Preparatory Studies for Eco-design Requirements of EuPs

(Tender TREN/D1/40-2005)

LOT 14: Domestic Dishwashers & Washing Machines

Part II – IMPROVEMENT POTENTIAL

Task 6: Technical Analysis

Rev. 3.0

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NOTE: according to international standards dealing with quantities and units, the numbers in this study are written according to the following rules:

1. the comma “,“ is the separator between the integer and the decimal part of a number
2. numbers with more than three digits are divided by a blank in groups of three digits
3. in case of monetary values the numbers are divided by a dot in groups of three digits

6. Task 6: Technical Analysis

6.1 The study Tasks

Washing machines and dishwashers, also known as "wash appliances", have been the second and most studied EuP in the European Union with the goal to reduce their energy consumption. In 1995, the study of the Group for Efficient Appliances (GEA, 1995) provided the technical basis for the energy labelling Directive, and later also partially for the Eco-label awarding criteria. Its results and methodology were the starting point for the second study on washing machines (NOVEM, 2000, known as the WASH-2 study) promoted by DG TREN in 1998, which took into consideration the methodological, technical, economical and market developments and proposed a new structure for a revised label and the possible setting of efficiency targets, which then for various reasons were not fully accepted by Member States.
Contemporarily, the European Eco-label Board started to address these two product groups more from the environmental impact point of view with other studies, which resulted in the definition of eco-labelling awarding criteria, the latest being:

- for washing machines: on December 1999[1] the Commission adopted the criteria valid until December 1st 2002. These criteria were then prolonged to November 30th 2005 (Decision 2003/240/EC);
- for dishwashers: on August 1998[2] the Commission adopted the criteria valid until January 20th 2003 through the extension given by Decision 2001/397/EC. Criteria were revised in August 2001 (AEAT, 2001) and are valid until August 26th 2006.

In the meantime, a series of monitoring studies were promoted by the SAVE Programme to evaluate the impact of the EU legislation on the market transformation of washing machines and their energy consumption (ADEME, 2000; ADEME, 2001). Dishwashers were monitored through the annual reports presented by the European Association of Household Appliance Manufacturers (CECED) to the EC and the Regulatory Committee responsible for the management of the EU energy labelling scheme, describing the effectiveness of the industry "Voluntary Commitment on Reducing the Energy Consumption of Household Dishwashers" issued in 1999 and ended in 2004. Also washing machine market was monitored through CECED annual reports under the two Voluntary Commitments issued in 1997 and in 2002 for this product group.

Since markets and technologies change continually, including in response to past policy settings, the present study proposal takes the results and methodology defined in the last decade of studies as the starting point to be updated and upgraded where necessary to evaluate the technical, economic and market developments of cold appliances and the new aspects of these products to be covered following the indications of the eco-design directive 2005/32/EC[3]. This is necessary in order to define the need of implementing measures and possible targets for voluntary or mandatory policies.

The study is divided in two working phases and seven Tasks or Chapters:

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[1] Commission Decision of 17 December 1999 establishing the ecological criteria for the award of the Community eco-label to washing machines (2000/45/EC).
[2] Commission Decision of 20 July 1998 establishing the ecological criteria for the award of the Community eco-label to dishwashers (98/483/EC).
[3] Directive 2005/32/EC of the European Parliament and of the Council of 6 July 2005 establishing a framework for the setting of ecodesign requirements for Energy-Using Products and amending Council Directive 92/42/EEC and Directives 96/57/EC and 2000/55/EC of the European Parliament and of the Council.

Part I: Present Situation, that envisages the following five Tasks:

- Task 1 - Definitions
- Task 2 - Economic and Market Analysis
- Task 3 - Consumer Behaviour
- Task 4 - Product System Analysis
- Task 5 - Definition of base case

Part II : Improvement Potential, with the following two Tasks:

- Task 6 - Technical Analysis
- Task 7 - Scenario, Policy, Impact and Sensitivity analysis.

Within the first part (Present Situation) the project team will set the study boundaries (Task 1), collect and organise the data for the economic, market (Task 2) and consumers behaviour analysis (Task 3), analyse the interaction of the studied appliances on the energy system to which the product belongs (Task 4) and set up the reference parameters, material, energy and costs inputs to define the starting base case (Task 5). All the data and information analysed within the first part of the study will serve as an input for the second part (Improvement Potential) during which the project team will carry out the technical and economic analysis to set up the optimal eco-design options of the analysed appliance (Task 6) and finally suggest the most suitable policies to achieve the recommended energy and ecological improvements (Task 7). A Glossary and References will be also included in the study.

This report refers to Task 6: Technical Analysis.

6.2 *Description of Task 6*

6.2.1 Subtask 6.1: Options, associated improvement, costs and impacts

First step is the identification of a list of design options to be applied to the base case models. To this end the information about possible options provided by the GEA 1995 study (for dishwashers and washing machines) and the WASH-2 study (for washing machines) will be analysed. Additional options will be defined through experts and stakeholders consultation and possibly further literature survey (mainly for the options not yet ready to be applied to the market).

The aim is to evaluate which of the already known options have been successfully applied to wash appliances and to what extent (i.e. to the overall amount of models or to a fraction of the production), and which new options can be added to the list. Each option will be described in detail. Should more than one base case be chosen, it is possible that not all the options can be applied to all base case models. Therefore, if necessary, the initial option list will be focused on each base case model.

After the consolidation of the options list(s), the associated environmental improvement (mainly decrease in energy/water consumption, but also noise decrease and detergent consumption) and the increase in consumer price (of the improved model) will be defined for each single option when applied to the base case. Environmental improvement and prices will be collected through the updating of the literature data and a large experts and stakeholders consultation.

The quantitative assessment of the environmental improvement per option will be performed using the EuP EcoReport methodology and software. Starting from the inventory improved data, a LCA using SimaPro6 will be also performed, taking advantage of the environmental balance data and the evaluation methods available in the software itself. Output, both for EuP-Ecoreport and for SimaPro6, will be presented in specific terms (per appliance and per functional unit), and compared by damage category and by Life Cycle Phase. Comparison between EuP-Ecoreport and SimaPro6 is possible only up to the characterization (list of environmental indicators) phase. The subsequent phases (up to damage evaluation), as explained in Subtask 5.2, implemented by SimaPro6 software, will be carried out in order to evaluate the whole environmental balance.

Improved model environmental performance will be compared with results of the best case LCA. This comparison will be carried out by analysing the results of the characterization phase (both with EuP-Ecoreport and SimaPro6) and then of the subsequent phases, in particular using the results provided by the damage evaluation. The aim of performing comparative life cycle analyses is to understand in depth the effects of the environmental performances of each design improvement. This means to understand not only if the whole performance of improved model is better than the base case one, but also to understand for which life cycle phase this improvement is relevant. Using specialised LCA software (like SimaPro6) it is moreover possible to underline and analyse each contribution of both the impact factors (characterization phase) and the damage indicators (damage evaluation), for each inventory data and for the life cycle phases.

6.2.2 Subtask 6.2: Analysis LLCC and BAT

The evaluation of the LLCC and the BAT will be achieved applying the Marginal Net Present Value approach. Through NPV analysis the net benefits of the technological options to consumers are estimated. At this stage, the manufacturing cost increases are assumed to be passed completely to consumers through price increase. Manufacturing price increase will be calculated according to and agreed amount of mark-up from purchasing price increase. The increase in consumer price will be then compared to the discounted annual economic savings (on the electricity) due to higher machine performance for the presumed lifetime of 15 years, resulting in the Net Present Value.

The NPV and LCC will be evaluated first for each (single) technological option referred to the base case models. Then the optimum combination of technological options will be defined. First, the single options are sorted according to the payback period (or the ratio of NPV/investment) with the higher return options first. Second, the savings are calculated for the combined options. Evidently the potential savings decrease as subsequent technological options are added, since less energy/water is available to be saved due to the impact of the previously added technological option(s).

Net Present Value is then calculated for the combined options. In order to see the impact of adding each subsequent option, the net present value of adding a specific option is calculated. This is known as the **Marginal Net Present Value** (MNPV) of adding a given option. Since the options are added in order of their potential economic contribution, we may add options until their marginal net present value is zero or negative. This determines the optimum design and is also the point in which the total net present value of the combined options is a maximum (or the LCC is at minimum). The BAT is represented by the latest option combination.

The NPV and Life Cycle Cost methods are equivalent. This is due to the fact that the life cycle cost is a constant value (the base case) minus the NPV of the improvements, thus the maximum NPV gives the minimum life cycle cost (LLCC). The output of the NPV analysis is the input in the LCC analysis where the constant values are added.

The main difference between the more traditional Life Cycle Cost analysis developed and reported in previous studies and the Marginal Net Present Value analysis (which both use the same design options input from the technical/economic analysis) lies in the fact that in traditional LCC design option impacts (savings and costs) are calculated one independent from another and then their effects are added, while the MNPV analysis calculates the effects of any option taking into account that a previous option has already been implemented and part of the savings has already been achieved. The other difference is that in the traditional LCC the options sequence is decided by "clustering" the options according to an engineering, not necessarily following their simple pay back time, while in the MNPV approach the options are applied mainly considering their economic feasibility for consumers (in terms simple payback time) and initial engineering considerations about their compatibility.

6.2.3 Subtask 6.3: Long-term targets (BNAT) and systems analysis

Long term technical potential for wash appliances, represented by the BNAT (Best Not yet Available Technologies) can be evaluated following the same approach used for the LCC. In fact, when the technological option list will be set, not only the available technologies will be collected, but also some options needing further applied and/or fundamental research. For these options stakeholders will be asked to estimate the possible price increase and environmental impact decrease. With this information a MNPV analysis could be developed, leading to the ranking of the identified option and the evaluation of the long term potential. This analysis will involve options working within the same product archetype.

The long term potential on the basis of system changes will be attempted if such changes could be identified for this specific product. Possibly only the product-service substitution could be hypothesised for wash appliances.

In addition to the product system analysis developed in Task 4, some specific aspects will be dealt in this paragraph, mainly for washing machines:

1. the standby definition for washing machines and dishwashers
2. the trade-off between the amount of washed load and the nominal washing machine capacity
3. the indirect energy used in detergent production
4. the trade-off between high spin speed and the subsequent use of a (tumble) dryer (methodological analysis)

6.2.4 Subtask 6.4: Environmental assessment of the technological improvements

The quantitative assessment of the environmental improvements for the identified targets will be developed in this subtask.

6.3 Subtask 6.1: Options, Associated Improvement, Costs and Impacts

Washing cycle in a dishwasher can be divided in the following phases:
1. Regeneration of the water softener (with a salt)
2. Cold pre-rinse
3. Hot wash (+ detergent), temperature ranging from 75°C to 45°C; cold wash is also possible is special cycles
4. Cold rinse
5. Hot rinse (+ rinsing agent), temperature: 65°C (75-77°C in special cycles)
6. Drying.

The sequence is fixed a part from the regeneration phase which can be performed before or after any rinsing phase including the wash phase.

Main technical characteristics of the dishwashers on the market in 2005 dealing with energy/water consumption and noise are:
1. Heating system:
    - Instantaneous water heater (electric resistance with water flowing)
    - Tubular electric resistance (electric resistance with storage)
- Drying system:
    - Condensation: humidity freely condensate on the colder internal walls of the cabinet
    - Ventilation: a fan is added to drain humidity from inside the machine
    - Condensation and ventilation: a combination of the two systems
- Insulation materials:
    - Bitumen: to reduce the noise of the water sprayed against the metallic walls of the tub
    - Phono-absorber material: to further reduce the noise (especially for machines to be used during the night)
- Control system:
    - Program clock, electro-mechanical or electronic
    - Temperature control: on/off or electronic thermostat
    - Water level control: mechanical or electronic sensor

- Washing cycle time:
  - Standard cycle, used for the energy labelling, is declared at 140-150 minutes, shorter cycles, down to a 30 minute rapid cycle, are also available in almost all the machines.

The technological trends can be summarised as:

- water consumption is about 13-14 litres, with values going down to 9-10 litres;
- improvements in mechanical and hydraulic aspects (alternating water spraying and higher pressure water spraying);
- introduction of intelligent sensors (substituting the older and less precise ones), evaluating the degree/type of dirtiness on the dishes and in the water, the detergent type, the tableware weight and adapting consequently the washing cycle phases (temperature, amount of water, detergent an time);
- new enzymatic detergents, active at 45°C allow the washing cycle at 45°C: some machines use a reference cycle temperature at 50°C, some at 45°C;
- increased number of place settings to 15, for larger families or higher use: this aspect allows theoretically to reach a higher energy efficiency class with the same machine, due to the inclusion of the place settings in the formula for the calculation of the energy efficiency index E_I, on the other side, more place settings means additional load weight to be heated). If the standard 12 ps load has an estimated weight of 3kg cutlery and 22 kg dishes, plates and glasses, 3 place settings more mean 6,25kg of additional load weight. On the other side, the index $E_I = C/C_R$ where $C_R = 1{,}35 + 0{,}025 \times ps$, that is $C_R = 1{,}65$ for the 12ps model. If the number of place settings is increased to 15, $C_R = 1{,}73$, the new larger machine is allowed to consume 105 Wh more to fulfil the "A class" requirement $E_I \leq 0{,}64$. If the additional energy input needed to compensate the additional load weight is lower than 105 Wh, the residual energy can be used for other purposes (better drying, for example) or to improve the energy efficiency of the machine;
- attention to noise (for night washing cycles and reduced noise pollution);
- increase in the number of washing cycles designed for specific purposes: glasses, crystals, rapid cycle for very low dirty dishes, longer and stronger cycle for pottery, etc, and very recently plastic toys and dishes (building bricks, rattles and other toys are cleaned gently by the Lego 40°C cycle)[4];
- increase time control: "delay start" option, to delay the start of the washing cycle (for example to use the night electricity tariffs) or on the contrary "time to end the cycle" to end the cycle at a set time independently (up to certain degree) from the starting moment (cycle type, temperature and water to be adjusted consequently taking into consideration the allowed time to wash)
- increased attention to hygiene problems: specific "hygiene cycle" added or an "hygiene phase" added to an already existing washing cycle. Micro-organisms reduction is achieved mainly through high temperature (very hot programme or hotter rinse at 75-77°C) sometime complemented by other physical means, such as UV irradiation at the end of the hygiene cycle.

