Old washing machines wash less efficient and consume more resources

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Abstract

In German households washing machines can be found which are up to 40 years old and still in use. The target of this investigation was to measure performance, water and energy consumption values for old machines under today’s washing conditions and especially when using a modern detergent. Comparing this data with that of new washing machines, allows conclusions about the sustainability of the continued use of old machines to be made. When this information is combined with data about the real usage time of washing machines, saving potentials in terms of water, energy and costs may be calculated.

The energy and water usage of washing machines has lowered significantly over the last few decades. Although this is ecologically and economically sound, it is possible that this trend may have been at the expense of declining washing performance. As this has not previously been investigated, it forms one of the major components of this paper. First, an investigation into the age distribution of washing machines in German households is reported. This is established by examining the age of washing machines delivered for recycling at recycling plants. Second, this paper tries to give a picture of the development of average-energy and water usage values for washing machines in Germany over the last 30 years. Third, washing machines up to 30 years old were subjected to washing performance tests conducted in accordance with current washing conditions. Surprisingly, new washing machines with significantly reduced water and energy usage do not suffer from lower washing performance.

The results show that, in order to achieve the same washing performance as a modern machine does in a 40 °C wash, a 15-year-old washing machine must be operated in a 60 °C programme, and a 30-year-old one in a 90 °C programme (on average). By contrast, on average a 15-year-old washing machine requires approximately twice as much energy and water as a new one to achieve the same level of performance, and a 30-year-old washing machine about 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 how it is used (i.e..the 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 for a shorter period than in households which use 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 is in existence, 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 end of their life: at the recycling stage.
The second aim is to examine the development of washing machines in terms of performance (cleaning effect), water and energy usage over time. Here our approach follows two routes. First, historically published data about the measured performance of new washing machines is collected and analysed. Second, tests are done and reported on a limited number of old washing machines to verify their performance under current washing conditons i.e. conditions that are close to those under normal household use. Methodologically, this is done in accordance with the test procedure used under the present European energy labelling scheme by comparing these results with results from actual machines.
A third aim – deriving from the first two – is to assess the implications of the actual lifespans of washing machines and the evolution of their usage conditions in terms of their economic and environmental impacts.

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:

1. brand and model
2. product identification code
3. 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's 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 useful lifetime 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 change drastically within the last few 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, energy and performance. 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 the best-known consumer organisation in Germany. It has tested washing machines on a regular basis, usually once a year. By examining their publications [1] from 1973 to 1991, it is possible to retrace the history of water and energy usage values of old washing machines

(Fig. 3). In total 318 published data records were found. However, the published energy consumption and water usage values are only reported per kg of textile load and comparability cannot be taken for granted. In the early nineties, tests started using 60 °C programmes in place of the earlier 90 °C programmes and switched 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 also changed.
In view of the uncertainty that these changes may make on the comparability of data tested under different test conditions, 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 [2] 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 narrowed 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 (this is done because the most common rated load capacity of washing machines is 5 kg). Conversion factors deriving from thermodynamic calculations of an 'average European washing machine' [3] and used for official purposes [4] were used to calculate energy usage at different wash temperatures (Table 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 (Fig. 4 and Table 2) of the likely development of average energy and water consumption values of washing machines in Germany since the beginning of the seventies. This picture is somehow different to what is published elsewhere [5], 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 the same time but rather in a more continuous process. Therefore a smooth improvement of the average consumption values each year is the more likely trend to be observed and a linear interpolation as shown in Fig. 3 fits 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! The reductions in energy use over time for a defined washing temperature were also impressive, but not as great as for water. In recent years, however, the reduction in water usage has slowed significantly, showing that it is becoming increasingly difficult to further reduce water and energy usage values.

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 what wash-performance, water and energy usage levels do older appliances attain when functioning under current operating 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 of studying the characteristics of old washing machines tested under comparable conditions, could only be done by using real old machines and testing them under today's washing conditions, especially with respect to the use of detergent.

