WISSENSCHAFTLICHER BEITRAG

Old Washing Machines Wash Less Efficiently and Consume More Resources

Rainer Stamminger / Alexandra Barth / Susanne Dörr

In the last few decades the energy and water usage of washing machines has been reduced significantly. Although economically and ecologically sound, the effect of the reductions on washing performance may have been negative. As it has never been looked at previously, this effect is one of the major subjects of this report. First the age distribution of washing machines in German households is examined and secondly an average picture of the development in the values for energy and water usage of washing machines in Germany over the last 30 years is outlined. Then, thirdly, the results of washing performance tests of machines up to 30 years old are given. Somewhat surprisingly, the significantly lower usage of water and energy by new machines is not associated with inferior washing performance. On average, to achieve the same performance as a modern machine does by washing at 40 °C, a fifteen year old machine must use a temperature of 60 °C, while a thirty year old one requires 90 °C. A fifteen year old machine uses approximately twice as much energy and water to achieve the same performance as a new one, while a thirty year old machine requires four times as much.

1 Introduction

Why think about one's old washing machine as long as it is doing its job? Such is the dominant attitude towards household appliances. Totally unlike automobiles or leisure appliances, household appliances are not regarded as being subject to fashion or rapid innovation. In most households they do not attract much attention.

Accordingly, household appliances normally remain in operation for as long as possible, to be replaced only when they break down completely and without a chance of repair at reasonable cost. A washing machine's durability depends on its design and quality, but also on user behaviour (e. g. number of cycles completed or hours used) and on the user's willingness to have smaller defects repaired.

In appliances in which the main stress results from specific operations, such as washing cycles, durability can be measured in cycles. This measure has the advantage of being more or less independent of user behaviour: in households with many cycles per week/month, washing machines will last fewer years than in households using their washing machines less often. Consumer organisations (e. g. Stiftung Warentest) use this approach in investigating the durability of appliances, using them over a short period of time but in as many cycles as would occur over a normal lifespan, assuming the 'normal' lifespan of washing machines to be ten years.

Very little is known about the actual lifespan of washing machines or about the total number of cycles they withstand. Neither is there much information on the actual lifespan of washing machines in households, lifespan here referring to the number of years for which an appliance actually exists, i. e. from the date of manufacture to the date of disassembly. As mentioned before, this has little to do with the durability of appliances calculated in cycles.

Therefore, the first aim of this investigation is to determine – with a focus on Germany – what is the actual lifespan of washing machines. This is done by investigating washing machines at the real end of their life: at the stage of recycling.

The second aim is to look at the development of washing machines in terms of performance (cleaning effect) and usage of water and energy through time. Here our approach follows two routes: First, it is collected and systematically analysed what was measured and published in history about new washing machines. Second, tests are done and reported here on a limited number of old washing machines to verify their performance under today washing conditions close to normal household use. Methodological this is done following today European energy labelling scheme comparing these results with results from actual machines.

As a third aim – deriving from the first two – the implications of the actual lifespans of washing machines and the development of their usage conditions shall be assessed in terms of economic consequences and environmental impact.

2 Age Distribution of Used Washing Machines

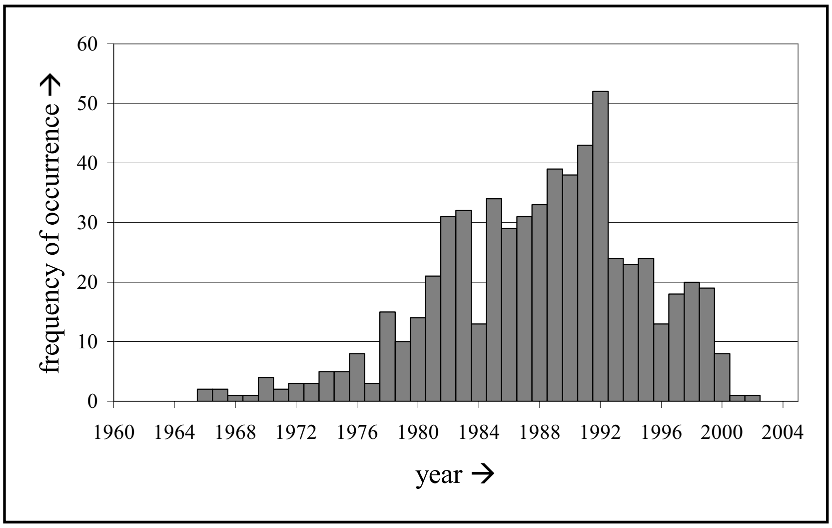
How old are the washing machines in German households? We examined this question in 2004 by looking at end of life washing machines. In Germany electric waste is collected by municipalities or retailers and recycled at specialized recycling plants. At three such plants hundreds of washing machines were examined for the following classes of data:

- brand and model
- product identification code
- date of manufacture on the built-in capacitor.

