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DEVELOPMENT OF ENERGY EFFICIENT ELECTRICAL HOUSEHOLD APPLIANCES

Part Three: WASHING MACHINES

Report

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Part Three: WASHING MACHINES

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FINAL REPORT

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OBJECTIVE

This report describes the third out of three parts of the work on designing more energy efficient appliances. The objective of this part was to develop and build a prototype of a low energy washing machine, making it possible to do the washing with only around 15 percent of the electricity typically consumed in 1975.

SUMMARY

This third part of the final report is on washing machines. The first part is on refrigerators and the second part is on cooking.

Earlier analyses indicated significant potentials for saving electricity in the process of washing clothes (5 and 6). Three major measures could be applied: 1) Reducing the amount of water, 2) reducing the temperature and 3) taking in hot water heated by other (and cheaper) energy sources than electricity. We have used most of our efforts on 1) but with some considerations given to 2). The project was intended to be carried out in cooperation with a manufacturer of washing machines, Vølund Husholdningsapparater A/S, but this factory closed down shortly after the project was started.

During the period of the project, a new washing process and a prototype washing machine has been developed and tested. The basic change in this washing process is less use of water during the period with high temperatures. In a second stage the process was further improved into a resource efficient (RE-)process which uses less detergent and less water for rinsing in addition to the energy savings. Washing quality is found to be similar to that of average, 1982-washing machines.

The annual electricity savings would be 140 kWh when compared to average 1982-machines. The necessary extra costs for a machine with this washing option would be paid back in saved electricity in 6.5 years, but including the detergent and water saved, the payback period is estimated to be less than 4 years. Since there is less mechanical action in this RE-process, it is likely that the wear of the clothing will be lower than usual.

Alternatively we suggest a process with an hour long pre-soaking in enzyme detergent followed by washing at lower temperature than usual today. With intake of warm water from the hot water system, this method, which we have not fully explored, would save more than 300 kWh per year as compared to average 1982-machine, but in return use some energy in the cheaper form of low temperature heat. With this method we could reach our target.

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INTRODUCTION

The background for the project is an energy analysis carried out in 1974 to 1979, investigating future energy options for Denmark, (5,6). This analysis included theoretical studies of how energy efficient the major household appliances could be designed. On the average it was found that their annual electricity consumption could be reduced through technical measures to about one third of what the 1975-stock of appliances consumed. For some appliances like refrigerators and freezers the potential savings were larger, and for others like cookers they were smaller.

Later studies confirmed these findings and indicated a tendency among manufacturers to design more energy efficient models (10,11).

It seemed natural to supplement these theoretical studies with some experimental investigations, including the building of prototype appliances.

The purpose of the project was to construct and test such prototypes, designed for actual production. Three types of appliances were chosen because of their large distribution and importance to many European households. The three are: refrigerator, cooking devices and washing machine. The project was started September 1981 to run until April 1984 but was by a new contract extended till August 1984.

This report only covers the part of the work carried out concerning washing, but similar reports are made for the two other parts of the project. The progress of the work has steadily been reported in five progress reports to the Commission of the European Communities. This report is part three of the final report summing up the former progress reports, as well as reporting the latest two periods of progress under the two contracts.

Technology and habits

For clothes washing - like for cooking - it is difficult to separate behavioral and technical measures to save energy. In Northern Europe there is a long tradition for washing hot wash, - originally in boiling water. Hot water was used whenever the fabric could stand the temperature. This is still reflected in Danish washing pattern even though there has been a significant change over the last decade. Today only around 30% of the laundry is done as "hot wash" (90^{o}C) compared to 50% in 1975. "Warm wash" (60^{o}C) account also for 30% compared to 25% in 1975 and "fine wash" (40^{o}C and below) makes up the remaining 40% today (4, 5 and 6). This change has occurred partly because many new synthetic fibres cannot stand the hot wash and partly as an energy saving measure.

Target for electricity savings

In setting the target for energy savings in clothes washing we have assumed that the service to be provided is a certain cleanness of the clothes. As seen from Fig. 1, our target was to reduce electricity consumption to about 15% of the average in 1975, see Fig. 1. This target was suggested to be reached partly by substituting electricity with energy in the form of hot water, taken from the hot water supply in the house. Such washing machines which allow intake of both cold and hot water were essentially unknown in Scandinavia until few years ago. Still this type of machines are not promoted on the market, despite the fact that energy in the form of hot water usually cost less than half the price for electricity. Hot water heated by district heating from combined heat and power plant is especially cheap.

The target shown on Fig. 1 includes some change in habits, and with such changes we are most likely almost able to reach our goal with some of todays machines on the market.

We have then mainly pursued a different path, aimed at achieving substantial savings in electricity consumption while still maintaining the high temperature washings and without connecting the machine to the hot water supply system. Also, however, some preliminary experiments have been conducted with low temperature washing combined with soaking the laundry in enzyme detergents.

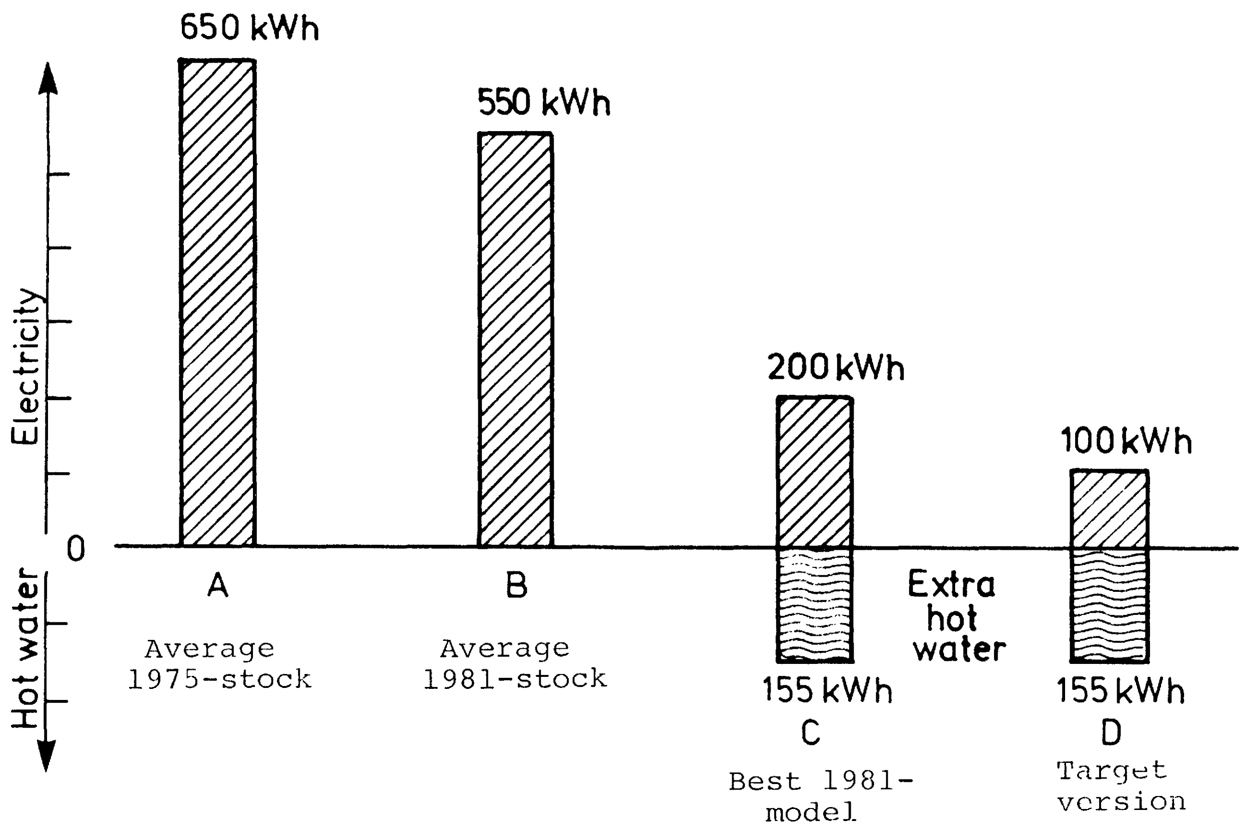


Fig. 1 Annual electricity consumption and hot water consumption for different versions of washing machines, all with todays Danish average of 5 uses per week. For "B" and "C" the fraction of hot washes (90°C) is assumed to be the 1981 average of 1/3, while for "A" it is 1/2. The difference between "C" and "D" lies basically in washing patterns.

Cooperators

In the field of washing, we started the project by discussing feasible ways of cutting energy consumption with the Danish washing machine manufacturer Vølund Husholdningsapparater A/S. This company had agreed to cooperate with us on the project.

However, before we reached any decision on how to achieve the savings, Vølund Husholdningsapparater was sold and the production moved to Sweden.

After this event we started on our own and worked our way to a new washing principle and a prototype washing machine.

During the project we have received substantial support, primarily from the Danish Government Home Economics Council (DGHEC). At the laboratory of DGHEC standard measurements of reflection of the washed test strips have been carried out. This made it possible through standard measurements to compare the washing quality of our process with the quality of washing in a number of commercially available washing machines.

Also NOVO Industries A/S, Enzymes Division, and Danish Institute of Technology, Department of Washing Technology have added to the results in commenting and advising on our hypotheses.

THE LOW ENERGY WASHING PRINCIPLE

A significant part of energy consumption of washing machines is used for heating up water. For a 90°C washing the heating of water normally accounts for more than 85% of the electricity consumed.

Water in the main wash is used 1) for transferring heat to the laundry, 2) to provide the chemical active detergent solution, and 3) to provide the mechanical belabouring of the laundry.