6.3.1 Option collection

A *Technological Option List* will be created through the consultation of the previous European studies on household appliances, the specialised literature and the discussion with manufacturers and other stakeholders. Not only the presently available technologies will be collected, but also options needing further applied and/or fundamental research.

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[4] Source: "Cutting Edge Washing from BSH", October 2006, Appliance Magazine, Europe Report.

For all the identified options, the possible price increase and environmental impact, energy /water consumption decrease when applied to the base case(s) will be evaluated (for already applicable options) or estimated (for BNAT options), along with the percentage of their application to the market.

A specific *Technological Option Data Collection form* (an electronic sheet) will be used to facilitate the data collection and the collected information sistematisation.

6.3.2 Options, associated improvement, costs and impacts for Dishwashers

6.3.2.1 The hypothesised technological options for dishwashers

Since no other studied on dishwashers were performed at European level after 1995 (GEA), all the technological options starting from that year have been looked for, even if some have been completely applied to go from the 1995 base case to the 2005 base case.

The GEA study, the specialised literature, the discussion with manufacturers and stakeholders lead to define the following list of technological options:

- **Option No 1 - weight reduction of heated parts** (5% = 2,5kg out of a 50kg machine): heat loss through radiation and convection from the heating up of the machine occurs during the washing cycle. Savings can be achieved through (i) improving thermal insulation or (ii) reducing the cabinet energy storage. In the second case, a weight reduction of the components heated to 65°C can lead to the same result as using new materials with a lower heat capacity, since no better material than the already used stainless steel can be easily found. A 2,5% reduction or 2,5kg is considered as in previous GEA study. This option is already applied to all the dishwasher models on the market.
- **Option No 2 - reduced thermal bridging between inside and outside**: an improvement of the thermal insulation is achieved by reducing the thermal bridging effect of inner and outer casing. This reduction can be obtained either by eliminating the some of the steel flanges surrounding the inner casing or by using some foam (insulating material) securing the outside shell to the inside. Both systems are possible, depending of the design of the specific dishwasher models. This option was already proposed in GEA study. This option is already applied to all the dishwasher models on the market.
- **Option No 3 - improved pump and motor efficiency**: the 1995 base case dishwasher is equipped with two electric pumps (one for re-circulation and one for draining) with motors. The running time of the draining pump is negligible as its energy consumption, therefore only the re-circulation pump improvement is considered. A 10% overall improvement of the motor and pump system efficiency is considered, from 20% to 30%, as already considered in the GEA study. A comment was made on the fact that this option improves the efficiency of the system, but also the running time, resulting in a lower energy saving. This option is already applied to all the models on the market.
- **Option No 4.1 - lower wash temperature (55°C) and longer time (+ 25 minutes)**: in 1995 the standard base case machines had a normal cycle at 65°C. At that time manufacturers started to propose as alternative a normal cycle with the temperature of the wash phase reduced at 55°C and a longer duration (estimated in 25 minutes). It should be noted that the hot rinse phase was still run at 65°C to reach a good drying of the dishes. This option was applied to all the models

on the market and was already considered in the GEA study. In the today dishwashers this option is totally replaced by options 4.2 and 4.3.

- **Option No 4.2 - lower wash temperature (50°C) and longer time**: a further improvement was the reduction of the washing temperature at 50°C, with an increase of the cycle duration to 1,5 hours (90 minutes). The hot rinse phase is still 65°C. This option is still applied to about 30% of the models on the market (the other 70% of the models using Option 4.3). It is applied to 9ps and 12ps base cases.
- **Option No 4.3 - lower wash temperature (45°C) and longer time**: a further improvement was the reduction of the washing temperature at 45°C, with a further increase of the cycle duration. The hot rinse phase is still at 65°C. Although this option is applied to 70% of the models on the market, it decreases the cleaning efficiency on specific "difficult" stains (especially tea and coffee), because present detergents work better at 50°C or higher temperatures. This option is less applicable with detergents whose bleaching action starts at 50°C. Possibly, detergents active at a lower temperature should be introduced.
- **Option No 4.4 - lower wash temperature (40°C) and longer time**: a further possible improvement is the reduction of the washing temperature at 40°C, with a further increase of the cycle duration. The hot rinse phase is still at 65°C. This option has been recently made possible by new 7-in-one tablet detergent, marketed under the name of "Somat 7" by the detergent manufacturer Henkel. It is claimed that *with the help of a low-temperature activator, dishes become sparkling at just 40°C. The new detergent booster with washing active enzymes removes stubborn stains, such as egg and sauce residues, so that they can be rinsed off at only 40°C. The bleaching agents completely remove even tea stains*[5]. A further research is needed to evaluate if this low-temperature detergent is available on the overall EU market and if the claimed washing performance at lower temperature is confirmed.
- **Option No 5 - improved accuracy of water level**: accuracy of water levels can be improved by the use of more accurate mechanical or electronic sensors. At present electronic sensors are widely available, which can give better results compared to mechanical ones. This option was already considered in the GEA study and is currently applied to all the models on the market.
- **Option No 6 - alternating spraying of water**: dishwashers are equipped with two or more water arms, which work alternatively or in combination. If the water is alternatively sprayed (from for example the upper and the lower arms alternatively) a water saving can be achieved. A different (patented) technique is used by some manufacturers with the same final effect. This option was already considered in the GEA study and is currently applied to about 40% of the models on the market.
- **Option No 7 - (partly) reuse of last rinsing water**: an apparently simple way to reduce the water consumption is to store water from the last rinse phase and (re)use it in the pre-rinse phase of the following cycle. The last rinse water should in fact be sufficiently clean to be reused. This option requires the addition of a water storage tank, which is already forecast is some of the described options. However, due to the already achieved reduction of the water use in the present dishwashers, the last rinse water in considered by manufacturers too soiled to be stored for many hours without hygiene problems. Although this option was taken into consideration in 1995 in GEA study, no machines are today equipped with this system and its application is considered highly critical, nevertheless it could be studied for future applications (BNAT). For some manufacturers it affects only the water consumption reduction of pre-wash phase and has no impact on the reduction of the energy consumption; for others, also some energy savings can be achieved. This Option is an alternative to Option 15.1.
- **Option No 8 - heat exchanger (with storage tank)**: defined as "heat buffer" in the GEA study, this option forecast the addition of a water storage tank to be used as heat buffer. At the end of the washing phase the tank is filled with fresh water and - due to the difference in temperature -

[5] Source: Henkel, Sustainability Report 2006, pag. 19 (English version).

heat flows from the tub to the stored water, which is then used in the so called cold rinse phase after the hot wash. Less energy (heat) is therefore necessary during the hot rinse to reach the necessary load temperature for drying. This option is at present applied to 15% of the models on the market.

- **Option No 9 - cross flow heat exchanger** (with storage tank): another way to recover waste heat from the hot wash is the use of a cross flow heat exchanger between the incoming fresh water and the drained hot water. The heated fresh water is then stored in the storage tank described in the previous option. Already considered in the GEA study this option is not used at present, but it is under study. It is worth noting that GEA study considered the use of the *cross flow heat exchanger* as an alternative to the *water storage tank*, while today the exchanger is seen - and studied - as an improvement of previous Option 8, although this option is still not applied. This option is not applicable to 9ps machine due to lack of space to accommodate the exchanger.
- **Option No 10 - elimination of heating element for drying**: this option was initially applied in 1995. The heating elements used for heating the load for the drying phase were removed and heat was provided during the hot rinse phase. This option was applied to all the models on the markets and lead to an increase of 20 minutes of the drying phase. At present it is estimated that the system is still used by 5% of the models. Possible ways to shorten the drying phase or to achieve better drying performance are to provide an extra aid in the form of a condensation system or the ventilation of the moist air, described in Options 11.1, 11.2 and 11.3.
- **Option No 11.1 – condensing system for drying without additional heat**: the hot load is left to dry "naturally" by condensation of the (hot) water vapour on the inner walls of the cabinet. This option is presently applied to 45% of the models and to the 9ps and 12ps base cases. The possible improvement is to use Options 11.2 and 11.3.
- **Option No 11.2 – (water tank) condenser for drying**: the condensing system might use an amount of fresh water to act as a condensing coolant. Different designs are possible, but GEA proposed the use of a water storage tank bordering the tub and filled with fresh water at the beginning of the drying cycle just after the draining of the hot rinse water. The moist hot air coming from the load condensates at the surface of the tub walls cooled by the stored cold water and creates also air circulation by natural convection. The condensed water is drained. The clean stored water is (or can be) used in the pre-rinse phase of the following cycle. As alternative, a fan can be used to cool down the condenser surface instead of the water. At present this option is applied to 25% models on the market and was already considered in the GEA study.
- **Option No 11.3 – condenser plus fan for drying**: to achieve a better drying performance a fan is combined to the condenser (in about 25% of the models on the market). A condensing system is equipped with a fan to create what is today referred as "turbo dry system": the air flow from the fan improves the drying performance and can reduce the drying time.
- **Option No 12 - hot rinse at 55°C**: this option was described in GEA study as one way to reduce energy consumption. However, it was never used in dishwashers. Its application requires a total re-design of the drying phase and the development of a drying aid. In addition it could cause problems of drying spots (water re-deposition on dry load). No rinse aid is currently available on the market working at 55°C and more energy is needed if no rinse aid is used. Also the rinse aid used in the EN standard is active at 65°C. This option could be considered for future application (BNAT) even if it is considered critical by manufacturers.
- **Option No 13 - differentiation of water levels**: the total amount of water needed in a cycle is given mainly by the water that is travelling through air or running down the load, which in turn depends on the recirculation flow. If a reduction of water flow is possible in certain phases the total amount of used water can be reduced. Described in GEA study, this option is already applied to all the models on the market.
- **Option No 14 - insulated water tank**: a further saving could be achieved if the storage tank described in Option 8 is insulated and used to store the hot water from the last hot rinse. This

option was mentioned as a possible future long-term development in GEA study but it is still not applied to dishwashers as considered not feasible due to hygiene problems deriving from the long storage time of the water, especially when one or less washing cycle per day is run in households. In addition, the energy savings can occur only if the interval between to successive washing cycles is short, otherwise the water temperature inside the insulated tank will decrease to ambient temperature. This option is technically not applicable to 9ps machines due to the lack of space to accommodate the tank in compact machines.

- **Option No 15.1 - avoidance/reduction of the cold pre-rinse**: the cold pre-rinse (= pre-wash) is generally used to prepare the load for the following hot wash by starting to remove the dried soil. Water used for the cold pre-rinse can be reduced (or even the phase deleted) if the following hot wash phase is sufficient to reach a good washing performance. This options can cause drawbacks of cleaning performance, but is nevertheless already used by 40% of the market. It is in alternative to Option 7. It is applied to the 9ps and the 12ps base cases.
- **Option No 15.2 – partly draining and re-filling (of water):** there is the possibility to drain only part of the soiled water and re-fill the machine with the same amount of fresh clean water. This option can be applied mainly to the cold rinses and main wash, but not in the final rinse. It is at present applied to 20% of the market.
- **Option No 16 - avoidance/reduction of the intermediate cold rinse**: the water consumption for this phase could be decreased (or even the phase deleted) if the rinsing performance of the following hot rinse phase guarantees an good rinsing of the load. Due to the reduction of the water for rinsing it can cause drawbacks of drying spots and severe soil re-deposition. For some manufacturers the drawbacks can be avoided by adding a second pre-wash, which in turn increases again the water demand of the same amount thus neutralising the effect of this option on water savings, leaving just an energy savings. The application of this option has been reduced (due to the re-deposition problems and consequent low washing performance class) to 5% of the present models on the market, and it is expected to disappear soon.
- **Option No 17 - direct heating of the load (avoid last hot rinse)**: it could be possible to perform the last rinse without additional heating and instead heat up directly the load to 65°C after the last rinse water has been drained. In a normal cycle in fact the last hot rinse is usually needed to heat up the load to a suitable temperature for the following drying phase. Despite the fact that this option was mentioned in the GEA study as a potential long term option, it is at present considered not feasible due to the lack of suitable technology. Microwave heating of the load has bees studied but without acceptable results. The energy used in the alternative way of heating the load should be taken into consideration. To be addressed as BNAT.
- **Option No 18 - DC brushless motor and reciprocating pump**: mentioned in GEA study as further improvement of pump and motor system, the DC brushless motor entered into market around 2003 as option, and is at present used by 5% of the models. The use of the reciprocating pump not feasible due to noise problem, a different type of pump is used.
- **Option No 19 - Dual speed motor (HPS system)**: mentioned in recent specialised journals as a way to save energy (and water) through the use of a dual speed pump which is claimed to increase the pressure of the water flow in the spray arms, doubling the (cleaning) power and thus allowing a temperature reduction with a possible energy savings. This option is considered not leading to the claimed savings in the “normal cycle”, but it could be used for more intensive cycles.
- **Option No 20 - optimized hydraulic system with less water**: optimisation of the hydraulic system can lead to a reduction in water consumption by saving the water filling the system itself, which is not used for the pure washing/rinsing activity. This option is already applied to all the models on the market.
- **Option No 21 - optimized regeneration of softener**: soft water system regeneration with a salt can be performed before or after any rinsing phase including the wash phase. Its optimisation through the use of an electronic system can lead to significant saving of water (and salt) since

the regeneration is run only when really necessary and not after each washing cycle or phase. An electronic sensor measures the water hardness and starts the regeneration consequently. This option is already applied to all the models on the market.

