacement of ball bearings requires the purchase of a complete washing unit (including the drum), whose cost is comparable to a new device. Other problems related to quality of materials and reasons of early failures concern the rubber of sealants and the membrane of pressure switches. Heaters can also stop working prematurely, especially in regions with hard water.

The consequences for the durability of washing machines due to the use of plastic suds containers were analysed in Prakash et al. (2016). Plastic suds are often made of fibre-glass reinforced polypropylene, which is used because of its properties (e.g. low density, hardness, water and electrical isolation, chemical and corrosion resistance). According to manufacturers, it is possible to design plastic components that meet the specifications of washing machines. Plastic suds are reported to be reliable over many years of use, beneficial from an economic and technical point of view (there is no corrosion, acoustic properties are improved, thermal losses are lower). The independent tests of 600 washing machines carried out by Stiftung Warentest over 15 years showed that only few machines had problems that could be attributed to a plastic suds container. It can be assumed that some 90% of the tested machines had a plastic suds container; however only machines costing more than 350 € were tested.

Recent decades have also seen a significant change in the construction of almost all domestic appliances, away from electrical appliances with motor, heating and switches towards electronic appliances with microprocessors, sensors and digital displays. Such changes also lead to different failure behaviour of the appliances. Electrical parts (such as mechanical switches, bimetallic thermostats, press buttons, relays) are often operated at the mains voltage with high currents (up to 16 A in the household), whereas in contrast, integrated electronic components can combine various functions and work at low voltages (a few volts). With electrical components it is important to provide adequate clearance and creepage spacing in order to avoid failures and short circuits. But even then, problems can be easily caused by moisture, dust and fluff. In contrast, electronic sensors and microprocessors can be placed much closer together, and functions can be integrated on a semi-conductor chip or a circuit board. This in turn reduces the numbers of plug contacts between individual parts and makes possible to test parts before they are installed in an appliance. Electronic components are available in a range of ratings, appropriate for the conditions under which they are to be used (in particular the temperature range). However, components with lower failure rates at higher temperatures can be much more expensive (Prakash et al. 2016).

1.5.2 Target lifetime / number of cycles

Miele reported that their washing machines are designed with the target to last 5000 programme cycles, which corresponds to about 20 years in a normal household. On the basis of trials in test households, programmes are chosen and individual settings determined. A statistically significant number of machines then go through appropriate tests before the series is launched on the market. A very low failure rate of the tested machines is required before the series is released (only reparable faults are allowed). In addition, parts that are particularly exposed during operations are tested individually to ensure a satisfactory lifetime under conditions that come as near as possible to the real use. Field experience of manufacturers with their own machines is important for the design of new models that can function for a satisfactory lifetime. The lack of field experience could lead to unexpected failures. Less durable washing machines differ mainly in the specifications for critical parts (drum bearings, the mounting for the suds container, shock-absorber ratings and fixings, the bearings of the motor and pumps, and the design of seals and the materials used for them). In addition, it is possible to cut costs when designing and choosing materials for parts that carry water (Prakash et al. 2016).

It is reported that other brands set a lifetime target of 200 wash cycles per annum during 10 years (for a total of 2000 cycles)[7]. No information is available about lower lifetime targets set by other manufacturers. However, the tests carried out by Stiftung Warentest in the last years suggest that, normally, washing machines more expensive than 350 €

[7] http://www.spiegel.de/karriere/berufsleben/ingenieure-entwickeln-waschmaschinen-fuer-die-zukunft-a-927797.html

(the lower limit of costs for the tested washing machines) did not fail endurance tests (Prakash et al. 2016).

However, since the price not only reflects the quality of materials and parts used, but also the services provided and other factors (including fashion design characteristics), it is complicated to establish a strict relationship between price and lifetime.

1.5.3 Maintenance and proper use

The Preparatory Study for the revision of "Ecodesign and Energy Label for household washing machines and household washer-dryers" (Boyano et al. 2017) reports that maintenance and repair are very important. Products are provided with installation and maintenance instructions to ensure that durability is not impacted. For washing machines, for example, recommended actions that can have intuitive effects on durability include:

- To clean the filter on a monthly basis;
- To clean the pump;
- To clean surfaces, including door gasket and detergent dispenser drawer;
- To carry out hot washes every couple of months for avoiding build-up of detergent;
- To use of descaling agents in case of very hard water.

1.6 Existing practices for testing the durability

The testing of the durability of products can target different aspects, as for example:

1. Resistance to stresses (e.g. drop tests);
2. Endurance of the product and other reliability metrics (including functionality check).

In particular, reliability assessment methodologies (IEC 60605) can be applied for a more comprehensive analysis of failures and loss of function(s) during the use of the product. The reliability of a product or part is the ability to perform as required, without failure, for a specified duration (e.g. time, cycles, distance) and under given conditions of use. Typical reliability metrics include: probability of functioning over time, Mean Time to First Failure (MTTFF), Mean Time to Failure (MTTF), Mean Time Between Unit Repair (MTBUR), Mean Time Between Unit Failure (MTBUF) (Alfieri et al., 2018).

Testing the durability of a potentially long-lasting product as washing machines is a lengthy process. Solutions are needed to accelerate them while not losing significance and correspondence with user experience (Tucci et al. 2014). There are different methods of accelerating a reliability test, in particular by increasing the use rate of the product, and/or by increasing the level of stress under which test units operate.

Depending on the product, different types of tests can be applied, to the product as a whole system and/or to specific parts of it. In their detailed analyses, Prakash et al. (2016) could not identify a key part responsible for the majority of failures of washing machines but they rather observed that almost all parts can fail. Therefore, the testing of the entire machine is the only choice to assess the durability of the product consistently.

Existing practices for testing durability of washing machines are summarised in the "Study for the development of an endurance testing method for washing machines" (Tecchio et al. 2017).

1.6.1 Stress and endurance tests

No international standards are currently available for the assessment of the durability of washing machines (Tecchio et al. 2017). Consumer testing organisations typically focus on the measurement of washing performance parameters (such as dirt removal, spinning performance, rinse performance, water consumption, energy consumption, ease of use and noise) although they have access to laboratories equipped to carry out endurance tests on household appliances.

Several manufacturers of household appliances perform durability tests on sample devices before putting them on the market. Tests are generally based on intensive use, in order to simulate the total number of washing cycles during lifetime.

The consumer association Altroconsumo[8] published results of a research on durability and failure modes of washing machines in 2015. A particular endurance test was performed: for each washing machine 2500 rinse and spinning cycles were executed, setting the spinning at the maximum speed. The used load was composed by cotton clothes (85%) and a spongy material (15%), corresponding to 60% of the rated capacity. A total of 24 washing machines, representing high-end and low-end models from 12 brand sold in Belgium, Italy, Portugal and Spain, were tested in order to understand their resistance to overstressed conditions. Cycles combining rinsing and spinning were chosen as the main source of stress for the whole washing machine (see Section 1.4.2). 2500 cycles were considered as representative of a 10 year lifetime. The spinning function was performed at the maximum speed. A final inspection, performed through the partial disassembly of machines, highlighted that main components stressed in these conditions were the motor, the pump and the door. A total of 4 devices failed during testing and consequently

[8] www.altroconsumo.it

they needed repairs before finishing the 2500 cycles; repairs were not covered by warranty and were performed by professional repair operators in two occasions. After the test, the main parts subject to wear were the belt, the shock absorbers, the counterweight and the drain hose. Twelve devices experienced breaks in the door gasket and noise was produced by an unspecified number of machines (Altroconsumo, 2015).

The duration of each rinse and spin cycle was not specified by Altroconsumo and it is not clear if the programme time and the programme schedule were the same for all of the washing machines. In the case the washing machines were able to recognise the load and vary the cycle duration, this may result in different stresses during the test, and the consequent low reliability in comparing the results.

The German Stiftung Warentest[9] has been also carrying out durability tests for washing machines. For each model of washing machine, three washing machines of the same model are run for a total of 1840 cycles in different programs with practice-oriented load and usual heavy duty detergents, corresponding to a lifetime of around 10 years if 3.5 wash cycles per week are considered.

Tests on parts are easier and faster. A ball bearing manufacturer, for instance, used endurance tests for a new one-way clutch with built-in ball bearing which was developed and adopted for fully automatic washing machine. Results and detail of the research were published in 2000. The rotating endurance test was run for over 3000 hours at 1000 rpm (equivalent to 36000 loadings of approximately 5 minutes of spin-drying). Cycle tests in actual washing machines have been performed too and consisted of 2600 hours of continuous cycle operation (equivalent to 5200 washing cycles) (Ishiyama and Iga 2000). These tests lasted respectively 125 and 108 days, in the condition of continuity. Even if not directly applied on the washing machine as a whole, these experiments highlight the need for an accelerated procedure able to reduce the time required to obtain reliable results. Although manufacturers have their own internal protocols, standardised procedures intended for such purposes are not available.

1.6.2 Accelerated Life Testing

Engineers in the manufacturing industries have used Accelerated Test (AT) experiments for many years; the purpose of these experiments is to acquire reliability information quickly. However, estimating the failure-time distribution or long-term performance of components of high-reliability products remains particularly difficult (Escobar and Meeker, 2007).

There are different methods of accelerating a reliability test, in particular by increasing the use rate of the product, and/or by increasing the level of stress under which test units operate. Accelerated Life Tests (ALTs) with increased use rate do attempt to simulate actual use and they can be an effective method of acceleration for some products; use-rate acceleration may be appropriate for products such as electrical motors, relays and switches, and certain home appliances. Also, it is common practice to increase the cycling rate (or frequency) in fatigue testing; the manner in which the use rate is increased may depend on the product. Anyway, the relationship between accelerating variables and the actual failure mechanism is usually extremely complicated. Thus other environmental factors should be controlled to mimic actual use environments (Escobar and Meeker, 2007).

Accelerated life tests were used by Tucci et al. (2014) as an integrated method for washing machine design. In detail, they used ALTs to test the behaviour of a new mechanical oscillating system for washing machines. The independent variable chosen for the reliability model was the number of standard washing cycles, with a censoring time fixed at 500 cycles, corresponding to an average of 2 years of use (250 cycles per year). The test was run with a total number of 24 washing machines, each equipped with a load

[9] https://www.test.de/

imbalance placed inside the drum, representing the only overstressing parameter (since it intensifies the drum deformation). Each test cycle consisted of two phases, with 90 minutes of low speed cycles and 20 minutes of spin cycle. For each test, every 50 cycles, an actual washing cycle was performed, in order to control how the washing performance evolves during the test (Tucci et al. 2014).

In another study developed by the same Institute, De Carlo et al. (2013) used the same strategy to estimate the reliability of washing machine parts through Accelerated Degradation Tests (ADTs). ADTs focus on to so-called soft failures, damages caused by the degradation process that will eventually lead to failure and malfunction, while during ALT execution researchers look for traditional failures that permanently affect the functionality of the product. The test procedure was the same used by Tucci et al. (2014), a uniform overstress during the entire duration of the experiment, in order to make some inferences about the performance in normal conditions of use. Again, 24 machines were tested with 500 spinning cycles of 30 min each (reducing therefore the duration of each washing cycle from 1.5 hours to 30 min). In this case the spinning cycle is relevant since the target of the study is again to observe the drum deformation. The maximum imbalance permitted in the drum was a rubber plate with a load of 400 g, then other three levels of stress were applied (650, 800 and 950 g) (De Carlo et al., 2013).

Regarding ATs and washing machine parts, Park et al. (2006) conducted a research aimed to develop an accelerated test as to demonstrate a reliability goal of the pump assembly, within an affordable amount of time and in an economic way. In this case study, the authors used a step-stress test in order to verify the operating limit of the pump assembly in certain environmental stresses. Moreover, an accelerated test was conducted also to measure the annual failure rate and the mean time to failures (MTTF) of the component. High temperature and voltage were used as stress factors to accelerate the failure of the assembly. The value of the acceleration factor (AF) was estimated to be 16 at the high stress condition compared to the use condition. It also showed that all of the tested units survived for 500 hours at the overstressed condition (40°C and 264 V, instead of 220 V, as it is well known that the failure of a pump motor assembly is stimulated by temperature, voltage and solid particles suspended in water) (Park et al. 2006). The authors used 255 hours as representative of the annual operating time of the assembly.

ALTs showed their potential but also highlighted some critical issues and limitations. For example it is essential to have a dedicated laboratory for the experimental measurements and to have investigated all of the possible failure modes (Tucci et al., 2014). Park et al. (2006) concluded their work by asking how reliability of a product can be improved. First of all, it is necessary to identify the failure modes through various time-consuming tests (this conclusion is in line with Tucci et al. (2014)). Next, failures should be analysed and failure mechanism determined. The analysis of stress conditions can be supported by the Finite Element Method (FEM)[10] (De Carlo et al. 2013).

The above information can be relevant for the development of tests to assess and verify the durability of new products (or new parts). A load unbalance may represent the easiest way to introduce a mechanical overstress during the test. However, the drum unbalance is normally regulated by the electronic control unit during the actual use, which stops the washing cycles if it exceeds a threshold value decided by the manufacturer. To overcome this issue, Tucci et al. (2014) first measured what was the maximum allowable unbalance (i.e. the mass of the load unbalance, placed inside the drum of the washing machine) tolerated by the machine (i.e. the control unit allows the spinning function). Then they bypassed the control unit of the device with external controls and used the maximum allowable imbalance as a baseline, adding then three levels of overstress (165%, 200% and 237% of the maximum allowable unbalance).

[10] FEM is a numerical method for solving problems of engineering and mathematical physics. Studying or analysing a phenomenon with FEM is often referred to as finite element analysis (FEA)

Tecchio et al. (2017) have worked on a procedure for the accelerated testing of the endurance of washing machines (see also Stamminger et al. 2018). The procedure is based on the testing of the whole product under conditions of stress. The test is based on a number of steps:

- Pre-conditioning: the appliance is installed according to the instructions of the manufacturer, provided in the user manual;
- Initial examination: the washing machine undergoes an initial visual inspection, to verify whether the machine is intact and undamaged, and fit for the test. Furthermore, the maximum unbalance tolerated by the machine (at rated highest speed) is identified;
- Testing: the test consists of a series of 500 spinning cycles, spaced out by one washing cycle every 100 spinning cycles. The spinning cycles are run with a fixed unbalance tolerated by the machine. The washing cycles are run without the artificial load, which is substituted by a base load;
- Recovery: between the spinning cycle, the washing machine observes a rest period;
- Final examination: the washing machine performs a final washing cycle, monitoring the performance parameters (e.g. energy and water consumption, cycle duration) and then undergoes a visual inspection.

The proposed test was applied to two machines. Even though no hard failures occurred during the experiments, results indicated that not all washing machines could be able to sustain such a test without abrasion, or performance deterioration. An issue concerning the applicability of such test may be represented by the type of control procedure software implemented in the washing machine. The control procedure detects unbalanced loads and makes the machine react in different ways according to the software settings. For instance, three main options have been observed:

- The washing machine recognises the unbalanced load thanks to the control procedure, and it performs the spin cycle normally if the unbalance is below a certain threshold defined by the manufacturer of the device;
- The washing machine recognises the unbalanced load, tries to correct the unbalance by re-distributing the load in the drum, limiting the overstress as much as possible, and then performs the spin cycle. The attempts to re-balance the load could be repeated several times;
- The washing machine recognises the unbalanced load as too high and does not perform the spin cycle or it alters the way of spinning (shorter time and/or reduced spin speed).

During the experimental trials, it was observed that the third option influenced particularly the behaviour of one of the two washing machines. As a result, spinning cycles were run with a reduced spin speed, for longer time, making a comparison with the performance of the other washing machine not possible. This reaction of the machine might eventually result on the one hand in a reduced stress for its mechanical parts (and potentially a longer lifetime) but, on the other hand, users do not obtain the expected performance of the machine (e.g. lower spinning speed and lower water extraction performance compared to the value declared by the machine programme).

It is important to remark that the trials performed did not show a correlation between the stress induced by the spinning and potential failures that the machine could suffer during its lifetime, or a correlation with the number of years a device will mechanically last. Even if failures had occurred (e.g. when running a trial with a higher number of spinning cycles), it would have been difficult to correlate these with the lifetime of the device. As such, a testing protocol based on pure spinning cycles could even be counter-productive if used to "measure" and compare the durability of washing machines, as it induce stresses that are not usual in the washing machine common use. As a consequence, the actual performance of the device (e.g. water extraction, washing time) has already deteriorated after some cycles so that it does not allow assessing the durability under conditions for which the machine is declared to operate.

1.6.3 Preliminary indications for the development of a durability testing procedure

Durability is an important aspect for washing machines, as highlighted by the early failure of some models on the market, but no widely agreed procedure for testing durability exists yet.

Spinning operations cause vibrations and oscillations, especially due to unbalanced load. This results in mechanical stress to all main parts of the washing machine, which can be considered as a main cause of damages for the device.

Based on the review of the existing testing methods, a procedure for testing the durability of the washing machine should:

- Focus on the testing of the entire product as close as possible to real life conditions;
- Reduce the length of the testing by applying Accelerating Life Testing;
- Cover mechanical and thermal stresses, as main cause of damages;
- Cover functionality aspects as loss of performance;
- Be suitable for verification purposes (i.e. be reproducible and repeatable).

To undertake this complex task, a combination of two test philosophies would be appropriate:

1. On the other side, stress tests should impose a realistic thermal and mechanical stress to the washing machine in short time and be executed many times mimicking the requested lifetime period;
2. On the one side, performance tests should allow verification and should be aligned as far as possible to existing regulations.

The procedure proposed by Tecchio et al. (2017) was considered the best proposal available so far. However, this should be further developed in order to be closer to real life operating conditions. This can be pursued in particular by:

- Avoiding the use of a fixed unbalance as this neglects the strategies of the individual manufacturer to cope with the unbalance formation;
- Integrating also stresses due to washing (temperature) and rinsing cycles;
- Assessing washing performance information before, in between, and after the stress cycles.

The durability of washing machines should be thus tested based on a series of washing and spinning and rinsing cycles, in order to take into account the main mechanical and thermal stresses which the appliance is subjected to.

Moreover, a balance has to be sought between the desirable lifetime target for the testing procedure (e.g. the average lifetime of the product) and a practical length that can be applicable for verification purposes. For example, the coverage of the first two years of use of washing machines could be useful for identifying early and potential future failures, as well as malfunctioning and loss of performance, in worst performing products; more time and resources would be instead needed in case longer lifetimes are considered.

2. DEVELOPMENT OF A TEST FOR ASSESSING AND VERIFYING THE DURABILITY OF WASHING MACHINES

2.1 Introduction

Building on the existing knowledge about the testing of washing machines, a durability testing procedure for the product is further developed. The procedure has been applied to two models of washing machines available on the market (see Section 3).

The following sections define such a testing procedure, which was developed also based on the discussion held with manufacturers, consumer testing organisations, and experts from the European Commission during two workshops (on 15 March and 22 March, 2018) (see Annex A).

Modifications could be applied to the procedure in the future to align with the final output of the ongoing revision of the Commission Regulation (EU) No 1015/2010 and of the Commission Regulation (EU) No 1061/2010.

2.2 Scope

A procedure to test the withstand of washing machines for household use is described. The procedure is applicable to electric horizontal axis washing machines for household use (see IEC 60546:2010, section 3.1.8), that are intended to be used for washing clothes and textiles, their rated voltage being not more than 250V for single-phase appliances (EN 60335-2-7; EN 60335-1).

The procedure aims to fulfil the following requirements:

- It is representative for consumer use;
- It is suitable for verification purposes (i.e. it is repeatable and reproducible);
- It minimizes circumvention by test cycle detection;
- It applies accelerated testing principles resulting in a reasonable amount of resources to be used and offers the option for further automation of the test.

The procedure focuses not only on detecting the occurrence of break-downs but also on the measurement of the product's functionality, which is monitored through key performance parameters, as described in the following sections.

The procedure covers the first two years of use of washing machines. Although much lower than the average lifetime of the product (12-13 years), this can allow the identification of early failures in worst performing products and keep the length of the test limited[11].

[11] This is in particular useful for regulatory purposes, since the testing of a representative lifetime of 12 years could require about 6 times the time and resources required by the application of this procedure. The possibility of conducting further analyses covering a longer testing time could be explored as follow-up of this study.

2.3 Terms and definitions

The following terms and definitions are used in this context:

Washing machine: appliance for cleaning and rinsing of textiles using water which may also have a means of extracting excess water from the textiles (IEC 60456, 2010).

Programme: series of operations which are pre-defined within the washing machine and which are declared by the manufacturer as suitable for washing certain textile types (IEC 60456, 2010).

Operations: each performance of a function that occurs during the washing machine programme, such as pre-wash, washing, rinsing, draining or spinning (IEC 60456, 2010).

Washing cycle: complete washing process, as defined by the programme selected, consisting of a series of operations (wash, rinse, spin, etc.) and including any operations that occur after the completion of the programme (IEC 60456, 2010)[12].

Spin extraction operation: water extracting function by which water is removed by textile by centrifugal action. This is included as a function (built-in operation) of an automatic washing machine but may also be performed in a spin extractor (IEC 60456, 2010)

Spinning cycle: a spinning cycle of a washing machine consists of spin extraction operation

Rinse&spin cycle: a cycle of a washing machine consisting only of a rinse cycle followed by a spin extraction operation.

Spin speed: rotational frequency of a drum during spin extraction operation (IEC 60456, 2010).

Rated spin speed: the rated highest spin speed as declared by the manufacturer in the product fiche.

Maximum spin speed: maximum spin speed measured in revolutions per minute 'rpm' attained in accordance with the test procedures of the harmonized standards ((EN60456:2016, ZA.4.7).