4.1 Testing methodology

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 (Table 3). As the composition of the IEC reference detergent [6] 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 average, consumers only use about ¾ of washing machines' maximum rated capacities.
Four test runs were carried out for each parameter setting, and water usage, energy consumption 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 the performance class used in the European Energy Label system [7]. All other conditions followed international standards [6].

Tests using nominal (100 %) detergent doses 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 washing performance index and class definitions used in the European energy labelling scheme, although the test conditions were not all in accordance with those used in 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. 5, a) in a 90 °C programme with only 50 % of the rated detergent dose, in a 60 °C programme with the 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. 5,b). 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 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.
By taking class A performance as a fixed level of required washing performance, it is possible to assess the efficiency of a washing machine, in terms of the amount of energy needed 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. A typical new machine uses 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 class A 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 5 cycles per week in a new washing machine, its washing will consume about 76 € annually at average German rates for water (3.96 €/m³) [8] and electricity (0.1719 € / kWh) [9] (tab. 4). Accordingly, a 15 year old washing machine would cost about twice as much (150 €/year) and a 30 year old machine about four times as much (250 €/year) in water and energy running costs when the same program mix is used as in a new one . If the effect of degrading performance of older washing machines is taken into account, these costs would additionally increase by about 20% for 15 year old and by about 40% for 30 year old machines.

5 Conclusion

This series of investigations has shown that a considerable number of rather old washing machines are 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 need to spend much more money to operate 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.

Acknowledgment

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

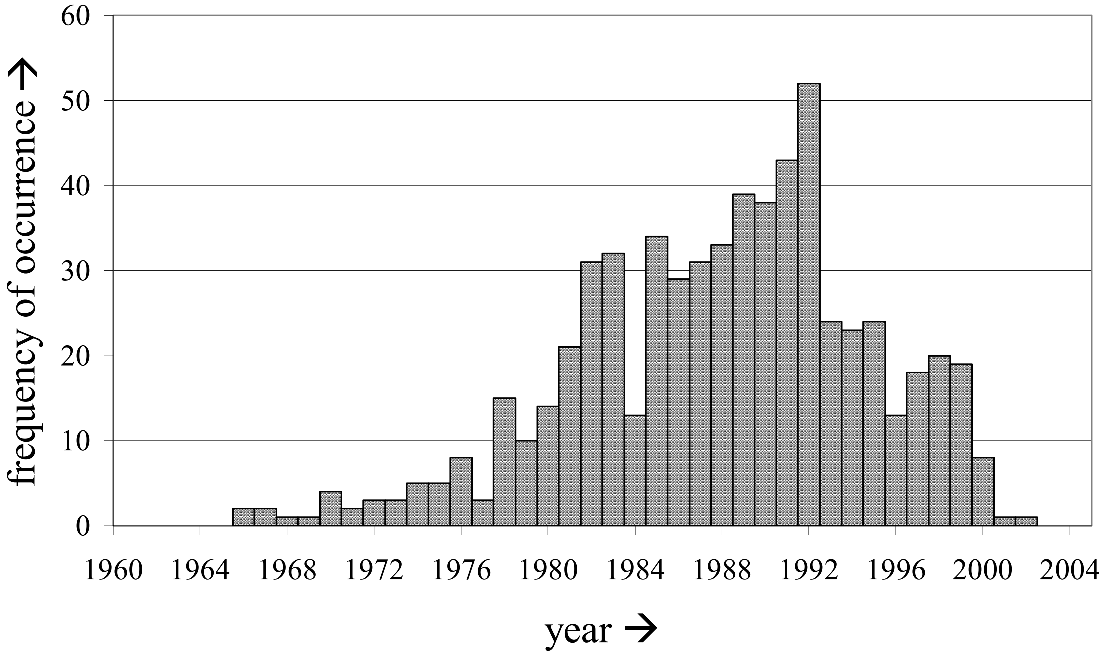


Fig. 1: Occurrence of capacitors in washing machines by year of manufacture of capacitor (n=625); data collected between middle and end of 2004 in Germany.