- **Option No 22 - accuracy of temperature in main wash and hot rinse**: a better accuracy of the temperature levels can be achieved with better sensors. Electronic sensor are widely available and used today. This option is already applied to all the models on the market.
- **Option No 23.1 - noise reduction, level 1: 50 dB(A)**: noise level is today considered an important element of the profile of an appliance. Can be achieved through a combination of factors: better insulation, redesign of the hydraulic system, dampers for the tub and the pumps, motor placed on insulated supports, etc.. Here a better insulation is especially taken into consideration, since the other possibilities are generally used to achieve improvements other than noise reduction (the redesign of the hydraulic system for the optimisation of water levels and dampers for the tub and the pumps to reduce the overall appliance vibrations). The increase in insulation improves the machine weight and therefore the energy consumption. This option is applied to most of the models on the market, and to the 9ps and 12ps base cases. Other models having a lower noise level apply Options 22.2 and 22.3.
- **Option No 23.2 - noise reduction, level 2:** the same as Option 23.1 but to a level of 44dB(A), which is today applied to 20% of the models on the market.
- **Option No 23.3 - noise reduction, level 3:** the same as Option 23.1 but to a level of 41dB(A), which is the lowest available on the market today in some models. This reduction is applied to 5% of the models on the market.
- **Option No 24 - increase the temperature of the last rinse to 70-75°C (hygiene considerations)**: in most of the recently advertised machines the hygiene problem of the dirty tableware (left in the machine before being washed) and the consequent machine contamination are addressed. High temperature and UV (see following option) have an antimicrobial effect on micro-organisms reducing their presence. Hygiene is claimed to be achieved through a very hot final rinse at 70-75°C (in some models the temperature could reach 77°C[6]) used at the end of the washing programme or as and independent hygiene high temperature cycle.
  In general there are three, increasing, micro-organisms reduction levels: 99% or "hygiene" level, 99,9% or "sanitisation" level and 99,999% or the "sterilisation" level. The first and second levels are claimed to be reached by manufacturers in advertising their dishwashers, the third one deals with public health and should not be addressed when dealing with simple household appliances. The final very hot rinse option is today applied to about 20% of the models on the market.
  It should be discussed if this option, which implies an increase in the energy consumption for a washing cycle (from the energy point of view it is exactly the opposite of Options 4.1, 4.2 and 4.3) has to be considered a special cycle or consumer-behaviour dependent, or if - on the contrary - the hygiene could shortly become part of a "normal" washing cycle as other Options. Should this the case, further consideration is needed about the contradiction between the 'policy-driven' efforts to decrease the dishwashers energy consumption by reducing the washing/rinsing/drying temperature and the 'consumer-driven' increase in energy consumption due to (real or perceived) hygiene problems.
- **Option No 24.1 - UV irradiation** (after the increase of the temperature of the last rinse to high temperature): in some machines the very hot last rinse is followed by a (20 minute) UV irradiation[7]. The UV irradiation is applied by one manufacturer, but is considered by other manufacturers as having no hygiene effect due to the shadows created by one piece of tableware on the others and therefore not considered as an effective option.

[6] Source: model LG Inverter Direct Drive, Trade Bianco, September 2006, pag. 114.
[7] Source: model LG Inverter Direct Drive, Trade Bianco, September 2006, pag. 114.

- **Option No 25 - electronic sensors for the detection of the load weight**: there are two possibilities:
  - a soil sensor detects the actual load soiling and adjusts consequently the best programme (amount of water, length of the washing programme and temperature) to be used;
  - a sensor (indirectly) detects the actual weight of the load and adjust consequently the best programme characteristics.

  The first option is already applied to 40% of the models on the market, using software intelligence with existing sensor technology; more advanced sensors will not give better results. In real-life conditions, the savings are proportional to the soil reduction (compared to the standard load soiling). The second option is already applied to 20% of the models on the market, and is referred to the decrease of the standard place settings in real life washing cycles.
  Since the energy consumption, washing and drying performance are at present measured for the standardised programme operating at full load and standard soiling, these options have no impact on the overall water/energy consumption nor to the energy labelling rating, at least for the moment; they can save energy and water in the real-life base cases.
- **Option No 26 - delay start**: the washing cycle can be delayed to the decided time, leaving the machine loaded and ready for start. Delaying the machine start, this option allows to use the off-peak tariffs (thus decreasing the cost of the used energy) or to have the washing cycle at different moment during the day selected by the consumer. There is no effect on energy and water consumption per washing cycle, and not affect on the energy efficiency class of the present energy labelling scheme. The machine is turned "on" and ready to start at the given time (at the end of the delay), therefore at least a certain power consumption is needed for the timer and the associated electronics to function. This is more to be dealt in the framework of stand-by considerations and system analysis and within real-life base cases. Nevertheless, this option is already applied to 30% of the machines on the market. The definition of "delay start" mode in the IEC/EN standards is the pre-requisite to allow the measurement of the power consumption (in W) of this mode.
- **Option No 27 - electronic update of the programmes/diagnostics**: update of the software managing the different washing cycles can be done by connecting the machine to the assistance PC. This option could be also used for machine diagnostic[8]. There is no immediate impact on energy/water consumption, but by updating the software a better washing cycle management could be achieved (if and when a better software is developed) in case of change in external conditions such as the development of a new detergent, with potential consumption reduction. 20% of machine on the market already have this option.
- **Option No 28 - Internet connectivity**: this option enables remote diagnostics and programmes update, in this sense it is an evolution of Option 27. When connected to Internet the unit is linked to the company's (or assistance's) servers and automatically reports service issues and orders replacement parts and repair. An added benefit is the user's ability to start or stop the machine when outside home via the Internet connection. It is applied to none or very few models on the market (0,1%). A machine with this feature can not have an hard-switch, and will remain in a WOL state thus increasing the energy consumption in non-on mode (standby or low power modes). The same considerations of Option 26 apply. To be considered for long term development (BNAT).
- **Option No 29 - voice controlled appliances**: as appliance control become more capable and precise, one of the challenges facing designers is how to keep controls from getting too complicated while giving choices to users. One approach, little used in the appliance industry, is voice technology, allowing for example to program a machine to follow a customised programme with just a few spoken words. Voice controls can add a bit of differentiation and give personality to an appliance, not to mention the advantages for the aged and disabled users,

[8] Source: model MIELE 1000G, Trade Bianco, September 2006, pag. 117.

because of the hands- and eyes-free approach, even if the loading and unloading of the machine requires the use of both hands and eyes. Not applied for the moment, but to be considered for long term development (BNAT).

6.3.2.2 The Technological Option List for dishwashers in 2005

Considerations about the applicability of the hypothesised options led to the definition of a Technological Option List for dishwashers, including some long term/BNAT options. The selected set of options has been rearranged and renumbered as:

- **Option a.1** (Option 4.3): Lower wash temperature (45°C) with longer time
- **Option a.2** (Option 4.4): Lower wash temperature (40°C) with longer time (note: to be further investigated for global applicability)
- **Option b** (Option 6.1): alternating spraying of water
- **Option c** (Option 8): heat exchanger (with storage tank)
- **Option d** (Option 9): cross flow heat exchanger – **not applicable to 9ps dishwasher**
- **Option e.1** (Option 11.2): (water tank) condenser for drying
- **Option e.2** (Option 11.3): condenser with fan for drying
- **Option f.1** (Option 15.1): avoidance/reduction of the cold pre-rinse
- **Option f.2** (Option 15.2): partly draining and re-filling (of water)
- **Option g** (Option 18): DC brushless motor
- **Option h.1** (Option 23.2): noise reduction (through better insulation), level 44 dB(A)
- **Option h.2** (Option 23.3): noise reduction (through better insulation), level 41 dB(A)
- **Option i** (Option 24): hot rinse at 70-75°C <for real life base case only>
- **Option j.1** (Option 25): electronic sensors for the load soiling <for real life base case only>
- **Option j.2** (Option 25): electronic sensors for the load weight <for real life base case only>
- **Option k** (Option 26): delay start <for real life base case only>
- **Option BNAT 1** (Option 7): (Partly) reuse of last rinsing water
- **Option BNAT 2** (Option 12): Hot rinse at 55°C
- **Option BNAT 3** (Option 14): insulated water tank - **not applicable to 9ps dishwasher**
- **Option BNAT 4** (Option 17): Direct heating of the load (avoid last hot rinse)
- **Option BNAT 5** (Option 28): Internet connectivity
- **Option BNAT 6** (Option 29): Voice controlled appliances.

All Options will be applied to the standard base cases with the exception of where it is indicated that options will be applied to real life base-case only since they will have no effect on the standard base case, due to for example the measurement method used in the standard (which does not take into account that specific aspect). All options will be applied to the real-life base case.

6.3.2.3 Costs and impacts for dishwashers technological options

The selected technological options are shown in Table 6.1 for the 9ps and in Table 6.2 for the 12ps dishwasher, along with the average rate of application, the improvement in manufacturing cost/price and consumer price and the associated energy/water savings when each option is applied to the relevant standard base case. Shown data have been gathered through a data collection exercise with manufacturers and were validated through a discussion with experts and stakeholders.

Main cost/price parameters shown in Tables 6.1-6.2 are:

- **Unit production costs** (manufacturing costs): directly related to production including materials, energy, components, labour, any allocated overhead costs and annual investment cost per unit.

Annual investment cost per unit is equal to the total investment cost for the technological improvement divided by 10 (years of depreciation) divided by the capacity or units produced annually. The reference capacity is one million units/year. Unit costs directly related to production of that unit/technical option are: materials, components, energy, labour, R&D related to the development of that unit/technical option, overhead costs that can be allocated to that unit/technical option, investment that can be related to that unit/technical option.

For example, if total investment cost is 5 million Euro, the capacity is 1 000 000 units/yr with 10 years depreciation, the annual investment cost per unit is 0,50 Euro. This is summed with the other unit costs of materials, energy, component, labour and any allocated overhead costs.

– **Unit production price** (manufacturing price): unit production costs plus all other costs that are not directly related to that unit/technical option: sales and marketing, general and administrative costs, general R&D expenses, profit before taxes, any other general overhead cost. In the past, the product price at the factory was approximately 1,3 times the unit production cost.
– **Consumer price**: is the price paid by the consumer at the retailing place including transport costs, profit of retailer, advertising of product from retailer, etc. Consumer price was estimated by the product price at the factory plus the mark-up. A mark-up value of 2,75 was used in WASH-2 study for washing machines.

Table 6.1: Technological Option List, improvement in cost/price and energy/water savings for the 9ps dishwasher

Options		Application to the market	Unit production		Savings				Cycle time variation	Increase in consumer price	Notes
			cost	price	Electricity		Water				
No	Description	(%)	(€)	(€)	(Wh/cycle)	(%)	(litre/cycle)	(%)	(± min)	(€)	
a.1	Lower wash temperature (45°C) longer time	70	2,7	3,51	+30	+0,0362	0	0	+30	10,53	standard base case washing temperature is 50°C
a.2	Lower wash temperature (40°C) longer time	0	2,7	3,51	+30	+0,0362	0	0	+30	10,53	option to be further investigated, at present to be applied only to the **real-life** base case
b	Alternating spraying of water	40	7	9,1	+50	+0,0604	+2,5	+0,1825	+20	27,3	
c	Heat exchanger (with storage tank)	15	7	9,1	+30	+0,0362	0	0	--	27,3	
d	Cross flow heat exchanger										not feasible for 9ps
e.1	Condenser for drying	25	10	13	+15	+0,0181	0	0	-10	39	
e.2	Condenser with fan for drying	25	10	13	+15	+0,0181	0	0	-10	39	
f.1	Avoidance/reduction of the cold pre-rinse = prewash	60	0	0	+10	+0,0121	+2,5	+0,1825	-5	0	alternative to Option BNAT1
f.2	partly draining and re-filling (of water)	20	1	1,3	+5	+0,0060	+1,5	+0,1095	--	3,9	
g	DC brushless motor	0	20	26	+20	+0,0242	+0,5	+0,0365	--	78	reciprocating pump not usable due to noise
h.1	Noise reduction (better insulation), level 44dB(A)	20	8	10,4	-70	-0,0845	0	0	+10	31,2	base case 50 dB(A)
h.2	Noise reduction (better insulation), level 41dB(A)	3	18	23,4	-90	-0,1087	0	0	+10	70,2	base case 50 dB(A)

Table 6.1: Technological Option List, improvement in cost/price and energy/water savings for the 9ps dishwasher – continued