Duration of maximum spin speed: time period of the spin extraction operation when the maximum spin speed was reached at a tolerance of 50 rpm.

Water extraction performance: measured as the **remaining moisture content** (RMC) (IEC 60456, p. 49);

Base load: textile load used for testing, without stain test strips or wool shrinkage specimens (IEC 60456, 2010).

Arbitrary load: load made out of cotton articles without further specification.

Rated capacity: maximum mass in kg of dry textiles of a particular type which the manufacturer declares can be treated in the washing machine on the selected programme (Commission Delegated Regulation (EU) No 1061/2010 of 28 September 2010)

Rated voltage: voltage assigned to the appliance by the manufacturer (IEC 60456, 2010).

Energy consumption: the energy consumed over a programme (IEC 60456, p. 51);

Water consumption: measured as water volumes (IEC 60456, p. 51).

[12] The terms used for this definition in IEC 60456:2010 is simply "cycle". "Washing cycle" is here used to avoid possible misunderstandings.

2.4 General procedure and conditions

The durability testing procedure has to be compliant with the following actions, according to IEC 60068-1 Part 1:

- Pre-conditioning;
- Initial examination;
- Testing (exposure of a washing machine to test conditions and measurements);
- Recovery (stabilization);
- Final examination.

For the purpose of this test, the "testing" consists of two parts:

1. one which measures the performance, and
2. one which induces stress to the machine.

According to IEC/EN 60456 the following laboratory conditions has to be maintained during a test. For the purpose of this durability test, those conditions may be relaxed for cost reasons.

- The supply voltage to each test washing machine has to be maintained at the rated voltage ± 1% through the test (EN 60456:2016 section 5.2.1);
- The supply frequency to each test washing machine has to be maintained at the rated voltage ± 1% through the test (EN 60456:2016 section 5.2.1);
- Hard water has to be used, with a total water hardness of (2.5 ± 0.2) mmol/l [(2.5 ± 1.0) mmol/l] (EN 60456:2016 section 5.2.2);
- The temperature of water supply has to be (15 ± 2) °C [(15 ± 5) °C] (EN 60456:2016 section 5.2.2);
- The static pressure of the laboratory supply water at the inlet of each washing machine has to be maintained at (240 ± 50) kPa [(240 ± 100) kPa] throughout the test, including during filling operations (EN 60456:2016 section 5.2.2);
- The ambient temperature of the test room has to be maintained at (23 ± 2) °C (EN 60456:2016 section 5.2);
- Test materials (base loads) have to be compliant with EN 60456:2016 section 5.3) [average load age > 80 cycles permitted]
- Test strips have to be as defined in EN 60456:2016 section 5.3.3 and Annex A (without the requirement of Table A.1 - Ratios and tolerances of standardised soils, as the results of the washing performance tests are compared only between the beginning and the end of the durability test and not between laboratories as usually done when applying IEC 60456).

2.5 Pre-conditioning

The appliance has to be equipped with a drum speed measurement device (as specified in "ZA.4.7 Measurements to determine maximum spin speed" of EN60456:2016) and means for the measurement of water consumption, energy consumption and time of the programme (following "ZA.4.8 Measurements to determine water consumption, energy consumption of the programme and programme time"). Those values have to be recorded in intervals of preferably one second.

Any sensor installed to record spin speed and water temperature in the tub does not have to alter the machine conditions.

The appliance has to be installed according to the instruction of the manufacturer in the "user manual". In particular, the appliance has to be placed on a horizontal support and has to be levelled during a spinning cycle (meaning to adjust feet so a minimum of vibration occurs during spinning). The position of the appliance has to be marked on the floor.

2.6 Initial examination

The washing machine has to undergo an initial visual inspection, in order to verify whether the machine is intact and undamaged, and the appliance is fit for the test use:

1. First, the packed machine is inspected visually for any damages.
2. Second, after unpacking, the machine is inspected visually for any damages.
3. Third, after opening the back plate (needed to place the drum speed sensor) and taking off the work top, all visible components are checked for damages and are documented by taking pictures. All places where debris may be found after a durability test (e.g. below the belt) have to be inspected and documented by taking pictures. After this visual inspection the parts are put back on the machine in positions as before.
4. Fourth, also the status of the door gasket has to be checked and documented.

Fifth, the main washing programmes for cotton load (cotton wash from cold up to 60°C, separate spinning, separate rinse & spin cycles) are executed with empty load, with and without using any option which allows the reduction of the duration of the programmes, following the manufacturer instructions. Data of these operations are recorded.

2.7 Washing performance and stress testing

The performance and stress testing of a washing machine has to take into account its mechanical robustness and the capability to perform washing operations after a series of stress cycles. The testing consists in the repetition of two phases:

1. Washing performance test: series of 10 washing cycles.
2. Stress test: series of 100 washing and spinning cycles under conditions of mechanical and thermal stress.

Washing performance tests are executed to check the possibility of the washing machine to perform the washing function before and after the stress induced tests. Stress cycle tests are executed to check the robustness of the machine to mechanical and thermal stresses.

All tests are based on cotton programmes as they are the most used programmes by the consumer (Boyano et al. 2017). Modifications could be applied to the procedure in the future to align with the final output of the ongoing revision of the Commission Regulation (EU) No 1015/2010 and of the Commission Regulation (EU) No 1061/2010.

2.7.1 Washing performance test

A washing performance test consists of a series of 10 washing cycles to be run following closely EN60456:2016[13], meaning:

- 2 cycles at normal cotton 40 °C programme half load;
- 3 cycles at normal cotton 40 °C programme full load;
- 2 cycles at normal cotton 60 °C programme half load; and
- 3 cycles at normal cotton 60 °C programme full load.

The maximum possible time reduction offered by the washing machine for these programmes may be used to save time of testing, but the maximum spin speed does not have to be reduced. If a verification of the requirements as set out in Commission Regulation (EU) No 1015/2010 and of the Commission Regulation (EU) No 1061/2010 – or any follow-up regulation – is intended, the test should follow strictly the requirements of the relevant standard or transitional measures.

[13] Modifications could be applied to be consistent with the final output of the ongoing revision of the Commission Regulation (EU) No 1015/2010 and of the Commission Regulation (EU) No 1061/2010

In all tests, test load and test strips have to be applied as defined in section 2.4. Strips have to be evaluated after the test.

The washing performance tests have to be conducted at the beginning and after every 100 stress cycles (meaning after the 100th, 200th, 300th and 400th stress cycles, and resulting in a total of 450 cycles).

The following performance parameters have to be measured for each washing cycle according to EN 60456, and compared to the measurements obtained during the first washing performance tests:

- Total energy consumption (in kWh);
- Total water consumption (in L);
- Cycle duration (in min);
- Water extraction performance (in %);
- Washing performance.

Another parameter that has to be monitored is the actual maximum spin speed (in rpm) and duration of maximum spin speed (in s) reached by the washing machine and a rpm-diagram [min; rpm] of the cycle has to be developed.

Inlet water temperatures has to be also recorded and used to analyse differences in energy consumption and washing performance of the tested washing machine.

The test load has to be conditioned[14] and normalised[15] following IEC 60456:2010 before and after the test series and has to be normalised always after the 10 washing cycles of a washing performance test, to avoid that the load changes its properties and influence the washing performance of the following washing cycles.

IEC A* detergent has to be used and dosed according to EN60456:2016.

A visual inspection has to follow the washing to detect leakages.

2.7.2 Stress test

A stress test consists of 4 blocks of 100 washing and spinning cycles. For each block of cycles, 70% of the cycles have to be rinse & spin cycles and the other 30% have to be washing cycles performed according to the washing programmes included in Table 7. The execution of those 100 cycles may be in arbitrary order to allow adaptation to local testing conditions, e.g. to adjust the workflow in an optimal way.

Washing cycles (see Table 7) consist of running cotton washing programmes. The following conditions have to be respected:

- The washing machine has to be loaded with an arbitrary load having a mass equal to half of the rated capacity;
- Neither soil strips nor other ballast soil have to be used;
- No detergent has to be used;
- The temperature of each washing programme has to be between 20°C (cold) and 60°C[16];
- The washing cycles average temperature has to be 40±5°C, calculated with nominal values of the programme temperature;
- Short programmes or options shortening the programme duration may be used if they are not reducing the maximum spin speed (see section 2.6).

14 Conditioning is the process of bringing the base load to reach a known remaining moisture content after normalisation and drying at the completion of a test series in order to check the standardised mass of each load item prior to commencing the next test series (IEC 60456:2010, 6.4.5.1)

15 Normalisation is the process of washing the base load in the reference machine using a specified programme in order to bring the base load back into a standardised state prior to commencing the next test series. (IEC 60456:2010, 6.4.4.1)

16 90°C has been not considered because not frequently used

Spinning cycles consist in running the rinse & spin cycles of the washing machine. The following conditions have to be respected:

- The washing machines have to be loaded with cotton articles having a mass equal to two thirds of the rated capacity (because formation of unbalance is highest at this load size).
- The load has to be dried, or at least spun at 1400 rpm, before loading the machine.
- The load has to be untightened between two successive spinning cycles.

After each cycle a rest period with a minimum duration of 5 minutes has to be respected before starting a new cycle.

2.7.3 Overview of the durability testing procedure

Table 7 gives an overview of the whole test procedure:

Table 7: Overview of the durability testing procedure

Step	Test cycle #	Details of the step
Initial inspection	-	To be done outside and inside of the machine
Set-up and preparation	-	Time-temperature-spin diagrams of all relevant programmes with empty load, with and without applying time reduction options Marking of the machine on the floor Conditioning of the load
Washing performance tests (10 cycles) – series I	1-10	Normalisation of the load 2 cycles with normal cotton 40°C programme at half load, 3 cycles with normal cotton 40°C programme at full load, 2 cycles with normal cotton 60°C programme at half load, 3 cycles with normal cotton 60 °C programme at full load
Stress test (100 cycles) – series I	11-110	In arbitrary order: 70% rinse&spin (two third load) and 30% washing cycles (half load) Washing cycles: 10 cycles with normal cotton 40°C 10 cycles with normal cotton 30°C 5 cycles with normal cotton 60°C 5 cycles with normal cotton cold (20°C) Average temperature of the washing programme = ~40 °C
Washing performance test (10 cycles) – series II	111-120	As for test cycles #1-10
Stress test (100 cycles) – series II	121-220	As for test cycles #11-110
Washing performance test (10 cycles) – series III	221-230	As for test cycles #1-10
Stress test (100 cycles) – series III	23–330	As for test cycles #11-110
Washing performance test (10 cycles) – series IV	331–340	As for test cycles #1-10
Stress test (100 cycles) – series IV	341-440	As for test cycles #11-110
Washing performance test (10 cycles) – series V	441-450	As for test cycles #1-10
Final inspection		To be done outside and inside of the machine Components may be extracted and taken apart

2.8 Final examination

At the end of the test, the following assessment has to be carried out:

- Analysis of the spin speed profile for all washing and spinning cycles executed during the entire test, with a particular emphasis on its behaviour over the 400 stress cycles.
- Analysis of the performance parameters (see 7.1) assessed in the five blocks of the washing performance test, consisting each one of 10 washing cycles.
- Analysis of the movement of the machine during the entire set of 450 cycles.
- Analysis of the level of abrasion or wear and tear for all parts which can be visually checked, in comparison with the results of the initial inspection (see 6).
- Analyse the durability of the machine with respect to reference failure and malfunctioning categories (see below).

Failure and malfunctioning categories:

- Cat 1: damage of parts of the machine during the test.

  - Cat 1a are damages which can be repaired by a service technician with reasonable amount of money (<50% of the price of the machine).

  - Cat 1b are damages which cannot be repaired at a reasonable amount of money (≥ 50% of the price of the machine).

  - The amount of money needed for a repair is the standard cost for the repair of such a failure (see Section 1) and does not consider that the repair may be done under any guarantee.

- Cat 2: visible wear and tear of parts of the machine, which have not yet caused neither a damage nor a loss of function but may lead to failures at a later stage of use of the machine;
- Cat 3: misbehaviour of the machine during the tests, like strange noise or vibrations or movements of the machine;
- Cat 4: loss of functional performance between the initial and the final washing runs. A loss is manifested if the difference is found to be larger than twice the verification tolerance values as defined in Regulation 1061/2010 (a certain variation may be considered as "natural")[17].

[17] Modifications could be applied to be consistent with the final output of the ongoing revision of the Commission Regulation (EU) No 1015/2010 and of the Commission Regulation (EU) No 1061/2010

2.9 Information to be reported

Information to be reported at the end of the testing are shown in Table 8

Table 8: Overview of information to be reported

Step	Information
General procedure and conditions	Actual conditions maintained throughout the test, including range observed: • Supply voltage; • Supply frequency; • Total water hardness; • The temperature of water supply; • The static pressure of the laboratory supply water; • The ambient temperature of the test room; • Test materials and base loads characteristics; • Test strips characteristics
Initial inspection	Written and graphical observations from the initial inspection of the product, both in packed and unpacked situation. Records of data (energy and water consumption, residual moisture content, cycle duration, spin speed over time) when executing the main washing programmes.
Washing performance tests	For each test cycle, the following data has to be recorded: • Total energy consumption (in kWh); • Total water consumption (in L); • Cycle duration (in min); • Water extraction performance (in %); • Actual maximum spin speed reached by the washing machine (in rpm) and duration of this speed (in s); • Washing performance; • Any break or un-normal behaviour (e.g. sound, movement) of the machine. Mean values and standard deviations have also to be calculated and reported.
Stress tests	For each test cycle the maximum spin speed reached by the washing machine (in rpm) and the duration of this speed (in s) have to be recorded.
Final examination	Documentation of each observed failure and malfunctioning according to the defined categories.

3. APPLICATION OF THE TESTING PROCEDURE

The testing procedure was applied to two models of washing machines on the market. Background information and results of the testing are presented in this section.

3.1 Materials and conditions

3.1.1 Machines selected and experimental set-up

Main characteristics of the front loading washing machines selected for the testing are described in Table 9. Both machines are declared as A+++ energy class[18] with spin speed of 1400 rpm and class B spinning performance.

Table 9: Characteristics of the selected washing machines[19]

Parameter	Device "D"	Device "E"
Energy Efficiency class	A+++	A+++
Annual energy consumption	166 kWh	153 kWh
Annual water consumption	9586 L	10560 L
Rated capacity	7 kg	6 kg
Max spin speed	1400 rpm	1400 rpm
Spinning performance class	B	B
Price	329 EUR	379 EUR

The machines were connected to a test bench in the climatic controlled laboratory at University of Bonn. Internal water temperature was measured by a thermo-element (type NiCr-Ni coated thermocouple sensor) implemented through the fixation of heating element. Both devices were connected to the local water supply which has a water hardness of about 1.2 mmol/L.

In parallel to the first series of washing performance tests five washing cycles in a Reference machine (type Wascator FOM 71 CLS) in the reference programme Cotton 60 °C were operated using similar conditions to assess the reference values for measuring the cleaning performance following EN 60456:2016.

3.1.2 Testing conditions

The following ambient conditions are maintained throughout most of the time of the tests:

- Room temperature: (23 ± 2) °C
- Relative humidity: (50 ± 5) % RH

[18] The selection was also based on logistic reasons. No machine with a lower energy performance was made available for the laboratory at the time the testing had to start.

[19] The identification codes "A", "B", "C" were used for devices analysed in previous test campaigns (Tecchio et al., 2017)

- Voltage: 230 V ± 1 %
- Frequency: 50 Hz ± 1 %

During a period of about four weeks the room temperature and humidity could not be maintained within the given range due to a break-down of the air conditioning system in the testing laboratory. No influence on the performance of the machines was observed.

3.1.3 Initial examination

The washing machines underwent an initial visual inspection. There was no visual damage on the packaging or on the machines itself.

After opening the back plate and taking off the work top of both machines, all visible components were checked for visual damages. No visual damages were found. The door gaskets were checked as well, with no visual damages.

Pictures were taken of the machines. Visible components on the inside were photographed, to be compared with pictures of the same components after the test.

3.1.4 Installation of spin speed measurement

The spin speed sensor (Wachendorff Elektronik, inkrementaler Drehgeber WDG 40A-60-ABN-G24-K2) was installed by connecting the sensor with a flexible hose to the shaft of the drum. A frame was custom made for each machine to fix the sensor on the back side cover (see Figure 10).

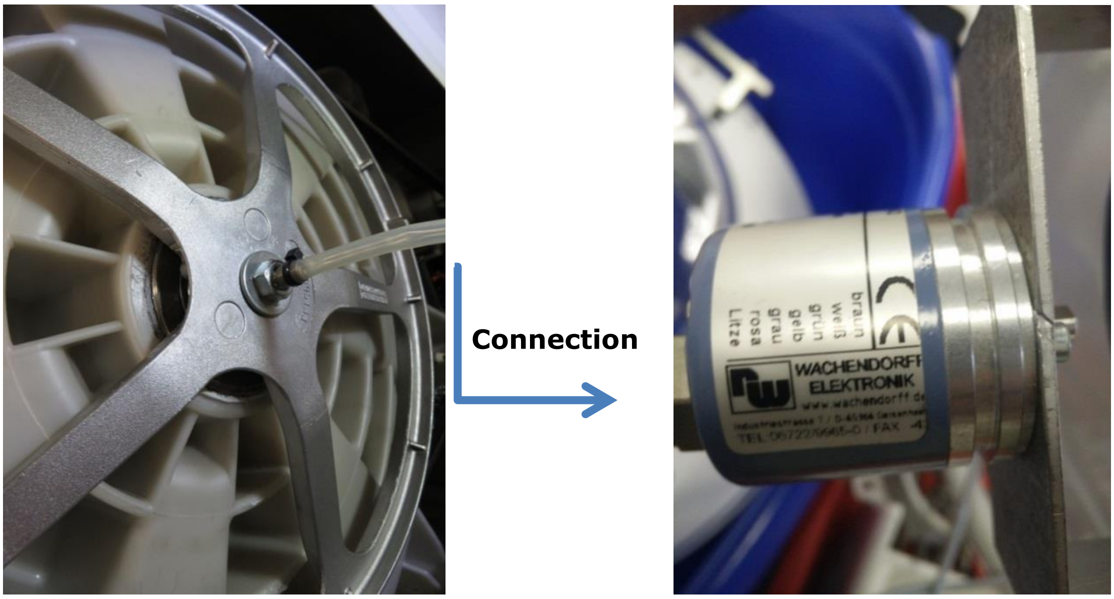

Figure 10: Spin speed sensor installed for the test

3.1.5 Check of relevant programmes

Following the procedure described in Section 2, all relevant cotton washing programmes were operated once, with empty load and without detergent, to observe the main characteristics of these programmes. Additionally, the time-saving option was selected to see the influence of this option. Performance parameters are reported in Table 10 and in

Table 11. The analysis of performance data show that consumption values at empty load are significantly lower for Device E.

When the time saving option is selected, Device D reduces the water consumption by about 10 L for all programmes with temperatures of 40 °C or higher, while Device E reduces the water consumption by about 5 L independently of the temperature.

The maximum spin speed of declared 1400 rpm is approached by both devices. However, when the time reduction option is activated, the programmes of Device E run the highest spin speed only for some ten seconds.

The analysis shows that both machines have very different characteristics of their basic programmes for cotton loads as well as different sensor systems to detect load and, probably, also unbalance. Cotton ("Baumwolle") programmes are likely to be used frequently by consumers (see Section 2.7). The rinse and spin ("Spülen") programmes are used in the stress tests.

Table 10: Initial check of programmes for Device D

Programme	Energy (Wh)	Water (l)	Time (min)	Max. temp. (°C)	Max spin speed (rpm)	Max spin speed duration(s)
Baumwolle 95 °C	1499	56.6	133	85.0	1385	143
Baumwolle 95 °C schnell	1630	48.3	122	95.6	1380	144
Baumwolle 60 °C	1147	49.7	159	68.1	1381	143
Baumwolle 60 °C schnell	1020	37.7	101	69.9	1378	144
Baumwolle 40 °C	707	49.8	117	49.1	1384	143
Baumwolle 40 °C schnell	695	38.8	91	48.7	1379	143
Baumwolle 30 °C	375	39.0	121	35.1	1382	144
Baumwolle 30 °C schnell	381	38.2	84	33.5	1385	142
Baumwolle 20 °C	220	37.8	78	27.2	1389	144
Baumwolle 20 °C schnell	301	38.3	79	30.8	1386	143
Spülen (Rinse and Spin)	83	38.9	25	25.2	1382	144

Table 11: Initial check of programmes for Device E

Programme	Energy (Wh)	Water (l)	Time (min)	Max. temp. (°C)	Max spin speed (rpm)	Max spin speed duration(s)
Baumwolle 90 °C	802	27.3	102	93.6	1401	82
Baumwolle 90 °C speed perfect	924	22.3	83	93.6	1401	81
Baumwolle 60 °C	547	23.5	108	82.6	1401	68
Baumwolle 60 °C speed perfect	597	20.0	72	83.3	1401	12
Baumwolle 40 °C	352	23.6	107	71.2	1401	82
Baumwolle 40 °C speed perfect	319	17.4	64	73.8	1402	13
Baumwolle 30 °C	249	23.7	105	67.3	1401	67
Baumwolle 30 °C speed perfect	217	17.8	64	67.2	1401	13
Baumwolle 20 °C	150	23.9	106	37.5	1403	66
Baumwolle 20 °C speed perfect	119	17.7	65	53.1	1402	12
Spülen (Rinse and Spin)	39	13.9	22	25.3	1402	47

3.1.6 Washing performance test

3.1.6.1 Selected programmes

The programmes reported in Table 12 were selected for the washing performance test.