Retrieving all relevant information from all machines proved impossible. While information on brand and model give only a rough indication of a washing machine's date of manufacture, the product identification code requires the manufacturer key on every single washing machine's rating plate to be decoded.

There is no direct link between a washing machine's date of manufacture and that of its capacitor, but with all washing machines having a capacitor, and with every capacitor having to be removed before shredding, capacitors are the most reliable source of information concerning the age of a washing machine, providing that there is a correlation between the production dates of the capacitor and of the machine. This was proven for washing machines in which the dates of manufacture both of the machine and of the capacitor could be decoded (112 machines); in these cases the time difference was verified to be small (the average month of production being October 1987 in the case of the capacitors and November 1987 in the case of the washing machines). Thus, the capacitors' dates of manufacture (Fig. 1) were good indicators of the washing machines' dates of manufacture. While the newest ones were only a few years old, the oldest machine found was almost 40 years old. With 1988 being the average year of manufacture, the machines were approximately 16 years old at the time of disassembly. Assuming an interval of about one year between manufacture and original installation, and assuming another six months to pass between a washing machine's end of use in a household and its being transported to a recycling plant, the average use-time of washing machines in Germany is approximately 14 years. The accumulated percentages by year (Fig. 2) show a characteristic lifespan of 17.5 years (at 63.2 % failure rate), while 20 % of washing machines have a lifespan of more than 22 years. As washing machine technology did not

Figure 1: Occurrence of capacitors in washing machines by year of manufacture of capacitor (n = 625); data collected between middle and end of 2004 in Germany



Source: Own representation

Vergleich neuer und alter Waschmaschinen: Trotz reduziertem Energie- und Wassereinsatz bieten neue Waschmaschinen bessere Waschwirkung

Dass der Energie- und Wassereinsatz von Waschmaschinen sich in den letzten Jahrzehnten deutlich verringert hat, ist allgemein bekannt. Ob diese ökologisch und ökonomisch sinnvolle Reduzierung an Betriebsstoffen nicht auch mit einer Reduzierung der dafür erhaltenen Waschwirkung erkauft wurde, ist bisher nicht untersucht und ein wesentlicher Gegenstand der vorliegenden Arbeit.

Zuerst wird aber berichtet, wie über eine Feldstudie auf Recyclinghöfen die Altersverteilung der Waschmaschinen zum Zeitpunkt ihrer Verschrottung gewonnen und daraus Rückschlüsse auf die Benutzungsdauer der Geräte im Haushalt gezogen wurden. Mit der Analyse der durchschnittlich erforderlichen Mengen an Wasser und elektrischer Energie für verschiedene Waschprogramme wird die notwendige Datenbasis geschaffen, um Vergleiche über die Entwicklung der Waschmaschinen der letzten 30 Jahre anstellen zu können.

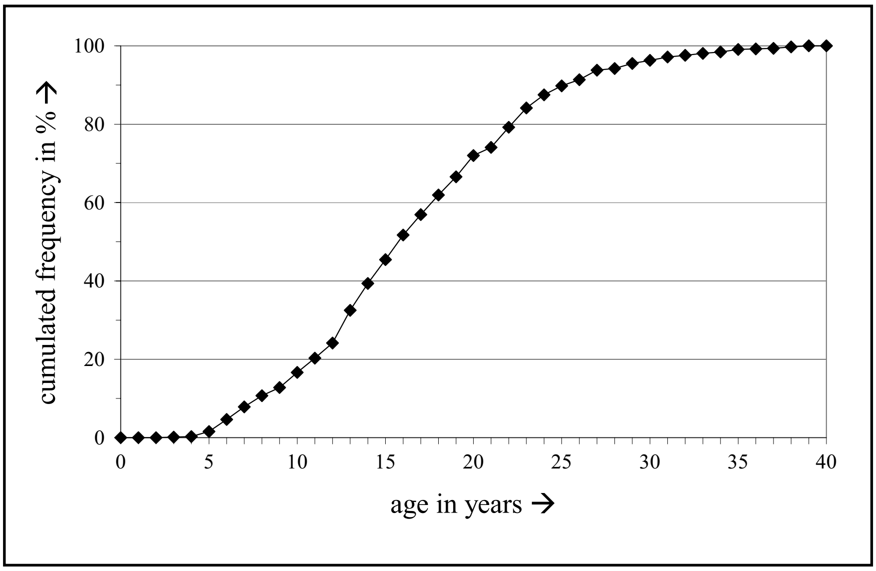
Da die Untersuchungen gezeigt haben, dass es viele Waschmaschinen gibt, die 15 oder gar 20 Jahre ihren Dienst tun, wird sodann experimentell untersucht, wie sich, unter heutigen Waschbedingungen, die Effizienz alter Waschmaschinen im Vergleich zu neuen Modellen darstellt.