Fig. 2: Cumulated frequency of washing machine capacitors with their age at recycling state. Line is for visualisation only.

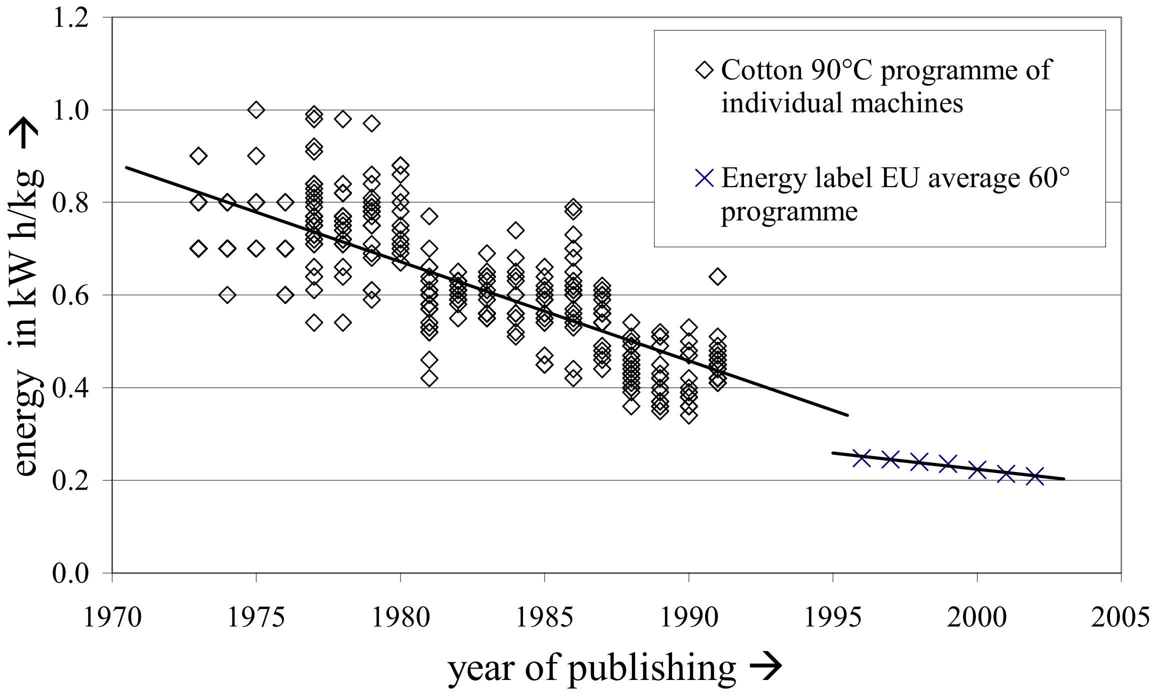


Fig. 3: Specific energy usage values for washing machines as published by *Stiftung Warentest* for the years 1973 through 1991 [1] and average specific energy usage values for the energy labelling programme as published by CECED for 1996 through 2002 [2].

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 (a)
> ε = annual improvement in specific energy usage
> x = year
> x_r = reference year