Table 12: Programmes selected for testing the washing performance

Device D	Device E	Load	Repetitions
Baumwolle + 40 °C	Baumwolle + 40 °C	Half	2
Baumwolle + 40 °C	Baumwolle + 40 °C	Full	3
Baumwolle + 60 °C	Baumwolle + 60 °C	Half	2
Baumwolle + 60 °C	Baumwolle + 60 °C	Full	3

3.1.6.2 Loads

Loads were composed of load items as defined in EN 60456:2016, but of an age of more than 80 washing cycles. The loads consisted of items reported in Table 13.

Table 13: Loads used for testing the washing performance

Item	Number of items loaded	
	Device D (total load = about 7 kg)	Device E (total load = about 6 kg)

Sheets	2	2
Pillow cases	12	8
Towels	24	25

Normalisation of the load was done before and after each block of ten washing performance tests. Conditioning was done at the beginning of the tests in the climatic controlled room at (23 ± 2) °C and (50 ± 5) % relative humidity (equivalent to (20 ± 2) °C and (65 ± 5) % relative humidity as defined in EN60456:2016). The conditioned weights were recorded on a balance (type Mettler Toledo, BBK 422-35 LA)

3.1.6.3 Detergent

Given the supply with local water the amount of detergent was adjusted accordingly at the mid-point between the given (6.3.2 in EN60456:2016) water hardness dosing of soft and hard water using the formula 33.5 g + 10 g/kg. The amounts of detergent to be used (in grams) is reported in Table 14.

Table 14: Amount of detergent to be used (in grams) for different load sizes and for the reference machines

Detergent composition (%)		Machine's load size				Reference machine	Batch identification
		3 kg	3.5 kg	6 kg	7 kg		
Basic det. A*	77%	48.9 g	52.7 g	72.0 g	79.7g	70.8 g	150-285
Bleach	20%	12.7 g	13.7 g	18.7 g	20.7 g	18.4 g	239-509
TAED	3%	1.9 g	2.1 g	2.8 g	3.1 g	2.8 g	001193
Sum	100%	63.5 g	68.5 g	93.5 g	103.5 g	92.0 g	

3.1.6.4 Test strips

Test strip type 108 (IEC/EN 60456-Streifen, IEC Ed. 5) from Swissatest Testmaterialien AG batch 120 were used (Test strip data sheet in the Annex C).

3.1.6.5 Data recorded

Operational data were recorded in 1 sec intervals. All in all, following data are reported:

- Total energy consumption (in kWh);
- Total water consumption (in L);
- Cycle duration (in min);
- Water extraction performance;
- Actual maximum spin speed reached by the washing machine (in rpm) and duration of this speed (in sec);
- Washing performance;
- Any break or un-normal behaviour (e.g. sound, movement) of the machine.

3.1.7 Stress test

A block of 100 stress tests consists of

- 70 rinse & spin cycles; and
- 30% washing cycles.

3.1.7.1 Rinse & spin cycles

3.1.7.1.1 Selected programmes

The programmes selected for the rinse & spin cycles in the two devices are reported in Table 15.

Table 15: Programmes selected for the stress test as rinse & spin cycles

Device D	Device E
"Spülen" (rinse)	"Spülen" (rinse) +1400 rpm

Note: Device D is spinning at 1400 rpm as default setting in this programme

3.1.7.1.2 Loads

As defined in Section 2, the load consists of arbitrary cotton articles with a mass of about two third of the rated capacity of each device. Small load items were put in a washing bag. In each load one or two jeans trousers were included as a critical load for unbalance formation.

The load was dried or spun in a small spin extractor at about 2800 rpm between each cycle. The load was loosened between two successive spinning cycles.

3.1.7.1.3 Detergent

No detergent was used

3.1.7.1.4 Test strips

No test strips were used[20]

3.1.7.1.5 Data recorded

Operational data were recorded in 1 sec intervals. All in all following data are reported:

- Total energy consumption (in kWh);
- Total water consumption (in L);
- Cycle duration (in min);
- Actual maximum spin speed reached by the washing machine (in rpm) and duration of this speed (in sec);
- Any break or un-normal behaviour (e.g. sound, movement) of the machine.

[20] Since washing performance is not measured in the stress tests

3.1.7.2 Washing cycles

3.1.7.2.1 Selected programmes

The requirement for the washing programmes is that the average temperature is about 40 °C. The programmes reported in Table 16 were chosen in the two devices.

Table 16: Washing cycle programmes selected for the stress test

Programme	Device D	Device E
10 x Cotton 40 °C	Baumwolle + 40°C	Baumwolle + 40°C
10 x Cotton 30 °C	Baumwolle + 30°C	Baumwolle + 30°C
5 x Cotton 60 °C	Baumwolle + 60°C	Baumwolle + 60°C
5 x Cotton cold	Baumwolle + * (cold)	Baumwolle + cold

Since the maximum spin speed did not change when the time saving option is activated in both devices, as shown in Section 3.1.5, the "fast" option and the "speed perfect" option were always selected in machines D and E in order to reduce the length of testing.

3.1.7.2.2 Loads

The load consisted of load items with an age above 80 cycles as defined in EN60456:2016 at a load mass of 50% of the rated capacity (Device D: 3.5 kg, Device E: 3.0 kg).

3.1.7.2.3 Detergent

No detergent was used

3.1.7.2.4 Test strips

No test strips were used

3.1.7.2.5 Data recorded

Operational data were recorded in 1 sec intervals. All in all, following data are reported:

- Total energy consumption (in kWh);
- Total water consumption (in L);
- Cycle duration (in min);
- Actual maximum spin speed reached by the washing machine (in rpm) and duration of this speed (in sec);
- Any break or un-normal behaviour (e.g. sound, movement) of the machine.

3.2 Results

3.2.1 Initial inspection

The visual inspection of both machines is documented in Annex B.

3.2.2 Washing performance tests

3.2.2.1 Device D

The results of executing five times the 10 cycles of the washing performance tests at 40 and 60 °C with full (1) and half (1/2) load for Device D are shown in the tables and graphs reported below in this section.

Table 17: Energy consumption values measured for each washing cycle for the washing performance test

Energy in Wh	40 °C ½	40 °C ½	40 °C 1	40 °C 1	40 °C 1	60 °C ½	60 °C ½	60 °C 1	60 °C 1	60 °C 1	Avg (10 runs)
1-10	647	631	1083	1202	1206	1643	1047	1683	1814	1844	1280
111-120	599	608	1084	1035	1107	1079	1130	1813	1804	1825	1208
221-230	605	627	1119	1110	1062	1112	1059	1773	1729	1719	1191
331-340	602	582	1091	1017	1064	1137	1099	1787	1712	1689	1178
441-450	1148	581	1090	1119	1165	1155	1112	1793	1797	1799	1276
Avg.	663		1103			1157		1772			
Std.	172		54			174		52			
Rel. Std. in %	26%		5%			15%		3%			

Table 18: Water consumption values measured for each washing cycle for the washing performance test

Water in L	40 °C ½	40 °C ½	40 °C 1	40 °C 1	40 °C 1	60 °C ½	60 °C ½	60 °C 1	60 °C 1	60 °C 1	Avg (10 runs)
1-10	45.7	45.5	52.6	53.1	54.5	53.0	44.5	55.7	54.5	53.7	51.3
111-120	46.4	49.6	54.7	49.7	54.6	45.5	45.2	54.2	53.3	55.7	50.9
221-230	45.3	46.4	53.2	53.9	54.1	46.0	44.7	53.5	54.4	53.4	50.5
331-340	44.8	46.1	54.4	54.6	54.7	45.3	44.5	53.7	53.7	54.6	50.6
441-450	54.3	45.4	54.6	53.8	53.9	45.3	45.5	53.3	53.7	55.2	51.5
Avg.	47.0		53.8			46.0		54.2			
Std.	2.9		1.3			2.5		0.8			
Rel. Std. in %	6%		2%			5%		1%			

Table 19: Duration of each washing cycle for the washing performance test

Duration in min	40 °C ½	40 °C ½	40 °C 1	40 °C 1	40 °C 1	60 °C ½	60 °C ½	60 °C 1	60 °C 1	60 °C 1	Avg (10 runs)
1-10	130	125	128	199	200	166	146	168	178	179	162
111-120	126	125	191	199	199	146	151	178	180	177	167
221-230	120	125	202	203	191	148	145	173	174	172	165
331-340	123	125	198	197	200	148	150	174	172	171	166
441-450	192	121	194	196	196	154	149	173	175	174	172
Avg.	131		193			150		175			
Std.	22		18			6		3			
Rel. Std. in %	16%		9%			4%		2%			

Table 20: Maximum spin speed measured in each washing cycle for the washing performance test

Max. spin speed in rpm	40 °C ½	40 °C ½	40 °C 1	40 °C 1	40 °C 1	60 °C ½	60 °C ½	60 °C 1	60 °C 1	60 °C 1	Avg (10 runs)
1-10	1382	1030	1032	1334	1372	1020	1020	1020	969	1381	1156
111-120	870	962	1247	1371	1322	1385	994	1295	914	1310	1167
221-230	920	960	1010	992	1386	995	1389	1386	1243	1315	1160
331-340	1385	1384	984	1010	1388	1198	1388	1362	1386	1381	1287
441-450	1393	1388	1392	1386	1355	1346	1390	1353	1344	1028	1338
Avg.	1167		1239			1213		1246			
Std.	234		175			186		170			
Rel. Std. in %	20%		14%			15%		14%			

Table 21 Duration of max. spin speed in each washing cycle for the washing performance test

Duration of max. spin speed in s	40 °C ½	40 °C ½	40 °C 1	40 °C 1	40 °C 1	60 °C ½	60 °C ½	60 °C 1	60 °C 1	60 °C 1	Avg (10 runs)
1-10	142	273	172	142	135	272	264	134	267	136	194
111-120	287	168	242	131	140	138	273	146	258	139	192
221-230	146	278	269	253	139	270	141	139	256	143	203
331-340	141	139	267	268	139	265	141	134	138	139	177
441-450	142	143	136	136	134	145	142	131	138	258	151
Avg.	186		180			205		170			
Std.	65		59			67		56			
Rel. Std. in %	35%		33%			33%		33%			

Table 22: Water extraction performance at the end of each washing cycle for the washing performance test

Water extraction performance in %	40 °C ½	40 °C ½	40 °C 1	40 °C 1	40 °C 1	60 °C ½	60 °C ½	60 °C 1	60 °C 1	60 °C 1	Avg (10 runs)
1-10	53.9	58.5	59.9	53.0	53.6	65.3	60.8	62.2	60.4	52.6	58.0
111-120	70.5	61.8	53.8	50.1	54.0	55.4	60.5	53.1	63.0	52.8	57.5
221-230	65.7	58.6	59.1	60.0	51.3	52.3	61.8	50.0	52.9	54.6	56.6
331-340	51.7	50.3	58.7	58.2	50.4	56.9	50.7	51.2	50.3	50.7	52.9
441-450	52.6	49.0	50.0	50.5	51.7	55.1	50.6	51.5	51.7	57.0	52.0
Avg.	57.3		54.3			56.9		54.3			
Std.	7.1		3.8			5.0		4.3			
Rel. Std. in %	12%		7%			9%		8%			

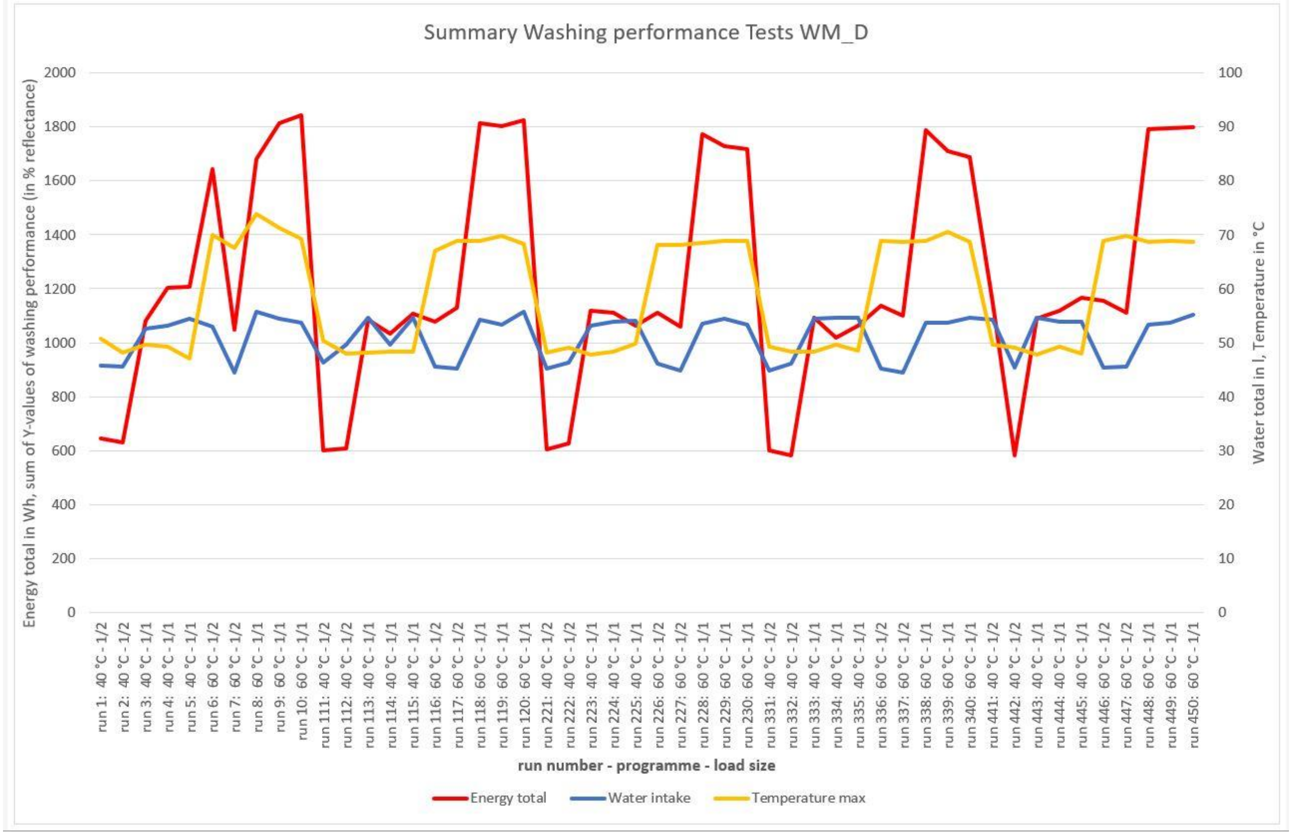

Figure 11: Summary of washing performance tests for device D: energy consumption, water consumption, maximum temperature

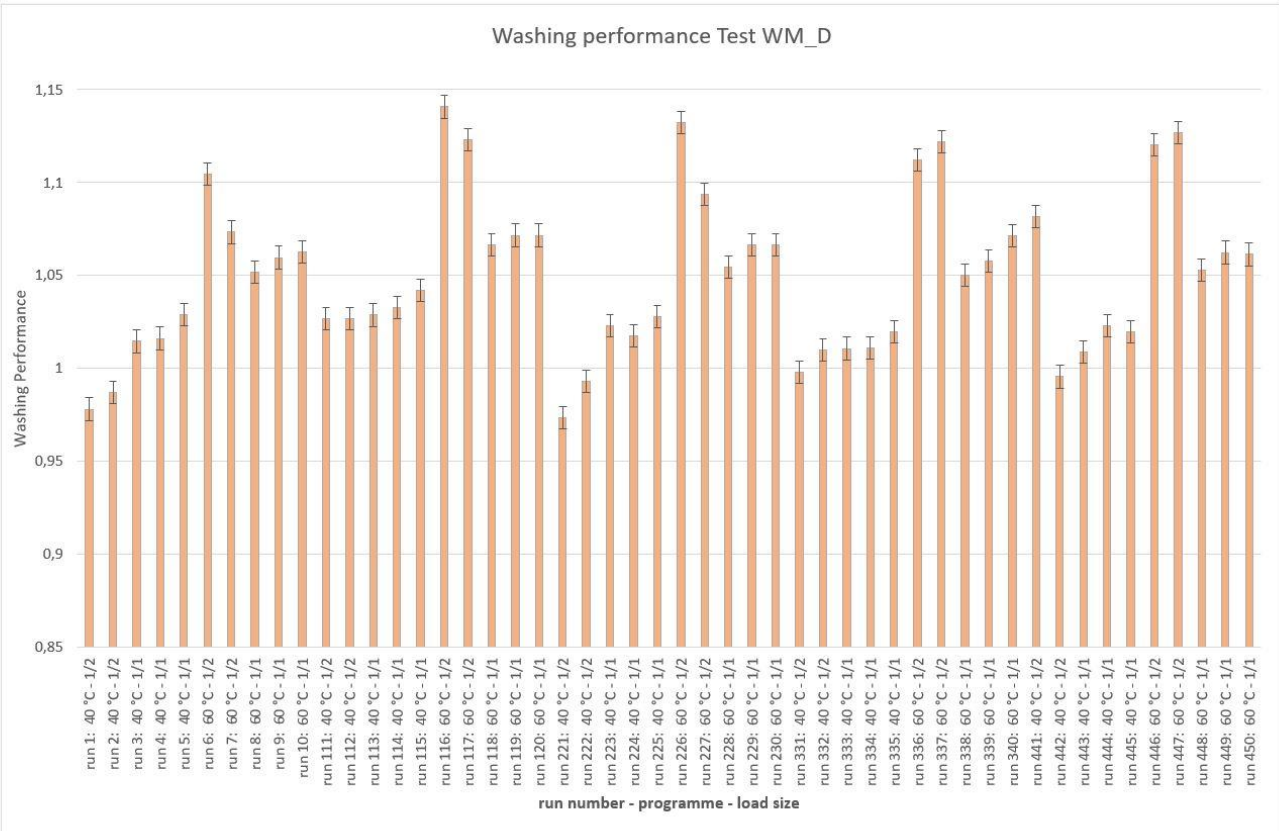

Figure 12: Summary of washing performance tests for device D: washing performance

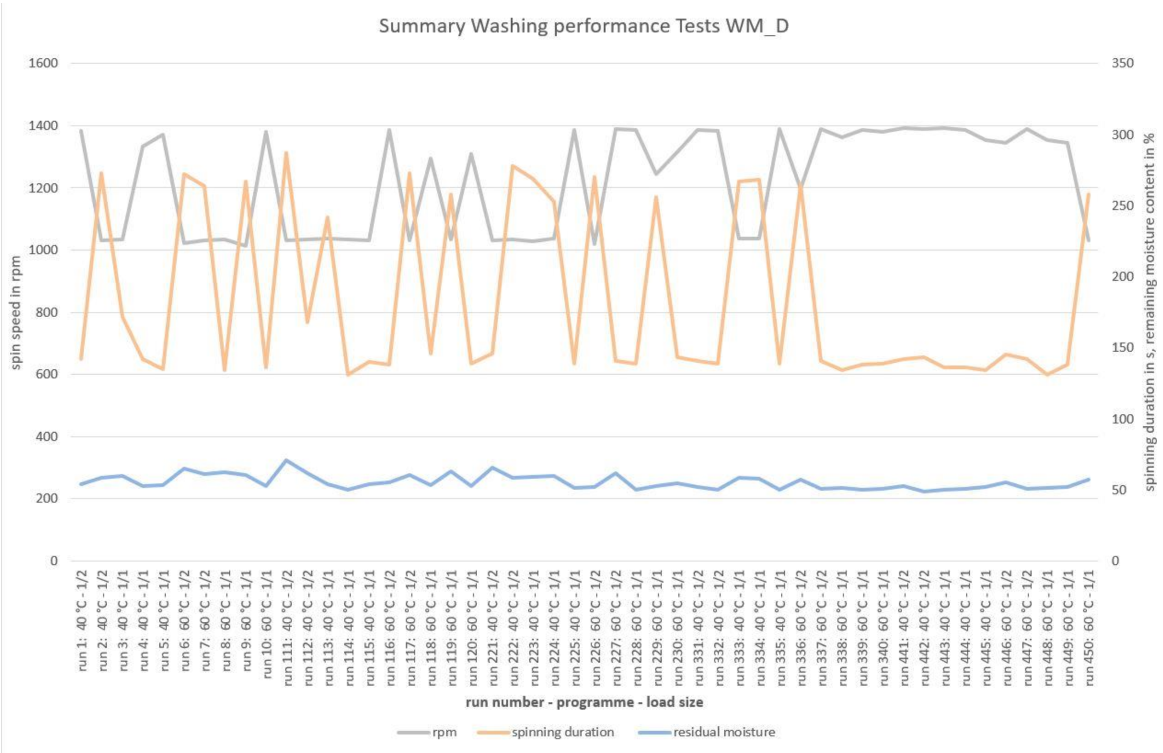

Figure 13: Summary of washing performance tests for device D: maximum spin speed (rpm), spinning duration, residual moisture

Variations for the same type of runs, especially on energy consumption, may be partially explained by variations of the inlet water temperature. Performance may be influenced also by sensors of the washing machine itself (e.g. fuzzy logic, foam detection). For instance, on run nr. 6 the automatic detection of the half load may have not worked properly (same as for run nr. 441).

Looking at the average of 10 washing performance tests there are some trends visible:

- Average energy, water consumption and time seems to be rather constant
- Average maximum spin speed increases (while the spin duration is more or less constant or decreasing). As a consequence, the spinning performance, measured as remaining moisture content, is getting better over time.