Überraschenderweise haben die Reduzierungen des Energie- und Wassereinsatzes nicht zu einer Beeinträchtigung der Waschwirkung geführt, sondern neuere Waschmaschinen bieten in der Regel sogar eine deutliche bessere Waschwirkung.

Das Ergebnis kann zusammenfassend und vereinfacht wie folgt ausgedrückt werden: Um dieselbe Waschleistung wie in einem 40-°C-Programm einer modernen Waschmaschine zu erreichen, muss in einem 15 Jahre alten Waschautomaten ein 60-°C-Programm benutzt werden, mit etwa dem doppelten Aufwand an Energie und Wasser, und bei einem 30 Jahre alten Waschautomaten ist der Aufwand für Strom und Wasser ungefähr viermal so hoch.

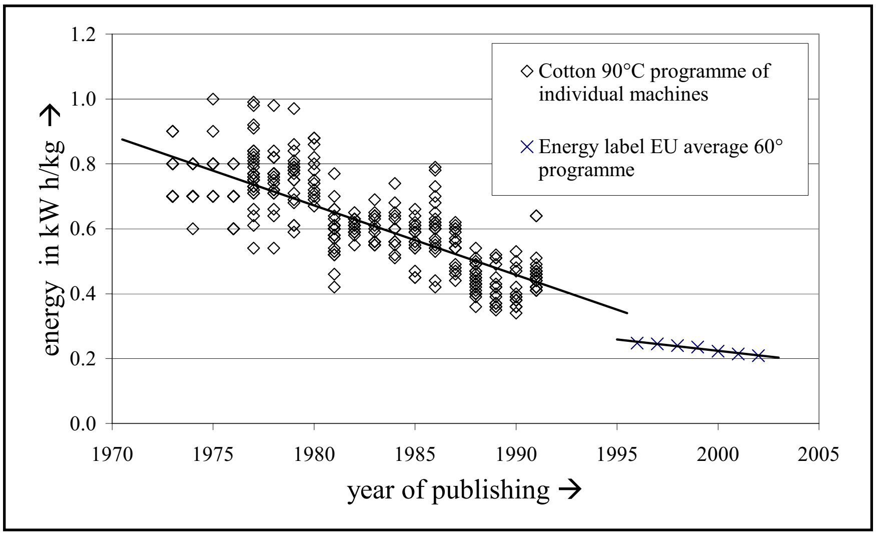
Ökologische und ökonomische Konsequenzen aus den gefundenen Resultaten werden diskutiert.

Figure 2: Cumulated frequency of washing machine capacitors with their age at recycling state



Source: Own representation. Line is for visualisation only

Figure 3: Specific values of energy usage by washing machines as published by Stiftung Warentest for the years 1973 through 1991 and average specific energy usage values for the energy label programme as published by CECED for 1996 through 2002



Sources: Test 1973-1991; Moretti 2003, p. 1125

Regression line $y = e_r + \varepsilon (x - x_r)$ characteristics are with:

- y = *specific energy in kWh/kg*
- e_r = *specific energy used in reference year*
- ε = *annual improvement in specific energy usage*
- x = *year*
- x_r = *reference year*

for 1973-1991:	*1996-2002:*
$x_r = 1970$	$x_r = 1995$
$\varepsilon = -0.0214$ *kW h/(kg a)*	$\varepsilon = -0.007$ *kW h/(kg a)*
$e_r = 0.866$ *kW h/kg*	$e_r = 0.259$ *kW h/kg*
$R^2 = 0.6353$	$R^2 = 0.9612$

change drastically within the last decades, this figure may be representative for the life-span distribution independent of the year of collection of the data used in this investigation.

3 Published Historical Data

Consumer organisations regularly test household appliances and publish data on water and energy usage and performance data. Many consumers appreciate this information as useful guidance in buying new appliances. Although testing always takes place under well-defined conditions, a comparison of publications by different institutions and from different times suggests that results are not always 100 % comparable. Moreover, tests usually refer to specific wash cycles.

Stiftung Warentest is a consumer organization in Germany that performs tests. It has tested washing machines on a regular basis, usually once a year. By examining their publications from 1973 to 1991 (Test 1973-1991), it is possible to retrace the history of the water and energy usage values of old washing machines (Fig. 3). In total 318 published data records were found. However, it is only specific values (per kg of textile load) that are published, and comparability cannot be taken for granted. In the early nineties, tests started looking at 60 °C programmes rather than 90 °C programmes, switching to 40 °C programmes not long after. At that time, too, the kind of programme (for moderately or heavily soiled textiles) used in the tests changed.