Chemical action is increased with decreasing amount of water, as detergent concentration is increased. Further, chemical action increases with temperature.

Mechanical action is increased with increasing amount of water, according to measurements, carried out by the Danish Technological Institute, Dept. of Washing.

Evidently both types of action are necessary in order to perform an adequate washing. According to tradition, these two types of action have taken place simultaneously. This of course requires an amount of water giving the necessary mechanical action, which again calls upon an amount of detergent, giving the necessary chemical action, and an energy consumption, giving the necessary temperature.

Now, if mechanical and chemical action could be separated, we could reduce the amount of water in the heat-requiring part of the process, that is, the chemical part.

We started, asking around, whether specialists thought that this could be done. Generally these people were reluctant, as this way of thinking was evidently new. So we set off to prove that mechanical action and chemical action could be separated in what we have termed a low energy washing process, giving a better energy-efficiency and less use of detergent.

The Low Energy process or LE-process is a standard washing process as far as prewash and rinsing is concerned. The main wash, however, is separated into a chemically active part and a mechanically active part.

During the chemically active part just enough water is added to the laundry to soak it. Detergent solution, dripping from the washing drum is drained from the washing vessel, recycled through an external heating-element, and sprayed over the laundry, see Fig. 2. Thus, a permanent recycling of the detergent is maintained during the chemically active period.

Typical data for the chemically active part are shown on Table 1. This part takes 44 minutes with a water temperature of 90°C for a hot wash.

The mechanically active part of the process starts by adding so much cold water that a free surface appears in the washing vessel. The washing drum dips into this surface so that water and laundry interfere eagerly during rotation of the drum. Recycling of water is stopped, together with heating. During the mechanical period, the degraded smudge is removed from the laundry. After a proper time, water is drained out of the washing vessel, and rinsing starts in a traditional fashion.

Typical data for a mechanical part following the above chemical part are also shown on Table 1. The temperature has dropped to around 50°C, and the mechanical part takes 24 minutes. The amount of laundry is typical 3.2 kg.

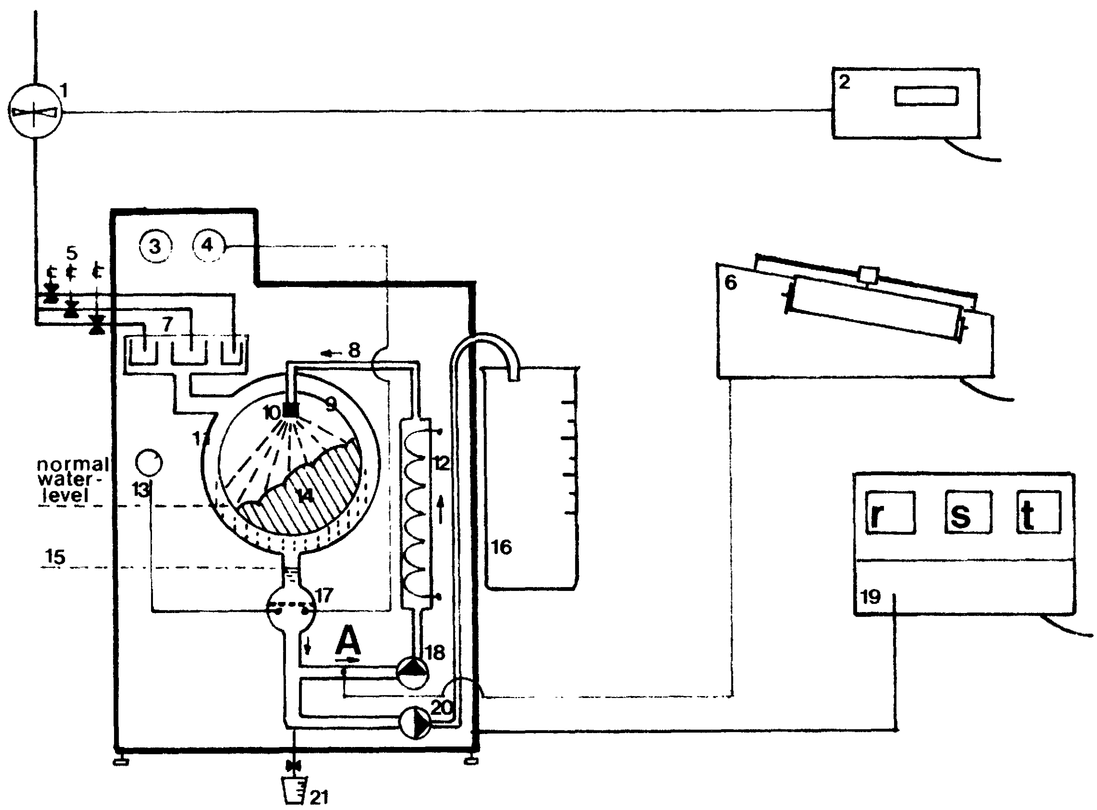
LOW ENERGY WASHING PROCESS

Time (minutes)	Washing activities
2 . 8	PREWASH No heating, appr. 20 litres of water.
10	DRAINING
12	EXTRACTION
14 . . . 56	MAIN WASH Chemical active part: Heat applied. Appr. 8.5 litres of water. Temperature of hot wash 90^{o}C. High concentration of detergent. Total time 44 min.
58 . . 78	Mechanical active part: Appr. 11.5 litres of cold water added. No heating. Temperature appr. 50^{o}C. Total time 24 min.
80	
82 84	1. RINSE
86 . . 105	DRAINING DRAINING
106	EXTRACTION
110	6. RINSE
112	DRAINING
114 120	EXTRACTION

Table 1. The various steps in the Low Energy washing process with appr. 3.2 kg laundry.

PROTOTYPE WASHING MACHINE

A programmable washing machine was built in order to carry out the necessary tests, see Fig. 2 and 3. The machine is based on a BBC-Rondoprins, production no. 10.802.



Numbers at figure refers to:

1. water-meter
2. water-meter display
3. programmer
4. temperature controller
5. solenoid valves
6. x-t recorder
7. soap-containers
8. recycling detergent
9. washing drum
10. nozzle
11. washing vessel
12. heat-element
13. water-level controller
14. laundry
15. lowest water level
16. measuring glas
17. filter
18. recycling pump
19. energy-meter
20. drain-pump
21. measuring glass

Fig. 2 Diagram of the prototype low water washing machine and the measuring equipment. Note the lowest water level,15, as compared to that in a normal washing process. Some of the elements were established in the second phase of measurements, the resource efficient washing process, RE-process.

By cutting the amount of water drastically, heat cannot any longer be transferred from heat elements to clothing in the traditional way. Therefore the prototype washing machine was built, so that the water with detergent is drained from the bottom of the washing vessel and recycled to the laundry through a heat element by means of a pump. The detergent is sprayed over the laundry by means of a nozzle.

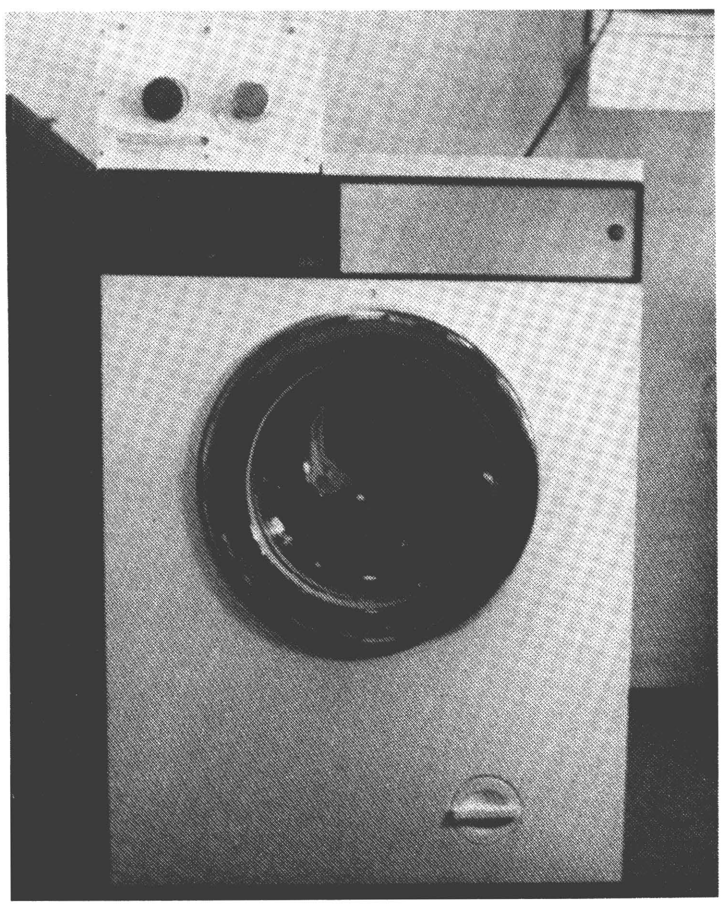


Fig.3 Photo of the prototype Low Water washing machine. The only difference visible from the outside is the extra programmable controller added on top of the prototype. This extra controller will not appear on a commercial version.

Modifications of the machine are significant, namely:

1. A recycling system, which recycles detergent and rinsing water.
   The recycling system includes a filter, a 75 W pump, a 2000 W external heat-element and a nozzle for spreading detergent over the laundry.
2. Adding a programmable process-timer. (Wascator FL 403) for controlling solenoid valves, washing drum motor, water level controls, recycling pump, drain pump, heat elements, and temperatur controller.
3. A fast reacting temperature controller. The transducer is placed in the filter at the upstream side of the recycling pump.
4. An additional water level control for handling the low water level during recycling, also mounted in the filter.