This is remarkable, as this means that this washing machine D does not deliver the declared spin speed at the beginning of the test, so when brought in the market. However, the residual moisture content measured as a result of the spinning process does not show such a strong variation as expected from the change of the spin speed. This is explained by the counter-action of the machine itself: whenever the maximum spin speed is not reached, the machine prolongs automatically the spinning process and thus achieves a better spin extraction.

Differences in washing performances between programmes reflect what could be expected: washing at higher temperature and at lower loads deliver a better washing performance.

3.2.2.2 Device E

The results of executing five times the 10 cycles of the washing performance tests at 40 and 60 °C with full (1) and half (1/2) load for Device E are shown in the tables and graphs reported below in this section:

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Table 23: Energy consumption values measured for each washing cycle for the washing performance test

Energy in Wh	**40 °C ½**	**40 °C ½**	**40 °C 1**	**40 °C 1**	**40 °C 1**	**60 °C ½**	**60 °C ½**	**60 °C 1**	**60 °C 1**	**60 °C 1**	**Avg (10 runs)**
1-10	536	600	845	852	832	946	962	1200	1239	1275	929
111-120	652	614	625	757	747	915	890	1134	1212	1290	883
221-230	470	604	679	741	737	894	927	1246	1156	1160	861
331-340	568	482	767	684	692	927	867	1192	1229	1227	863
441-450	588	584	748	795	802	938	900	1258	1268	1295	918
Avg.	570		754			917		1225			
Std.	58		65			29		50			
Rel. Std. in %	10%		9%			3%		4%			

Table 24: Water consumption values measured for each washing cycle for the washing performance test

Water in L	**40 °C ½**	**40 °C ½**	**40 °C 1**	**40 °C 1**	**40 °C 1**	**60 °C ½**	**60 °C ½**	**60 °C 1**	**60 °C 1**	**60 °C 1**	**Avg (10 runs)**
1-10	37.6	38.1	43.5	44.1	43.0	35.7	36.3	41.2	43.2	43.4	40.6
111-120	36.0	36.3	39.5	40.3	41.1	34.6	35.2	40.3	39.8	40.7	38.4
221-230	24.9	36.0	39.3	39.6	39.7	34.4	35.1	41.0	39.4	39.8	36.9
331-340	33.9	32.6	39.1	38.7	37.6	33.1	33.2	38.5	38.6	38.6	36.4
441-450	33.0	33.2	36.4	38.5	38.8	33.2	33.2	38.4	38.3	38.6	36.2
Avg.	34.2		40.0			34.4		40.0			
Std.	3.8		2.2			1.2		1.7			
Rel. Std. in %	11%		5%			3%		4%			

Table 25: Duration of each washing cycle for the washing performance test

Duration in min	**40 °C ½**	**40 °C ½**	**40 °C 1**	**40 °C 1**	**40 °C 1**	**60 °C ½**	**60 °C ½**	**60 °C 1**	**60 °C 1**	**60 °C 1**	**Avg (10 runs)**
1-10	130	133	131	130	133	127	129	128	129	128	130
111-120	131	133	130	132	137	128	128	127	129	127	130
221-230	132	132	131	131	130	128	128	129	128	128	130
331-340	130	129	129	131	131	126	128	129	127	128	129
441-450	130	130	129	131	130	128	129	128	126	127	129
Avg.	131		131			128		128			
Std.	1		2			1		1			
Rel. Std. in %	1%		2%			1%		1%			

Table 26: Maximum spin speed measured in each washing cycle for the washing performance test

Max spin speed in rpm	40 °C ½	40 °C ½	40 °C 1	40 °C 1	40 °C 1	60 °C ½	60 °C ½	60 °C 1	60 °C 1	60 °C 1	Avg (10 runs)
1-10	1401	1400	1401	1400	1403	995	1405	1404	1404	1403	1362
111-120	1405	1401	1406	1407	1404	1403	1405	1364	1403	1402	1400
221-230	1407	1405	1409	1405	1409	1408	1403	1406	1405	1407	1406
331-340	1405	1406	1407	1406	1404	1402	1404	1404	1403	1403	1404
441-450	1408	1409	1406	1409	1409	1407	1404	1375	1408	1411	1405
Avg.	1405		1406			1364		1400			
Std.	3		3			130		13			
Rel. Std. in %	0%		0%			9%		1%			

Table 27 Duration of max. spin speed in each washing cycle for the washing performance test

Duration of max. spin speed in s	40 °C ½	40 °C ½	40 °C 1	40 °C 1	40 °C 1	60 °C ½	60 °C ½	60 °C 1	60 °C 1	60 °C 1	Avg (10 runs)
1-10	93	92	92	92	93	74	66	67	68	68	81
111-120	91	92	91	91	92	66	66	70	66	68	79
221-230	91	92	93	91	93	66	66	66	69	66	79
331-340	92	92	92	91	92	67	67	68	65	66	79
441-450	93	92	92	91	91	67	66	67	66	67	79
Avg.	92		92			67		67			
Std.	1		1			2		1			
Rel. Std. in %	1%		1%			4%		2%			

Table 28: Water extraction performance at the end of each washing cycle for the washing performance test

Water extraction performance in %	40 °C ½	40 °C ½	40 °C 1	40 °C 1	40 °C 1	60 °C ½	60 °C ½	60 °C 1	60 °C 1	60 °C 1	Avg (10 runs)
1-10	54.2	57.5	66.8	53.9	53.7	67.3	60.8	53.2	54.4	54.0	57.6
111-120	53.5	59.1	52.9	52.1	53.1	54.4	61.2	54.3	53.1	53.3	54.7
221-230	57.1	56.2	51.4	52.2	52.3	59.7	54.1	52.3	52.3	53.3	54.1
331-340	56.5	50.6	51.5	51.8	52.1	59.0	53.7	52.2	52.6	52.9	53.3
441-450	56.9	51.8	50.9	52.1	52.7	59.9	53.3	53.1	52.5	52.7	53.6
Avg.	55.3		53.3			58.3		53.1			
Std.	2.7		3.8			4.5		0.7			
Rel. Std. in %	5%		7%			8%		1%			

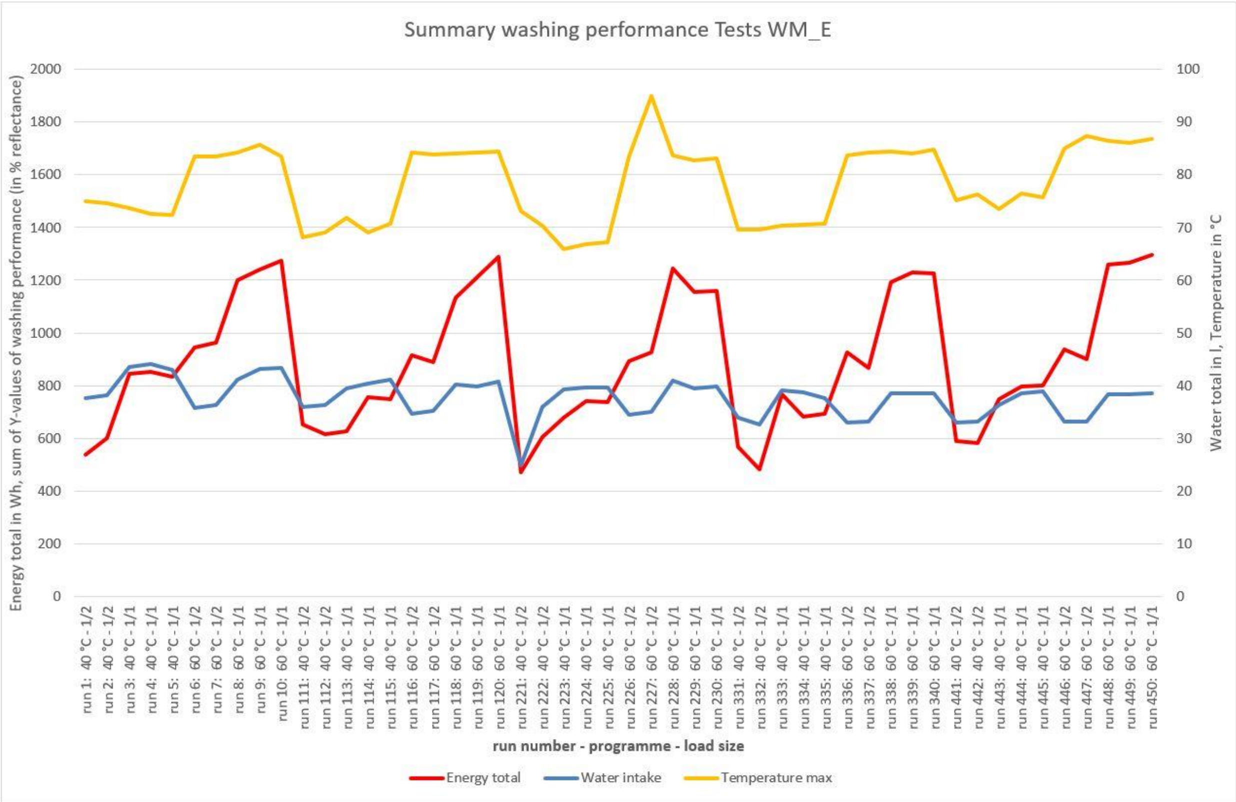

Figure 14: Summary of washing performance tests for device E: energy consumption, water consumption, maximum temperature

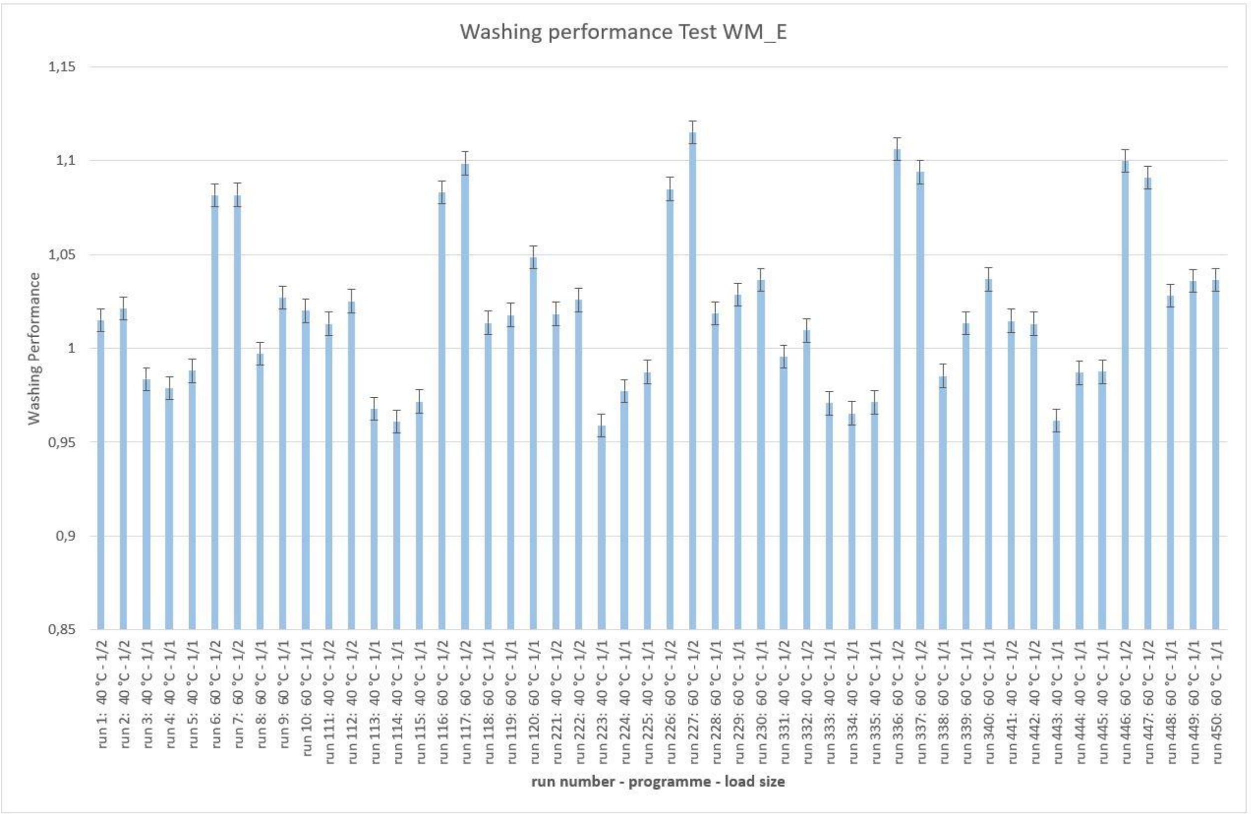

Figure 15: Summary of washing performance tests for device E: washing performance

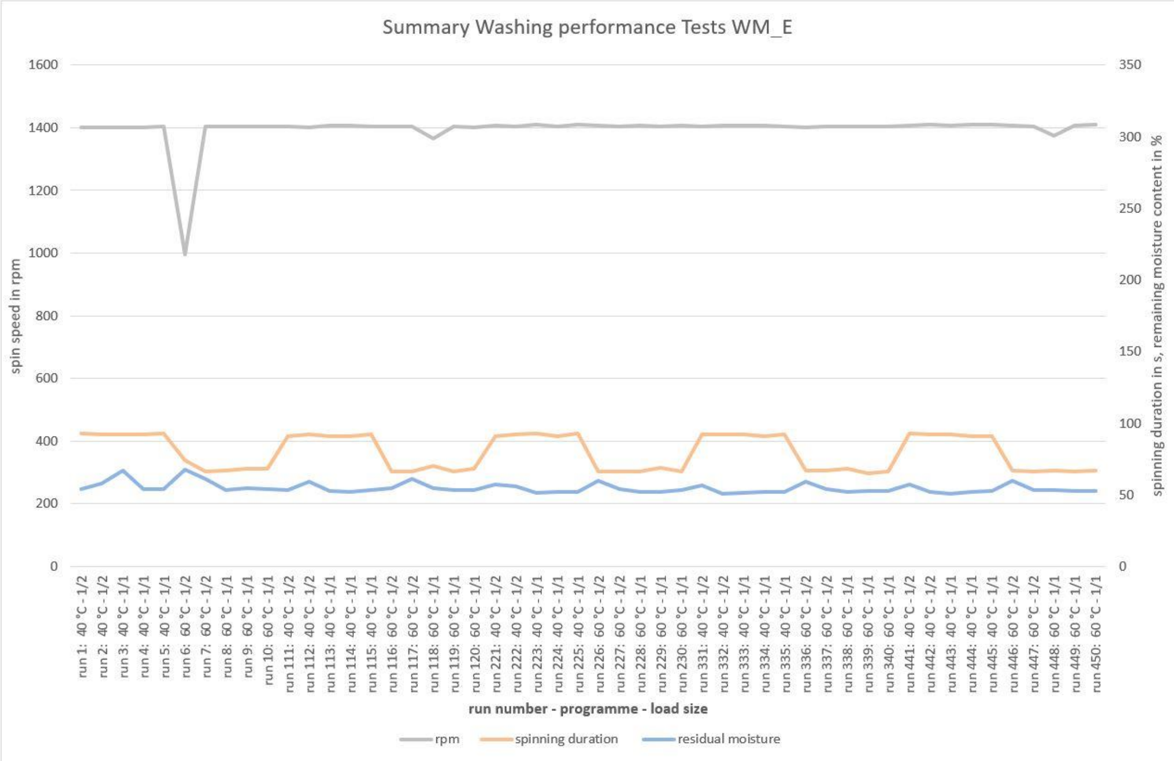

Figure 16: Summary of washing performance tests for device E: maximum spin speed, spinning duration, residual moisture

Variations shown by Device E, especially on energy consumption, may be explained by variations of the inlet water temperature or result from sensory measures of the washing machine itself (fuzzy logic, foam detection). However, Device E shows in general a much more constant behaviour within a test set and over time compared to Device D. Device E manages to perform the washing performance test with less energy and water. This is somehow expectable due to the lower rated capacity (about 85% of that of D). A more careful comparison shows that the energy consumption per kilogram of laundry washed is similar in case of half load, while there are more important differences (about 25%) in case of full load. The specific consumption of water in device E is instead lower (15% or more) independently of the programmes. This could indicate that machine E has a better ability to adapt its performance to the loading conditions. In terms of programme time, Device E is in general faster in full load conditions.

Looking at the average of 10 washing performance tests, the most significant change observed during the test is the remaining moisture content (RMC), which is reducing by about 4 % points from the first to the last set of measurements. As the spinning speed and the spin duration do not show a trend which could explain this behaviour, the effect is considered to be due to the load itself. Albeit the load is normalised always after 10 washing performance tests, there may be some change in the textile structure (e.g. incrustation, loss of fibres) which could influence the water retention properties of the load. However, as the conditioning of the load was done only at the beginning of the test series (following the procedure described in Section 3.1.6.2) no verification of this effect (and possible correction) is possible.

3.2.3 Stress tests

Stress tests consist of rinse & spin cycles and washing tests at different programme temperatures and arbitrary load. These are carried out to check the robustness of the machine to mechanical and thermal stresses. Following the procedure described in

Section 2, the order of execution of programmes has been kept random. A summary of the data is provided in the Annex.

3.2.3.1 Device D and Device E

Looking on the measured maximum spin speed and spinning duration reconfirms the results achieved in the washing performance tests: Device D does not reach the claimed spinning speed in most of the cycles (probably due to unbalance problems) but tries to balance the effect of not reaching the maximum speed by prolonging the spinning process at lower spin speed. Device E reaches the maximum spin speed of 1400 rpm in most cycles but stays at this maximum speed for different times.

3.2.4 Observations during test execution

3.2.4.1 Device D

Some colouring of the door gasket was observed after the third test run of the initial check of programmes, conducted without load and without detergent (see Figure 17 – please note that the picture was taken later).

The machine slightly moved during spinning in the tests nr. 17, nr. 18, nr. 287 and nr. 392. This was probably due to unbalance conditions which were not detected by the control system of the device. A major movement (about 10 cm) was observed in the test cycle nr. 186.

Interestingly, after the test nr. 360 (spin cycle) the display did not work properly and the machine did not provide any sound to indicate the end of the cycle. Nevertheless, everything went back to normal conditions after turning the knob.

Figure 17: Colouring observed in the door gasket of Device D in the early stage of the testing

3.2.4.2 Device E

Some abrasion was visible on the door gasket after the test nr. 3 (see Figure 18). More abrasion was visible on the door gasket after the test nr. 118. This was due to one cloth that was stuck in the door gasket and that was worn out by the gasket and got soiled by rubber abrasion (see Figure 18). Abrasion on the door gasket was more significant after tests nr. 224 and nr. 348 (see Figure 18). However, the device was still able to function properly.

During the test nr. 338, one cloth was partly caught inside the door gasket for about five minutes.

After the test nr. 387, some white smoke came out of the drum when opening the door. There was a smell similar to that of burned plastic/rubber. Some clothes were also smelling. The machine was detached from the electric source to prevent any damage. The service of the manufacturer was called. The technician checked the machine, but could not find any defect. Device E was declared for being safe for continuing to be used. No additional malfunctioning was detected in the remaining runs.

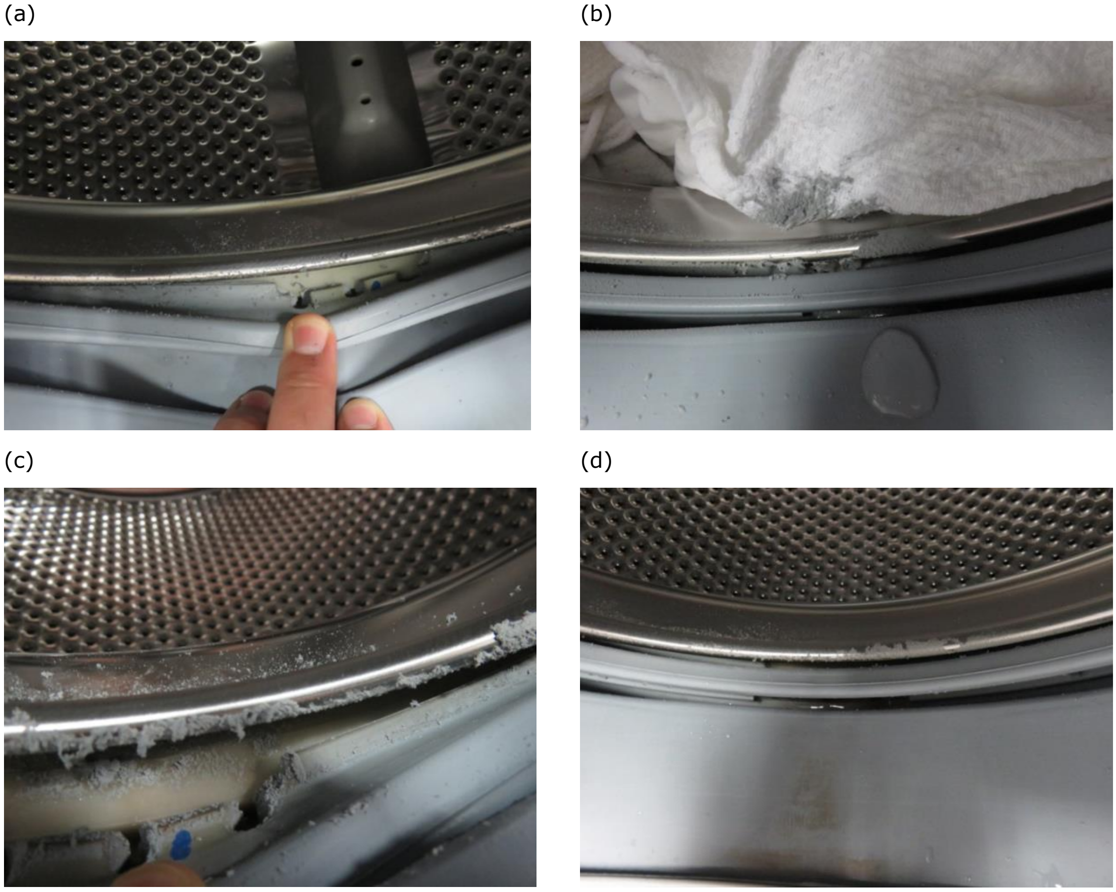

Figure 18: Snapshots of abrasion observed on the door gasket of Device E during the testing

3.2.5 Final inspection

Annex A shows photographs taken to compare the state of some parts of the devices between the initial and the final inspections.