Options		Application to the market	Unit production		Savings				Cycle time variation	Increase in consumer price	Notes
			cost	price	Electricity		Water				
No	Description	(%)	(€)	(€)	(Wh/cycle)	(%)	(litre/cycle)	(%)	(± min)	(€)	
i	Hot rinse at 70-75°C	20	2	2,6	-230	-0,2778	0	0	+10	7,8	consequences of use by consumers to be investigated, to be applied to the **real-life** base case
j.1	Electronic sensors for the load soling (50% soiled)	40	5	6,5	+80	0,1208	+0,8	+0,058	-10	19,5	applied to **real-life** base case, 50% of the standard soiling
j.2	Electronic sensors for the load weight (50% mass)	20	4	5,2	+100	0,1449	+1,0	+0,073	-10	15,6	applied to **real-life** base case, 50% of the standard place settings
k	Delay start (results form Task3 indicated in parenthesis)	30 (used by 10%)	0	0	-(0,0105 at 3,5 W)	-0,000013	0	0	(3h = average time in this mode)	0	applied to **real-life** base case, and to be considered together with standby within system analysis

*standby power

Table 6.2: Technological Option List, improvement in cost/price and energy/water savings for the 12ps dishwasher

Options		Application to the market	Unit production		Savings				Cycle time variation	Increase in consumer price	Notes
			cost	price	Electricity		Water				
No	Description	(%)	(€)	(€)	(Wh/cycle)	(%)	(litre/cycle)	(%)	(± min)	(€)	
a.1	Lower wash temperature (45°C) longer time	70	2,7	3,51	+40	+0,0374	0	0	+30	10,53	standard base case washing temperature is 50°C
a.2	Lower wash temperature (40°C) longer time	0	2,7	3,51	+40	+0,0374	0	0	+30	10,53	option to be further investigated, at present to be applied only to the **real-life** base case
b	Alternating spraying of water	40	7	9,1	+70	+0,0654	+3,0	+0,1974	+20	27,3	
c	Heat exchanger (with storage tank)	15	7	9,1	+30	+0,0280	0	0	--	27,3	
d	Cross flow heat exchanger	0	16	20,8	+40	+0,0374	0	0	+10	62,4	improvement of Option c
e.1	Condenser for drying	25	10	13	+15	+0,0140	0	0	-10	39	
e.2	Condenser with fan for drying	25	10	13	+15	+0,0140	0	0	-10	39	
f.1	Avoidance/reduction of the cold pre-rinse = prewash	60	0	0	+10	+0,0093	+3,0	+0,1974	-5	0	alternative to Option BNAT1
f.2	partly draining and re-filling (of water)	20	1	1,3	+5	+0,0047	+2,0	+0,1316	--	3,9	
g	DC brushless motor	5	20	26	+20	+0,0187	+0,5	+0,0329	--	78	
h.1	Noise reduction (better insulation), level 44dB(A)	20	10	13	-95	-0,0888	0	0	+10	39	base case 50 dB(A)
h.2	Noise reduction (better insulation), level 41dB(A)	5	20	26	-120	-0,1121	0	0	+10	78	base case 50 dB(A)

Table 6.2: Technological Option List, improvement in cost/price and energy/water savings for the 12ps dishwasher - continued

Options		**Application to the market**	**Unit production**		**Savings**				**Cycle time variation**	**Increase in consumer price**	**Notes**
			cost	**price**	**Electricity**		**Water**				
No	Description	(%)	(€)	(€)	(Wh/cycle)	(%)	(litre/cycle)	(%)	(± min)	(€)	
i	Hot rinse at 70-75°C	20	2	2,6	-250	-0,2336	0	0	+10	7,8	consequences of use by consumers to be investigated to be applied to the **real-life** base case
j.1	Electronic sensors for the load soling (50% soiled)	40	5	6,5	+100	+0,0935	+1,0	+0,0658	-10	19,5	applied to **real-life** base case, 50% of the standard soiling
j.2	Electronic sensors for the load weight (50% mass)	20	4	5,2	+120	+0,1121	+1,5	+0,0987	-10	15,6	applied to **real-life** base case, 50% of the standard place settings
k	Delay start (results form Task3 indicated in parenthesis)	30 (used by 10%)	0	0	-(0,0105 at 3,5 W)	-0,000010	0	0	(3h = average time in this mode)	0	applied to **real-life** base case, and to be considered together with standby within system analysis

Starting from collected unit production costs, the manufacturing price has been calculated from by multiplying them by 1,3. Consumer price increase has been calculated using a mark-up value of 3,0. The electric energy price is 0,17 €cent/kWh in real terms. The standard and real-life base-cases annual energy consumption (see Task 5 report) are reported in Table 6.3:

Table 6.3: Standard and real-life base-cases annual energy consumption and noise

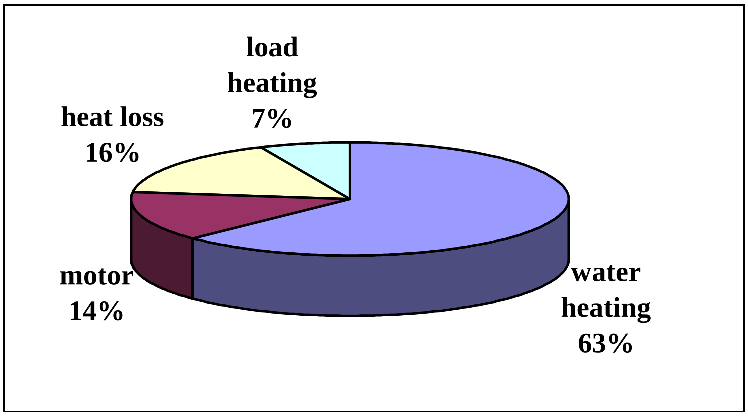
Machine type	**Electricity consumption** (kWh/cycle)	**Water consumption** (litre/cycle)	**Noise** (dBA)
STBC 9ps	0,828	13,7	50
STBC 12ps	1,070	15,2	50
RLBC 9ps	0,903	13,9	50
RLBC 12ps	1,167	15,4	50

6.3.3 Options, improvements, costs and impacts for Washing Machines

6.3.3.1 Introduction

The washing process uses energy, which can be subdivided into heating, mechanical action and pumping. The amount of energy used for heating is influenced by the amount of water (the suds level), the wash load, the temperature of the cold water inlet and the temperature to be reached (i.e. the final ΔT). The energy used for mechanical action depends on the total wash time. The energy use for pumping is in general fixed in the wash programme, and is not influenced substantially by any of the process variables. All the different phases of the washing process use a portion of the energy consumption of the wash cycle. During the washing process the energy used to heat the water also flows to other parts of the machine, for example the steel drum, the glass door and the wash load, and part is lost to the environment. The amount of energy that is lost to the environment depends on a number of variables, among which the insulation of the machine, the duration of the cycle, the ambient temperature and the temperature of the heated water. Figure 6.1[9] shows the relative share of the components of the energy consumption of a 60°C cotton cycle in 1993.

Figure 6.1: Relative energy consumption for the different components of the washing cycle in 1993.



[9] Source: GEA 1993.

Washing cycle in a washing machines can be divided in the following phases:

1. Water intake (+ detergent) for load wetting
2. Heating (to the set water temperature)
3. Main wash phase (ending with the drain of the wash phase liquor)
4. Post wash: cold water intake, rinse, drain
5. Rinsing phase, with intermediate spinning between rinses (+ softener in the final rinse)
6. Final spinning phase.

Main technical characteristics of the washing machines on the market in 2005 dealing with energy/water consumption and noise are:

- Heating system:
  - Instantaneous water heater (electric resistance with water flowing)
- Insulation materials:
  - phono-absorber material: to further reduce the noise (especially for machines to be used during the night)
- Control system:
  - Program clock, electro-mechanical or electronic
  - Temperature control: on/off thermostat or electronic sensor
  - Water level control: mechanical or electronic pressostat
  - Load weight control: electronic sensor
- Washing cycle time:
  - 60°C cotton cycle, used for the energy labelling, is declared at 110-130 minutes, shorter and longer cycles and different temperatures are also available in all the machines
- Washing water (sud volume) and ΔTemperature:
  - the low cost washing machines are assumed to have suds level (at rated capacity) of 20 litres in the main wash, this is 16 litres for medium cost machines and 14 litres for high cost machines equipped with electronics. Lower volumes are achieved in more recent machines, up to 12-13 litre due to 100% electronics and sensor use
  - in all machines the ΔT was assumed to be 40°C to 45°C for the 60°C cotton cycle (cold water intake at 15-20°C)
- Rinsing phase: rinsing changed over the year:
  - reference type around 1985: 4 rinses without intermediate spins with 22 l of water per rinse (total 88 litre of water)
  - program type around 1993: 3 rinses with intermediate spins., 15 l of water per rinse (total 45 litre of water)
  - low consumption program type: 2 rinses with intermediate spin, 15 l of water per rinse (total 30 litre of water)
  - 2005 machines: have 3 rinses with intermediate spin, 8-10 l water per rinse (total 24-30 litre of water).

6.3.3.2 The reviewed technological options in 1998 (WASH-2 study)

The presented options were revised in the WASH-2 study, taking into consideration that in the period 1993-1998 the industry addressed most of the issued described in the GEA study and added a few new design options, and through an extensive discussion with industry and non-industry experts. Updated technological options and related estimated energy/water savings and additional cost in 1998 were:

- **Option 1 - *motor efficiency***: an estimate of motor efficiency options is shown in Table 6.4.

Table 6.4: Estimated motor efficiency options in WASH-2 study

Motor options	relative costs (Euro)	market share 1998 (%)	motor efficiency (%)	contribution to average efficiency (%)
Asynchronous motor 50-500 rpm	-25	25,0	20,0	5,0
AC phase controlled 60-1400 rpm	0	70,0	30,0	21,0
DC phase controlled 40-1600 rpm	5	3,4	36,0	1,2
Chopper motor	18	1,5	38,0	0,6
Brushless DC (+ control)	50*	0,1	50,0	0,1
Brushless DC Direct Drive (+ control)	90**	0,01	50,0	0,0
Total		100,0		27,8

*10 Euro motor + 40 Euro control; **40 Euro motor + 50 Euro control

Apart from the motor efficiency, a better motor enables the engineers to enter other efficient design options. The improvement in motor efficiency alone causes a reduction of around 30Wh/cycle (chopped) to 50 Wh/cycle (brushless DC or Switched Reluctance). The additional benefit of the more (brushless DC, SR motor) or less (chopper motor) sophisticated variable speed drive will help the reduction of the sud volume;

- **Option 2 - *time-temperature trade-off***: the total cycle time between 1993 and 1998 has increased by some 10 to 20%, whilst at the same time the number of rinses has on average diminished. A total cycle time of 120 to 130 minutes was common in 1998, whereas in 1993 the cycle time was 100 to 110 minutes. Manufacturers claim that there is zero benefit from time-temperature trade-off referring to the situation from 1998 onwards. It is concluded that, although in the period 1993-1998 the optimisation of time, temperature and other parameters will have played a role, for the immediate future it will be a saving option only for low-range machines.
- **Option 3 - *mechanical action***: one of the most important *new* design options, not mentioned in the GEA study, is the introduction of complex mechanical action and even spinning action during the wetting phase to reduce the sud volume by 2 to 3 litres. In terms of energy this is a saving in the range of 100 to 150 Wh/cycle (including a sophisticated control, see next option).
- **Option 4 - *full electronic and controls***: apart from suitable variable speed motors, the previous option also needs a sophisticated water level and process control. This option creates the methodological problem of re-clustering all the design options, as it makes no sense to add a variable speed drive motor without the sophisticated controls that go with it.
- **Option 5 - *thermal efficiency***: the total energy consumption for machine-heat up, heat-up of the glass door, radiation and convection losses has been reduced from 276 Wh/cycle in 1993 to 175Wh/cycle in 1998. Yet, the industry indicates that a further reduction of thermal losses is possible by some 50 Wh/cycle at an expense of 12 Euro.
- **Option 6 - *tub-drum geometry***: diminishing the tub-drum clearances and increasing the drum volume (volume to load ratio), thus reducing the required sud volume and, because of the better wash performance, being able to save energy by reducing the cycle time (alternatively reducing the temperature). Manufacturers expect only little improvement from a reduction of tub-drum tolerances (25 Wh/cycle and 0,5 litre of water) and no benefits at all of increasing the drum volume versus the load capacity. This is debatable as many highly efficient washing machines were recently presented with drum volumes of 48, 52 and even 60 litres. The claimed capacity of these machines is 5,5, 6 or even 7 kg, but often the test load (for the energy label) is 5 kg. This means at a volume to load ratio of almost 10:1, whereas in the past even ratios of 8:1 were not uncommon. The dimension of the outer casing is the same as with a "normal" machine,

therefore the clearances between tub and drum or tub and outer casing must have been reduced; probably both. The water consumption of these machines can be as low as 39 litres/cycle and the sud volume during washing is only 12,5 to 13 litres. It is disputed whether at such low sud levels a satisfactory wash performance is possible: industry and some test-house experts claim that a minimum of 13 litres sud volume (at 5 kg load) is required. With respect to 1993 the volume-to-load ratio of the average washing machine has increased by around 10 to 15% (from a 42-44 litre drum at 5 kg load in 1993 to 48 litre drum at 5 kg load in 1998, while the rated capacity has not been changed). The tub-drum clearances have been reduced significantly with values found as low as 10 mm. Both these factors have lead to an improved wash performance (trade-off with energy through e.g. lower temperatures) and a reduction in sud volume (translates directly into less energy).