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

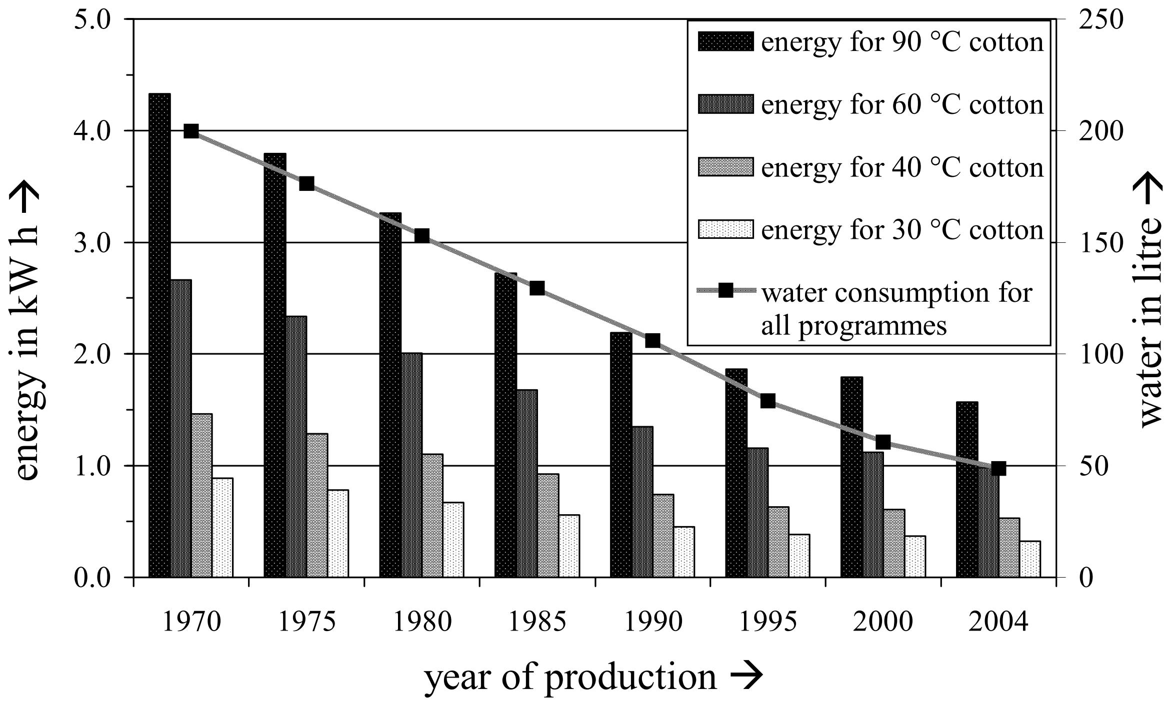
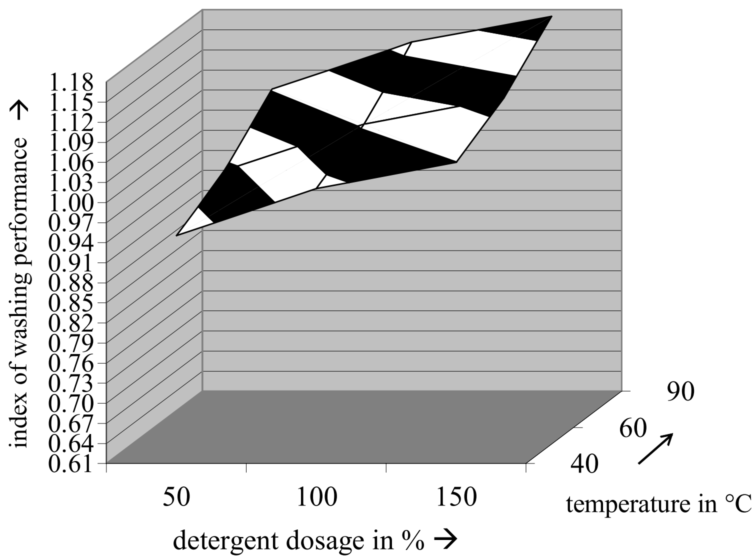


Fig. 4: Calculated average energy and water usage for a 5 kg cotton wash by year of washing machine manufacture. Line is for visualisation only.