3.2.5.1 Device D

No change between the initial and the final inspections was observed on most of parts. However, a lot of abrasion was visible in folds of the door gasket (see Figure 19). Closer inspection revealed that there was a hole in the gasket (at 7 o'clock position) which would cause a water leakage during washing operation when the water level is sufficiently high (e.g. in synthetic programme).

Also the heating element showed some level of mechanical abrasion at the point where it is fixed to the tub (see Figure 20).

Figure 19: Abrasion and hole observed on the door gasket of Device D during the final inspection

Figure 20: Abrasion observed on the heating element of Device D during the final inspection

3.2.5.2 Device E

No change between the initial and the final inspection was observed on most of parts. However, as observed during the test cycles, abrasion was visible in folds of the door gasket. This was likely originating from the runs where clothes were stuck in between the gasket and the drum.

To try to identify the origin of the smell observed in test nr. 387, the tub of this machine was dismounted and opened (see Figure 21). No indication of any failure mechanism could be found. However, at the outer side of the front drum ring, a thin grey layer was observed which could be easily wiped away. This was not observed at the cylindrical part and the rear part of the drum. It is presumed that this was coming from the cycle nr. 387. Also the heating element showed some level of mechanical abrasion (see Figure 22).

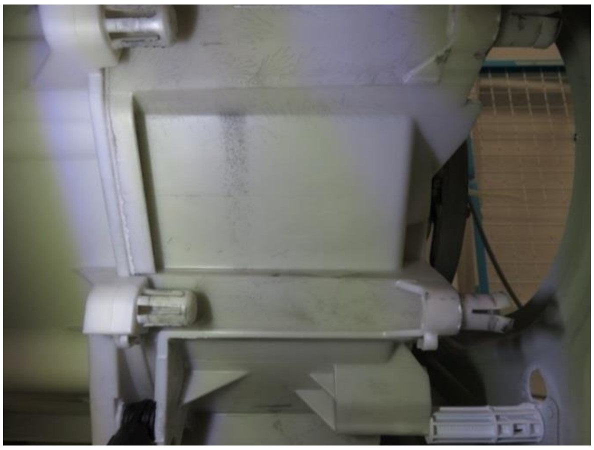

Figure 21: Grey layer observed on the front drum ring of Device E

Figure 22: Abrasion observed on the heating element of Device E during the final inspection

3.3 Summary and discussion

The test procedure described in Section 2 was executed on two different washing machines (called device D and E) over a simulated lifetime period of two years. Both machines are declared as A+++ energy class with spin speed of 1400 rpm and class B spinning performance. Laboratory conditions of IEC/EN 60456 were maintained with some exceptions (local water, usage age of the textiles, storage age of the test strips), mainly for cost reasons. No significant influence on the results is considered to be associated to this simplification.

For the washing performance tests, normal cotton 40 °C and 60 °C programmes were selected without activating the time saving option. These were operated with full and half of the rated capacity.

The stress test consisted of:

- Rinse & spin cycles, where extra rinse programmes were selected consisting of a rinse cycle with a consecutive spinning at the maximum speed (1400 rpm)
- Washing cycles, where cotton programmes at different temperatures were selected and the time saving option was selected.

In total 400 stress test cycles and 50 washing performance test cycles were executed. Where relevant, data of energy and water consumption, programme duration time, drum spin speed and remaining moisture content of the load were recorded, as well the washing performance.

The testing shows that the execution of the washing and rinse & spin programmes are not carried out uniformly throughout the four hundred stress and the forty washing cycles. The reason for the variation can be manifold, coming from variable test conditions, different programmes and sensor controlled programme execution. This is regarded as not critical as it reflects real-life operation of a washing machine.

The analysis of the washing performance tests show some moderate variation in the amount of energy, water and time needed for the same programme.

For device D, significant differences are visible for the maximum spin speed and for the duration of how long this maximum spin speed is applied. This is most probably caused by a too high load unbalance, so that a spin speed of at least 1300 rpm is reached only in 50% of the test cycles. However, the device tries to balance the negative effect of a lower maximum spin speed on the water extraction performance by prolonging the spinning duration (about the double). In average, the water extraction performance for the washing performance tests is measured as 55.4 % for device D, not much different from the 54.6% measured for device E. Device E reaches a spin speed above 1300 rpm in 98% of test cycles and maintains the spinning duration much shorter than device D and constant for each programme.

Overall, no systematic change is measured for any of the average performance parameters measured in the test after 450 cycles, which means no decrease of performance. On the contrary, the water extraction performance was improving.

The results show the relevance of the control procedure for unbalance on the stress induced to the structure and components of the washing machine. This control procedure for unbalance influences, initially, the distribution of the textile load during the start of the spinning. When an equal distribution is achieved, the unbalanced load is low and a high spinning speed may be achieved (allowed). If the load cannot be equally distributed, this control procedure limits, secondly, the mechanical stress to the structure by reducing the spinning profile, especially by reducing the maximum spin speed and its duration. Using this control procedure in the way described allows the stress to the structure to be limited so that the durability of the structure and components is maintained and an acceptable lifetime of the machine is achieved. For the consumer, this procedure guarantees, on the one hand, the lifetime of those parts under mechanical stress. However, on the other hand, the consumer may have to wait longer for the execution of the washing programme, as the repeated attempts to distribute the load equally takes time and, if the maximum spinning speed and duration is limited, it also reduces the spinning efficiency, meaning that the load is wetter than it could or should be.

During the test execution it was observed that Device D moved occasionally during the spinning (by a maximum of about 10 cm). Shortly after the start of the whole test, some colouring of the door gasket was also observed, perhaps due to tap water.

Abrasion was instead observed in device E between the door gasket and the rotating drum. It also happened that a cloth was stuck in the door gasket, worn out and soiled by rubber abrasion. After completion of a spin test, the door was opened and smelly white smoke was formed. The machine was detached from the electric source and the customer service was called in these situations. A complete check was performed without identifying any failure so that the test on the machine was continued.

At the end of the test protocol a final check was performed. On Device D it was found that the rubber door gasket had a hole of some mm in diameter (at about 7 o'clock position). This could have caused a water leakage. Traces of abrasion were also identified on the heating elements.

Some abrasion was visible also on the heating elements of device E, as well as on the door gasket. A thin grey layer was moreover observed in the outer side of the front drum ring which could be easily wiped away. This was not observed in the cylindrical and in the rear parts of the drum. Presumably, this was coming from those cycles where smell was formed.

The stainless steel front side of the drum in both devices seems to come in contact with the rubber door gasket under the stressing test conditions, causing abrasion of the rubber. Under no stress conditions, there is normally a gap of about 1 to 3 mm between the (rotating) drum and the door gasket. When under stress from the unbalanced weight, the drum is deformed during spinning and the gap may be reduced to 0 mm and, consequently, abrasion starts.

For both devices, there was no other sign of abrasion, stress or leakage.

According to the procedure described in Section 2, some failures/malfunctioning categories were detected in the two devices:

- Device D has a category 2 event (a hole in the door gasket which could lead to a water leakage during the lifetime of the appliance) and a category 3 event (occasional movement during the operation).
- Device E has two category 1a events (a cloth stuck in the door gasket that was worn out and soiled by rubber abrasion; a smell that appeared after opening the door).

No loss of function was observed for both devices (category 4 failure), as well as no significant failure of electronic parts, at least for the representative time of this experiment (~2 years). The abrasion on the heating elements of both devices is not considered as relevant for the lifetime operation of the machines.

The results show that the testing protocol, although not representative for the average lifetime of washing machines, can deliver relevant information about the occurrence of failures, malfunctioning and loss of performance.

The total time to execute the test procedure is still considered very long, especially if applied for regulatory purposes, since preparation, initial and final inspections took about 15 h, while the execution of the cycle tests carried out in parallel on two washing machines took about 697 h. Ways to reduce the efforts to run the tests are needed and discussed in Section 4. Modifications should be moreover applied to the procedure in the future to align with the final output of the ongoing revision of the Commission Regulation (EU) No 1015/2010 and of the Commission Regulation (EU) No 1061/2010, and of the related standards.

4. LESSON LEARNT AND WAY FORWARD

The purpose of this study was to provide further knowledge about how to assess and verify the durability of a product, which is a key strategy to save materials and reduce the amount of waste to handle at the End of Life.

A guidance developed by JRC for the assessment of the durability of Energy-related products (Alfieri et al. 2018) was applied to the analysis of washing machines. The methodological steps applied in this study successfully allowed:

- Understanding the durability needs of the product, and identify technical problems which can disrupt the delivery of key functions;
- Analysing stress conditions, design aspects and misuses that could produce failures of key parts and loss of function(s)/sub-function(s) during the operation of the product;
- Identifying key aspects and/or correction measures to avoid / delay possible failures during the lifetime of the product and thus increasing its longevity;
- Developing further knowledge about how to assess and verify the durability of the product.

The general approach followed for the analysis of washing machines could be tailored and applied also to other products. This could serve also as input to the work carried out by CEN/CENELEC JTC10 under Mandate 543 and aimed at the development of general standard methods on material efficiency aspects of Energy-related Products[21].

The application of the guidance to the analysis of washing machines was in particular oriented to improve the technical background related to the assessment and verification of the durability of the product through the development and application of a testing procedure.

It was recognised that a testing procedure should:

- Be as representative as possible for real conditions of use;
- Be suitable for verification purposes (i.e. be reproducible and repeatable);
- Minimize the risk of circumvention by test cycle detection;
- Allow drawing conclusions about the durability of the product with a reasonable effort (in terms of time and resources);
- Define durability not only as avoidance of break-down but also as conservation of the functional performance.

The presented testing procedure, which builds on existing experience on durability testing and main failure mechanisms of washing machines (Tecchio et al. 2017), intends to:

- Focus on the testing of the entire product under conditions closer to real life operations (the use of a fixed unbalance is avoided; stresses due to washing and rinsing cycles are integrated)
- Reduce the length of the testing by applying Accelerating Life Testing;
- Cover mechanical and thermal stresses, as main cause of damages, as well as functionality aspects as loss of performance (washing performance parameters are monitored).

Moreover, a balance has to be sought between the desirable lifetime target for the testing procedure (e.g. the average lifetime of the product) and a practical length that can be applicable for verification purposes.

This complex task resulted in a series of test cycles which impose realistic thermal and mechanical stresses to washing machines and which are executed many times mimicking

[21] https://www.cenelec.eu/dyn/www/f?p=104:7:1299206399119101::::FSP_ORG_ID:2240017 (accessed on 1 October 2018)

a specific lifetime period of the device in a shorter period of time. The procedure was executed in a trial with two washing machines for a simulated usage period of two years. The coverage of the first two years of use of washing machines can allow identifying early failures, malfunctioning and loss of performance in worst performing products, as well as any potential sources of failures. This could be potentially suitable for Ecodesign purposes. The testing of a representative lifetime of 12 years could instead require about 6 times the time and resources required by the application of this procedure.

The procedure has appeared to be suitable for laboratory testing and to be realistic in the sense that the induced stresses caused thermal and mechanical wears and tears typically found in washing machines during their lifetime. However, due to the limited sample of models tested, it is not possible to deduce whether results are repeatable and reproducible, or extendable to other models and for longer durations.

As follow-up of this study, it is recommended to apply the testing procedure to a larger sample of devices and for longer periods of time, to understand if and how the functional performance is decreasing after the first 2 years of use of washing machines, as well as if and when minor problems encountered during the operation of the device could become major failures. This would help understanding better what makes sense to monitor and how long in the procedure, especially if this is intended to be applied in the future for regulatory purposes. Further developments should address the monitoring of noises and of possible movements of the machine. Alignment with the final output of the ongoing revision of the Commission Regulation (EU) No 1015/2010 and of the Commission Regulation (EU) No 1061/2010 (and related standards) should be moreover sought.

However, it should be noted that, in practice, the testing procedure has already taken a considerable amount of time (in total 697 h for one person for two washing machines in parallel). This time is equivalent to about 87 working days (considering 8 working hours per day), or to 29 days if experiments could be run 24 h a day. If this were to be refined and applied for verification / monitoring purposes, this is deemed too long and ways to shorten the testing time would be needed. Without changing the general set-up of the procedure, options to reduce the testing time could include:

1. Leave out or reducing washing performance tests in between the stress tests: This would mean to have washing performance tests only at the start and at the end. As a consequence, possible changes in washing performance and consumption values cannot be tracked over time but only compared between the beginning and the end of the test. As an example, 30 washing cycles less could allow saving about 120 h (17% of the total time).
2. Use "short" programme options for the washing performance tests. This would save about 1 h per cycle, for a total of about 50 h (7%). However, it is recognised that washing performance tests should be aligned as far as possible to the methods enforced under Ecodesign and Energy Labelling regulations, which could require longer testing times if the test is foreseen as a verification test under these regulations.
3. Leave out the intermediate (spin) drying of the load between the stress test cycles. This would allow performing those cycles in a continuous process, with or without pauses between different cycles. As the load is spun at the end of the stress cycle anyhow, the extra (spin) drying performed in a separate (spin) dryer does not change the starting conditions for the following process a lot. If it is assumed that this process (unloading, spin drying, loading) takes about 15 min, this would sum up to a total saving of 100 hours (=400 cycles for 15 min) (14% of the total time).

If points 1 and 3 are implemented, robots could be potentially used for restarting programmes during the stress tests (rinse & spin or washing cycles), with possible saving of costs and/or operator time. Only the execution of the washing performance tests at the start and at the end of the stress tests would necessarily need an operator. Moreover, the overall duration of the test would decrease of one third.

This saving of time could be alternatively invested to test the product for a duration representative of longer lifetimes and/or tracking the functional performance along different moments of the lifetime.

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ANNEX A - MINUTES OF THE WORKSHOPS HELD WITH STAKEHOLDERS

1st Workshop about testing the durability of WM (15 March 2018, 9:00-11:10)

Agenda

1. Introduction on context (JRC)
2. State of play and review of durability aspects for WM (University of Bonn)
3. Proposed approach for assessing the durability of WM + timeline (University of Bonn)
4. Initial discussion about parameters for testing the durability of WM and selection of machines to be tested (University of Bonn)
5. Sum-up and closure (JRC)

List of organisations

Organisation
Aankoop
Altroconsumo
BSH
Electrolux
European Commission - DG ENV
European Commission - JRC
LGE
University of Bonn

Minutes

JRC presented the study, which is developed in the framework of the Circular Economy Action Plan and aims to improve the technical background related to the assessment and verification of the durability of washing machine. The project is managed by the Joint Research Centre Directorate B - Circular Economy & Industrial Leadership unit –, in close cooperation with prof. R. Stamminger for the testing of washing machines. The work, which is the follow-up of a former study published in 2017 by JRC, is expected to be completed by the end of 2018 and has a research orientation. Outcomes will allow making a further step in the durability testing of washing machines, possibly feeding also in the CEN/CENELEC JTC10 standardisation process, but will not interfere with ongoing policy processes.

The University of Bonn presented the results of the previous study and testing campaign performed in collaboration with JRC Ispra, as well as the proposed approach for the new testing procedure (details made available).

Test-Aankoop reported about its experience in doing a pure spinning test with washing machines. According to them, the use of warm water would be relevant.

Altroconsumo expressed some concern about a stress focusing on 440 cycles, corresponding to an amount of time equivalent to the warranty period and thus much less than the expected lifetime. The University of Bonn highlighted that the proposed endurance test is made of a mix of spinning and washing cycles, and also focuses on the performance of the washing machine. It will be possible through this test to verify whether or not the machine is doing what is supposed to do during the warranty lifetime. A pure spinning test run for 2500 cycles would not make sense.

BSH expressed concerns with respect to the failure classification at the end of the test and suggested to remove economic considerations, also considering that repair services strongly depend on company policies and would be provided for free during the warranty period.

BSH also suggested to focus on electronics. The University of Bonn clarified that the procedure developed does not directly address electronic components because they are not considered the main cause of failures, however the test procedure includes washing cycles at high temperature which would induce thermal stresses on electronics.

BSH asked about the status of the load used for the washing test. The University of Bonn confirmed that the washing tests will always start with a properly dried load.

Comments were also raised about the use of fixed unbalance masses, in order to simulate the mechanical stress on the machines. BSH and Electrolux argued that this could penalize the washing machine with a better capacity of balancing the load in the pre-spinning phase. Not-fixed masses would be more realistic. Electrolux is going to further investigate this aspect internally in his company and inform the study team. As general comment, BSH highlighted the need to design a test that is as much as representative of the consumers use patterns.

Participants were also asked by the University of Bonnr to provide an opinion/feedback on the following issues:

- Washing verification tests: washing cycles according to EN60456:2015 vs. normal programmes run in less time;
- Stress test: ratio of spinning to washing cycles (e.g. 70/30 or 50/50);
- Type and numbers of washing machine to be tested: A+ vs A+++, high- vs. low-end models, high vs. low spinning speeds (e.g. 1000 rpm to 1600rpm).

No comments were raised in this first web-meeting about the programmes to use as washing verification test. With respect to the ratio between spinning cycles and washing cycles, Test-Aankoop suggested to go for the 70/30 option. Most of participants moreover agreed to test low- and high- end models labelled A+++ and representative of average products on the market. Electrolux in particular suggested to test A+++ -10%/-20% washing machines. In terms of spin speed, most participants suggested to focus on 1200/1400 rpm, while BSH recommended to include the extremes (1000-1600 rpm).

JRC and the University of Bonn thanked the participants and informed that the outcomes of the meeting will be circulated and used as input for the second and last web-meeting, organised on 22 March.

2nd Workshop about testing the durability of WM (22 March 2018, 9:00-12:00)

Agenda

1. Recap on context (JRC)
2. Recap on state of play and review of durability aspects for WM (University of Bonn)
3. Revised approach for assessing the durability of WM + timeline (University of Bonn)
4. Final discussion about parameters for testing the durability of WM and selection of machines to be tested (University of Bonn)
5. Sum-up and closure (JRC)

List of organisations

Organisation
Altroconsumo
BSH
Electrolux
European Commission - JRC
LGE
Samsung
University of Bonn

Minutes

JRC introduced experts to the 2nd and last day of the workshop. It was explained that:

- The study is the follow-up of a former study published in 2017 by JRC and aims to improve the technical background related to the assessment and verification of the durability of washing machine.
- The project is managed by the Joint Research Centre Directorate B - Circular Economy & Industrial Leadership unit –, in close cooperation with prof. R. Stamminger for the testing of washing machines.
- The work ,is expected to be completed by the end of 2018 and has a research orientation which will allow making a further step in the durability testing of washing machines, possibly feeding also in the CEN/CENELEC JTC10 standardisation process, but with no interfere with ongoing policy processes (e.g. ED/EL revision of washing machines).

The University of Bonn presented

1. The results of the previous study and testing campaign performed in collaboration with JRC Ispra.

2. The proposed approach for the new testing procedure, which was circulated to all experts involved in the consultation.

Most of participants criticised the use of a fixed unbalance, being this: not representative for normal conditions of use, penalising machines that are able to balance the load, and possibly enabling circumvention. Moreover, since water acts as a lubricant, performing a dry spinning cycle is also not representative of real conditions of use, which is what a testing procedure should try to simulate. The University of Bonn explained that the aim of the study it to carry out an Accelerated Life Testing, and not endurance tests. This means a certain deviation from real life conditions, but there is the need to ensure market and users representativeness. As a consequence, it was agreed that the following changes will be applied to improve the procedure:

1. The rinse & spin cycle will be used (instead of the spin cycle) in 70% of the stress cycles
2. Normal load will be applied during the rinse & spin cycle (instead of a fixed unbalance).
3. 30% of stress cycles will be normal washing cycles to keep costs and time controlled.
4. Washing (stress) cycles will have a temperature between 20°C and 90 °C, with an average temperature of 40±5°C, and will be loaded at half of the rated capacity.

Some concerns were also expressed about:

1. The fact that testing conditions may have an effect on the performance of the machine and should be kept as tight and adherent as possible to the existing standard.
2. The testing of washing machines for 2 years, since problems encountered in the first 2 years are covered by warranty and refer mainly to electronics and small parts, which are not the main focus of the proposed testing protocol.

Prof. Stamminger pointed out that

1. Testing conditions will be kept as much adherent as possible to the existing standard, within the time and cost constraints of this study
2. There are several machines in the low-end segment that fails early, also during the first 2 years. Categories of failures have been defined preliminarily and will be refined in the course of the study

JRC moreover remarked that this is a research-oriented study which does not aim to come out with a policy proposal / official testing procedure, but rather to gain further knowledge about the assessment of the performance of the product over time. This is an innovative aspect of investigation which will probably require follow-up. Moreover, being the testing procedure an Accelerated Life Testing, the test could actually stress the machine in a way representative of a period of time longer than 2 years.