- **Option 7 - *rinsing optimisation***: improved rinsing efficiency using only 3 rinses and increasing the intermediate spinning action, saving water. This saves some 13 litres per cycle. There is a general acceptance of 3 rinse cycles instead of 4 or 5, with a higher number of intermediate spins. The cost of this option, which was introduced in the 1993-1998 period, is estimated at 7 Euro (instead of the estimated 11,8 Euro mentioned in the GEA study).
- **Option 8 - *water level and temperature control***: improved water level control, reducing the sud volume. Manufacturers claim that 80% of all machines now have a sophisticated mechanical water level control. The suds volume of the base case was set at 16,6 litres, which means a saving potential of 30 Wh/cycle (6 Wh/kg) to be expected for the future at an average cost of 1,5 Euro.
  The electronic thermostat is clearly a more expensive and more sophisticated item, saving by itself through better control of the temperature curve. With a price of 20 Euro however it is believed to be applicable in only a limited number of machines.
- **Option 9 - *Sophisticated electronic controls***: introduction of "fuzzy" or other type of sophisticated control enables the machine to determine a large part of the program by itself. This option (or rather this set of options) optimises the consumer behaviour regarding programme settings, thus saving considerable amounts of energy and water. Since this option does not affect energy and water consumption in the standard base case it was not included in the LCC analysis.

The most important element emerging from the description of the technological option was that more and more, the design of a washing machine is a systems design requiring specific combinations of sensor, central intelligence and motors rather than the addition of extra features to an already existing design. The clustering of design options, which is a necessity in order to apply the LCC methodology, is therefore a somewhat arbitrary process. Discussion and refining of the options costs and savings lead to the creation of the LCC input Table 6.5, including 8 options, which were later reduced creating Option (1+2) as the combination of the two single motor improvements (that were assumed to be applied contemporarily with a ratio of 70:30 and an overall price of 24,75 Euro). Option 8 about better rinses in applied only to 25% of the market. A mark-up of 2,75 was used to calculate the consumer price increase from the manufacturing cost increase. The Net Present Value for the single technological options is presented in Table 6.6.

Conclusions from the technical/economic analysis in 1998 were:

- Between 1993 and 1998 there has been no breakthrough in washing machine technology. Nor can we foresee basic new insights from laboratory experiments running today. The technical economic analysis by GEA in 1993 estimated that an electricity consumption of 0,165 kWh/cycle was possible and this still is roughly the best that can be expect for the coming years (for the 60 ºC cotton cycle);
- Various technological options have matured since 1993 and have been implemented. Mass production of previously seen as more “experimental” features has started and prices have

dropped. Notably this is true for motor technology, where DC motors will probably soon be the new standard for all top-range washing machines. This also applies to evolution of electronics in washing machines, which will affect both energy and water consumption for the 1998 standard base case but probably even more appliances in real life. As a consequence, many design options identified have become more 'economical' to the consumer in terms of LCC and payback time;

- What also changed between 1993 and 1998 is that the machines are designed more and more as a total concept. The basically electro-mechanical concept has evolved to an electronically controlled machine with sophisticated sensors as inputs and sophisticated motors (and heating element controls) as outputs. This evolution makes the identification of single, "add-on" design options (and their costs) more difficult.

Table 6.5: Base-case values and technical options energy/water savings and costs in 1998 (WASH-2 study)

Option	Technological options	Energy savings over the base case		Water savings over the base case		Costs	Price
(No)	(description)	(Wh)	(%)	(litre)	(%)	(EURO)	(EURO)
1	DC motor phase control	50	4,35	0	0	5	13,75
2	DC chopper motor	70	6,09	0	0	18	49,5
3	Time temperature trade-off	50	4,35	0	0	1	2,75
4	Mechanical action	50	4,35	0	0	5	13,75
5	T, W sensors, full electronic and 100% AC phase control	100	8,70	12,5	19,841	10	27,5
6	Thermal efficiency	50	4,35	0	0	4	11
7	Tub-drum clearance	25	2,17	0,5	0,794	3	8,25
8	Rinses	0	0	2,5	3,97	0,5	1,375

Table 6.6: Net Present Value results for single technological option in 1998 (WASH-2 study)

Single options (No)	Option price (EURO)	Energy saving for option (%)	Water saving for option (%)	Payback time EU (years)	NPV lifetime 10 y	NPV lifetime 12 y	NPV lifetime 15 y	NPV lifetime 17 y
1+2	24,75	4,88	0	16,56	-13,75	-12,21	-10,24	-9,06
3	2,75	4,35	0	2,06	7,05	8,43	10,18	11,24
4	13,75	4,35	0	10,32	-3,95	-2,57	-0,82	0,24
5	27,5	8,70	19,841	3,73	26,76	34,35	44,08	49,90
6	11	4,35	0	8,26	-1,20	0,18	1,93	2,99
7	8,25	2,17	0,794	9,65	-1,96	-1,08	0,05	0,72
8	1,375	0	3,97	1,46	5,57	6,54	7,79	8,53

The LCC analysis led to the following *conclusions for a 60ºC cotton cycle standard base case*:

- the average energy consumption of a washing machine is at 0,24 kWh/kg (1998 situation);
- the lowest LCC point is at 0,188 kWh/kg for the standard base case, but at a rather long pay-back period of 8,3 years;
- the best technically feasible is at 0,17 kWh/kg, which is some 10% higher than the present "A" level. At this point the LCC is still below the level of the base case scenario for 1998, but the calculated pay back period (of 16,9 years) is longer than the average appliance life time (of 15 years).

6.3.3.3 Technological options for washing machines in 2005

The review of WASH-2 study options, the consultation of specialised magazines and an extensive discussion with industry and non-industry experts lead to the definition of the following list of possible technological options to be applied to the improvement of the 2005 base case:

- **Option No 1.1 – increased motor efficiency**: an estimate of possible motor efficiency improvement is presented in Table 6.7.

Table 6.7: An estimate of possible motor efficiency improvement in 2005

Motor options	market share in 2005 (%)	motor efficiency (compared to the AC phase motor)
Brushless DC (+ control)	0,5	+6%
Brushless DC direct drive (+ control)	0,5	+6%
Three-phase (+control)	5	+6%

  Improvement in motor efficiency alone causes a reduction of around 50 Wh/cycle (brushless DC or Switched Reluctance). The additional benefit of the more sophisticated variable speed drive will help the reduction of the suds volume. The brushless DC motor eliminates the heat losses and time needed to make the motor cool down; when the Direct Drive system (the motor is mounted directly on the axis of the drum, without the traditional belt drive with low energy losses and better control) is also added the machine vibrations and noise are reduced; the three-phase motor is more used at present (5% of the market); the direct drive and the three-phase motor allow the reduction of the washing cycle noise to 48dB(A). Apart from the motor efficiency, a better motor enables the engineers to enter other efficient design options. The three motor types are alternative systems.
  The different motor options are alternatives of the same technological innovation
- **Option No 1.2 - optimised materials in motors**: motor can be optimised also by optimising the amount of construction material; less iron and copper have no impact on energy/water consumption but reduce the material composition of the machine and the costs for manufacturers which can compensate the raw materials price increase; 5% less material can be used at present with no modification of the other motor characteristics. Apparently this option is still not applied to models on the market.
- **Option No 2 - time-temperature trade-off**: the savings due to this options have been already applied to all the market and not further improvement is considered possible.
- **Option No 3 - optimised mechanical action**: improvements in mechanical laundry agitation properties possible with the new motors and sophisticated controls (see next option); the effect on energy/water consumption is unclear, especially in the standardised cycle used for the Energy Labelling scheme, but some saving is still considered possible through a further optimisation.
- **Option No 4 - full electronic and controls**: electronic controls can be applied to different elements of the washing machine and washing cycle phases:
  - **Option No 4.1 - unbalance control:** control is achieved by the use of sensors for the motor, shock absorbers and machine mechanical construction. Shock absorbers can be mechanical (frictional) or high pressure (filled with gas or oil). Some sort of simple unbalance control is included in about 90% of the machines (see Option 4.2). A more sophisticated unbalance control, achieved by the use of special methods which detect the unbalance, is already applied to 5% of the market.

- **Option No 4.2 - load/water/temperature sensors**: about 90% of the machines on the market have at least partial electronic control. Sensors evaluate the load weight and the degree of dirtiness of the laundry, adapting consequently the washing cycle phases (temperature, amount of water, detergent and time); other sensors avoid the presence of too much water in the drum and stop the heating in case of overheating, thus improving the textile protection against thermal shocks. A simple unbalance control is also included.

  Load sensors: weight sensor can be used for optimal energy and water consumption with some reduction possible, but not detected with the present test method. This option has to be applied to real life base case for partial load detection and addressed in the new standard when dealing with partial load.

  Water sensors: analogue water sensor is applied only to 5% of the machines.

  Temperature sensors: the electronic thermostat, considered too expensive by the WASH-2 study, is now implemented in 80% the machines on the market together a simple unbalance control system. Some energy can still be saved when compared to electromecanical switch.
- **Option No 4.3 - sophisticated electronic controls:** introduction of "fuzzy" or other type of sophisticated control enables the machine to determine a large part of the program by itself. This option (or rather this set of options), already applied to 50% of the market, optimises the consumer behaviour regarding programme settings, thus could save energy and water. Since this option does not affect energy and water consumption in the standard base case it will be applied to the real-life base case, when the "reduced load" option is evaluated. Fuzzy logic is applied to produce more "sophisticate" machines.

* **Option No 5 - thermal efficiency**: the total energy consumption for machine-heat up, heat-up of the glass door, radiation and convection losses have been optimised. No further reduction is considered possible.
* **Option No 6 - tub-drum geometry**: considered fully optimised in the machine on the market.
* **Option No 7 - decrease in washing temperature**: new detergents and bleaching active at low temperature allow washing at lower temperature with decrease of energy consumption; however, contemporarily, an increase in detergent dosage is needed to maintain the same washing performance (all the other conditions being the same), but additional detergent might imply an increase in water consumption to achieve an acceptable rinsing performance, or to maintain the same performance of today at 60°C;. Not detectable at present with current EN standard and cotton cycle at 60°C. To be addressed in a new EN standard, where a lower temperature wash (40°C cycle) and rinsing performance considerations could be included. Both issues are addressed in the new edition of the IEC 60456 (5^{th} edition).
* **Option No 8 - rinsing phase optimisation**: a better rinsing efficiency, with a decrease of the water needed to rinse, can be achieved through different improvements (for example: optimised drum shape, spinning speed, water flow through the laundry, etc.). The rinsing performance (amount of detergent residual in the washed laundry) not addressed in the present standard (see before). Applied to about 20% of the market.
* **Option No 9 - noise reduction**: noise in washing machine is caused by the motor and the water circulation during washing phase and by the spin during spinning. Noise reduction (to 48 dB(A)) in the wash phase can be achieved with the use of the direct drive and the three-phase motor (see before) plus the optimisation of the drain pump. Spinning noise to be reduced to 68-65 dB(A) by unbalance control (see before).
* **Option 10: increased time control (start delay)**: the use of "delay start" feature allows to start the washing cycle at a decided time, leaving the machine loaded and ready for start. Delaying the machine start could allow to use the off-peak tariffs (thus decreasing the cost of the used energy) or to have the washing cycle at different moment during the day selected by the consumer. The machine is turned 'on' and ready for the start at the given time (at the end of the delay), therefore at least a certain power consumption is needed for the timer and the associated electronics to function. This is more to be dealt in the framework of stand-by considerations

within system analysis and real-life base cases. Nevertheless, this option is already applied to 30% of the machines on the market. The "delay start" mode is not included in the revision of IEC 60456, nor in any of the present or planned policy measures around the world (see Task 1). Another new function for washing machines is the "time to end of the cycle" to end the cycle at a set time independent from the starting (cycle type, temperature and water to be adjusted consequently taking into consideration the allowed time to wash);

- **Option 11: increased amount of load** (for larger families, less frequent cycles or large laundry items): allows to reach a higher energy efficiency class with the same machine. If an class A machine of 5kg is allowed to consume 0,19 kWh/kg or 0,950 kWh for the cotton 60°C cycle, a 6kg machine of the same dimensions is allowed to consume 1,14 kWh/cycle (or 190 Wh for the extra 1 kg load). If the additional energy input needed to compensate the additional load weight is lower than 190 Wh, the residual energy can be used for other purposes or alternatively to improve the efficiency. "Big size" models (washing from 8 to 10 kg load) are introduced on the market today; the declared target is large families or small communities (restaurants, sport clubs, agritourisms, beauty centres, etc.) but also to wash very large laundry items (blankets, etc.) home or to make only one washing cycle per week in a 'normal' household. However, there is another reason at the basis of this marketing (and technological) choice: market globalisation and increased competition requires manufacturer to rationalised and optimise the production, by reducing the product platforms. Global market allows consumer to know, understand and appreciate the features of appliances sold in – once – far markets. Traditionally, the European market of washing machines was focussed on 5kg, front loading, horizontal axis machines, while the American (Canada, US, Mexico and other Latin American countries) market was focussed on larger, top loading, vertical axis machines. Increasing the load of European washing machines, and contemporarily reducing the load of the vertical axis machines to improve efficiency, could be also interpreted as an attempt by industry towards platforms harmonisation (or at least increased compatibility). Which in turn is the pre-requisite for international standard harmonisation and shared policy measures.
  Whether this effort will be successful depends in the end on changes in consumers behaviour and perception of own needs, which can be – to a certain extent – guided/matched through the introduction of appliances with new characteristics such as a larger capacity.
- **Option 12 – laundry and machine hygiene**: increased attention is registered to hygiene problems: micro-organisms reduction in the laundry and in the machine (drum and detergent dispenser) is achieved mainly through high temperature (the old boiling water 90-95°C cycle used for a different purpose, steam cycle), Ag+ ions release (through a silver bar positioned outside the drum or silver nano particles mixed with the gaskets and the internal coating material); high temperature (77°C) water intake at the beginning of the washing cycle for few minutes (typically 3 min, claimed to saturate the laundry with hot water long enough to kill most of the of the common household bacteria but not long enough to damage the fibres). Silver ion system is considered more a marketing tool than an effective mean to reduce micro-organisms contamination. The same results can be achieved using chemicals: traditional bleaching and more modern oxidising agents, specific detergents.
  It should be discussed if the increase in washing temperature, which implies an increase in the energy consumption for a washing cycle (just the opposite of other options) has to be considered a special cycle, and therefore not included in the evaluation of the machine energy consumption in standardised conditions, or if 'hygiene' should become part of a "normal" washing cycle and therefore considered in the overall evaluation of a machine consumption.
- **Option No 13 – single stain removal system**: presented in Munich in June 2006 by BSGH[10] a washing machines with a new stain removal system for different stains. The stain removal system allows the washer to be set to one of 14 different stain types, and the wash cycle will be

[10] Source: "Cutting Edge Washing from BSH", October 2006, Appliance Magazine, Europe Report.

adapted accordingly. Bloodstains, for example, are treated with a long, cold pre-wash. The user is expected not to mix differently stained items (as it is done at present for the normal laundry), but to collect all items with the same fabric and stain and wash lighter loads separately. The washer control adjusts water usage accordingly and provides detergent-use guidance to the consumer.