a: new washing machine



b: washing machine from 1975

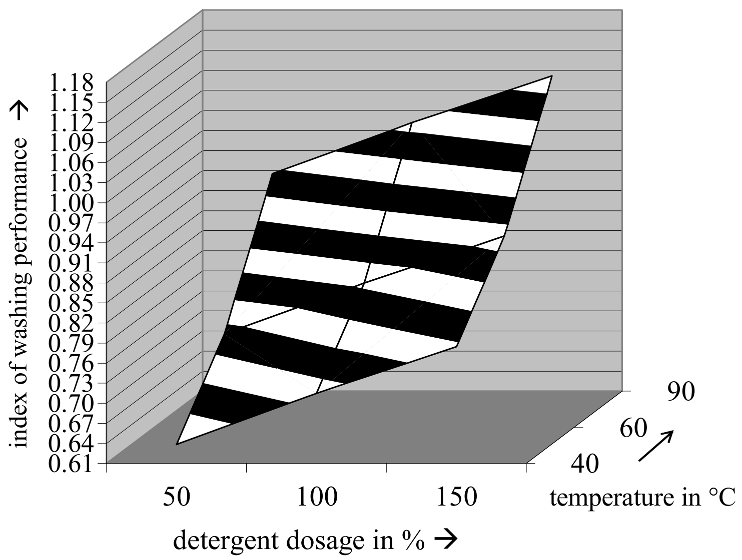


Fig. 5: Index of washing performance of a new and an old washing machine respectively under varying conditions. Shaded areas represent classes of washing performance according to the European Energy Label system and are for visualisation only. The machines' performance with reduced and increased doses of detergent at 40 and 90 °C was calculated by linear extrapolation.

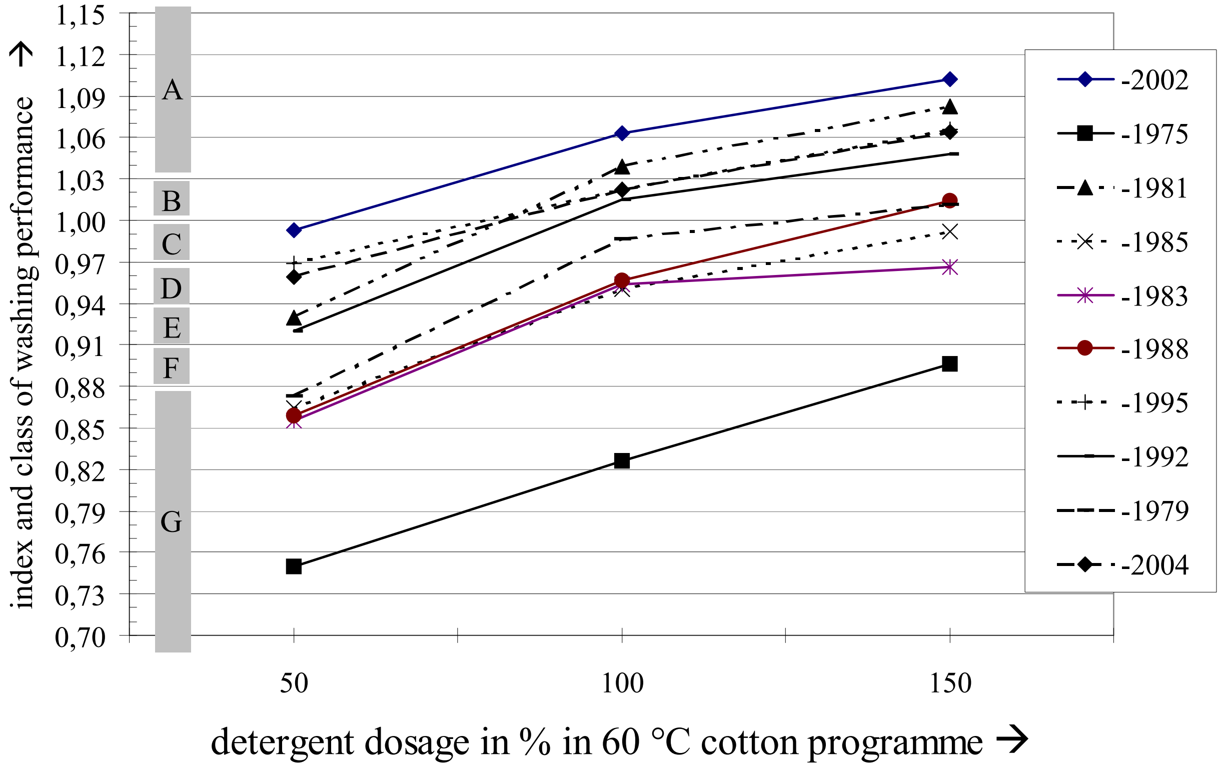


Fig. 6: Washing performance in 60 °C cotton programme dependent on detergent dosage (machines are coded by year of production). Washing performance is given according to the index and corresponding class A to G as used by the European Energy Label. The standard deviation of washing performance index is of the same order of magnitude as given in Fig. 7. Lines are for visualisation only.