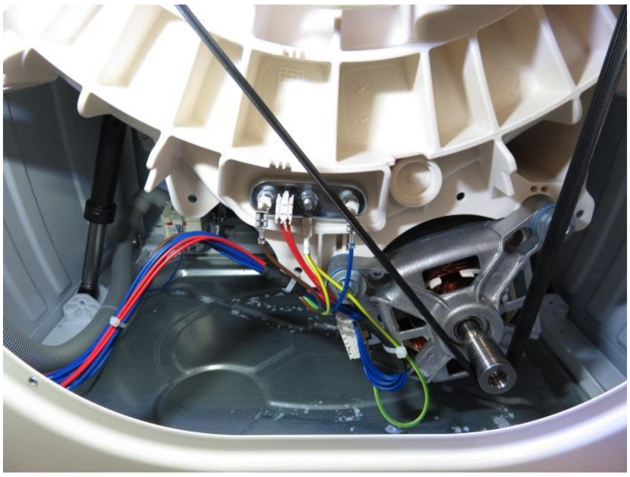
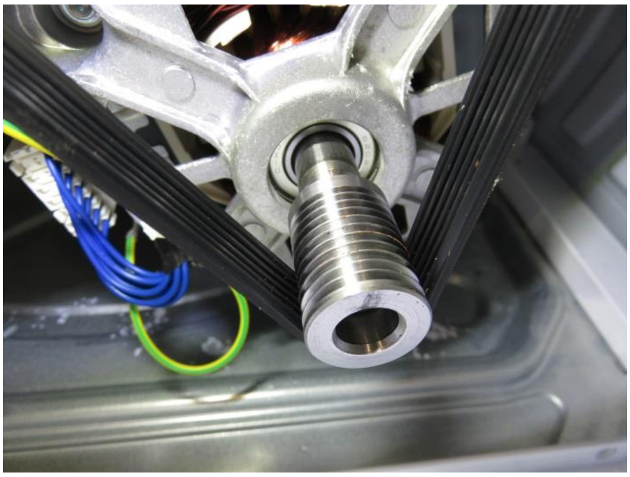
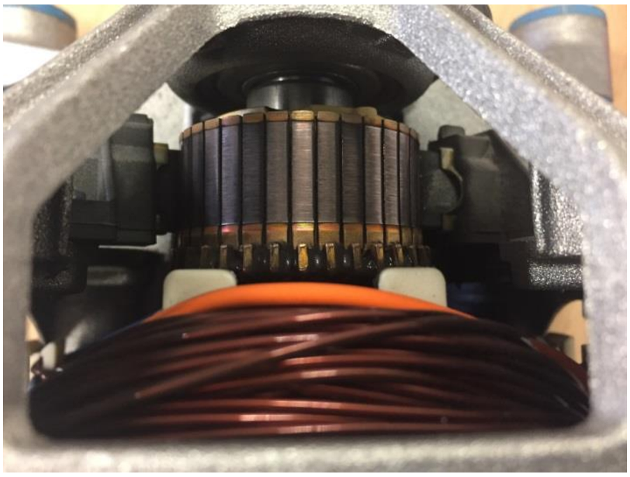
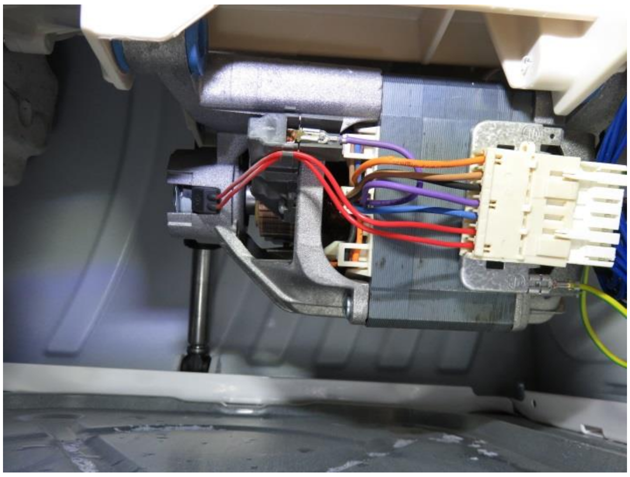
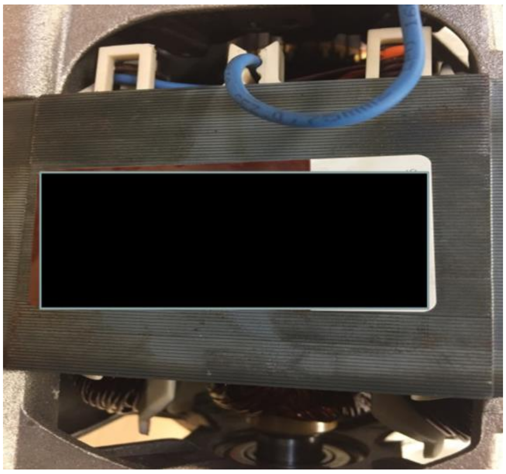
It was suggested to test the performance of washing machines only at the end of the stress cycles, but it was clarified that it is important to keep track of it more frequently to understand the behaviour of the machines in this first experiment. Performance testing will focus on normal cotton programmes (Alternative 2). A table will be made to provide an overview of the overall testing cycles included in the protocol.

With respect to the choice of machines, it was proposed to test a high-end frontload machine (A+++) and a low-end frontload machine (A+), both with 1400 rpm as max spinning speed, to check the influence of the quality of the machine at the same stress conditions. A relevant part of the market has 1400-1600 rpm. It was also clarified that washer-dryers are out of the scope of this study.

ANNEX B: PHOTOGRAPHS OF MACHINE AND COMPONENTS AT INITIAL AND FINAL INSPECTION

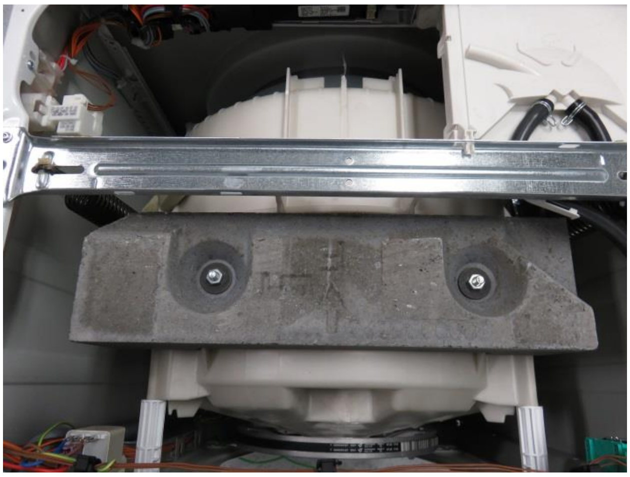
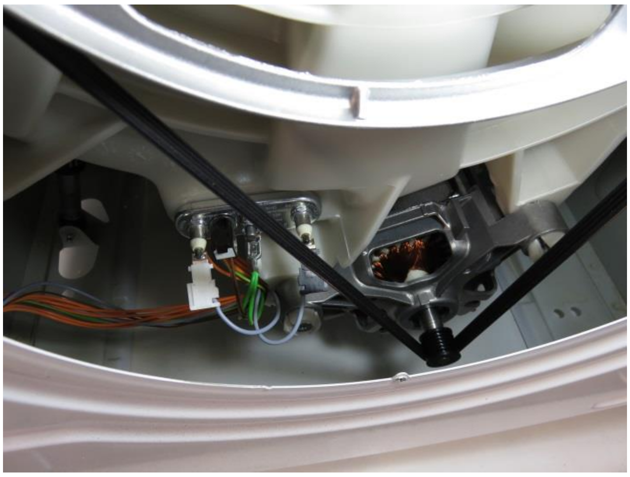
Device D

Initial inspection	Final inspection
	
	

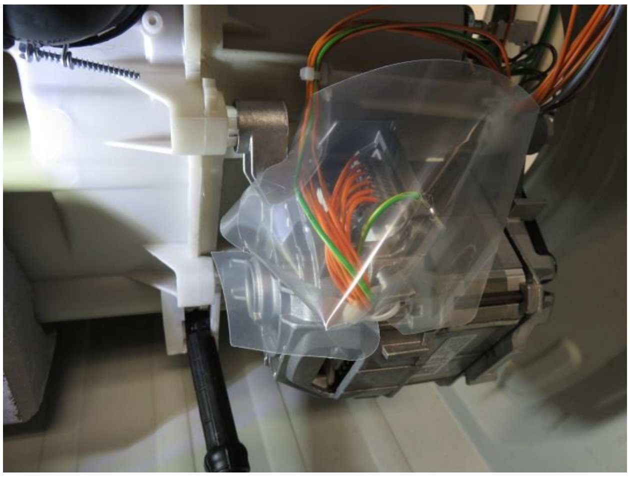
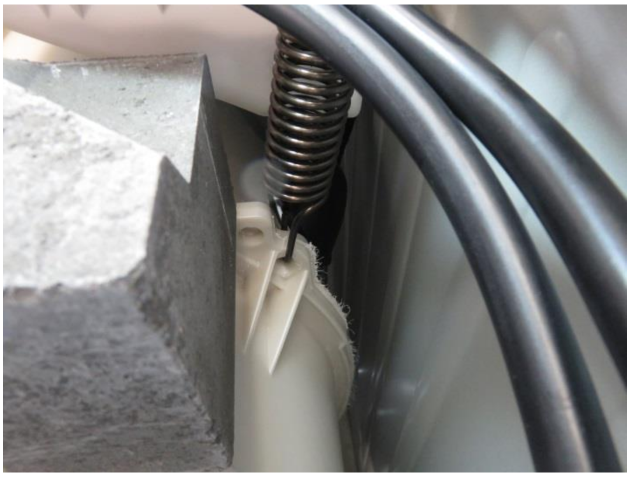
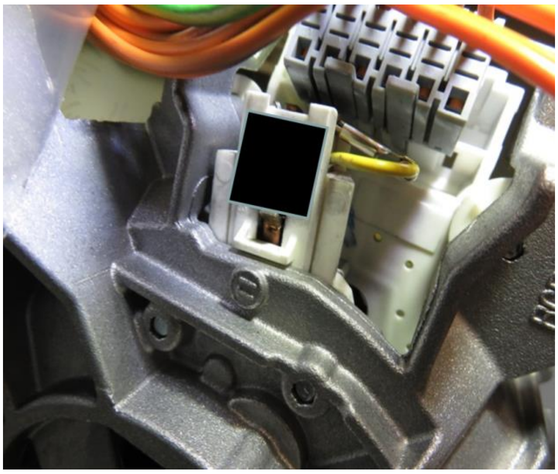
	
	
	 [redacted]

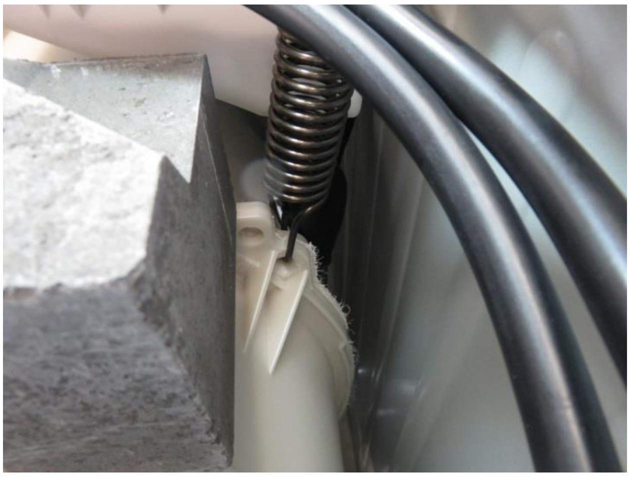
Device E

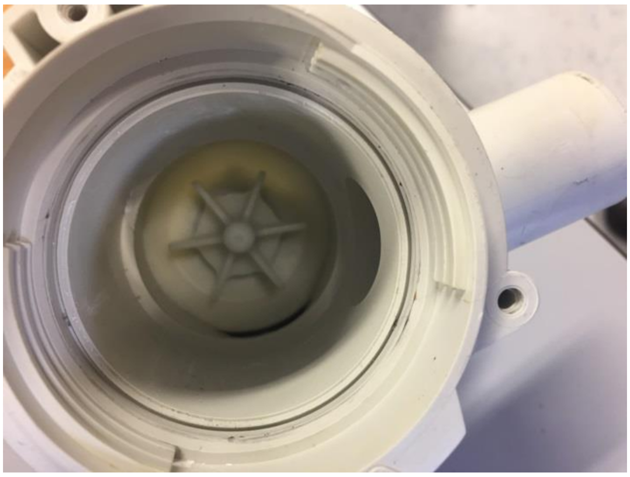
Initial inspection	Final inspection
	
	
	

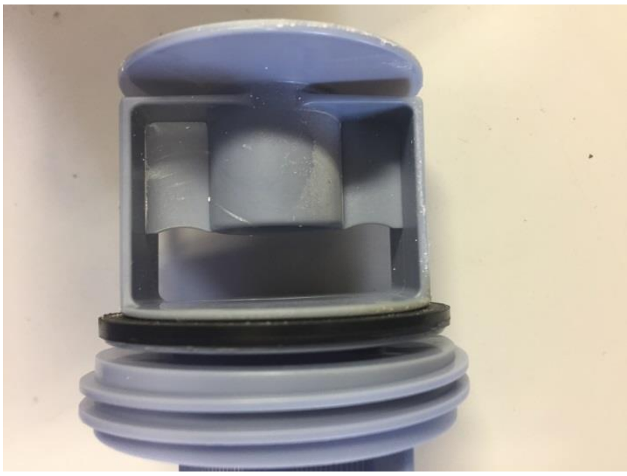






ANNEX C: TEST STRIP DATA SHEET

swissatest

Swissatest Testmaterialien AG
swissatest.ch

[illegible]

TEST 108 Serial number: 120

Test strips according to IEC / EN 60456, (IEC 5th Ed. / EN 3th Ed.)

Limit date for use: 30.04.2017

Storing conditions: On receipt of a batch of test strips, the strips must be stored at once in a cool, dark place and kept well packed.

Storage temperature: Between -20°C and +5°C.
Packaging: vacuumed

Please note: Before opening a packet of test strips please allow packet to acclimatise to room temperature.

Tristimulus values Y:

	soiled fabric	cotton 60°C 110 g	cotton 60°C 180 g	cotton 40°C 180 g	cotton 60°C 90 g	ratio 40°C/60°C	ratio 90 g/180 g	defined ratios and tolerances 40°C/60°C	defined ratios and tolerances 90 g/180 g
Sebum/Pigment	49.5	71.4	73.0	69.1	71.1	0.95	0.97	0.93	0.98
s	0.5	0.3	0.3	0.6	0.6			±0.03	±0.03
Carbon black	25.1	41.6	45.4	40.7	41.7	0.90	0.92	0.88	0.94
s	0.4	0.2	0.6	0.7	0.2			±0.03	±0.03
Blood	17.0	83.1	86.6	78.4	81.0	0.91	0.94	0.91	0.92
s	0.1	0.4	0.3	0.7	0.6			±0.04	±0.05
Cacao	36.6	61.0	65.5	58.0	60.1	0.89	0.92	0.86	0.88
s	0.5	1.0	0.6	0.7	1.1			±0.04	±0.05
Aged Red Wine	43.9	75.3	81.3	71.7	73.4	0.88	0.90	0.86	0.89
s	0.4	0.7	0.1	0.2	0.3			±0.03	±0.03
Sum	172.1	332.4	351.8	317.9	327.3	0.90	0.93	0.89	0.92
s	0.9	1.9	0.7	1.5	1.9			±0.02	±0.02

Washing conditions:

According to IEC / EN 60456, (IEC 5th Ed. / EN 3rd Ed.)
Washed with Wascator FOM71 CLS
Number of cycles: 5
Detergent IEC-A*. Batch: 249-186
Dosage: 180 g (60°C and 40°C) and 90 g (60°C)
Sodium Perborate Batch: 228-815
TAED Batch: 342844-03
Water hardness: 2.5mmol/l
Load: 4/4

Measuring conditions:

Instrument: Spectraflash 500 (Spectral photometer)
Illuminant / observer: D65 / 10°
Measuring geometry: d/8°
Wavelength range: 420 to 750nm
UV filter: UV barrier at 420nm
Measuring diameter: 26mm
Gloss: excluded

ANNEX D: WASHING PERFORMANCE TESTS (INDIVIDUAL RUN DATA)

Device D

Washing performance reflectance readings (Y value of the spectrometer) from executing the 10 cycles of a washing performance test series at 40 and 60 °C with full (1) and half (1/2) load for device D.

Washing performance (Y_{sum} value in %)	**40 °C ½**	**40 °C ½**	**40 °C 1**	**40 °C 1**	**40 °C 1**	**60 °C ½**	**60 °C ½**	**60 °C 1**	**60 °C 1**	**60 °C 1**	**Avg (10 runs)**
1-10	320.4	323.3	332.3	332.8	337.1	361.8	351.5	344.5	347.1	348.1	339.9
111-120	336.2	336.4	336.9	338.3	341.2	373.6	367.9	349.3	351.0	351.0	348.2
221-230	318.8	325.2	335.0	333.3	336.7	370.8	358.2	345.3	349.3	349.3	342.2
331-340	326.9	330.9	331.0	331.1	334.0	364.3	367.4	344.0	346.5	350.9	342.7
441-450	354.2	326.1	330.5	335.0	334.1	366.9	369.1	344.9	348.0	347.6	345.6
Avg.	329.8		334.6			365.2		347.8			
Std.	10.4		3.0			6.5		2.4			
Rel. Std. in %	3%		1%			2%		1%			

Device E

Washing performance reflectance readings (Y value of the spectrometer) from executing the 10 cycles of a washing performance test series at 40 and 60 °C with full (1) and half (1/2) load for device E.

Washing performance (Y_{sum} value in %)	**40 °C ½**	**40 °C ½**	**40 °C 1**	**40 °C 1**	**40 °C 1**	**60 °C ½**	**60 °C ½**	**60 °C 1**	**60 °C 1**	**60 °C 1**	**Avg (10 runs)**
1-10	332.4	334.5	322.1	320.6	323.6	354.2	354.3	326.5	336.3	334.1	333.9
111-120	331.8	335.7	317.0	314.8	318.2	354.7	359.8	332.0	333.3	343.4	334.1
221-230	333.5	335.9	314.0	320.1	323.4	355.3	365.2	333.6	336.9	339.5	335.7
331-340	326.0	330.6	317.9	316.2	318.1	362.3	358.3	322.7	331.9	339.6	332.4
441-450	332.3	331.8	314.9	323.2	323.4	360.2	357.3	336.7	339.3	339.5	335.9
Avg.	332.5		319.2			358.2		335.0			
Std.	2.9		3.4			3.7		5.4			
Rel. Std. in %	1%		1%			1%		2%			

Reference machine

Washing performance reflectance readings from executing 5 runs in the Wascator reference machine in the Cotton 60 °C programme.