In view of these uncertainties, European averages of water and energy usage determined by the methods set out for the European Energy Label, which was introduced in 1996, seem more reliable. The data collected by CECED, the European Committee of Domestic Equipment Manufacturers (Moretti 2003, p. 1125) have been averaged over all of Europe and are the best estimate available (note: differences between the market offer of washing machines in Germany and the rest of Europe have been levelled since the introduction of the Energy Label).

These averages were fitted by a linear curve and multiplied by five to calculate water and energy usage per cycle (the most frequent rated load capacity of was-

Table 1: Conversion factors to calculate the energy usage for washing programmes at different temperatures

Washing programme temperature in °C	Conversion factor used based on 90 °C	based on 60 °C
90	**1.000**	1.600
60	0.615	**1.000**
40	0.335	0.540
30	0.200	0.330

Source: Own representation

hing machines being 5 kg). Conversion factors deriving from thermodynamic calculations of an 'average European washing machine' (Kemna 2001) and used for official purposes (SAVE 2001) were used to calculate energy usage at different wash temperatures (Tab. 1), whereas water usage was assumed to be the same for all wash temperatures. Extrapolations for 1995 were possible both from earlier and from later years, averages of both were used to calculate what would be the most realistic usage value for 1995.

In general, this results in a consistent picture (Tab. 2 and Fig. 4) of the likely development of average usage values of washing machines in Germany since the beginning of the seventies. This picture is somehow different to what is published elsewhere (e. g. HEA 2002, p. 41), as here the focus is on the average of the market offer (as represented in the selection of models of Stiftung Warentest and CECED database) and not on the best available technology in this specific year. As millions of washing machines are sold per year, new technologies will not be introduced in all machines at a time but more in a continuous process. Therefore a smooth improvement of the average values per year is the more likely trend to be observed and a linear interpolation as shown in figure 3 does fit the data reasonably well.

However, it must be stressed that our picture is based on a number of assumptions, that it required a number of corrections, and that individual machines may have diverged significantly from this picture. Nevertheless, there have been significant improvements in the energy and water usage of washing machines over the last three decades. For example, water usage was about four times as high in 1970 as in 2004, and more than two times as high only 15 years ago! On energy, the reductions over time for a defined washing temperature were also impressing, but not as high as on water. In recent years, however, this reduction in water usage has slowed down significantly, suggesting that it is becoming increasingly difficult to reduce water and energy usage values further.

4 Performance of Old Washing Machines

As a rule, the performance of a washing machine will stay the same – or even deteriorate – throughout its lifespan. Declines in performance due to material fatigue resulting from prolonged use can be detected in accelerated life tests, but at what levels of performance and water and energy usage do older appliances operate under current conditions?

While households use appliances for ten or even many more years, other factors change more rapidly. For example, the textiles to be washed are changing constantly, not only due to fashion, but also as a result of new fibres or finishings being put on the market. Detergents are yet another field of constant change. Consumers usually purchase detergents in quantities sufficient for a few weeks, but the next purchase may already have different ingredients and a different chemical formulation. Thus, innovations in detergents enter the market much more rapidly than innovations in the washing machines for which the detergents are bought. Therefore, the aim to study the behaviour of old washing machines under comparable conditions could only be done in using real old machines and testing them under today washing conditions, especially regarding the use of detergent.

4.1 Methodology of Tests

Tests were carried out on eight washing machines between 9 and 29 years old and previously used in households in Bonn, Germany. For comparison, two new washing machines (manufactured in 2002 and 2004) were tested under the same conditions (Tab. 3). As the composition of the IEC reference detergent (IEC 60456 2003) is quite similar to that of modern compact detergents, only programmes without pre-wash were selected.

To ensure comparability, all washing machines were loaded with the same amount of textiles. Washloads of 4 kg were used in order to ensure that none of the machines under study would be operated under extreme loading conditions; overloading might have caused unrealistic problems in cleaning performance. Moreover, studies have found that, on

Table 2: Calculated average energy (in kWh) and water usage (in l) for washing machines manufactured between 1970 and 2004 (for 5 kg cotton load)