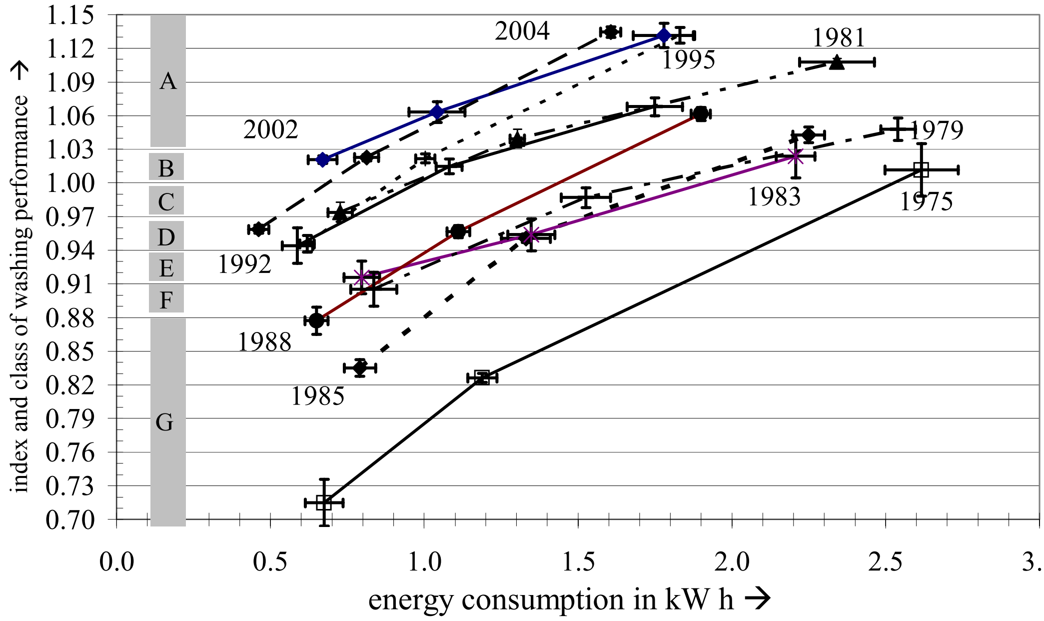


Fig. 7: Washing performance versus energy usage values for all machines under study (coded by year of production). Reading from left to right the energy values indicate the machines' energy use for 40, 60 and 90 °C programmes; washing performance is given both as the index and corresponding class A to G as used in the European Energy Label. Error bars indicate standard deviation of washing performance index and energy measured. Lines are for visualisation only.