Main data of the prototype machine:

- Size: width 60 cm
  dephts 52 cm
  heights 99 cm
- Power of heating elements 2000 W
- Cloth capacity acc. to IEC: 3.2 kg.

<u>TEST PROCEDURES</u>

The LW-proces was tested and compared to a number of processes from commercially available machines by means of two standard test methods:

1. <u>Washing quality</u> was tested through a method established by the International Electrotechnical Commission. The method is described in publication No. 456 from the Commission (7). In short, the method is based upon measurements of reflection. The amount of light reflected from a number of test strips, each 150 x 150 mm and each polluted before washing with either oil and soot, blood, red wine or chocolate, is measured and compared to the reflection from a standard MgO

surface. The strips are sewn onto a piece of cotton and washed together with 3 kg cotton clothes of different sizes. Normally reflection from a clean test strip will be around 90%. A good washing result is obtained when average reflection exceeds 65% at 90°C and 55% at 60°C. The strips are produced by Eidgenossische Materialprufungs and Versuchsanstalt, EMPA, Sct. Gallen, Schweiz.

There is considerable doubt about the validity of these test procedures (14). We have, however, not found any better established and recognized method of testing washing quality. One of the doubt is about the weighing of results from the four types of dirt. In many cases we list them all. In other cases we list the result for "oil and soot" and an average of all four.

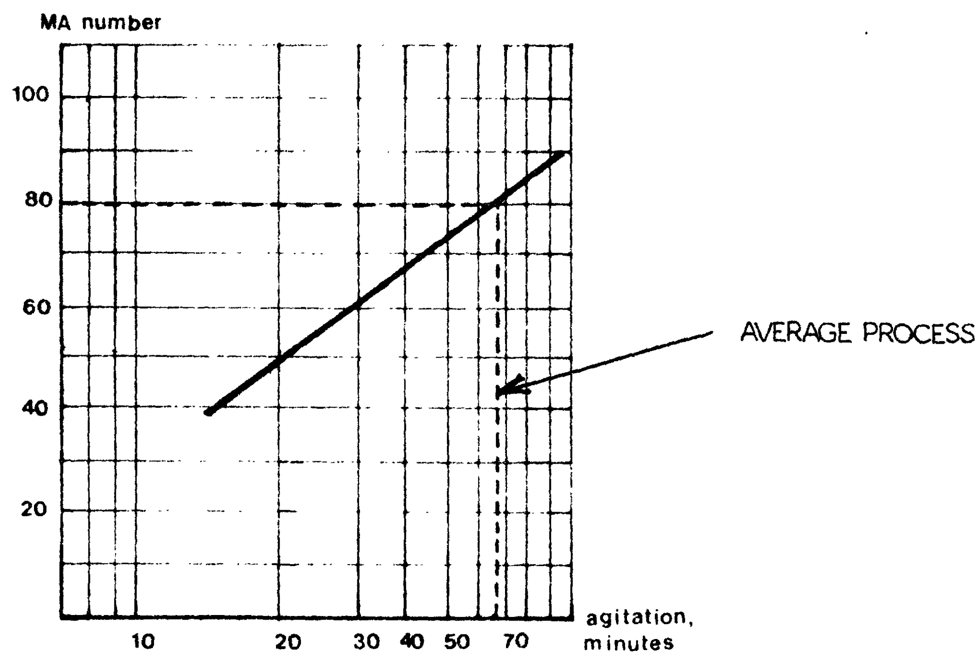
2 Mechanical action is the other parameter tested. The purpose is to evaluate how much of the cleaning process is due to mechanical action as compared to chemical action. The mechanical action is also a measure for the wear of the clothes. Mechanical action was measured by means of a test method developed by the Danish Technological Institute, Dept. of Washing Technology (2). The basic principle of the method depends on the fact that when a piece of cloth with a circular hole is washed, the mechanical action will tear the hole up leaving a number of fibres intact, see Fig. 4. The fibres lay as chords to the circle, perpendicular to each other, according to the production method of the clothing.

Mechanical action of a washing process is tested by means of four pieces of clothing each with five holes. The number of intact fibres is counted for each piece and is called the MA-number. The average MA-number characterizes the mechanical action of the washing process and has proven very reproducible. A typical value corresponding to a normal mechanical belabouring in a household washing machine is MA = 70-90. Unfortunately the Home Economics Council has not yet introduced the method in their test programmes so we are not able to compare our measurements with their last test series.

<u>Fig.4</u> Mechanical action test is carried out with a piece of cloth with circular holes. The photos show a hole before and after washing.

The MA-number and another measure for the action, the standard agitation time, are correlated as shown in Fig. 5.

For further information about the MA-method: see ref. (2) and (8).



<u>Fig. 5</u> The relationship between mechanical action in a washing process, expressed by the MA-number and <u>standard agitation time</u>, taken from (2).

Measurement set-up

During the washing process, the following parameters could be recorded:

1. **Temperature.** Measured at point A in the recycled fluid. (See Fig. 2). Temperature was recorded by an x-t plotter.

2. **Water.** Water entering the washing machine was measured by a water-meter.

   - water drained from the machine was measured by means of a measuring glass.
   - Water left in the machine after the process was drained into measuring glass.
   - Laundry was weighed before and after washing.

3 **Performance**

   - Washing-quality was measured by means of the described test-trips, which were sent to the Danish Government Household Economics Council (DGHEC) for reflection measurements.
   - Mechanical action was measured by means of fabric test-sheets from the Danish Technological Institute, Dept. of Washing, (ref. 2).

4. **Energy.** The machine is wired so that energy for mechanics and heat can be measured separately.

Two test programmes

The experimental testing of washing took place in two steps. First a test programme was carried out only emphazising energy savings through the use of low water level in heat requiring parts of the washing process. This is referred to as the LE-process (low-energy). Afterwards followed a test programme in which was added less use of water also for rinsing. This second process is referred to as the RE-process (resource efficient).

RESULTS OF LOW ENERGY WASHING

First test programme included series of experiments with the LE-process emphasizing:

1) Energy consumption and washing quality at 60°C and 90°C.
2) Mechanical action at 60°C.
3) Washing quality versus detergent concentration at 60°C.

Furthermore, we washed some extremely dirty rags from a mechanical workshop in a normal washing process and in a LE-process.

Also we washed some red rags together with some white ones in a normal and a LE-process, in order to test to which degree the color came off.

Washing quality in LE-process

Results of washing with the LE-process in the prototype washing machine are listed in table 2.

The process-type marked NW (Normal water) is identical to the LE washing process, apart from the main washing, where the full amount of water is entered from the beginning and temperature is maintained, during the main wash. In short, the NW-process is our "normal" washing process, which we use as one of our references in the evaluation of the LE-process, and which we can carry out on our prototype washing machine. The processes were tested at 90°C and 60°C.

Laundry is according to Danish Standard 71 and IEC. We use 1 kg laundry per 12 l netto washing vessel volume at 90°C, and 1 kg laundry per 26 l netto washing vessel volume at 60°C.

Detergent is according to amendment no 2, IEC-publication no 456 (7), and purchased from Henkel as standard test detergent, IEC-TDI. It is delivered in two packages: bleaching and soap. Before washing, soap and bleaching are mixed, 80:20 by weight.

Dosing at 90°C, according to IEC, is 22 g/kg laundry in prewash and 30 g/kg laundry in main wash. At 60°C no detergent is used in the prewash. In mainwash the dose is 32 g/kg laundry. In table 2 detergent concentration refers to the use of detergent in per cent of what should be used according to the IEC standard amendments.

The α and β-runs comprehend measurements of mechanical action of the laundry.

Test no.	Process type	Detergent conc.	Temp. °C	Energy kWh	Reflection Oil/soot	Blood	Red wine	Chocolate	Average	Result acc. to DGHEC
3	LE	100%	60°	1,15	41,48	64,88	79,93	47,65	58,5	very good
4	NW	100%	60°	1,75	43,90	71,28	74,08	47,23	59,1	very good
5	LE	100%	90°	1,79	56,00	75,58	86,23	54,93	68,2	good
6	NW	100%	90°	2,63	54,63	75,98	84,73	54,28	67,4	good
1A	LE	100%	60°	1,12	45,33	74,80	76,63	38,70	58,9	very good
2A	LE	80%	60°	1,11	48,13	69,55	73,28	37,75	57,2	very good
3A	LE	60%	60°	1,14	45,38	70,85	65,95	38,75	55,2	good
4A	LE	40%	60°	1,16	38,45	66,68	60,20	37,80	50,8	acceptable
5A	LE	20%	60°	1,13	35,43	57,60	55,38	36,23	46,2	bad
6A	NW	100%	60°	1,73	48,98	67,03	67,80	42,63	56,6	very good
7A	NW	80%	60°	1,72	43,20	70,53	62,95	40,03	54,2	good
8A	NW	60%	60°	1,69	34,98	68,38	60,63	38,60	50,7	acceptable
9A	NW	40%	60°	1,73	35,25	61,33	58,33	36,13	47,8	bad
α	LE	100%	60°	mechanical action : MA = 52 , stand. agitation time 22 min.						
β	NW	100%	60°	mechanical action : MA = 77 , stand. agitation time 65 min.						

<u>Table 2</u> The most important tests, carried out with the prototype washing machine, which can carry out normal water (NW) washing processes as well as our low energy (LE) processes.

<u>Evaluating the washing quality</u>

In order to evaluate the results of our tests, we compared them to results from tests of commercially available washing machines, extracted from internal reports from the Home Economics Council (DGHEC). This comparison is shown in Table 3 and 4 for 90°C and 60°C respectively.