Washing performance (Y_{sum} value in %)	**60 °C cotton**	**60 °C cotton**	**60 °C cotton**	**60 °C cotton**	**60 °C cotton**
1-5	319.28	329.67	329.46	330.11	329.07
Avg.	327.5				
Std.	4.6				
Rel. Std. in %	1%				

ANNEX E: STRESS TEST DATA

Device D

Cycle (Nr.)	Programme	Energy (Wh)	Water (l)	Time (min)	Max spin speed (rpm)	Max spin speed duration (s)
11	Spülen	91	31.4	25	1380	94
12	Spülen	89	31.5	28	1195	173
13	Spülen	74	31.2	26	955	156
14	Spülen	73	30.1	26	917	247
15	Spülen	76	31.1	26	1019	141
16	Spülen	75	32.1	26	1018	191
17	Spülen	73	31.1	26	839	334
18	Spülen	73	33.5	29	839	339
19	Spülen	87	30.5	24	1381	145
20	Spülen	65	30.6	26	1368	106
21	Spülen	88	31.0	25	1381	140
22	Spülen	90	31.9	26	1291	145
23	Spülen	93	30.7	24	1371	140
24	Spülen	92	31.7	28	1380	129
25	Spülen	72	31.4	26	1009	253
26	Spülen	72	30.6	27	905	273
27	Spülen	78	32.2	29	965	232
28	Spülen	78	30.9	26	1033	205
29	Spülen	74	32.8	28	872	341
30	Spülen	73	30.1	27	841	334
31	Spülen	75	31.8	27	992	256
32	Spülen	76	30.3	28	960	237
33	Spülen	74	30.8	31	866	283
34	Spülen	74	31.8	27	1032	123
35	Spülen	72	32.1	28	959	126
36	Spülen	77	30.9	29	994	269
37	Spülen	93	31.5	24	1380	134
38	Spülen	90	31.2	27	1375	129
39	Spülen	90	30.9	27	1381	135
40	Spülen	72	30.5	27	959	270
41	Spülen	75	32.8	27	945	159
42	Spülen	74	31.1	27	850	257
43	Spülen	77	30.9	26	1021	269
44	Spülen	77	30.2	27	1011	254

Cycle (Nr.)	Programme	Energy (Wh)	Water (l)	Time (min)	Max spin speed (rpm)	Max spin speed duration (s)
45	Spülen	78	30.9	25	1005	266
46	Spülen	71	31.0	29	874	287
47	Spülen	80	30.7	25	1022	256
48	Spülen	80	30.5	27	1001	260
49	Spülen	76	31.9	27	1013	253
50	Spülen	77	31.0	27	963	180
51	Spülen	78	31.2	24	1021	241
52	Spülen	91	31.5	25	1377	129
53	Spülen	70	30.7	26	908	279
54	Spülen	76	31.3	28	1006	97
55	Spülen	102	30.3	29	1271	143
56	Spülen	78	32.3	25	1009	201
57	Spülen	90	32.1	27	1379	132
58	Spülen	90	32.1	26	1382	139
59	Spülen	98	30.7	28	1328	118
60	Spülen	72	30.2	26	850	341
61	Spülen	71	30.9	26	956	280
62	Spülen	77	29.5	29	959	275
63	Spülen	77	30.3	26	936	237
64	Spülen	77	30.1	29	960	270
65	Spülen	85	30.5	29	957	203
66	Spülen	77	30.5	26	957	78
67	Spülen	76	30.8	26	838	336
68	Spülen	93	31.1	26	1303	146
69	Spülen	78	31.2	30	1020	263
70	Spülen	76	32.6	27	941	176
71	Spülen	74	32.2	24	864	257
72	Spülen	78	30.5	31	1017	254
73	Spülen	91	30.1	24	1383	140
74	Spülen	72	30.8	23	841	334
75	Spülen	79	33.0	27	793	304
76	Spülen	73	30.6	22	959	216
77	Spülen	78	30.3	24	980	274
78	Spülen	80	30.3	26	1023	262
79	Spülen	92	30.3	24	1375	137
80	Spülen	78	31.7	25	1027	245
81	Baumwolle 40 °C	609	35.2	96	1371	140
82	Baumwolle 40 °C	665	35.8	95	921	204

Cycle (Nr.)	Programme	Energy (Wh)	Water (l)	Time (min)	Max spin speed (rpm)	Max spin speed duration (s)
83	Baumwolle 40 °C	588	35.4	94	835	343
84	Baumwolle 40 °C	637	36.3	101	1380	141
85	Baumwolle 40 °C	605	36.2	95	1303	147
86	Baumwolle 40 °C	637	35.9	87	1015	247
87	Baumwolle 40 °C	622	35.7	94	1379	140
88	Baumwolle 40 °C	493	36.2	91	1013	270
89	Baumwolle 40 °C	703	35.3	96	1380	141
90	Baumwolle 40 °C	633	35.0	84	951	278
91	Baumwolle 30 °C	247	35.2	85	1380	140
92	Baumwolle 30 °C	241	36.7	84	957	278
93	Baumwolle 30 °C	311	36.0	84	1384	141
94	Baumwolle 30 °C	292	34.9	78	1340	145
95	Baumwolle 30 °C	258	36.2	83	1020	271
96	Baumwolle 30 °C	317	35.0	85	959	276
97	Baumwolle 30 °C	283	34.7	85	959	273
98	Baumwolle 30 °C	249	36.3	80	1379	133
99	Baumwolle 30 °C	335	36.1	88	838	343
100	Baumwolle 30 °C	324	35.7	84	1379	140
101	Baumwolle 60 °C	1128	35.3	105	832	346
102	Baumwolle 60 °C	983	35.8	102	1384	142
103	Baumwolle 60 °C	1121	34.9	108	1386	140
104	Baumwolle 60 °C	1037	35.7	102	915	277
105	Baumwolle 60 °C	1035	36.4	95	1020	202
106	Baumwolle kalt	243	35.1	77	1384	139
107	Baumwolle kalt	236	35.7	80	1388	142
108	Baumwolle kalt	218	36.0	78	1384	141
109	Baumwolle kalt	213	35.8	80	920	239
110	Baumwolle kalt	220	34.2	81	979	273
121	Spülen	73	31.9	27	1024	273
122	Spülen	90	31.0	25	1334	145
123	Spülen	74	30.7	27	1019	253
124	Spülen	85	30.1	26	1387	144
125	Spülen	75	31.6	27	1014	249
126	Spülen	97	30.6	28	1383	140
127	Spülen	71	30.6	29	941	268
128	Spülen	73	32.6	27	824	288
129	Spülen	73	30.2	27	850	249
130	Spülen	85	30.5	27	1248	125

Cycle (Nr.)	Programme	Energy (Wh)	Water (l)	Time (min)	Max spin speed (rpm)	Max spin speed duration (s)
131	Spülen	94	30.6	27	1363	138
132	Spülen	89	33.0	24	1370	144
133	Spülen	69	31.4	26	853	261
134	Spülen	91	31.0	27	1380	138
135	Spülen	71	31.5	26	905	180
136	Spülen	94	30.6	26	1371	137
137	Spülen	69	31.1	25	1193	244
138	Spülen	71	31.2	26	915	254
139	Spülen	90	31.1	26	1242	259
140	Spülen	91	30.5	26	1371	135
141	Spülen	88	30.3	25	1341	143
142	Spülen	87	30.3	26	1383	138
143	Spülen	70	30.8	26	909	195
144	Spülen	75	32.0	28	945	197
145	Spülen	91	30.9	28	1386	141
146	Spülen	68	31.9	26	815	168
147	Spülen	75	30.4	27	868	311
148	Spülen	92	32.1	26	1339	143
149	Spülen	92	30.8	27	1378	135
150	Spülen	69	30.8	26	938	98
151	Spülen	73	29.7	26	959	218
152	Spülen	90	32.5	28	1296	146
153	Spülen	74	32.0	26	1017	135
154	Spülen	90	30.5	24	1364	142
155	Spülen	89	30.9	27	1381	136
156	Spülen	67	29.9	26	848	344
157	Spülen	74	30.8	26	1002	121
158	Spülen	70	32.9	21	856	244
159	Spülen	70	30.7	26	837	345
160	Spülen	70	31.2	26	908	245
161	Spülen	76	29.9	29	861	277
162	Spülen	76	29.7	30	834	341
163	Spülen	90	30.1	26	1358	142
164	Spülen	67	31.3	25	832	211
165	Spülen	68	29.7	24	974	88
166	Spülen	71	29.3	26	956	120
167	Spülen	72	30.0	30	948	232
168	Spülen	75	30.4	27	994	230

Cycle (Nr.)	Programme	Energy (Wh)	Water (l)	Time (min)	Max spin speed (rpm)	Max spin speed duration (s)
169	Spülen	74	30.7	29	834	346
170	Spülen	77	29.9	28	837	343
171	Spülen	73	31.9	27	987	204
172	Spülen	68	30.2	27	867	308
173	Spülen	76	31.0	27	1018	270
174	Spülen	70	29.9	26	955	280
175	Spülen	71	30.4	27	842	344
176	Spülen	70	29.5	26	853	340
177	Spülen	71	30.5	26	938	222
178	Spülen	77	32.9	28	999	240
179	Spülen	83	30.9	29	992	205
180	Spülen	89	31.0	26	1379	133
181	Spülen	69	30.6	29	917	257
182	Spülen	74	31.1	29	936	270
183	Spülen	87	31.9	26	1196	259
184	Spülen	71	31.7	27	867	288
185	Spülen	73	30.8	26	992	270
186	Spülen	82	31.3	29	833	345
187	Spülen	77	30.3	28	869	300
188	Spülen	76	31.1	29	860	289
189	Spülen	96	30.8	28	1365	139
190	Spülen	89	30.7	27	1384	140
191	Baumwolle 40 °C	592	37.3	94	1342	149
192	Baumwolle 40 °C	663	35.2	84	1384	140
193	Baumwolle 40 °C	661	35.6	93	1380	140
194	Baumwolle 40 °C	538	35.3	88	1195	264
195	Baumwolle 40 °C	642	35.0	100	1013	262
196	Baumwolle 40 °C	630	34.6	91	1386	141
197	Baumwolle 40 °C	574	35.3	93	991	277
198	Baumwolle 40 °C	624	35.0	92	1297	147
199	Baumwolle 40 °C	658	34.3	94	1381	139
200	Baumwolle 40 °C	633	35.7	95	1380	141
201	Baumwolle 30 °C	302	35.6	85	1384	141
202	Baumwolle 30 °C	335	36.3	86	1383	141
203	Baumwolle 30 °C	321	35.3	93	930	55
204	Baumwolle 30 °C	310	34.5	84	942	274
205	Baumwolle 30 °C	313	35.4	83	947	265
206	Baumwolle 30 °C	272	36.3	84	838	344

Cycle (Nr.)	Programme	Energy (Wh)	Water (l)	Time (min)	Max spin speed (rpm)	Max spin speed duration (s)
207	Baumwolle 30 °C	312	34.7	86	917	282
208	Baumwolle 30 °C	304	36.3	83	1015	264
209	Baumwolle 30 °C	291	34.6	83	852	332
210	Baumwolle 30 °C	332	35.6	80	1381	142
211	Baumwolle 60 °C	1132	34.6	108	1390	141
212	Baumwolle 60 °C	1074	36.3	108	843	344
213	Baumwolle 60 °C	1046	35.6	107	990	275
214	Baumwolle 60 °C	1109	34.9	104	1383	142
215	Baumwolle 60 °C	1050	35.6	107	991	256
216	Baumwolle kalt	212	36.0	79	1389	141
217	Baumwolle kalt	205	34.7	83	1024	272
218	Baumwolle kalt	198	36.2	78	851	284
219	Baumwolle kalt	206	35.6	81	929	271
220	Baumwolle kalt	201	35.6	83	933	173
231	Spülen	91	32.0	29	1382	138
232	Spülen	73	30.6	29	918	243
233	Spülen	67	30.2	26	846	341
234	Spülen	72	30.5	27	1008	265
235	Spülen	93	31.1	27	1361	136
236	Spülen	79	30.0	26	1022	218
237	Spülen	67	30.1	27	874	287
238	Spülen	77	30.2	29	987	157
239	Spülen	91	31.0	26	1318	140
240	Spülen	75	30.4	28	1012	270
241	Spülen	73	31.3	28	912	204
242	Spülen	70	30.8	27	923	279
243	Spülen	77	30.0	31	943	249
244	Spülen	65	32.1	27	830	336
245	Spülen	85	30.3	25	1247	260
246	Spülen	75	29.6	29	955	230
247	Spülen	66	31.6	28	910	245
248	Spülen	69	30.1	27	928	250
249	Spülen	71	29.9	26	837	287
250	Spülen	89	29.8	27	1390	141
251	Spülen	67	30.8	28	878	286
252	Spülen	65	30.0	25	918	277
253	Spülen	71	31.8	28	926	198
254	Spülen	83	30.1	25	1387	143

Cycle (Nr.)	Programme	Energy (Wh)	Water (l)	Time (min)	Max spin speed (rpm)	Max spin speed duration (s)
255	Spülen	75	30.7	27	995	169
256	Spülen	67	29.8	27	921	282
257	Spülen	65	29.8	26	871	289
258	Spülen	68	29.3	28	868	288
259	Spülen	68	30.4	28	906	282
260	Spülen	74	29.8	27	867	288
261	Spülen	74	30.4	26	837	295
262	Spülen	72	29.0	27	859	339
263	Spülen	66	31.1	28	835	340
264	Spülen	72	30.5	27	920	268
265	Spülen	76	30.6	26	1003	271
266	Spülen	67	31.9	26	1017	267
267	Spülen	72	30.6	28	821	310
268	Spülen	75	29.7	28	951	273
269	Spülen	73	29.7	28	928	279
270	Spülen	67	29.6	25	864	294
271	Spülen	66	31.6	27	908	167
272	Spülen	66	29.3	28	852	338
273	Spülen	66	31.3	27	844	344
274	Spülen	68	30.5	25	859	342
275	Spülen	72	30.8	26	942	194
276	Spülen	72	31.4	25	931	267
277	Spülen	69	30.3	26	982	274
278	Spülen	89	30.9	28	1382	142
279	Spülen	71	30.9	26	933	281
280	Spülen	74	30.5	26	1017	276
281	Spülen	91	31.3	26	1244	266
282	Spülen	71	30.8	26	942	279
283	Spülen	71	31.4	27	943	271
284	Spülen	90	29.6	26	1365	136
285	Spülen	73	29.6	30	946	277
286	Spülen	93	30.2	30	1376	139
287	Spülen	71	30.4	27	937	272
288	Spülen	69	29.1	30	831	342
289	Spülen	76	31.2	26	1015	271
290	Spülen	73	29.3	26	961	288
291	Spülen	92	29.6	27	1382	141
292	Spülen	74	32.3	27	1009	274

Cycle (Nr.)	Programme	Energy (Wh)	Water (l)	Time (min)	Max spin speed (rpm)	Max spin speed duration (s)
293	Spülen	73	30.4	27	822	335
294	Spülen	90	29.9	24	1341	141
295	Spülen	62	29.6	26	874	287
296	Spülen	66	30.0	24	928	282
297	Spülen	68	30.3	26	940	279
298	Spülen	68	29.4	27	830	344
299	Spülen	74	29.8	26	912	213
300	Spülen	74	30.6	25	834	344
301	Baumwolle 40 °C	639	35.6	93	1385	141
302	Baumwolle 40 °C	621	35.9	93	1198	257
303	Baumwolle 40 °C	624	35.3	92	1011	265
304	Baumwolle 40 °C	627	36.2	97	1018	244
305	Baumwolle 40 °C	582	34.7	98	844	345
306	Baumwolle 40 °C	552	34.4	90	1027	274
307	Baumwolle 40 °C	548	35.6	95	932	266
308	Baumwolle 40 °C	650	33.5	97	924	268
309	Baumwolle 40 °C	597	34.4	96	941	266
310	Baumwolle 40 °C	492	35.7	88	846	341
311	Baumwolle 30 °C	252	34.1	81	1385	141
312	Baumwolle 30 °C	241	35.3	79	1383	142
313	Baumwolle 30 °C	225	36.2	79	1026	275
314	Baumwolle 30 °C	271	34.6	80	1342	144
315	Baumwolle 30 °C	258	36.8	83	1381	139
316	Baumwolle 30 °C	237	35.1	80	914	261
317	Baumwolle 30 °C	232	34.6	83	990	271
318	Baumwolle 30 °C	225	36.7	79	915	243
319	Baumwolle 30 °C	198	35.8	86	921	204
320	Baumwolle 30 °C	255	34.8	82	1005	269
321	Baumwolle 60 °C	988	35.9	106	913	256
322	Baumwolle 60 °C	972	34.4	107	1394	142
323	Baumwolle 60 °C	875	25.9	102	1015	275
324	Baumwolle 60 °C	956	35.9	72	968	272
325	Baumwolle 60 °C	1049	34.6	107	872	287
326	Baumwolle kalt	212	35.4	81	1302	148
327	Baumwolle kalt	194	34.8	83	941	279
328	Baumwolle kalt	205	34.4	80	972	279
329	Baumwolle kalt	189	36.6	81	856	343
330	Baumwolle kalt	195	35.7	81	928	280

Cycle (Nr.)	Programme	Energy (Wh)	Water (l)	Time (min)	Max spin speed (rpm)	Max spin speed duration (s)
341	Spülen	69	31.9	26	865	254
342	Spülen	72	31.0	28	914	206
343	Spülen	70	30.6	26	843	341
344	Spülen	92	30.0	29	1389	138
345	Spülen	76	33.1	30	833	317
346	Spülen	67	30.4	26	849	335
347	Spülen	72	29.9	24	1012	271
348	Spülen	73	30.0	30	985	259
349	Spülen	67	31.7	28	862	314
350	Spülen	74	30.3	26	973	257
351	Spülen	89	31.3	24	1303	147
352	Spülen	73	30.9	26	978	274
353	Spülen	73	29.9	26	978	241
354	Spülen	87	29.6	25	1247	247
355	Spülen	71	31.8	27	916	281
356	Spülen	97	30.4	29	1383	142
357	Spülen	70	32.2	26	936	214
358	Spülen	71	29.7	26	1019	267
359	Spülen	71	30.2	25	836	332
360	Spülen	72	29.9	26	854	329
361	Spülen	78	30.2	27	1000	273
362	Spülen	76	30.6	25	947	254
363	Spülen	77	31.7	28	920	252
364	Spülen	78	29.9	31	853	343
365	Spülen	72	30.3	24	937	254
366	Spülen	79	29.6	26	1024	273
367	Spülen	68	30.0	25	868	291
368	Spülen	72	30.4	28	846	343
369	Spülen	73	30.6	28	915	283
370	Spülen	74	31.5	27	856	333
371	Spülen	79	30.9	30	931	237
372	Spülen	79	32.4	27	1015	276
373	Spülen	67	30.8	33	845	345
374	Spülen	66	31.8	28	916	254
375	Spülen	70	29.7	28	925	172
376	Spülen	69	30.6	26	908	221
377	Spülen	72	30.0	26	875	285
378	Spülen	94	30.8	27	1387	142

Cycle (Nr.)	Programme	Energy (Wh)	Water (l)	Time (min)	Max spin speed (rpm)	Max spin speed duration (s)
379	Spülen	92	30.1	27	1381	142
380	Spülen	92	29.9	25	1355	143
381	Spülen	68	30.2	25	979	256
382	Spülen	75	29.5	29	830	340
383	Spülen	74	30.2	25	950	280
384	Spülen	73	32.4	26	918	278
385	Spülen	86	30.5	30	1009	264
386	Spülen	97	30.1	25	1258	150
387	Spülen	74	30.6	26	909	168
388	Spülen	78	30.2	28	915	271
389	Spülen	83	30.3	28	1026	274
390	Spülen	92	29.7	25	1393	142
391	Spülen	76	30.6	25	922	60
392	Spülen	72	30.2	24	844	340
393	Spülen	74	29.5	26	920	278
394	Spülen	75	29.9	26	847	303
395	Spülen	79	28.7	27	1026	274
396	Spülen	76	30.1	25	942	259
397	Spülen	83	29.2	29	991	270
398	Spülen	100	29.8	32	1388	141
399	Spülen	77	31.0	28	976	274
400	Spülen	80	31.2	25	994	268
401	Spülen	81	29.5	28	939	182
402	Spülen	75	30.6	26	842	300
403	Spülen	72	30.2	24	952	278
404	Spülen	89	32.3	23	1391	141
405	Spülen	73	29.9	25	923	272
406	Spülen	74	30.9	26	940	271
407	Spülen	72	30.9	26	975	278
408	Spülen	81	30.4	30	945	158
409	Spülen	76	30.5	27	934	250
410	Spülen	74	30.6	25	949	274
411	Baumwolle 40 °C	634	36.4	95	1000	275
412	Baumwolle 40 °C	684	35.1	92	1391	143
413	Baumwolle 40 °C	641	34.9	96	1246	266
414	Baumwolle 40 °C	643	36.8	91	921	225
415	Baumwolle 40 °C	743	35.7	177**	1008	275
416	Baumwolle 40 °C	643	34.9	93	1381	140

Cycle (Nr.)	Programme	Energy (Wh)	Water (l)	Time (min)	Max spin speed (rpm)	Max spin speed duration (s)
417	Baumwolle 40 °C	611	36.1	95	984	266
418	Baumwolle 40 °C	646	35.2	95	1244	265
419	Baumwolle 40 °C	648	34.4	93	1386	142
420	Baumwolle 40 °C	598	35.8	93	911	130
421	Baumwolle 30 °C	324	37.0	86	1297	147
422	Baumwolle 30 °C	324	35.2	85	1385	141
423	Baumwolle 30 °C	283	36.3	86	944	257
424	Baumwolle 30 °C	299	36.1	85	865	274
425	Baumwolle 30 °C	305	35.0	88	929	274
426	Baumwolle 30 °C	334	36.2	88	1385	143
427	Baumwolle 30 °C	300	35.5	85	991	261
428	Baumwolle 30 °C	338	35.7	87	1383	141
429	Baumwolle 30 °C	341	35.6	85	1343	143
430	Baumwolle 30 °C	327	35.5	86	913	267
431	Baumwolle 60 °C	1122	36.0	106	1387	142
432	Baumwolle 60 °C	1018	34.1	105	946	275
433	Baumwolle 60 °C	1073	35.8	107	960	278
434	Baumwolle 60 °C	1067	36.4	107	1382	142
435	Baumwolle 60 °C	1024	35.0	107	911	274
436	Baumwolle kalt	220	35.2	83	1396	142
437	Baumwolle kalt	192	36.2	80	926	221
438	Baumwolle kalt	211	35.7	85	868	300
439	Baumwolle kalt	201	35.0	82	984	280
440	Baumwolle kalt	226	34.5	83	1195	269

** not the short programme

Device E

Cycle (Nr.)	Programme	Energy (Wh)	Water (l)	Time (min)	Max spin speed (rpm)	Max spin speed duration (s)
11	Spülen	49	13.4	22	1407	45
12	Spülen	49	13.9	22	1404	41
13	Spülen	56	14.0	24	1400	44
14	Spülen	47	14.0	22	1404	43
15	Spülen	50	14.2	21	1403	45
16	Spülen	49	14.0	22	1405	42
17	Spülen	49	13.9	23	1403	44
18	Spülen	47	13.9	21	1402	46
19	Spülen	48	14.3	22	1403	48
20	Spülen	48	13.4	22	1404	44
21	Spülen	48	14.0	22	1402	47
22	Spülen	31	14.0	21	995	67
23	Spülen	51	14.0	29	1343	49
24	Spülen	45	13.8	22	1402	42
25	Spülen	53	14.1	22	1403	44
26	Spülen	44	13.9	22	1405	49
27	Spülen	50	14.1	21	1400	45
28	Spülen	52	14.3	24	1401	44
29	Spülen	44	13.8	23	1406	45
30	Spülen	33	14.2	21	994	64
31	Spülen	38	14.0	24	998	68
32	Spülen	36	13.9	22	994	73
33	Spülen	47	13.9	22	1385	44
34	Spülen	47	13.8	23	1404	45
35	Spülen	45	13.9	23	1405	43
36	Spülen	48	12.4	25	1407	45
37	Spülen	48	12.6	25	1405	45
38	Spülen	51	12.3	24	1401	44
39	Spülen	45	12.3	24	1405	43
40	Spülen	38	12.3	23	997	53
41	Spülen	47	12.4	24	1404	45
42	Spülen	33	12.2	23	998	54
43	Spülen	52	12.3	21	1402	42
44	Spülen	51	12.3	23	1402	45
45	Spülen	48	12.3	24	1403	46
46	Spülen	51	12.4	22	1403	44