- **Option No 14 – drum construction**: (patented) integrated fibreglass housing with a counterbalance moulded directly into the shell of the outer drum (instead of the concrete or other materials counterbalance mounted to the outside). This option could decrease the manufacturing costs but the environmental impact of fibreglass, compared to the material used for the more traditional stand-alone counterbalance, has to be evaluated. No effect on energy/water consumption foreseen.
- **Option No 15 – automatic detergent dispensing** with sensor at the end of the reservoir. More typical for US machines, can be applied to European models[11] especially if liquid detergents will become the first choice due to the washing temperature decrease. However, the reservoir should be integrated in the external case, where available space is less and less due to the larger drum and used in parallel with the more traditional detergent dispenser (to allow the use of powder/tablet detergents). Positive effects of optimised (reduced) detergent dosage only in case the detergent is dosed according to the real load and programme type. It should be noted that washing machine and detergent manufacturers give generally extensive information to the customers about detergent use/dosage.
- **Option No 16 – increase of the spinning speed**: an improvement of the spinning speed increases the energy consumption of the washing cycle (higher consumption of the motor) and in general improves the spin drying efficiency by decreasing the remaining moisture content of the washed load. This in turn improves the overall efficiency of the washing-drying system, when a dryer is used. According to the German Agency Dena[12], a high-speed spinning, above 1 200 rpm, requires between 5% (at 60°C) and 10% (at 40°C) more energy than lower spin speeds.
- **Option No 17 – electronic update of the programmes/diagnostics**: update of the software managing the different washing cycles can be done by connecting the machine to the assistance PC. This option could be also used for machine diagnostic. There is no immediate impact with the energy/water consumption, but by updating the software a better washing cycle management could be achieved (if and when a better software is developed) in case of change in external conditions such as the development of a new detergent, with potential consumption reduction. 20% of machine on the market already have this option, to be used by an authorized after sale service.
- **Option No 18 – Internet connectivity**: this option enables remote diagnostics and programmes update. When connected to Internet the unit is linked to the company's (or assistance's) servers and automatically reports service issues and orders replacement parts and repair. An added benefit is the user's ability to start or stop the machine when outside home via the Internet connection. It is applied to none or very few models on the market (0,1%). A machine with this feature can not have an hard-switch, and will remain in a WOL state thus increasing the energy consumption in non-on mode (standby or low power modes). The same considerations of Option 10 apply. To be considered for long term development (BNAT).
- **Option No 19: LCD with actual load indication**: the indication of the actual load in LCD displays (possible due to the new load sensors, see before) could be a good system to address consumer behaviour towards full (or higher) loading of the machine. To be dealt for real life

[11] MIELE W 4449 WPS Liquid Washing Machine sold in UK, see:
http://www.miele.co.uk/Products/Features.aspx?pid=105% 20Miele%20W4449%20-%20liquid%20detergent%20dispensing.

[12] source: Revision of the Energy Labelling System, Final Report, 2006, Deutsche Energie-Agentur GmbH (Dena)

base case. At present no machines have this feature. The LCD display is present in some high end-range machines (0,5-1% of the market), and also the sensors for load weight, but not necessarily the load is displayed. It could be a good system to address consumer behaviour towards full (or higher) loading of the machine.

- **Option No 20 – voice controlled appliances**: (user-friendly interfaces in multiple languages and vocal interfaces) as appliance control become more capable and precise, one of the challenges facing designers is how to keep controls from getting too complicated while giving choices to users. One approach, little used in the appliance industry, is voice technology allowing for example to program a machine to follow a customised programme with just a few spoken words. Voice controls can add a bit of differentiation and give personality to an appliance, not to mention the advantages for the aged and disabled users, because of the hands- and eyes-free approach, even if the loading and unloading of the machine requires the use of both hands and eyes. Not applied for the moment, but to be considered for long term development (BNAT).
- **Option No 21 – mixed appliances**: a combination Washer/Dryer/Air-Conditioner has been presented in November 2006 by Toshiba Consumer Marketing: the Air Conditioning Cycle Drum TW-2500 VC/2000 VC is said to be the world's first washer/dryer with an air-conditioning function[13]. It sends out cool air, which is designed to improve the comfort in the room where the laundry appliance is used. The unit is designed with an air-conditioning cycle engine with dehumidifying and cooling functions, similar to an air-conditioner with a compressor. This allows the unit to dispense with the use of a heater when drying or water for cooling. Optimizing drying starts in the wash cycle, where the unit uses the S-DD Engine Plus 3, designed to give the machine the ability to perform powerful dehydration at a very high spin speed (1.500 rpm). In the drying cycles, the air-conditioning cycle engine accomplishes dehumidification using a 1 horsepower compressor and large-air-volume fan. The unit is a drum-type washer/dryer with a 9 kg laundry capacity. Electric power consumed for washing and drying a 6 kg load of laundry has been reduced to 1 600 Wh using 6 to 4 litre of water. Users choose from three modes of operation: "Standard" mode, "Speedy" mode (said to cut 40 minutes off the total washing/drying cycle) and the "Good Sleep" mode, designed to have a noise level as low as that of a library. The air-conditioning function is designed to have about 800 W of cooling capability, so that it can lower the temperature of about a 3,3 m^2 room from 30°C to 25°C in about 15 minutes. Integration of different functions to be addressed in system analysis and BNAT.
- **Option No 22 – Hot-fill feature**: several producers no longer offer it in the UK, where the application is declining. It is offered in no other of the EU27 country. The main reasons for the decreasing use are that as more water is saved by other measures the savings due to hot fill are reduced proportionately and also the fact that less hot water is needed makes the impact of pipe losses even greater as it is the initial volume of water that is lukewarm. Since the option is not expanding in the UK and not used elsewhere, the option can be considered not further usable. Recently, the UK consumer body "Which?" advised consumers that as long as most of the washing are at 40 °C there is little advantage to using a combination of hot and cold fill[14].
- **Option No 23 – "New and alternative" washing systems**: some new alternative washing systems are advertised and sold, mostly outside Europe, which do not use water or which try to re-use water or use in any case less water. These include: ozone treatment of the wash liquor, ultrasonic agitation, high performance osmosis/filtration and steam cleaning[15]. Although

[13] Source: November 2006 APPLIANCE Magazine.
[14] Source: Which? report : Washing machines, 28 June 2007, see: http://www.which.co.uk/reports_and_campaigns/house_and_home/Reports/cleaning/Cleaning%20appliances/Washing%20machines/washing_machines_essential_guides_574_73738_9.jsp
[15] Source: MTP Briefing Note: IBNW23: Innovation briefing note on domestic laundry washing products and services.

available on some markets, most of these systems are considered not attractive for the European market as it stands now. Nevertheless, since in the long term there may be environmental benefits to be gained from some of these alternatives a description for some of them is given in Subtask 6.3 dealing with long term targets.

6.3.3.4 The technological Option List for washing machines in 2005

The considerations about the applicability of the hypothesised options lead to the definition of a set of technological options for washing machines including some long term/BNAT options. The selected set of options has been rearranged and renumbered as:

- **Option a.1** (Option 1): Brushless DC motor (+ control), or as alternative
- **Option a.2** (Option 1): Brushless DC direct drive motor (+ control), or as alternative
- **Option a.3** (Option 1): Three-phase motor
- **Option a.4** (Option 1.2): Optimised motor composition
- **Option b** (Option 3): Optimised mechanical action
- **Option c.1** (Option 4.1): Unbalance control (with separate sensors)
- **Option c.2** (Option 4.2): Analogue water sensor
- **Option c.3** (Option 4.2): Temperature control sensor
- **Option d** (Option 8): Rinsing phase optimisation
- **Option e** (Option 11): Increased load capacity (from 5kg to 6kg load) in the same machine
- **Option f.1**(Option 12): high temperature (77°C) water intake <for real-life base case only>
- **Option f.2** (Option 12): Boiling water or steam cycle <for real-life base case only>
- **Option g** (Option 4.2): weight sensors (load control) <for real-life base case only>
- **Option h** (Option 4.3): sophisticated electronic controls (fuzzy logic) <for real-life base case only>
- **Option i** (Option 10): increased time control: delay start <for real-life base case only>
- **Option j** (Option 19): LCD with actual load display <for real-life base case only>
- Option k (Option 16): Increase spin speed (from 1 200 to 1 600 rpm)
- **Option BNAT 1** (Option 18):Internet connectivity
- **Option BNAT 2** (Option 20): Voice controlled appliances
- **Option BNAT 3** (Option 21): Mixed appliances
- **Option BNAT 4** (Option 23): Alternative washing systems

All Options will be applied to the standard base case, with the exception of where it is indicated that options will be applied to real life base-case only since they will have no effect on the standard base case, due to for example the measurement method used in the standard (which does not take into account that specific aspect). All options will be applies to the real-life base case.

6.3.3.5 Costs and impacts for washing machine technological options

The selected technological options are shown in Table 6.8, along with the average rate of application, the improvement in manufacturing cost/price and consumer price and the associated energy/water savings when each option is applied to the base case machine. Shown data have been gathered through a data collection exercise with manufacturers and were validated through the discussion with experts and stakeholders.

Main cost/price parameters shown in Table 6.8 are:

- **Unit production costs** (manufacturing costs): directly related to production including materials, energy, components, labour, any allocated overhead costs and annual investment cost per unit. Annual investment cost per unit is equal to the total investment cost for the technological

Table 6.8: Technological Option List, improvement in price/costs and energy/water savings for the 5kg washing machine

Options (No)	Options (description)	Application to the market (%)	Unit production cost (€)	Unit production price (€)	Savings Electricity (Wh/cycle)	Savings Electricity (%)	Savings Water (litre/cycle)	Savings Water (%)	Noise (dBA)	Cycle time variation (± min)	Increase in consumer price (€)	Notes
a.1	Brushless DC motor (+ control)	0,5	15,4	20	+50	+0,0501	0	0	-2/3	-10	60	300-800 W motor, alternative to Options a.2 and a.3
a.2	Brushless DC direct drive motor (+ control)	0,5	50,0	65	+40	+0,0401	0	0	-2/3	-10	195	300-800 W motor, alternative to Options a.1 and a.3
a.3	Three-phase motor	5	23,1	30	+50	+0,0501	0	0	-6	-10	90	300-800 W motor, alternative to Options a.1 and a.2
a.4	Optimised motor composition	0	-0,8	-1	--	-	--	--	--	--	-3	compensation of material cost increase
b	Optimised mechanical action	20	0,4	0,50	+100	0,1002	2	0,0394	0	--	1,5	
c.1	Unbalance control (with separate sensors)	5	5,8	7,5	0	0	0	0	-5	--	22,5	noise reduction in spinning at 1200 rpm
c.2	Analogue water sensor	5	1,5	1,5-3	+10	+0,0100	+5,07	+10	--	--	6	
c.3	Temperature control sensor	80	0,4	0,50	+50	+0,0501	0	+0,0592	--	--	1,5	includes a simple unbalance control
d	Rinsing phase optimisation	20	3,8	5	0	0	+7,5	+0,1479	--	-15	15	Improves rinsing and allows water savings
e	Increased load capacity in the same machine	30	0,08	0,1	-80	-0,0802	-3	-0,0592	--	+15	0,3	from 5kg to 6kg load

Table 6.8: Technological Option List, improvement in price/costs and energy/water savings for the 5kg washing machine – continued

Options (No)	Options (description)	Application to the market (%)	Unit production cost (€)	Unit production price (€)	Savings Electricity (Wh/cycle)	Savings Electricity (%)	Savings Water (litre/cycle)	Savings Water (%)	Noise (dBA)	Cycle time variation (± min)	Increase in consumer price (€)	Notes
f.1	high temperature 77°C 8 litre water intake	0,5	0,4	0,5	-215	-0,2154	0	0	--	+3	1,5	frequency of usage to be evaluated, to be applied to **real-life** base case
f.2	Boiling water/steam cycle (4 litre)	0,5	0,4	0,5	-370	-0,3707	0	0	--	+10	1,5	
g	Weight sensors (load control)	2	5,8	7,5	+90	0,0902	+4,5	0,0888	--	0	22,5	applied to **real-life** base case, load reduced to 5kg to 3,4kg (see Task 3); needs new standard for evaluation
h	sophisticated electronic controls (fuzzy logic)	50	9,6	12,5	+15	+0,0209	+1	0,0216	0	0	37,5	Lead to a more “sophisticate” machine; applied to **real-life** base case
i	increased time control: delay start (results form Task3 indicated in parenthesis)	30 (used by 8%)	3,8	5	-(0,0105 at 3,5 W)	- 0,00001 5	0	0	0	(3h = average time in this mode)	15	applied to **real-life** base case, and to be considered together with standby within system analysis
j	LCD with actual load display	0,5-1	7,7	10	the same values as Option g in absolute terms, but increases both energy and water consumption				--	0	30	to be applied to **real-life** base case; allows to go from 3,4kg to 5kg load
k	Increase spin speed (to ≥ 1 600)	15	7,7	10	-49,9	-0,05	0	0		+5	30	noise increase in spinning

improvement divided by 10 (years of depreciation) divided by the capacity or units produced annually. The reference capacity is one million units/year. Unit costs directly related to production of that unit/technical option are: materials, components, energy, labour, R&D related to the development of that unit/technical option, overhead costs that can be allocated to that unit/technical option, investment that can be related to that unit/technical option. For example, if total investment cost is 5 million Euro, the capacity is 1 000 000 units/yr with 10 years depreciation, the annual investment cost per unit is 0,50 Euro. This is summed with the other unit costs of materials, energy, component, labour and any allocated overhead costs.