90°C	Reflection, %					
	oil/soot	blood	red wine	chocolate	average	
LE-process* NW-process*	56,0 54,6	75,6 76,0	86,2 84,7	54,9 54,3	68,2 67,4	only cold water in prewash

*detergent was erroniously reduced from 90 g to 72 g in main wash and from 66g to 24 g in prewash. Reflection is thus not as high as could be obtained.

Table 3 Comparisons of the LE- and the NW-processes at 90°C carried out in our prototype. The reflection values shown are not comparable to the values published by Danish Home Government Economics Council for commercial washing machines, due to some special correction procedures used by the Council.

60°C	Reflection, %				
	oil/soot	blood	red wine	chocolate	average
LE-process* NW-process*	45,3 49,0	74,8 67,0	76,6 67,8	38,7 42,6	58,9 56,6

*in this 60°C warm washing process the amount of cotton fabric should have been reduced by 50% to appr. 1.5 kg according to standard test conditions. As we failed to do this the machine was in fact overloaded, causing less mechanical action and reduced washing quality compared to the other machines.

Table 4 Comparisons as in Table 4, but at 60°C.

Washing quality versus amount of detergent

A number of washing processes, LE and NW, at 60°C, were carried out with decreasing use of detergent. The result is shown in Fig. 6. It is worth noticing that the washing result will improve with excess use of detergent. It is worth noticing too that although the best possible washing result is never obtained, the LE-process is almost always the best compared to the NW-process.

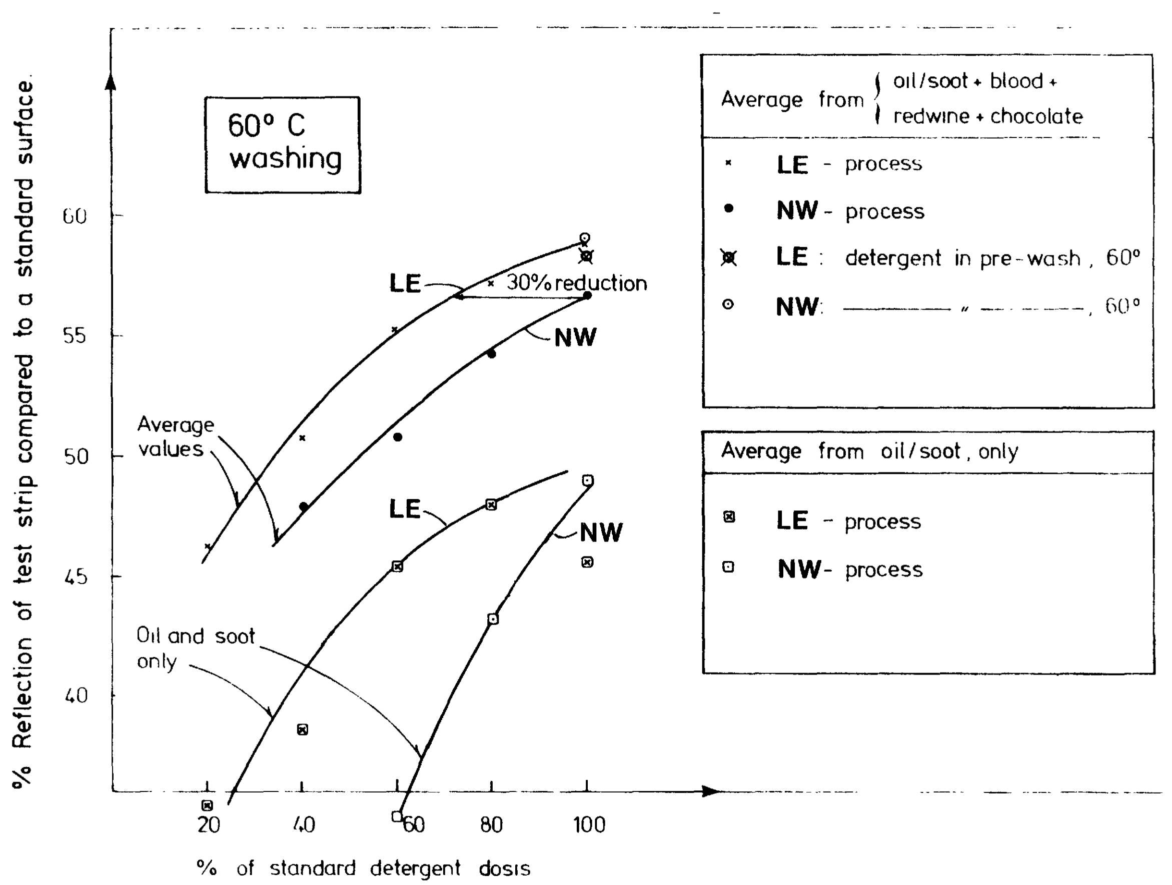


Fig 6 Washing quality, expressed by relative reflection values is here shown as a function of the detergent concentration for different processes in our machine. As stated in Table 3, the reflection values plotted here are not directly comparable to values published by DGHEC.

Mechanical action of LE-process

The LE- and the NW-processes were tested at 60^{o}C for mechanical action. The MA-numbers were measured by the Technological Institute and found to be:

LE-process: MA = 53. Standard agitation time: 22 min.
NW-process: MA = 77. Standard agitation time: 65 min.

According to the Technological Institute, Dept. of Washing Technology, the MA-number of the LE-process is low compared to a normal household washing machine standard, which is around MA = 70-90 at 90^{o}C. Thus the reduced amount of water in the washing process clearly reduces the mechanical action of the clothing.

It should be remembered that too much cotton fabric was used in the 60°C process. However, the drum was filled according to 90°C standards. As temperature is believed to have no influence on mechanical action, it should be fair enough to compare our results at 60°C with the results obtained at the Technological Institute at 90°C. Especially, as the temperature is the only different physical parameter of the processes.

Colour proofness in LE-Process

A number of red rags were washed together with some white ones in a LE- and NW-process at 60°C. In both cases red colour came off and made the white rags pink. However, a significant difference in the pink result was seen in favour of the LE-process.

Heavily-smudged clothing in LE-process

Working-clothes and rags from a mechanical workshop were washed in a LE- and a NW-process. The clothes were smudged with grease, oil, silicone rust preventives, etc.

In both cases the clothes were cleaned enough for further use, showing no significant difference. The grease spots, however, seemed more degraded on clothes from the LE-process, being more or less intact on clothing from the NW-process.

Energy savings of LE-process

Table 5 below shows the energy consumption of the LE- and the NW-process, as well as energy consumption of a number of commercially available household washing machines.

90°C		
Machine	Energy consumption/kWh	Average/kWh
LE-process	1,79	1,8
NW-process	2,63	2,6
<u>"1982"-machines</u>		
Haka 622	2,6	
Zanussi Z 915	2,3	
BBC-Rondoprins 502	2,9	
Miele W 426	2,6	2,6
<u>"1977"-machines</u>		
Gorenje ps 302	3,4	
BBC-Rondomatic 600	3,0	
Philips 808	3,0	
Sevamat 471	2,9	
Indesit de Luxe L7CH	3,4	
Bauknecht WA 657K	2,6	
Vølund 502	3,9	
Miele de Luxe 443	2,6	3,1

<u>Table 5</u> Energy consumption per wash (3.2 kg)for the LE- and the NW-process is here compared for a number of different washing machines, all at 90°C. The "1982"-machines and "1977"-machines refers to machines tested at the Danish Governments Home Economics Council (3,13). Energy consumption for the low energy process (LE) is reduced by 30% when compared to normal wash in our prototype (NW) and to "1982"-machines, but 42% when compared to "1977"-machines.

60^oC		
Machine	Energy consumption kWh	Average kWh
LE-process NW-process		1,13 1,72
"1982"-machines		
Haka 622	1,4	
Zanussi Z 915 - faults in measuring		
BBC-Rondoprins 502	1,4	
Miele W 426	1,3	1.37

Table 6. Energy consumption per wash (3.2 kg) compared as in Table 5, but at 60^oC. Energy consumption of LE-process is reduced by 34% when compared to NW and by 17% when compared to "1982"-machines.

Summarizing the test results of LE-process

- Washing quality.
  The LE-process gives results to the better side of the normal washing in our prototype washing machine when looking at reflection.
- Detergent.
  Results indicate that the use of detergent could be reduced in the LE-process.
- Mechanical action.
  A single test indicates a reduction in the mechanical action without loss of washing quality.
- Energy.
  The LE-process saves appr. 42% compared to 1975 machines at 90^oC. Compared to modern machines energy consumption is reduced appr. 30% at 90^oC.
  At 60^oC the LE-process saves appr. 17% compared to four average "1982"-washing machines.

RESULTS OF RESOURCE EFFICIENT WASHING

During the extension of the project, we added a number of new tests with our prototype low water washing machine.

RE-process

The prototype was equipped with a filter in the recirculation system, a new heating element which require less "dead" water volume around, and thermal insulation of the vessel.

The major aim of this RE-process was to reduce water consumption, as compared to the LE-process. This is mainly achieved by rinsing with very little water, recirculating the water during rinsing, and extraction of water after each rinsing process.

Tests were carried out with the RE-process at 90°C and 60°C as described for the LE-process. With our prototype, having a net washing vessel volume of 42 liters, the IEC-prescriptions result in the laundry and detergent amounts shown in Table 7, and used in our tests. The processes are also illustrated in Fig. 7 and 8.