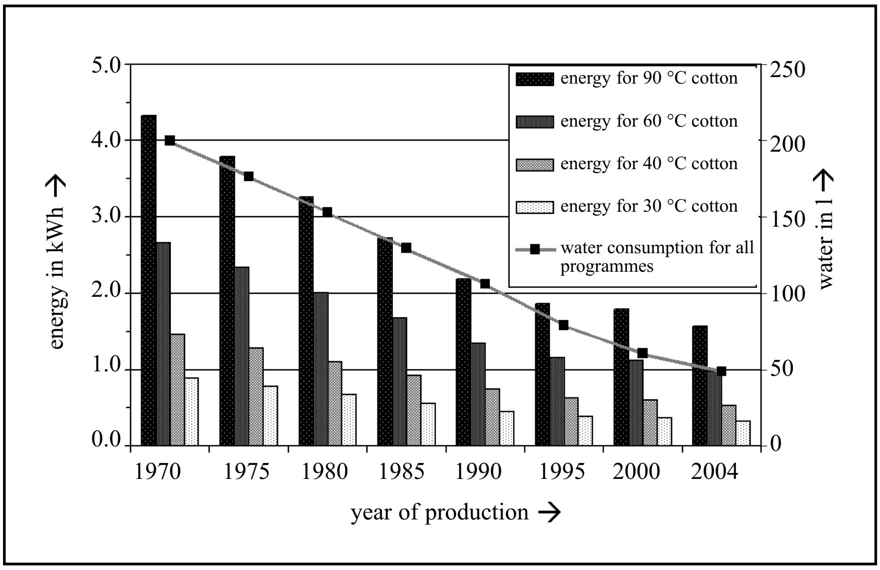
Temp.	Year of manufacture								
	1970	**1975**	**1979**	**1980**	**1985**	**1990**	**1995**	**2000**	**2004**
30 °C	0.89	0.78	0.69	0,67	0.56	0.45	0.38	0.37	0.32
40 °C	1.47	1.28	1.14	1.10	0.92	0.74	0.63	0.60	0.53
60 °C	2.66	2.34	2.07	2.01	1.68	1.35	1.16	**1.12**	**0.98**
90 °C	**4.33**	**3.80**	**3.37**	**3.26**	**2.73**	**2.19**	1.86	1.79	1.57
water (l)	200	176	157	153	129	106	79	61	49

Source: Own representation

Bold figures are averages from data base – others are calculated as described

WISSENSCHAFTLICHER BEITRAG

Figure 4: Calculated average energy and water usage for a 5 kg cotton wash by year of manufacture of washing machine



Source: Own representation

Line is for visualisation only

average, consumers use only about three quards of washing machines' maximum rated capacities.

Four test runs were carried out for each parameter setting, and usage of water and energy and performance data were recorded. Performance was measured (as is common practice in testing washing machines) by adding artificially soiled swatches to the wash and measuring their level of whiteness afterwards. A Wascator CLS washing machine was used as a reference machine to calculate the index of washing performance and to transfer it to class of performance as used in the European Energy Label system (EC95/ 12 1995). All other conditions followed international standards (IEC 60456 2003).

Tests using nominal (100 %) amounts of detergent were performed for 40, 60 and 90 °C cotton programmes. In addition, the machines were operated with reduced (50 %) and increased (150 %) doses of detergent in the 60 °C cotton programme. This was intended to take account of the flexibility of users in adjusting the performance of their washing machines by choosing different temperatures or by varying the amount of detergent.

4.2 Test Results

The results are presented here in terms of the index system and class definitions of washing efficiency as known from European energy labelling, although the test conditions were not all according to the definitions for this system. Nevertheless, a three-dimensional plot of the performance fields (Fig. 5) which washing machines can achieve depending on the amount of detergent used and on the temperature selected, provides the best overview of the results. It is evident that the same level of performance can be achieved (Fig. 5a) in a 90 °C programme with only 50 % of the rated detergent dose, in a 60 °C programme with rated detergent dosage, or in a 40 °C programme with 150 % of the rated detergent dose. Thus, consumers are basically free to select any one of these options to achieve a specific level of cleaning performance, the only limitation being the temperature stability of the fabrics to be washed.

Other washing machines, particularly older ones, have similar performance fields, but their absolute values are considerably lower, and their slopes show an increased influence of dosage and temperature on washing performance (Fig. 5b). A synopsis of the 60 °C cotton cycle measurements for all three detergent dosages (Fig. 6) shows that performance, in addition to varying greatly between machines, can be adjusted effectively via detergent dosage. This becomes even more obvious if the results are rated according to the European Energy Label index of washing performance, in which machines are graded in classes of 0.03 width ranging from A (best) to G (worst). Older machines rarely achieve class A performance

Table 3: Test conditions for all washing machines

Characteristics	Data and parameters
Load	
Mass	4.0 kg
Textiles (IEC 60456)	2 sheets, 4 pillowcases, 14 terry towels
Programme	
Kind	Cotton without pre-wash
Temperature	40 °C, 60 °C, 90 °C
Detergent (IEC 60456)	
Composition	77 % IEC A*, 20 % SPB4, 3 % TAED
Dosage	
40 °C	118 g (= 100 %)
60 °C	59 g (= 50 %), 118 g (= 100 %), 177 g (= 150 %)
90 °C	118 g (= 100 %)