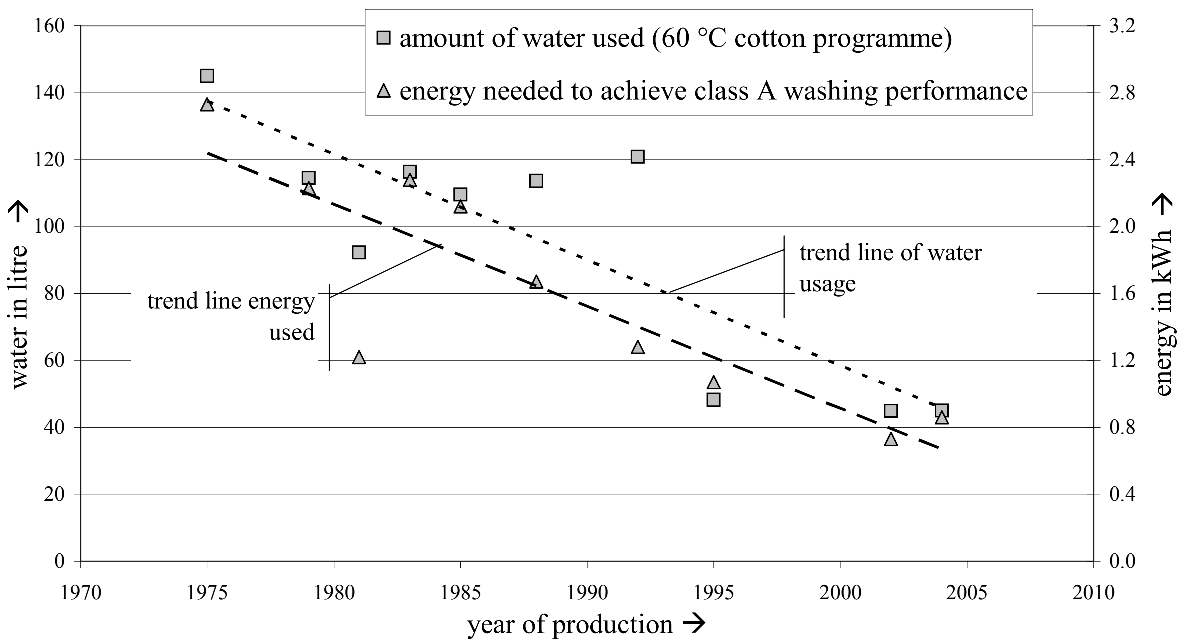


Fig. 8: Water usage and calculated energy usage for achieving class A washing performance by year of manufacture of washing machine.

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:	ε = -3.16 l/a	energy: ε = -0.061 kW h/a
	e_r = 153.2 l	e_r = 2.73 kW h
	R^2 = 0.7204	R^2 = 0.7444

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

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

Table 2: Calculated average energy and water usage for washing machines manufactured between 1970 and 2004 (for 5 kg cotton load)
Note: bold figures are averages from data bases as described in text – others are calculated as described

Program	Year of washing machine production							
Energy in kWh	**1970**	**1975**	**1980**	**1985**	**1990**	**1995**	**2000**	**2005**
30°C cotton	0,89	0,78	0,67	0,56	0,45	0,38	0,37	0,31
40°C cotton	1,47	1,28	1,10	0,92	0,74	0,63	0,60	0,51
60°C cotton	2,66	2,34	2,01	1,68	1,35	1,16	**1,12**	**0,95**
90°C cotton	**4,33**	**3,80**	**3,26**	**2,73**	**2,19**	1,86	1,79	1,51
Water usage in litre	**200**	**176**	**153**	**129**	**106**	**79**	**61**	**46**

Table 3: Test conditions for all washing machines

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

Table 4: Average running costs per cycle and costs per year for washing machines of a given year under the assumptions mentioned.

Program	Year of washing machine production							
	1970	1975	1980	1985	1990	1995	2000	2005
Running costs	**Energy: 0,1719 € / kWh**				**Water and sewage: 3,96 € / m³**			
in € per cycle								
30°C cotton	0,94 €	0,83 €	0,72 €	0,61 €	0,50 €	0,38 €	0,30 €	0,23 €
40°C cotton	1,04 €	0,92 €	0,79 €	0,67 €	0,55 €	0,42 €	0,34 €	0,27 €
60°C cotton	1,25 €	1,10 €	0,95 €	0,80 €	0,65 €	0,51 €	0,43 €	0,34 €
90°C cotton	1,53 €	1,35 €	1,17 €	0,98 €	0,80 €	0,63 €	0,55 €	0,44 €
Annual costs at 5 cycles per week = 260 cycles per year (16 x 90°, 81 x 60°, 91 x 40°, 72 x 30°)								
in € per year	288,48 €	254,10 €	219,72 €	185,34 €	150,96 €	117,04 €	96,85 €	76,19 €
Additional running costs compared to washing machine from 2005	212,29 €	177,91 €	143,53 €	109,15 €	74,77 €	40,86 €	20,66 €	- €

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