Temperature	90°C	60°C
Detergent		
Prewash	70,4 g	0 g
Main wash	95,0 g	51,2 g
Laundry, dry	3,15 kg	1,60 kg
After final extr.	5,64 kg	3,10 kg
Water, left in laundry	2,49 l	1,50 l
Pr. kg laundry	0,79 l/kg	0,94 l/kg
Energy consumption	1,758 kWh	0,855 kWh
Mechanics	0,386 kWh	0,310 kWh
Heat	1,372 kWh	0,545 kWh
Waterconsumption	78 l	70 l
Water in prewash	10,6 l	8,6 l
- in chem. part	11,0 l	7,7 l
- in mec. part	22,9 l	18,8 l
- , used for rinsing	51 l	29 l
Time, total	122 min.	100 min.
Main wash,		
Chem. part	56 min.	35 min.
Mech. part	15 min.	15 min.

Table 7 Main data for the RE-process.

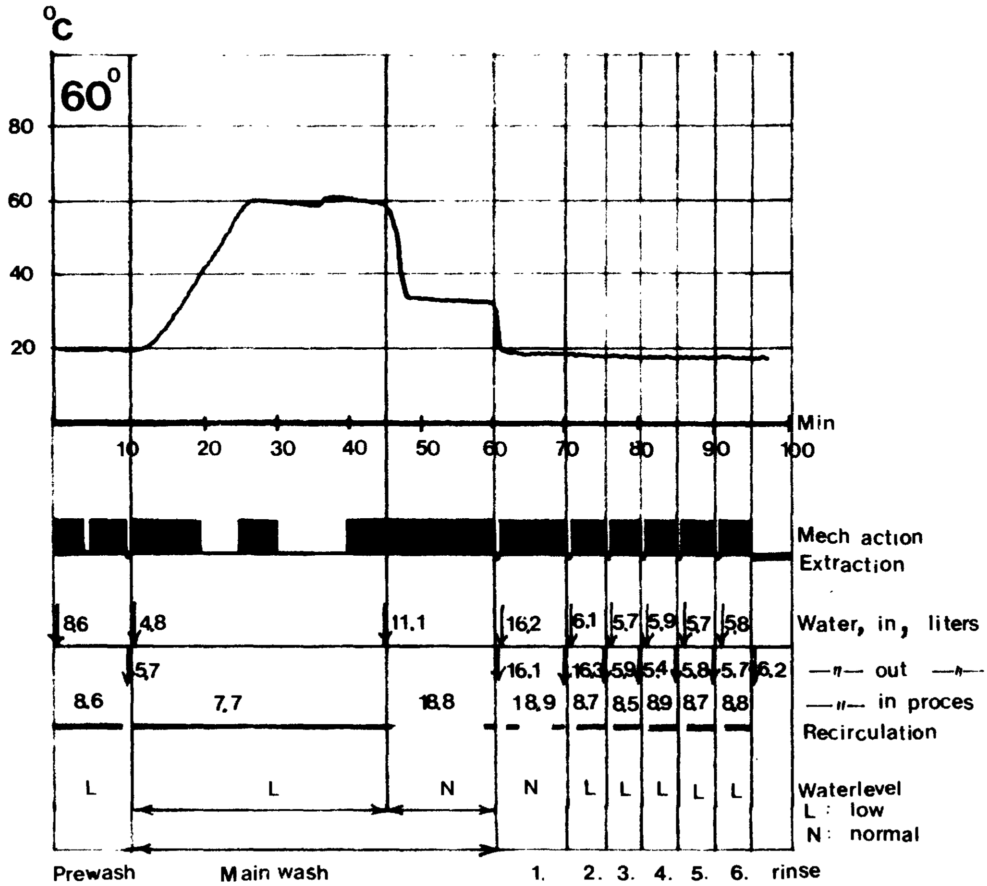


Fig. 7 Diagram of the RE-process at 60°C.

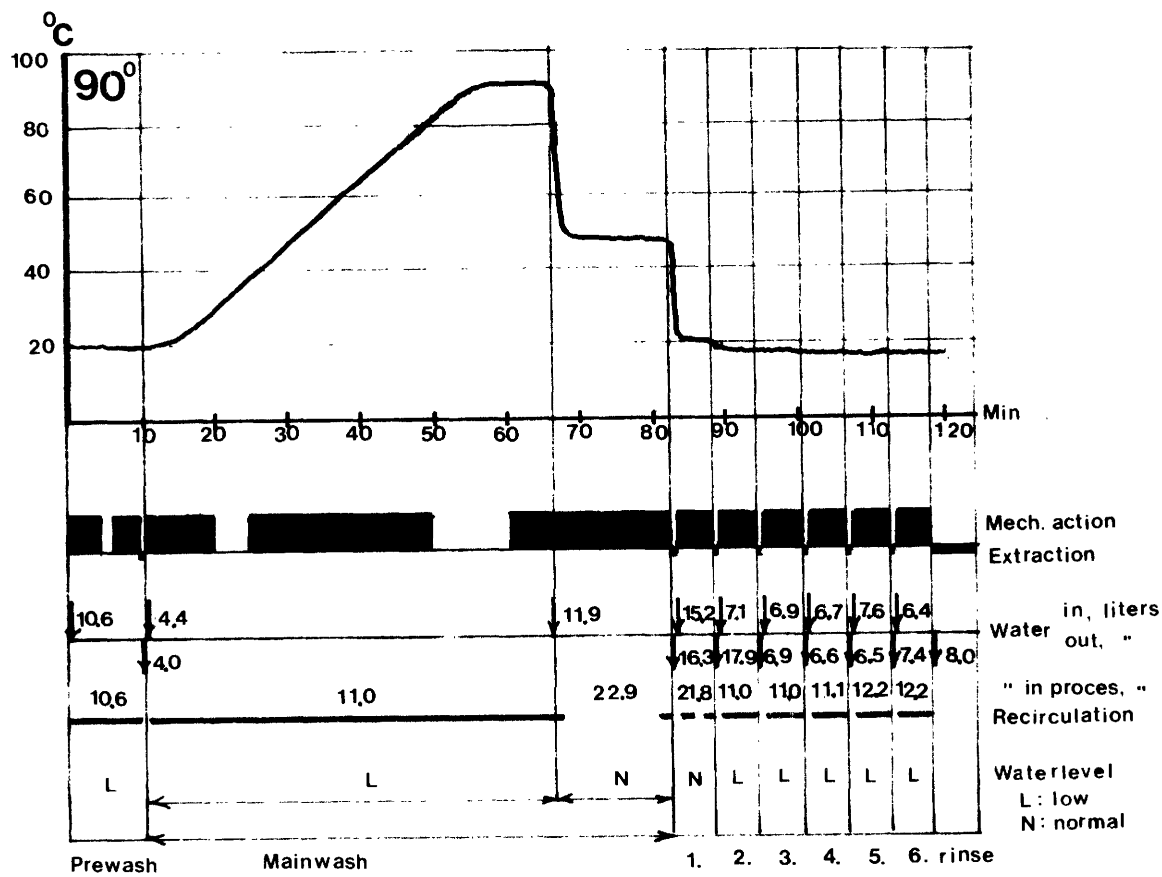


Fig. 8 Diagram of the RE-washing-process at 90°C.

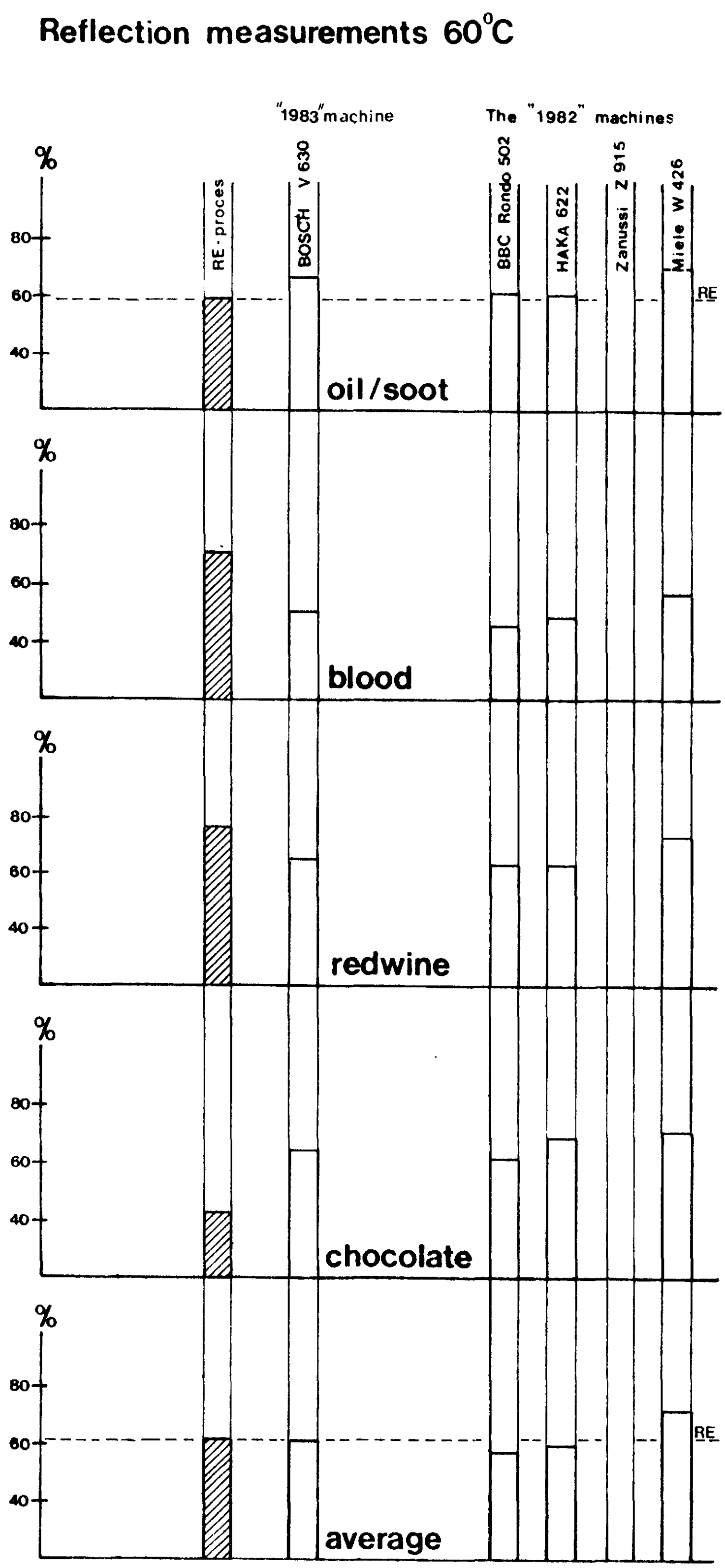


Fig. 9 Washing quality as measured by reflection for 60°C washing with the RE-process, compared to results from commercial machines (3,15).