Source: Own representation

Figure 5a: Index of washing performance of a new washing machine under varying conditions

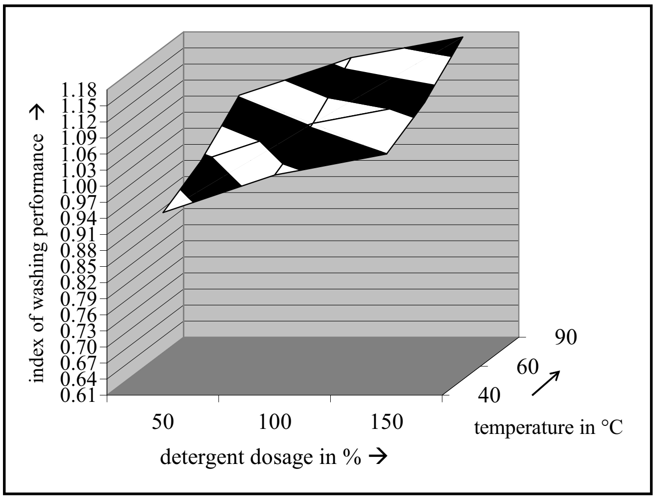
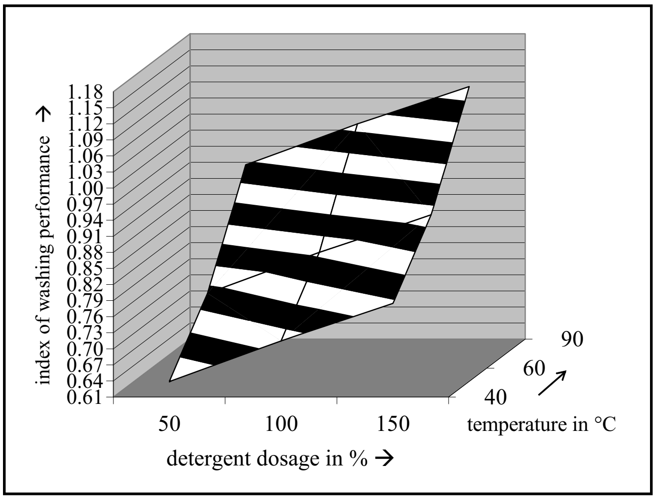


Figure 5b: Index of washing performance of an old (1975) washing machine under varying conditions



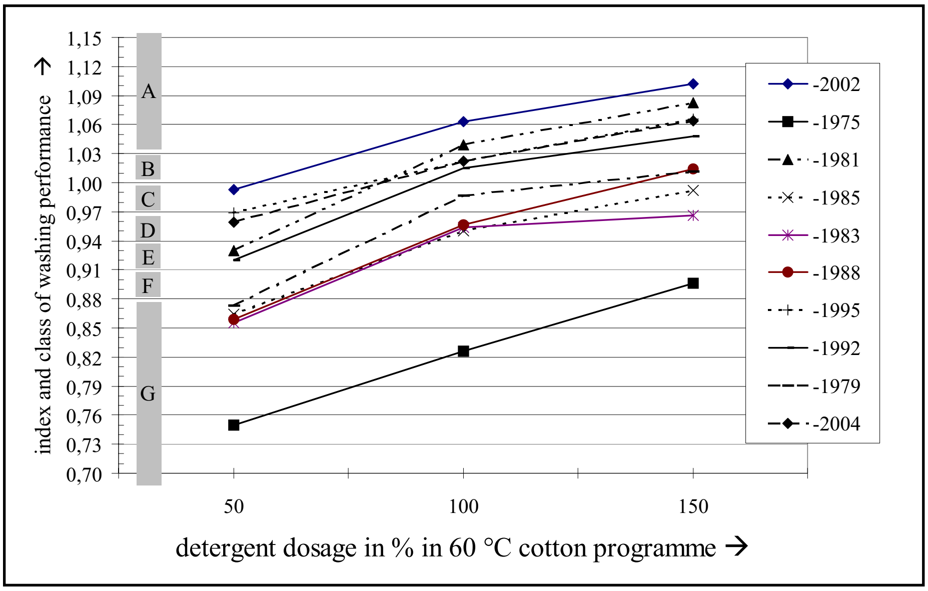
Source: Own representation

Shaded areas represent classes of washing performance according to the European Energy Label system and are for visualisation only. The machines' performance with reduced and increased doses of detergent at 40 and 90 °C was calculated by linear extrapolation

ratings, which are common in new washing machines (at rated capacity – which is not used here); and for doing so they usually require increased doses of detergent. Moreover, the slopes of older washing machines' performance fields differ significantly from that of newer machines, the loss in performance from 100 % to 50 % detergent dosage being significantly greater than from 150 % to 100 %. This may be due to the fact that in older washing machines there is nothing to prevent sump losses of detergent. Accordingly, large proportions of the detergent probably go unused.