Cycle (Nr.)	Programme	Energy (Wh)	Water (l)	Time (min)	Max spin speed (rpm)	Max spin speed duration (s)
47	Spülen	49	12.5	23	1401	44
48	Spülen	50	12.4	23	1403	47
49	Spülen	56	12.3	24	1359	50
50	Spülen	53	12.1	23	1363	48
51	Spülen	51	12.3	22	1405	47
52	Spülen	41	12.2	22	995	60
53	Spülen	51	12.4	25	1407	46
54	Spülen	50	12.2	22	1401	45
55	Spülen	53	12.1	24	1400	44
56	Spülen	44	12.1	23	1403	40
57	Spülen	44	12.2	23	1403	45
58	Spülen	50	12.0	24	1382	42
59	Spülen	46	12.3	21	1403	43
60	Spülen	47	12.3	23	1407	43
61	Spülen	47	12.4	22	1402	44
62	Spülen	51	12.4	22	1400	41
63	Spülen	50	12.5	23	1405	43
64	Spülen	44	12.3	22	1405	43
65	Spülen	54	12.3	24	1361	48
66	Spülen	47	12.5	22	1398	46
67	Spülen	48	12.4	23	1403	45
68	Spülen	48	12.6	24	1402	42
69	Spülen	47	12.4	22	1401	44
70	Spülen	46	12.4	22	1404	44
71	Spülen	54	12.4	20	1267	58
72	Spülen	44	12.4	22	1404	45
73	Spülen	45	12.4	22	1408	45
74	Spülen	43	12.3	23	1405	44
75	Spülen	46	12.2	22	1406	45
76	Spülen	48	12.3	22	1405	44
77	Spülen	47	12.3	23	1408	44
78	Spülen	48	12.3	23	1403	44
79	Spülen	35	12.4	20	997	51
80	Spülen	49	12.5	21	1403	43
81	Baumwolle 40 °C	609	29.3	72	1405	13
82	Baumwolle 40 °C	541	28.3	68	1405	11
83	Baumwolle 40 °C	573	29.3	69	1404	12

Cycle (Nr.)	Programme	Energy (Wh)	Water (l)	Time (min)	Max spin speed (rpm)	Max spin speed duration (s)
84	Baumwolle 40 °C	529	28.4	70	1402	12
85	Baumwolle 40 °C	516	28.5	76	1405	12
86	Baumwolle 40 °C	574	29.2	71	1405	13
87	Baumwolle 40 °C	516	28.3	83	1402	12
88	Baumwolle 40 °C	483	28.4	73	1403	12
89	Baumwolle 40 °C	524	27.3	72	1399	12
90	Baumwolle 40 °C	566	28.6	72	1403	13
91	Baumwolle 30 °C	313	28.0	73	995	20
92	Baumwolle 30 °C	282	28.1	70	1405	12
93	Baumwolle 30 °C	279	28.8	77	1400	13
94	Baumwolle 30 °C	359	26.1	73	1399	11
95	Baumwolle 30 °C	357	26.6	72	1404	12
96	Baumwolle 30 °C	284	26.9	71	1401	12
97	Baumwolle 30 °C	360	26.0	72	1404	11
98	Baumwolle 30 °C	310	25.2	73	1405	10
99	Baumwolle 30 °C	254	26.0	71	1400	12
100	Baumwolle 30 °C	353	25.6	71	1403	12
101	Baumwolle 60 °C	1022	27.5	78	1403	13
102	Baumwolle 60 °C	1026	28.4	76	1402	12
103	Baumwolle 60 °C	927	27.8	79	1403	12
104	Baumwolle 60 °C	1035	28.4	79	1400	13
105	Baumwolle 60 °C	1011	27.9	77	1407	12
106	Baumwolle kalt	114	25.9	71	1406	12
107	Baumwolle kalt	109	25.8	72	1403	12
108	Baumwolle kalt	102	26.0	71	996	19
109	Baumwolle kalt	111	26.2	71	1399	13
110	Baumwolle kalt	123	26.1	70	1405	11
121	Spülen	45	12.2	22	1401	48
122	Spülen	42	12.7	22	1408	49
123	Spülen	44	12.4	23	1401	46
124	Spülen	43	12.5	22	1409	47
125	Spülen	45	12.4	23	1409	45
126	Spülen	47	12.4	24	1402	48
127	Spülen	45	12.3	22	1402	46
128	Spülen	45	12.2	23	1403	46
129	Spülen	46	12.3	23	1407	46
130	Spülen	43	12.5	24	1407	45

Cycle (Nr.)	Programme	Energy (Wh)	Water (l)	Time (min)	Max spin speed (rpm)	Max spin speed duration (s)
131	Spülen	31	12.3	24	1000	53
132	Spülen	48	12.4	25	1404	45
133	Spülen	39	12.6	23	1406	46
134	Spülen	42	12.1	22	1407	46
135	Spülen	48	12.4	23	1407	46
136	Spülen	43	12.3	23	1407	44
137	Spülen	49	12.5	23	1381	51
138	Spülen	46	12.4	23	1406	44
139	Spülen	45	12.6	23	1407	44
140	Spülen	42	12.4	22	1406	44
141	Spülen	51	12.4	21	1398	44
142	Spülen	50	12.4	21	1401	45
143	Spülen	45	12.6	24	1408	45
144	Spülen	45	12.4	23	1407	44
145	Spülen	49	12.5	24	1405	46
146	Spülen	36	12.6	21	1408	47
147	Spülen	45	12.6	23	1406	46
148	Spülen	46	12.4	22	1404	48
149	Spülen	43	12.6	23	1404	45
150	Spülen	47	12.3	23	1380	47
151	Spülen	45	12.5	23	1404	47
152	Spülen	44	12.5	23	1407	44
153	Spülen	47	12.4	23	1402	46
154	Spülen	42	12.3	22	1406	45
155	Spülen	50	12.1	22	1350	47
156	Spülen	30	12.4	22	998	56
157	Spülen	42	12.3	23	1407	46
158	Spülen	46	12.3	22	1406	47
159	Spülen	43	12.5	23	998	56
160	Spülen	31	12.3	22	997	53
161	Spülen	44	12.4	23	1408	47
162	Spülen	43	12.4	24	1408	47
163	Spülen	43	12.2	22	1406	46
164	Spülen	46	12.2	21	1397	47
165	Spülen	44	12.3	25	1407	46
166	Spülen	41	12.2	22	1406	45
167	Spülen	48	12.3	24	1405	46

Cycle (Nr.)	Programme	Energy (Wh)	Water (l)	Time (min)	Max spin speed (rpm)	Max spin speed duration (s)
168	Spülen	42	12.4	24	1407	47
169	Spülen	30	12.4	22	997	58
170	Spülen	48	12.4	21	1291	58
171	Spülen	46	12.3	22	1376	48
172	Spülen	43	12.1	22	1408	45
173	Spülen	42	12.2	22	1408	47
174	Spülen	46	12.2	21	1408	46
175	Spülen	47	12.2	23	1406	46
176	Spülen	30	12.3	23	998	56
177	Spülen	43	12.2	24	1408	46
178	Spülen	40	12.2	22	1408	46
179	Spülen	42	12.2	22	1404	46
180	Spülen	41	12.1	22	1406	46
181	Spülen	43	12.2	22	1407	45
182	Spülen	47	12.3	22	1363	50
183	Spülen	44	12.1	23	1407	45
184	Spülen	44	12.4	23	1405	47
185	Spülen	45	12.1	26	1405	46
186	Spülen	45	12.2	23	1407	45
187	Spülen	43	12.2	26	1408	46
188	Spülen	27	12.5	22	999	58
189	Spülen	39	12.2	23	1409	46
190	Spülen	39	12.3	22	1408	47
191	Baumwolle 40 °C	510	26.4	82	1402	12
192	Baumwolle 40 °C	548	26.8	81	1404	11
193	Baumwolle 40 °C	559	26.2	82	1404	12
194	Baumwolle 40 °C	538	26.5	70	1404	12
195	Baumwolle 40 °C	478	26.3	72	997	19
196	Baumwolle 40 °C	513	25.7	72	1403	11
197	Baumwolle 40 °C	532	26.2	83	1408	12
198	Baumwolle 40 °C	522	26.2	71	1403	12
199	Baumwolle 40 °C	528	26.4	72	1406	12
200	Baumwolle 40 °C	530	26.9	72	1406	12
201	Baumwolle 30 °C	317	25.8	72	1406	12
202	Baumwolle 30 °C	353	27.1	73	1405	13
203	Baumwolle 30 °C	352	26.9	70	1403	13
204	Baumwolle 30 °C	344	26.3	83	1403	12

Cycle (Nr.)	Programme	Energy (Wh)	Water (l)	Time (min)	Max spin speed (rpm)	Max spin speed duration (s)
205	Baumwolle 30 °C	314	26.0	72	1404	13
206	Baumwolle 30 °C	347	27.5	72	1406	12
207	Baumwolle 30 °C	313	25.6	70	995	18
208	Baumwolle 30 °C	325	25.6	71	1404	12
209	Baumwolle 30 °C	302	27.1	72	797	17
210	Baumwolle 30 °C	334	25.9	72	1405	12
211	Baumwolle 60 °C	1014	28.5	77	1406	12
212	Baumwolle 60 °C	997	28.0	75	1406	12
213	Baumwolle 60 °C	1027	29.0	80	1404	11
214	Baumwolle 60 °C	1004	27.9	75	1405	13
215	Baumwolle 60 °C	963	27.8	78	997	19
216	Baumwolle kalt	109	26.5	74	1389	14
217	Baumwolle kalt	102	27.4	69	1406	13
218	Baumwolle kalt	107	27.0	72	1406	14
219	Baumwolle kalt	117	25.7	71	1404	13
220	Baumwolle kalt	101	26.3	72	1407	13
231	Spülen	41	8.8	26	1405	47
232	Spülen	46	11.6	25	1405	47
233	Spülen	47	11.7	21	1403	46
234	Spülen	47	11.7	22	1399	46
235	Spülen	32	11.7	21	999	53
236	Spülen	41	11.8	22	1407	47
237	Spülen	46	11.7	24	1408	47
238	Spülen	44	12.0	24	1410	47
239	Spülen	51	12.1	25	1392	51
240	Spülen	42	12.0	23	1410	47
241	Spülen	40	11.7	22	1409	47
242	Spülen	30	11.7	23	998	52
243	Spülen	42	11.7	22	1406	47
244	Spülen	41	11.7	22	1407	47
245	Spülen	46	11.7	23	1403	46
246	Spülen	42	11.6	22	1405	48
247	Spülen	43	11.6	22	1406	47
248	Spülen	46	11.7	22	1403	46
249	Spülen	48	11.8	22	1335	54
250	Spülen	44	11.6	23	1408	46
251	Spülen	41	11.6	23	1409	47

Cycle (Nr.)	Programme	Energy (Wh)	Water (l)	Time (min)	Max spin speed (rpm)	Max spin speed duration (s)
252	Spülen	40	11.7	22	1410	46
253	Spülen	40	11.6	22	1407	47
254	Spülen	43	11.6	21	1408	47
255	Spülen	45	11.7	21	1405	47
256	Spülen	44	11.8	23	1405	49
257	Spülen	37	11.5	22	1156	53
258	Spülen	43	11.5	22	1404	48
259	Spülen	39	11.7	23	1409	46
260	Spülen	47	11.6	22	1361	52
261	Spülen	28	11.7	22	997	52
262	Spülen	46	11.6	23	1374	49
263	Spülen	43	11.5	23	1404	47
264	Spülen	45	11.4	24	1406	47
265	Spülen	44	11.5	22	1405	47
266	Spülen	44	11.4	23	1407	46
267	Spülen	43	11.5	21	1406	47
268	Spülen	44	11.4	23	1409	46
269	Spülen	34	11.5	23	997	54
270	Spülen	50	11.4	23	1302	57
271	Spülen	42	11.4	22	1405	47
272	Spülen	46	11.5	22	1407	47
273	Spülen	48	11.5	21	1402	46
274	Spülen	53	11.5	24	1276	60
275	Spülen	44	11.5	25	1409	46
276	Spülen	45	11.5	23	1405	48
277	Spülen	43	11.5	24	1408	47
278	Spülen	48	11.4	23	1389	48
279	Spülen	50	11.5	23	1405	47
280	Spülen	54	11.5	24	1353	50
281	Spülen	54	11.4	25	1293	57
282	Spülen	48	11.4	22	1405	47
283	Spülen	49	11.4	23	1409	48
284	Spülen	47	11.4	24	1405	47
285	Spülen	50	11.2	21	1408	47
286	Spülen	53	11.4	22	1383	49
287	Spülen	47	11.5	24	1404	47
288	Spülen	42	11.3	21	1405	47

Cycle (Nr.)	Programme	Energy (Wh)	Water (l)	Time (min)	Max spin speed (rpm)	Max spin speed duration (s)
289	Spülen	45	11.2	24	1405	46
290	Spülen	47	11.0	23	1404	47
291	Spülen	32	11.1	23	998	54
292	Spülen	45	11.2	23	1405	48
293	Spülen	45	11.1	22	1395	48
294	Spülen	45	11.2	22	1406	47
295	Spülen	49	11.4	24	1402	46
296	Spülen	50	11.2	22	1328	55
297	Spülen	44	11.3	23	1407	47
298	Spülen	51	11.3	27	1365	50
299	Spülen	53	11.2	25	1380	48
300	Spülen	46	11.2	24	1404	47
301	Baumwolle 40 °C	*	26.4	72	1408	12
302	Baumwolle 40 °C	*	27.4	78	1405	12
303	Baumwolle 40 °C	*	27.0	97	997	18
304	Baumwolle 40 °C	983	27.1	86	1403	13
305	Baumwolle 40 °C	536	25.8	72	1406	12
306	Baumwolle 40 °C	517	26.0	72	1406	12
307	Baumwolle 40 °C	521	25.0	71	1394	12
308	Baumwolle 40 °C	487	24.8	73	1404	12
309	Baumwolle 40 °C	451	24.4	70	1405	13
310	Baumwolle 40 °C	435	24.8	70	1403	12
311	Baumwolle 30 °C	246	24.6	80	996	19
312	Baumwolle 30 °C	258	24.1	71	1404	12
313	Baumwolle 30 °C	266	25.2	71	1405	11
314	Baumwolle 30 °C	277	24.2	71	1406	12
315	Baumwolle 30 °C	227	24.6	70	1403	12
316	Baumwolle 30 °C	251	25.0	73	1403	12
317	Baumwolle 30 °C	242	24.4	70	999	17
318	Baumwolle 30 °C	245	24.0	69	1404	12
319	Baumwolle 30 °C	161	24.0	70	1409	11
320	Baumwolle 30 °C	283	24.3	70	1402	12
321	Baumwolle 60 °C	445	25.0	72	995	18
322	Baumwolle 60 °C	923	25.8	77	1406	11
323	Baumwolle 60 °C	875	25.9	78	995	18
324	Baumwolle 60 °C	903	26.1	80	1403	12
325	Baumwolle 60 °C	942	27.6	87	1402	13

Cycle (Nr.)	Programme	Energy (Wh)	Water (l)	Time (min)	Max spin speed (rpm)	Max spin speed duration (s)
326	Baumwolle kalt	111	24.0	71	1402	12
327	Baumwolle kalt	127	24.9	70	1403	13
328	Baumwolle kalt	127	24.7	76	1405	12
329	Baumwolle kalt	121	23.8	69	1406	12
330	Baumwolle kalt	107	23.9	72	996	19
341	Spülen	62	11.6	22	1405	51
342	Spülen	64	11.7	22	1402	52
343	Spülen	58	11.7	20	1405	46
344	Spülen	57	11.8	22	1406	47
345	Spülen	54	11.5	21	1303	57
346	Spülen	56	11.7	24	1311	56
347	Spülen	58	11.7	25	1307	56
348	Spülen	49	11.7	20	1410	47
349	Spülen	56	11.7	21	1387	49
350	Spülen	53	11.8	21	1405	47
351	Spülen	62	11.7	25	1404	35
352	Spülen	59	11.8	23	1405	47
353	Spülen	55	11.8	22	1405	48
354	Spülen	55	11.8	24	1404	47
355	Spülen	53	11.7	22	1403	47
356	Spülen	58	11.8	23	1377	49
357	Spülen	57	11.7	22	1405	46
358	Spülen	62	11.7	23	1404	47
359	Spülen	57	11.7	21	1404	47
360	Spülen	65	11.7	21	1405	46
361	Spülen	60	11.8	21	1403	43
362	Spülen	64	11.9	21	1404	47
363	Spülen	60	11.9	21	1406	47
364	Spülen	61	11.9	21	1404	49
365	Spülen	58	11.7	21	1405	46
366	Spülen	57	11.8	23	1404	47
367	Spülen	60	11.8	24	1374	50
368	Spülen	59	11.9	24	1407	47
369	Spülen	44	11.8	22	995	53
370	Spülen	43	11.9	23	996	54
371	Spülen	45	11.8	22	997	55
372	Spülen	43	11.8	22	997	54

Cycle (Nr.)	Programme	Energy (Wh)	Water (l)	Time (min)	Max spin speed (rpm)	Max spin speed duration (s)
373	Spülen	58	11.8	23	1406	47
374	Spülen	60	11.8	22	1401	47
375	Spülen	57	11.8	21	1381	49
376	Spülen	56	11.8	24	1406	49
377	Spülen	55	11.7	25	1406	48
378	Spülen	52	11.6	25	1407	47
379	Spülen	53	11.6	21	1402	46
380	Spülen	54	11.5	22	1405	47
381	Spülen	44	11.6	22	1404	47
382	Spülen	49	11.6	21	1362	50
383	Spülen	51	11.7	21	1406	47
384	Spülen	62	11.7	24	1404	47
385	Spülen	59	11.7	22	1406	47
386	Spülen	61	11.8	21	1404	48
387	Spülen	57	11.9	22	1403	47
388	Spülen	66	11.5	21	1120	63
389	Spülen	*	11.5	24	1402	48
390	Spülen	*	11.6	23	1411	45
391	Spülen	*	11.7	23	1413	47
392	Spülen	*	11.6	21	1407	47
393	Spülen	*	11.6	22	1407	48
394	Spülen	*	11.6	23	1408	46
395	Spülen	*	11.6	19	998	52
396	Spülen	*	11.7	22	1401	48
397	Spülen	51	11.3	23	1383	47
398	Spülen	33	11.5	21	999	53
399	Spülen	55	11.6	20	1215	64
400	Spülen	35	11.4	21	998	54
401	Spülen	44	11.6	21	1408	47
402	Spülen	48	11.5	24	1408	47
403	Spülen	39	11.5	22	798	51
404	Spülen	33	11.6	23	998	54
405	Spülen	31	11.6	21	997	53
406	Spülen	51	11.5	23	1409	47
407	Spülen	56	11.4	22	1304	56
408	Spülen	45	11.4	21	1408	46
409	Spülen	48	11.5	21	1407	47

Cycle (Nr.)	**Programme**	**Energy (Wh)**	**Water (l)**	**Time (min)**	**Max spin speed (rpm)**	**Max spin speed duration (s)**
410	Spülen	55	11.5	21	1371	50
411	Baumwolle 40 °C	596	25.8	71	1405	12
412	Baumwolle 40 °C	562	24.5	72	1405	12
413	Baumwolle 40 °C	560	24.8	69	1404	12
414	Baumwolle 40 °C	576	25.0	71	1402	12
415	Baumwolle 40 °C	566	25.9	71	1405	12
416	Baumwolle 40 °C	559	24.6	**	1404	11
417	Baumwolle 40 °C	545	24.7	71	1402	12
418	Baumwolle 40 °C	543	25.0	70	1403	13
419	Baumwolle 40 °C	587	26.0	70	1404	12
420	Baumwolle 40 °C	568	25.0	70	1404	12
421	Baumwolle 30 °C	355	24.9	73	1404	14
422	Baumwolle 30 °C	366	26.2	69	996	19
423	Baumwolle 30 °C	374	25.7	72	1404	13
424	Baumwolle 30 °C	355	24.8	70	1342	18
425	Baumwolle 30 °C	351	25.6	69	996	19
426	Baumwolle 30 °C	363	25.1	71	1403	12
427	Baumwolle 30 °C	387	24.9	72	1403	13
428	Baumwolle 30 °C	347	24.1	71	1402	12
429	Baumwolle 30 °C	379	25.2	69	1405	12
430	Baumwolle 30 °C	370	24.6	71	1401	13
431	Baumwolle 60 °C	1101	26.9	75	1405	12
432	Baumwolle 60 °C	1032	26.7	77	1407	11
433	Baumwolle 60 °C	1029	27.1	76	1407	12
434	Baumwolle 60 °C	1089	26.6	77	1406	12
435	Baumwolle 60 °C	*	26.6	79	1400	12
436	Baumwolle kalt	*	24.6	72	1404	12
437	Baumwolle kalt	112	25.4	69	1405	11
438	Baumwolle kalt	127	24.7	70	1405	12
439	Baumwolle kalt	114	25.6	72	1410	12
440	Baumwolle kalt	118	24.1	71	1406	12

* no energy recording

** programme stopped for about 1.5 h

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