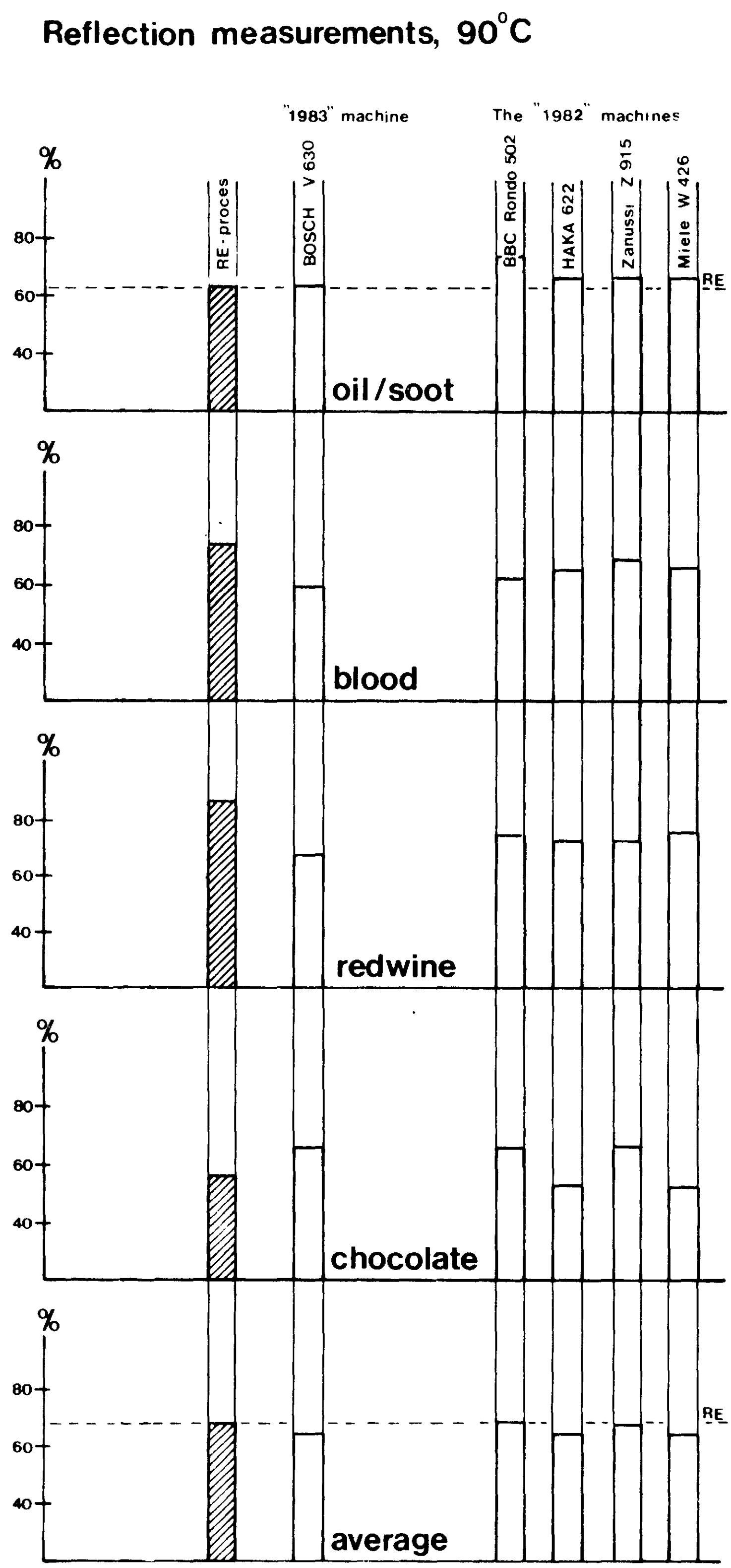


Fig.10 Washing quality as measured by reflection as in Fig. 9, but here for 90°C washing.

Washing quality of RE-process

Figure 9 and 10 illustrate the washing quality as measured by the reflection of the standard test strips from EMPA. The results for the RE-process has not been subjected to a correction, as the five results shown from commercial machines, tested at DGHEC (3,15). This correction refers to a standard machine, and the reflection percentage will typical be higher after this correction. This implies that our results for the RE-process probably are on the safe side.

In general the reflection graphs indicate that the RE-process washing quality is similar to that of commercial machines.

Mechanical-action

Typical MA-number for a household washing machine:

MA = 70-90. (Average: 80)

The prototype and the RE-process at 60^{o}C has a MA = 52

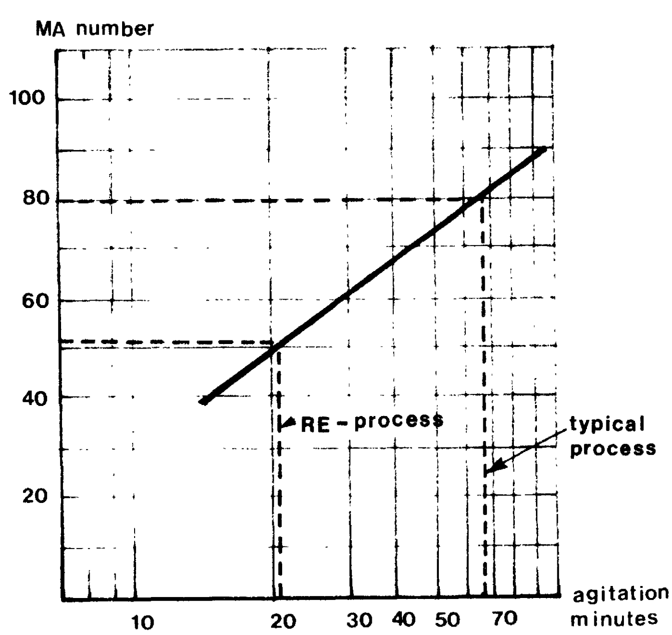


Fig. 11 MA-number as a function of standard mechanical agitation in minutes, taken from ref.(2). Result for the RE-process is plottet in the graph, together with that of a typical household washing machine.

According to the above relation, we have a standard mechanical agitation at $60^{o}C$ of:

The RE-process: 22 min.
Average process: ~70 min.

We take this as an indication that mechanical wear of the laundry is considerably reduced.

Rinsing in RE-process

Rinsing effect was estimated by calculating delution of washing detergent from main wash to last rinse.

Delution d is calculated by the following process:

1. Water drained from the machine at any time t after main wash is measured

2. Water left in the mashine W_e at the time t is then known, as the total amount of water in the process before draining was known.

3. Water let into the machine, W_i, at a time t + is measured.

4. $d_n = \dfrac{W_e}{W_e+W_i}$, where d_n is dilution from one rinsing to the next.

5. $d_{total} = d_1 \times d_2 \times \ldots . d_N$. (N = 6 for the RE-process).

We have measured d_{total} at $90^{o}C$ and $60^{o}C$.

$90^{o}C$: d_t = 0,0023 = 2,3 o/oo
$60^{o}C$: d_t = 0,0043 = 4,3 o/oo

Knowing the amount of soap and bleaching in the main wash, the amount of water left in the laundry after last rinsing, and the weight of dry laundry, we can calculate the amount p of soap left in each kg of dry laundry.

At 90^oC we have:
p = 17 mg/kg laundry

At 60^oC we have:
p = 24 mg/kg laundry

The DGHEC measures the amount of detergent-solution in ml, left in the wet laundry after last extraction. The amount is called F, and should not exceed 32 ml/l. From 16 to 8 ml/l, rinsing effect is good, and less than 8 ml/l is very good, according to the DGHEC.

At 90^oC we have F = 3 ml/kg (very good)
At 60^oC we have F = 9 ml/kg (good) for the RE-process in our prototype washing machine.

It should be noted that most of the rinsing processes are done with recirculating water and as little water in the process as possible.

Mechanical action and rinsing effect may be correlated. However, this effect will not be disclosed by our measurements, which are based on calculations of dilution. Thus an error could be hidden here, and in a further development of the process, chemical ways of measuring the rinsing effect should be applied.

Resource consumption for RE-process

Energy saving is the purpose of the project, but in this last part of the project, also water consumption was significantly reduced as seen in Fig.12. In certain parts of the world this can be of great importance, and indirectly it also saves energy for pumping, sewer treatment, etc.

With an average Danish use of washing machines, as described later in Table 9, annual electricity consumption for the RE-process is found to be 250 kWh, compared to the average for four 1982-machines on the Danish market which consume 390 kWh.