A comparison of the washing performances achieved in 40, 60 and 90 °C programmes with the corresponding amounts of energy used (Fig. 7) produces results that are even more surprising. The distribution of the curves is even less uniform, and it becomes clear that older washing machines need much more energy to achieve a good washing performance. Indeed, to achieve the same washing performance as new machines in a 40 °C programme, old machines must be operated in 90 °C cycles! Moreover, at 40 °C (the point furthest left in the graphs), the washing performance of old washing machines is much lower than that of new ones.

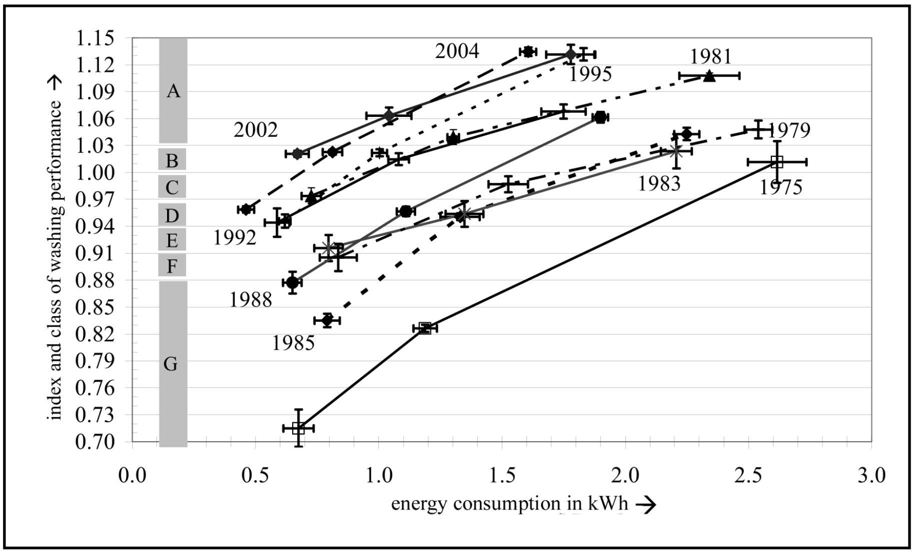
Figure 6: Washing performance in 60 °C cotton programme dependent on detergent dosage (machines are coded by year of production)



Source: Own representation

Washing performance is given as index and corresponding class A to G as used by the European Energy Label. Standard deviation of index of washing performance is in the same order of magnitude as given in Fig. 7. Lines are for visualisation only

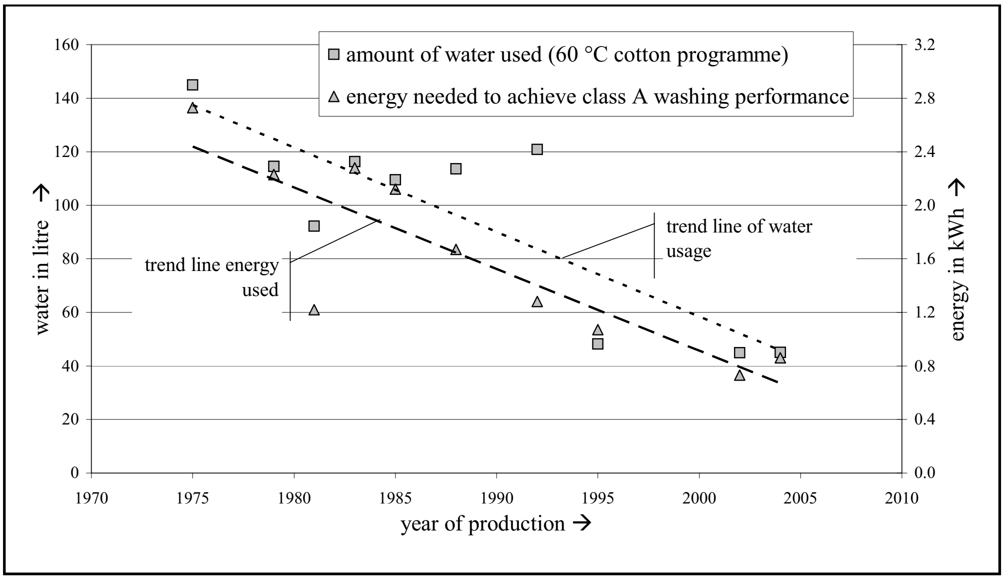
Figure 7: Washing performance versus energy usage values for all machines under study (coded by year of production)



Source: Own representation

From left to right the energy values indicate the machines' energy use for 40, 60 and 90 °C programmes; washing performance is given as index and corresponding class A to G as used by the European Energy Label. Error bars indicate standard deviation of index of washing performance and energy measured. Lines are for visualisation only

Figure 8: Water usage and calculated energy usage for achieving class A performance by year of manufacture of washing machine.