- **Unit production price** (manufacturing price): unit production costs plus all other costs that are not directly related to that unit/technical option: sales and marketing, general and administrative costs, general R&D expenses, profit before taxes, any other general overhead cost. In the past, the product price at the factory was approximately 1,3 times the unit production cost.
- **Consumer price**: is the price paid by the consumer at the retailing place including transport costs, profit of retailer, advertising of product from retailer, etc. Consumer price was estimated by the product price at the factory plus the mark-up. A mark-up value of 2,75 was used in WASH-2 study for washing machines.

Starting from collected unit production prices, the manufacturing costs have been calculated from by dividing them by 1,3. Consumer price increase has been calculated using a mark-up value of 3,0. The electric energy price is 0,17 €cent/kWh in real terms.

The standard and real-life base-cases annual energy consumption (Task 5) are given in Table 6.9.

Table 6.9: Standard and real-life base-cases annual energy consumption and noise

Machine type	**Electricity consumption** (Wh/cycle)	**Water consumption** (litre/cycle)	**Noise** (dBA)
STBC 5kg	0,998	50,7	53/70
RLBC 5kg	0,719	46,3	53/70

6.4 Subtask 6.2: Analysis LLCC and BAT

6.4.1 The NPV/MNPV Approach

As stated in the TREN/D1/40-2005 Call for Tender, the assessment of monetary Life Cycle Costs is relevant to indicate whether design solutions might negatively or positively impact the total EU consumer's expenditure over the total product life (purchase, running costs, etc.). The distance between the LLCC and the BAT indicates - in a case a LLCC solution is set as a minimum target - the remaining space for product-differentiation (competition). The BAT indicates a medium-term target that would probably more subject to promotion measures than restrictive action. The BNAT (= Best Not yet Available Technologies) indicates long-term possibilities and helps to define the exact scope and nature of possible measures.

The evaluation of the Least Life Cycle Cost and the BAT is achieved applying the Marginal Net Present Value (MNPV) approach: through Net Present Value (NPV) analysis the net benefits of the technological options to consumers are estimated; at this stage, the manufacturing cost increases are assumed to be passed completely to consumers through price increase; manufacturing price increase are calculated according to an agreed amount of mark-up from purchasing price increase. The increase in consumer price will be then compared to the discounted annual economic savings (on the electricity) due to higher machine performance for the presumed lifetime of 15 years, resulting in the Net Present Value.

The NPV and LCC are evaluated first for each (single) technological option referred to the base case models. Then the optimum combination of technological options will be defined. First, the single options are sorted according to the payback period (or the ratio of NPV/investment) with the higher return options first. Second, the savings are calculated for the combined options. Evidently the potential savings decrease as subsequent technological options are added, since less energy/water is available to be saved due to the impact of the previously added technological option(s). This approach has been already followed in previous studies, for example the GEA study for dishwashers[16].

Net Present Value is then calculated for the combined options. In order to see the impact of adding each subsequent option, the net present value of adding a specific option is calculated. This is known as the **Marginal Net Present Value** of adding a given option. Since the options are added in order of their potential economic contribution, we may add options until their marginal net present value is zero or negative. This determines the optimum design and is also the point in which the total net present value of the combined options is a maximum (or the LCC is at minimum). The BAT is represented by the latest option combination. The NPV and Life Cycle Cost methods are equivalent. This is due to the fact that the life cycle cost is a constant value (the base case) minus the NPV of the improvements, thus the maximum NPV gives the minimum life cycle cost (LLCC). The output of the NPV analysis is the input in the LCC analysis where the constant values are added.

The main difference between the more traditional Life Cycle Cost analysis developed and reported in previous studies and the Marginal Net Present Value analysis (which both use the same design options input from the technical/economic analysis) lies in the fact that in traditional LCC design option impacts (savings and costs) are calculated one independent from another and then their effects are added, while the MNPV analysis calculates the effects of any option taking into account that a previous option has already been implemented and part of the savings has already been achieved. The other difference is that in the traditional LCC the options sequence is decided by "clustering" the options according to an engineering analysis or their simple pay back time, while in the NPV/MNPV approach the options are applied considering their economic return for consumers (in terms of net present value) after initial engineering considerations about their feasibility and compatibility.

6.4.1.1 The MNPV approach limits

The described method of adding percentage savings is completely correct if all options give a fix percentage of improvement, but in reality some of the identified options could results in a fix absolute savings: for these options, the absolute savings value should be subtracted as fix amount from the residual energy consumption; if not, the saving is systematically underestimated and the introduced error is proportional to the option application sequence, being higher the later the option is used, and the amount of savings.
Compared to the previous studies, a more sophisticated mixed system including percentage and fixed saving has been developed in the case options with fixed absolute savings are identified. The

[16] "The saving potential of the combined options can not be found by simply adding the savings of the single options. In the first place with most options savings are not a fixed number but a fixed percentage of the initial consumption. So with a machine that already has a lower energy consumption that the base case savings of most options are lower too. In the second place some options can not be combined at all…." (GEA2 study, page 14.47)

energy-consumption implications of various higher-efficiency design options are evaluated using a simple software - an ad-hoc excel sheet - initially developed for use in the previous SAVE studies for household appliances in which ENEA was partner, but now improved.

6.4.2 The NPV/MNPV and LCC Analysis for Dishwashers

6.4.2.1 The key technical, economic and financial assumption

The key technical, common economic and financial assumptions (see Task 5) are:

– Product life	15 years
– Cycles per year	280
– Discount rate	5%/year (PWF = 10,38 for 15years)
– Electricity price	0,17 Euro/kWh
– Water price	3,7 Euro/m^3
– Detergent, softener, rinsing agent:	2,34[17] Euro/kg, 0,6 Euro/kg and 2,4 Euro/kg
– Maintenance & repairs	5,5 Euro/year
– Disposal & recycling	61 Euro/life (at the end of life)
– Average 12ps machine price	548,4 Euro
– Average 9ps machine price	520 Euro.

In particular:

- number of washing cycles per year: 280 cycle/year was found in a German study made by STIWA in 2003. In addition, also 208 cycle/year (kept for sake of comparison with previous results) and 220 cycle/year (used is the labelling directive) will be used in the sensitivity analysis;
- chemicals: the use of detergent is 30g/cycle, for softener (salt) 20g/cycle and for rinsing agent 4g/cycle;
- the sales weighted average price of the dishwashers sold in 2004 according GfK was on average of 548,4 Euro for the 13 EU member stated where GfK collected the market data, with 552 Euro in West EU countries and 464 Euro in East EU countries which will be used in the sensitivity analysis. The 9ps machine price is estimated in 520 Euro.

6.4.2.2 The Simple Payback Time and Net Present Value analysis for the standard base cases

The first step of the analysis is the evaluation of the Simple Payback Time (SPB) and the Net Present Value (NPV) of the single options when applied to the relevant standard base cases, which have been defined as the average 9ps and 12ps of the machines in 2005. The results are presented in Table 6.10. NPV is calculated for a lifetime of 15 years and 280 washing cycles. The same data are ordered in Table 6.11 by simple payback time for each base case: in general there is a good agreement between the SPB and the NPV values, where the former increases the latter decreases. Some Options increase the energy/water consumption, and therefore the calculated payback time will be negative. The NPV is positive for four options for both the 9ps and the 12ps machine. The first two options achieve water savings: "avoidance/reduction of the cold pre-rinse" (*Option f.1*) and "partly draining and re-filling of water" (*Option f.2*), followed by "alternating spraying of water (*Option b*) and by the reduction of the wash temperature to 45°C (*Option a.1*). The following options have SPB longer that the average appliance lifetime (15 years) and significantly negative net present values.

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[17] Low alkaline compact powder with enzymes.

Table 6.10: Simple payback time and net present value (at 15 years, for 280 cycles/year) for the identified technological options applied to the standard base cases for dishwashers

Dishwashers categories		9ps machine		12ps machine	
Options (n)	**Technology** (description)	SPB (years)	NPV (€)	SPB (years)	NPV (€)
a.1	Lower wash temperature (45°C) longer time	7,37	4,29	5,53	9,23
b	Alternating spraying of water	5,49	24,29	4,24	39,54
c	Heat exchanger (with storage tank)	19,12	-12,48	19,12	-12,48
d	Cross flow heat exchanger			32,77	-42,64
e.1	condenser for drying	54,62	-31,59	54,62	-31,59
e.2	Condenser with fan for drying	54,62	-31,59	54,62	-31,59
f.1	Avoidance/reduction of the cold pre-rinse	0,00	31,82	0,00	37,20
f.2	partly draining and re-filling (of water)	2,18	14,70	1,69	20,08
g	DC brushless motor	53,06	-62,74	53,06	-62,74
h.1	Noise reduction to 44 dB(A) (through better insulation)	-9,36	-65,79	-8,62	-85,94
h.2	Noise reduction to 41 dB(A) (through better insulation)	-16,39	-114, 7	-13,66	-137,3

Table 6.11: Technological options ordered by simple payback time (SPB) and net present value (NPV) at 15 years and 280 cycle/year for dishwasher standard base cases

Options	9ps dishwasher		Options	12ps dishwasher	
(n)	SPB (years)	NPV (€)	(n)	SPB (years)	NPV (€)
f.1	0	31,82	**f.1**	0	37,2
f.2	2,18	14,7	**f.2**	1,69	20,08
b	5,49	24,29	**b**	4,24	39,54
a.1	7,37	4,29	**a.1**	5,53	9,23
c	19,12	-12,48	**c**	19,12	-12,48
g	53,06	-62,74	**d**	32,77	-42,64
e.1	54,62	-31,59	**g**	53,06	-62,74
e.2	54,62	-31,59	**e.1**	54,62	-31,59
h.1	-9,36	-65,79	**i**	-0,66	-131,3
h.2	-16,39	-114, 7	**h.1**	-8,62	-85,94
d			**h.2**	-13,66	-137,3

6.4.2.3 The Marginal Net Present Value and the aggregated option LCC analysis

To evaluate the improvement potential of the single options, the aggregated option analysis is developed. This LCC analysis was run for the average standard base-case appliances and for the standard base case models. The former represents the average of the reference year and takes into consideration the percentage of application of each technological option on the market, or better the percentage of each option still available for application on the market. For the latter a technological level is specified for the base cases and then all the available technological options are applied.

In the first case the possible average improvement of the overall appliance category are predicted. The second analysis allows to predict the best available technology models an can be also considered a sort of inner validation of the previous scenario and more in general of the overall calculation model: if the calculation can predict in a technically and economically sound way the development from the base case model to the to the best available models on the market in 2005, then the overall simulation is coherent with the reality.

In Table 6.12 the applied options, with the order of application, the corresponding marginal net present value (MNPV) and the resulting energy/water consumption for a 15 year lifetime and 280 cycles per year are presented for the average standard base cases and the standard base case models. For the former also the cycle time is presented.