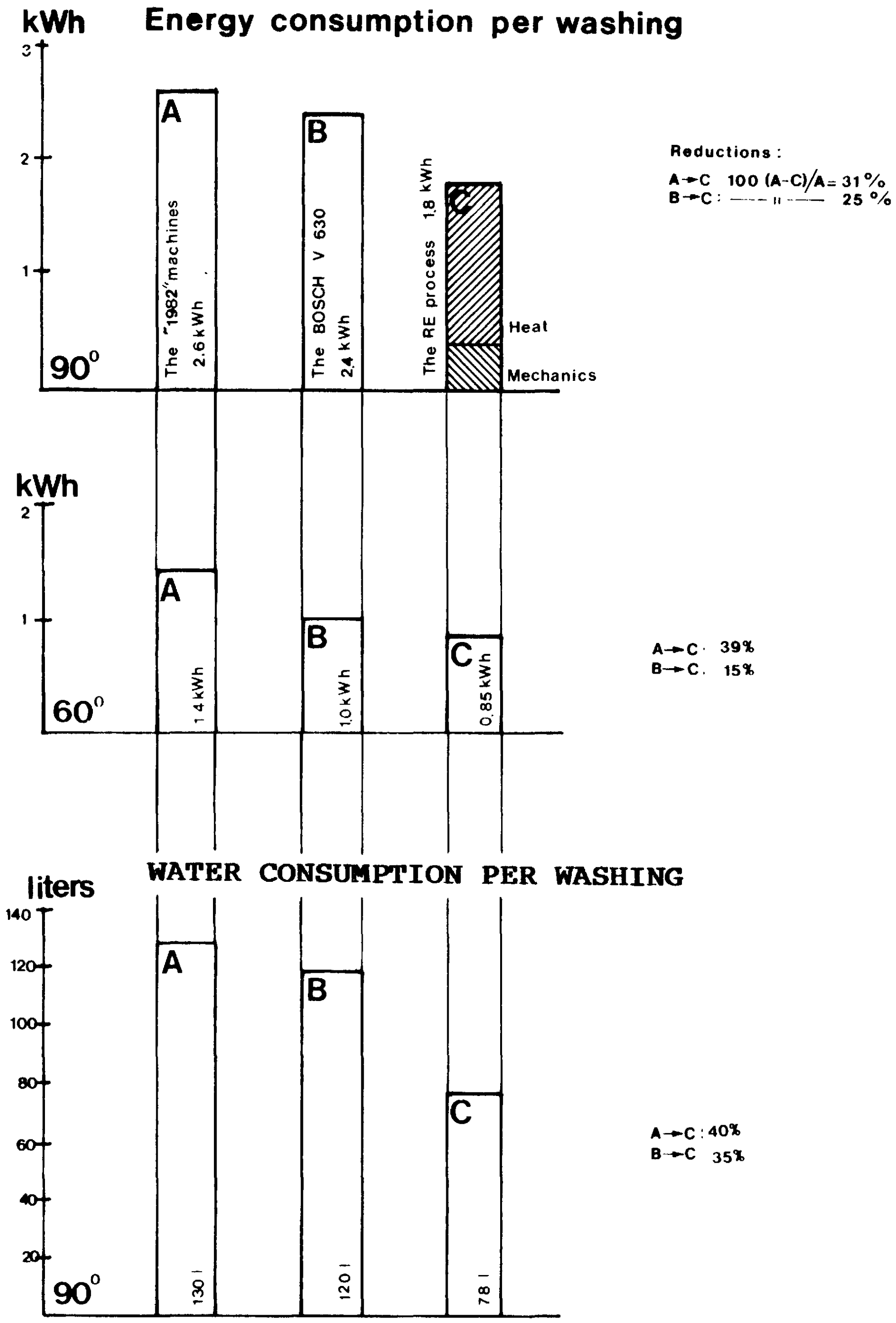


Fig. 12 Energy consumption for 90°C and 60°C washing with the RE-process compared to that of a good 1983-machine B and to an average for four 1982-machines, (3,15). For 90°C washing is shown total water consumption.

ALTERNATIVE MEASURES TO SAVE ENERGY

Besides the RE-washing process, we have considered also alternative ways of reducing electricity consumption for washing.

Presoaking as substitute for heating

As mentioned in the introduction, another way to save energy in washing is to reduce the temperature of the water instead of reducing the amount of water, since the major part of energy consumption of a washing machine is used to heat the water.

We have carried out some preliminary investigations of this option. What we basicly did was to replace the usual prewash with a presoaking. For 4 hours, before the main wash, the laundry was soaked in not-heated water with an enzyme detergent. Experiments with and without this presoaking were conducted at different temperatures of the main wash.

The results, which we find too uncertain to quote, indicate that a certain desired quality of washing can be achieved with a temperature reduction in the main-wash of 20-30^{O}C, if prewash is replaced by the presoaking described. The corresponding energy saving obtained is between 20 and 40%. The washing quality was registrated by the reflection coefficients as in the previous.

According to a statement by Danish Health authorities, quoted in ref.(12) "The disinfecting effect of washing is achieve primarily by removing dirt and by diluting (rinsing), while the heat treatment does not guarantee the killing of micro organisms present. Clothes from private households will normally not be soiled with disease causing micro organisms. Therefore from a microbiological hygienic point of view it will make no difference, whether normally soiled clothes are washed at 90^{O}C or at 60^{O}C"

If such long term presoaking turns out to be a viable measure to save energy in washing, the problem is, how to do it in practice. In a non automatic way it can be performed in most of todays washing machines by just stopping for say 4 hours in the prewash period and using the enzyme detergent for the prewash. In future washing machines it would require a modest change only to allow the program to include such a soaking preiod.

For certain cotton fabrics there is a tendency for the color to come off and onto other fabrics if left quietly soaking. This could probably be prevented by letting the motor move the drum a couple of turns each few minutes during the soaking. This could easily be build into the program and energy consumption for running the motor for such brief periods could be very low.

Washing habits would be affected in two ways. If one is used to wash at high temperature it takes some evidence to be convinced that a lower temperature can provide an equally good results, visually as well as hygienic. Having been convinced, the second question is how to fit this type of washing pattern into the daily routine, since the whole process takes hours. One pattern could be to start the machine in the morning before leaving the home. Another option would be to start late in the evening, assuming the noise will not disturbe the sleep of anybody. An extra advantage of the latter pattern is that it makes it possible to use electricity at low rates at night, whereever such options are available.

Intake of both hot and cold water

Washing machines with two water intakes, one for hot and one for cold water, have been available for years, but never really marketed in Scandinavia. If domestic hot water supply is heated with oil gas, district heating or other non-electric sources as in for the most Danish households the price will usually be lower than if electricity is used for heating the water as in most washing machines. This is especially the case, because we are here looking at the marginal price per extra liter to be supplied. Typical for hot water from oil and gas furnaces in Denmark, the price will be almost halved, compared to electrically heated water. Hot water from district heat from cogenerating heat-power plants will be much cheaper.

Despite these savings from double intake, this feature is, as mentioned, essentially unknown in Denmark. If combined with the suggested presoaking washing process it could eliminate the need for electrical water heating in the washing. The consequence could be a cheaper washing machine since the whole heating system could be omitted. We have not experimented with this option, but during the work on the RE-process we registrated the electricity consumption for heating and for the motor, etc. separately as shown for 90°C at Fig.11. Leaving out electricity for heating water, the RE-process consumed approximately 0.4 kWh per wash. This RE-process has a special 75 Watt recirculation pump, and hence for normal washing process the not-heating electricity consumption will be 0.11 kWh less, since the pump is running for a total of 90 minutes. In a presoaking process we would suggest, as mentioned, to turn over the laundry every few minutes during the soaking. This is estimated to consume only 0.02 kWh extra for the motor. The result would be an electricity consumption of only 0.40-0.11+0.02 = 0.31 kWh. Annually this would with the 250 laundries amount to 78 kWh for a presoaking washing process with intake of hot water from a non-electrical hot water supply. This we have, however, not verified experimentally.

EVALUATING THE ECONOMY

The economy in using a washing machine involves other costs than energy. Also the expenses to water and detergent must be considered. We have used the following prices which are typical for Denmark by 1984:

Electricity:	0.80 Dkr/kWh
Water (cold):	6.00 Dkr/m^3
Detergent:	6.00 Dkr/l
Rinsing fluid:	8.00 Dkr/l

The economy of using a future RE-process washing machine is in the following evaluated in comparison with using an "average 1982-machine" as defined by the four 1982-machines mentioned in Table 5.

In order to calculate the annual costs of washing we have used the average pattern of use found by Danmarks Statistik for the Danish Government Home Economics Council (16). This pattern consist of 250 laundries per year distributed on the three temperature levels as shown in Table 9.

Annual savings with RE-process

Table 8 shows the costs for each of the three temperature levels.

90^oC	av. machine kr	RE-machine kr
Energy 2,6/1,5 kWh Water 140 ℓ Detergent 4 dℓ/3 dℓ Rinsing 10 mℓ	2,08 0,84 2,40 0,08 5,40	1,41 0,47 2,40 0,08 4,36
60^oC	av. machine kr	RE-machine kr
Energy 1,4/0,9 kWh Water 140 ℓ Detergent 3 dℓ/2,3 dℓ Rinsing	1,12 0,84 1,80 0,08 3,84	0,69 0,42 1,80 0,08 2,99
40^oC	av. machine kr	RE-machine kr
Energy est. 0,9/0,7 kWh Water 100 ℓ Detergent 3 dℓ/2,3 dℓ Rinsing	0,72 0,60 1,80 0,08 3,20	0,47 0,39 1,80 0,08 2,74

Table 8 Variable expenses per washing. The av. machine refers to an average of 4 typical 1982-machines, see Table 5. RE-machine refers to a possible future washing machine with the Resource-efficient process.