Source: Own representation

Regression line $y = e_r + \varepsilon\ (x - 1970)$ characteristics are with:

y = energy in kWh or water in litre per cycle
e_r = energy or water used in the reference year
ε = annual improvement in energy or water usage
x = year

for water: $\varepsilon = -3.16$ l/a, $e_r = 153.2$ l, $R^2 = 0.7204$

energy: $\varepsilon = -0.061$ kW h/a, $e_r = 2.73$ kW h, $R^2 = 0.7444$

By taking class A performance as a fixed level of required washing performance, it is possible to asses the efficiency of a washing machine, as the amount of energy used to achieve this level of performance. Although some linear extrapolations are needed in older machines, it becomes possible to compare the efficiency of different washing machines over time (Fig. 8). As expected, the efficiency values are distributed rather unevenly, but the general trend is that older machines require a much higher energy input than newer machines for the same washing performance. The trend line shows a much higher level of improvement compared to the comparison based on constant wash temperature (compared to Fig. 3). This is the influence of the improved washing performance. New machines use about half as much energy as 15-year-old machines and one fourth of the energy used by 30-year-old machines to reach the same washing performance. A comparison of the amounts of water used for washing a fixed amount of load (Fig. 8) yields similar factors of improvement over time. Due to simple reasons, this trend can not continue forever.

Assuming that a household washes five cycles per week in a new washing machine, its washing will consume about 80 € annually at average German rates for water (3.96 €/m³) (BGW 2003a) and electricity (0.1719 €/kWh) (BGW 2003b). Accordingly, a washing machine 15 years old would cost about twice as much (160 €/a) and one 30 years old about four times as much (320 €/a) in annual running costs for water and energy.

5 Conclusion

This series of investigations has shown that a considerable number of rather old washing machines is being used in German households. Their efficiency under current washing conditions is worse than expected. This is probably due to innovations in detergents and to continuous adjustments of new washing machines to these innovations. In consequence, households owning old machines spend much more money on operating their machines on the performance level reached by new washing machines. Early replacement, meaning replacing old appliances with new ones after a certain time of use, may be a viable strategy to realise energy and water savings at national or global level. Similarly the possibility to update the programming of a washing machine, e. g. via Internet, after it has left the manufacturing plant, may be a good way of keeping washing programmes up to date and of realising energy savings and performance upgrades.

References

BGW (Bundesverband der Gas- und Wasserwirtschaft) (2003a): „Marktdaten Abwasser“. Presseinformation 24.3.2003

BGW (Bundesverband der Gas- und Wasserwirtschaft) (2003b): „Wasserpreise in Deutschland stabil“. Presseinformation 10.8.2003

EC95/12 (1995): Commission Directive 95/12/EC of 23 May 1995 implementing Council Directive 92/75/EEC with regard to energy labelling of household washing machines. Official Journal of the European Communities, No L 136/1

HEA (2002): Bilderdienst Informationen über Elektrizität und ihre Anwendung, Heft 6.5.1 Waschmaschinen. Frankfurt

IEC 60456 (2003): Clothes washing machines for household use – Methods for measuring the performance

Kemna, R. (2001): Epolis Monitoring Washing Machines 2001. Report for AISE (unpublished)

Moretti, F. (2003): Industrial Commitment – The Case of Wet Appliances. In: Bertoldi, P., et al. (Hrsg.): EEDAL-Conference 1-3 October 2003. Proceedings. P. 1125

SAVE (2001): Revision of energy labelling & targets washing machine (cloth). Final report. NOVEM, Utrecht 2001; EU-SAVE contract no. 4.1031/Z/98-091

Test (1973-1991): Magazine of Stiftung Warentest. ISSN 0040-3946. Berlin

Prof. Dr. Rainer Stamminger,
Dipl.-Oecotroph. Alexandra Barth,
Dipl.-Oecotroph. Susanne Dörr

University of Bonn
Institut für Landtechnik
Section Household and Appliance Technology
Nussallee 5
D-53115 Bonn
Germany
Tel. (+49-228) 73-5955
Fax (+49-228) 73-2596
stamminger@uni-bonn.de

Acknowledgment

This work was supported by Stiftung Warentest, Rethmann Elektrorecycling GmbH and EMPA Testmaterialien. Thanks to all.