Washing temp.	Uses pr.year	Energy per year av.machine	RE-machine	Var.expense per year av.machine	RE-machine
90^oC	75 times	190 kWh	112 kWh	405 kr.	327 kr.
60^oC	75 times	105 kWh	68 kWh	288 kr.	224 kr.
40^oC	100 times	90 kWh	70 kWh	320 kr.	274 kr.
Ialt	250 times	390 kWh	250 kWh	1013 kr.	825 kr.

Table 9 Annual electricity consumption and total variable expenses with the washing pattern shown in first collumn. The numbers are shovn for an average 1982-machine (3) and for our resource efficient process.

Annual electricity saving is as shown in Table 9 140 kWh which with the assumed price of 0.80 kr/kWh means 112 kr. per year.

With the assumed washing pattern, we find:

<u>Total annual savings: 188 Dkr</u>

out of which 112 Dkr is from savings in electricity.

It could be argued that further savings are obtained from less wear of the clothing, due to the lower mechanical action of the RE-process. We have, however, not tried to estimate the economic value of this extra benefit.

Extra investment in RE-washing machine

In order to achieve the above described savings in a convenient way we have to use a new type of washing machine with the features of our prototype washing machine. It is difficult to estimate the production cost in mass production, but we have made an estimate of the extra retail price due to the necessary modifications, see Table 10.

extra pump............................	40,00 kr
extra tubes...........................	15,00 kr
inlet in vessel.......................	15,00 kr
modifications in programmes...........	20,00 kr
external heat unit*...................	100,00 kr
installation, extra...................	200,00 kr
Estimated extra production cost	390,00 kr
Total extra retail price =1.9x prod.cost =	740,00 kr

* The heating element, water level control and termostat sensor used in normal machines are no longer necessary in washing vessel and the savings from this are estimated and subtracted here

<u>Table 10</u> The estimated extra price for the consumer to pay for a RE-washing machine.

Economic payback

From the above calculations of savings in electricity, water and detergent we reach:

Total annual savings for consumer	188 Dkr
Extra investment for consumer	740 Dkr
Simple payback period	3.9 years

If we assume an average lifetime of a washing machine, and hence of the extra investment, of 10 years (9) we get

Accumulated value of all savings with no interest	1880 Dkr
Annual rate of return	22%

If we include only the savings in electricity the figures will be:

Simple payback period	6.6 years
Accumulated value of electricity savings	1120 Dkr
Annual rate of return	8.5%

It should be noted that in the extra investment for the consumers are included special taxes and VAT, alltogether 32% of the extra retail price. On the other hand, in the price for electricity is also included taxes amounting to around 38%. Excluding all taxes in our calculations will therefore only make small changes in the resulting payback period or rate of return.

If, however, the 20% special Danish tax on household appliances was differentiated according to energy consumption, which has been considered in parliament, this could easily change the economy drastically in favor of the LE-washing machine.

However, even without any change in taxes, etc., the economy is in favour of the LE-washing machine compared to average machines with a rate of return of 22% (taxfree) or a 3.9 years payback period.

The presoaking washing process suggested would require very small changes in the machine, and probably result in no extra production costs.

ENVIRONMENTAL IMPACT

We have choosen not to make any quantitative environmental impact evaluation like in part one and two of the report because: 1) Washing habits probably vary a lot all over Europe and we have found no registration of them, 2) Uncertainty about which of our processes we should consider, and 3) the complexity of the environmental impact of using less washing detergent and less water. We will confine ourselves to qualitative considerations.

For the RE-process (D in Fig.13) there would be environmental benefits of less air pollution from electricity consumption as for the refrigerators and for cooking, part one and two. Furthermore, reduction in the use of detergent can reduce pollution of lakes and rivers, or reduce the need for sewer treatment. Less use of water also reduces the need for sewer treatment and the need to exploit new water reserves.

The not fully explored presoaking process with intake of warm water from hot water supply (F in Fig.13) saves more electricity and thereby reduces air pollution. However, the process uses hot water and the environmental consequences of that depend on the energy source for that. Ideally, it could be district heat from combined heat and power production. The ratio between the use of hot water and electricity in the presoaking process is almost the same as for the output of a combined plant. In that case the hot water consumption does not cause any pollution other than what is already accounted for in providing the electricity. Around 25% of Danish households today have district heat from combined heat and power plants.

CONCLUSION ON WASHING

Fig.13 summarizes the results of our investigation and compares to the target we started out with and the general development shown also in Fig.1.

Resource efficient washing process

The RE-washing process (resource efficient) is the method to which we have devoted most of our experimental effort in this project. The RE-process makes it possible to maintain the usual pattern of washing temperatures at 90, 60 and 40^{o}C, while saving around 35% of the annual electricity consumption when compared to an average for typical 1982-machines. Quality of the RE-washing, as measured by reflection, is similar to that of the other machines. As an extra benefit this RE-process also saves water as well as detergent.

Some substantial change in the machine are necessary in order to provide a RE-washing. The extra estimated cost of this

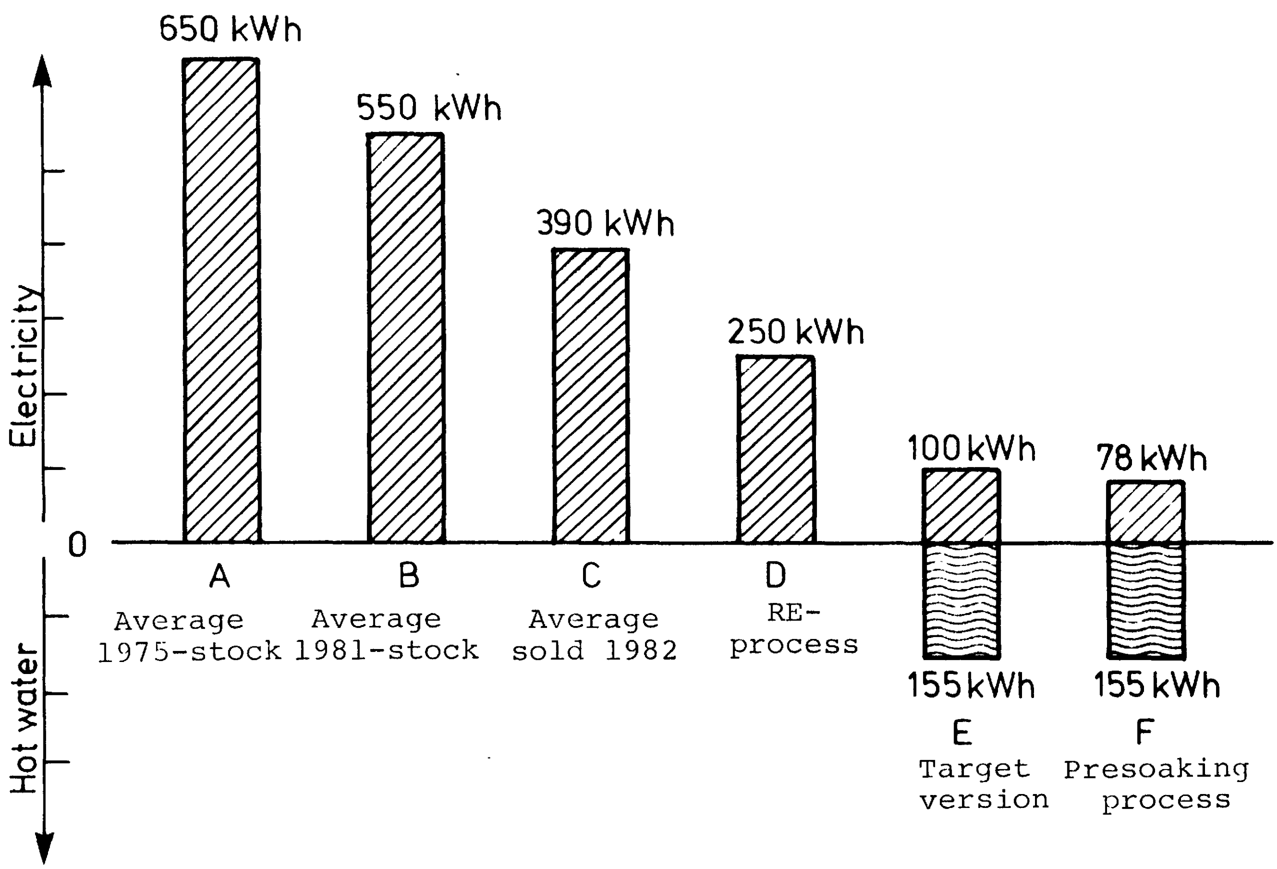


Fig.13 Electricity consumption of various washing processes. RE-process is compared to what is common today and to what we could suggest as a possibility in the future, the presoaking, low temperature washing with intake of warm water.

can in energy savings alone be paid back in around 6.5 years, but when savings in water and detergent is considered also, the payback period is less than four years.

A note on the main principles and results of the RE-process was distributed early in 1985 to most washing machine manufacturers in Europe.

Presoaking low temperature washing

An alternative method for saving electricity for washing has only preliminary been experimentally verified by us. The process consists of soaking for a couple of hours before main wash, which then in return is carried out at lower temperatures than usual. Furthermore, the warm water can be taken from a hot water system less expensive than heating water electrically.

This method, which we have not fully explored, requires only small changes in the washing machines. Actually a presoaking machine could probably be made cheaper than a traditional washing machine. This method of washing seems promising but requires further investigations.

ACKNOWLEDGEMENTS

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Finally we want to thank Margot Wisborg, Ulla Christensen, and Ingelise Nyberg for patiently typing the report and keeping the accounts and Birgitte Højland Christensen for printing the report.

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