Table 6.12: Technological options and marginal net present value (MNPV) at 15 years for the aggregated option analysis for dishwasher average standard base cases and standard base case models

Average standard base case		Consumption			Standard base case model		Consumption	
Options (n)	$MNPV_{av}$ (€)	energy (kWh/cycle)	water (litre/cycle)	time (min)	Options (n)	MNPV (€)	energy (kWh/cycle)	water (litre/cycle)
9ps dishwasher								
+b	14,57	0,798	12,20	102	**+b**	24,29	0,778	11,20
+f.1	11,48	0,794	11,31	100	**+f.2**	11,61	0,773	9,97
+f.2	9,43	0,790	10,32	100	**+a.1**	3,31	0,745	9,97
+a.1	1,09	0,782	10,32	109	**+c**	-13,96	0,718	9,97
+c	-11,31	0,758	10,32	109	**+e.1**	-32,57	0,705	9,97
+e.1	-16,11	0,751	10,32	104	**+e.2**	-32,69	0,692	9,97
+e.2	-24,21	0,741	10,32	97	**+g**	-69,74	0,676	9,61
+g	-64,54	0,723	9,94	97	**+h.1**	-55,51	0,733	9,61
+h.1	-47,84	0,770	9,94	104	**+h.2**	-109,56	0,813	9,61
+h.2	-108,19	0,851	9,94	114				
12ps dishwasher								
+b	23,73	1,028	13,40	102	**+b**	39,54	1,000	12,20
+f.1	13,27	1,024	12,34	100	**+f.2**	15,67	0,995	10,59
+f.2	12,74	1,020	11,04	100	**+a.1**	7,85	0,958	10,59
+a.1	2,49	1,009	11,04	109	**+c**	-14,03	0,931	10,59
+c	-11,33	0,985	11,04	109	**+e.1**	-32,55	0,918	10,59
+e.1	-16,09	0,978	11,04	104	**+e.2**	-32,64	0,905	10,59
+e.2	-24,17	0,968	11,04	97	**+d**	-45,68	0,871	10,59
+d	-44,53	0,931	11,04	107	**+g**	-65,56	0,855	10,25
+g	-65,56	0,914	10,64	107	**+h.1**	-76,46	0,937	10,25
+h.1	-55,62	0,975	10,64	114	**+h.2**	-129,51	1,042	10,25
+h.2	-125,43	1,079	10,64	124				

The optimum option combination varies with the base case and whether the LCC analysis was run for the average standard base-case appliances or for the standard base case models. Nevertheless some common elements can be drawn from the data presented in Table 6.12:

- the use of alternating spraying of water is always the most cost-effective design option for the
- average standard base cases and standard base case models;
- options saving water were always cost-effective;
- lower wash temperature was always cost-effective;
- the use of a heat exchanger was always the first of the non cost-effective options
- the improvement of the drying phase by adding a condenser and a fan was always non-cost effective

- the same happens for the DC brushless motor;

the decrease of the noise through a better insulation improves the energy consumption and has therefore always a negative effect on the energy efficiency.

a) The results for the average standard base cases

The resulting energy consumption and incremental purchase price for Base Case and average LLCC ($LLCC_{av}$) case for the two standard base cases are presented in Table 6.13. Also the energy efficiency index (E_I) is shown, calculated according to the algorithms of directive 97/17/EC (described in Task 1). The energy and water consumption for the 9ps machine is reduced by 46 Wh/cycle (or 5,6%) and 3,4 litre/cycle (or 24,8%); for the 12ps machine the energy and water consumption is reduced by 61 Wh/cycle (or 5,7%) and 4,2 litre/cycle (or 27,6%). The average E_I at $LLCC_{av}$ of the two products are below the threshold of the class A, with an improvement of 5,6% for the 9ps machine and of 5,7% for the 12ps machine. The forecast increase in purchase price at $LLCC_{av}$ is 4,4% for the 9ps dishwasher and 4,1% for the 12ps machine. The ratio between the predicted increase in purchase price and the efficiency improvement is:

Appliance	Ratio
9ps	0,79
12ps	0,72

The LCC is also presented in Figure 6.2 for the two average standard base cases. It is worth noting that *Option h.1* and *Option h.2* have been added as the last ones, despite their MNPV, due to the associated increase in the energy consumption of the machines. In the LCC analysis an attempt was made to predict the lowest possible achievable energy consumption before adding the energy consuming options.

The lowest predictable energy consumption after all options have been added, or the average Best Available Technology (BAT_{av}) to the base cases is presented in Table 6.14. For dishwashers, three BAT_{av} levels can be predicted, due to the fact the options applied to reduce the noise are also increasing the overall energy consumption of the dish-washing cycle. In particular an average machine with a noise level of 41dB(A) consumes about the same as the average machine in 2005, but need the contemporary implementation of several technological options to balance the consumption increase due to the added insulation. The energy consumption for the 9ps machine is reduced by 105 Wh/cycle (or 12,7%) and that of the 12ps machine by 156 Wh/cycle (or 14,6%). The water saving is 3,76 litre/cycle (or 27,4%) for the 9ps category, with a minimum of slightly less that 10 litres; for the 12ps machine the savings is 4,56 litre/cycle (or 30,0%) with a minimum of 10,64 litres.

When the Life Cycle Cost (lifetime=15 years, 280 cycles/year) is shown as a function of the energy consumption (in kWh/cycle) and the Energy Efficiency Index (E_I) in directive 97/17/EC the curves in Figures 6.3 and 6.4 result.

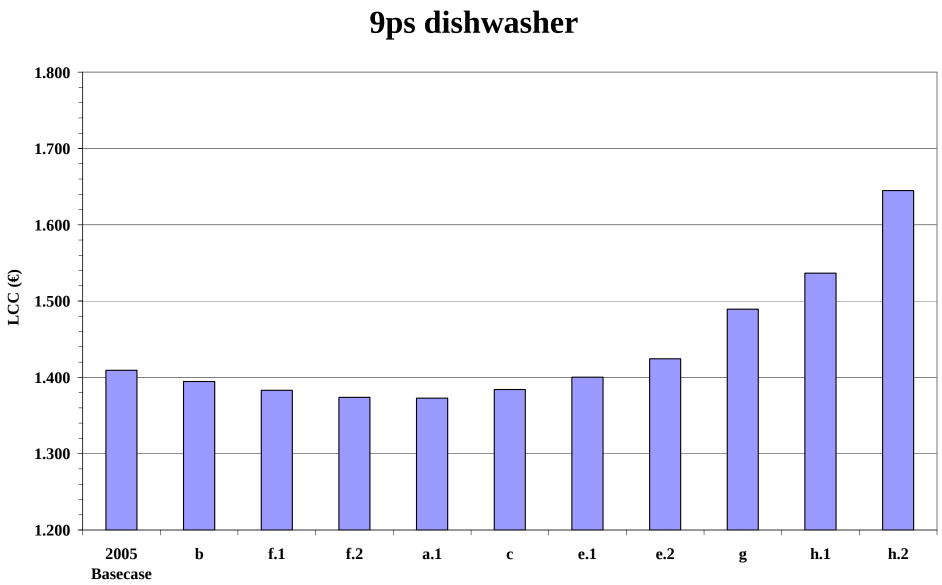
Table 6.13: Energy efficiency index (EEI), energy & water consumption and incremental purchase price for dishwasher Base Case and LLCCav for average standard base cases

Standard base case	Energy consumption		Water consumption		Energy efficiency Index (dir. 97/17/EC)			Purchase price			LCC (15 years, 280 cycles)	
	Base case (kWh/cycle)	$LLCC_{av}$ (kWh/cycle)	Base case (litre/cycle)	$LLCC_{av}$ (litre/cycle)	Base case E_I	$LLCC_{av}$ E_I	difference (%)	Base case (Euro)	$LLCC_{av}$ (Euro)	Increase (%)	Base case (€)	$LLCC_{av}$ (€)
9ps dishwashers	0,828	0,782	13,7	10,3	0,657	0,620	5,6	520,0	542,7	4,4	1.409	1.373
12ps dishwashers	1,070	1,009	15,2	11,0	0,648	0,611	5,7	548,4	571,1	4,1	1.594	1.542

Table 6.14: Energy efficiency index (EEI), energy & water consumption and incremental purchase price for dishwasher Base Case and BATav for average standard base cases

Standard base case	Energy consumption		Water consumption		Energy efficiency Index (dir. 97/17/EC)			Purchase price			LCC (15 years, 280 cycles)	
	Base case (kWh/cycle)	BAT_{av} (kWh/cycle)	Base case (litre/cycle)	BAT_{av} (litre/cycle)	Base case E_I	BAT_{av} E_I	difference (%)	Base case (Euro)	BAT_{av} (Euro)	Increase (%)	Base case (€)	BAT_{av} (€)
9ps dishwashers	0,828	0,723	13,7	9,9	0,657	0,574	12,7	520,0	692,6	33,2	1.409	1.489
		0,770				0,611	7,0		716,6	37,8		1.537
		0,851				0,675	-2,8		784,7	50,9		1.645
12ps dishwashers	1,070	0,914	15,2	10,6	0,648	0,554	14,6	548,4	779,5	42,1	1.594	1.699
		0,975				0,591	8,9		808,8	47,5		1.758
		1,079				0,654	-0,8		882,9	61,0		1.884

Figure 6.2: Life Cycle Cost (lifetime = 15 years, 280 cycle/year) as a function of the applied technological options for 9ps and 12ps dishwasher average standard base cases.



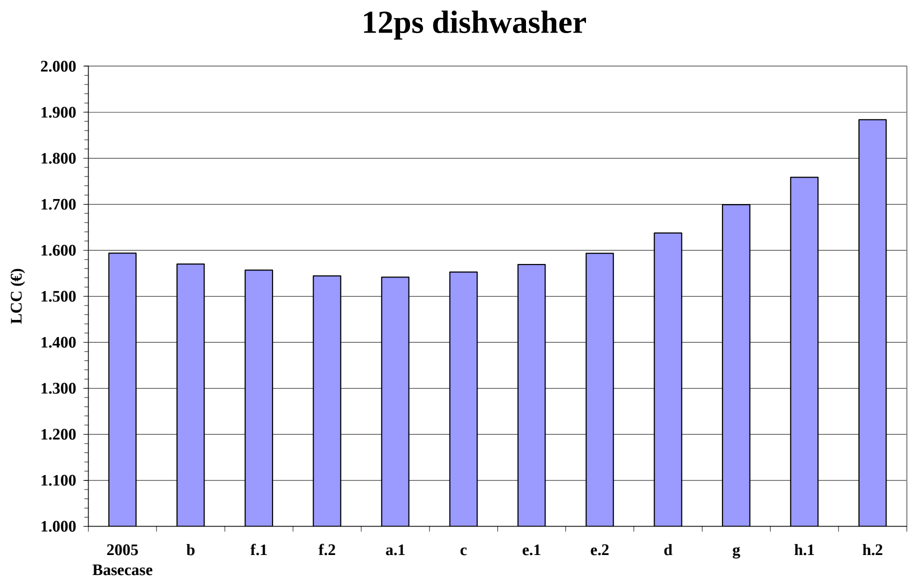


Figure 6.3: Life Cycle Cost (lifetime = 15 years, 280 cycle/year) as a function of the energy consumption for each dishwasher standard base cases. Average standard base cases are the red point on each curve. Appliance base cases are identified by their place setting number. Arrows (on the 12ps machine curve only) show the option application sequence.

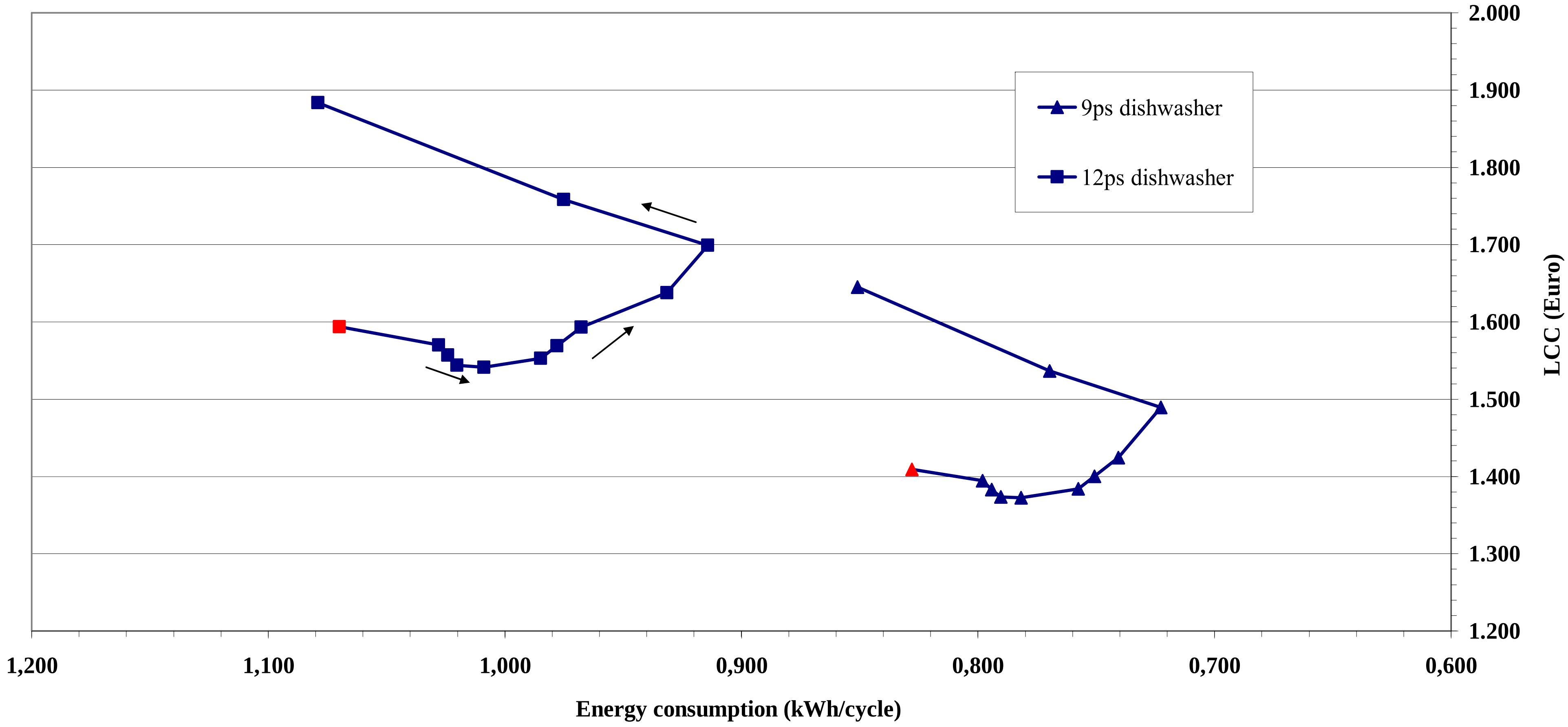
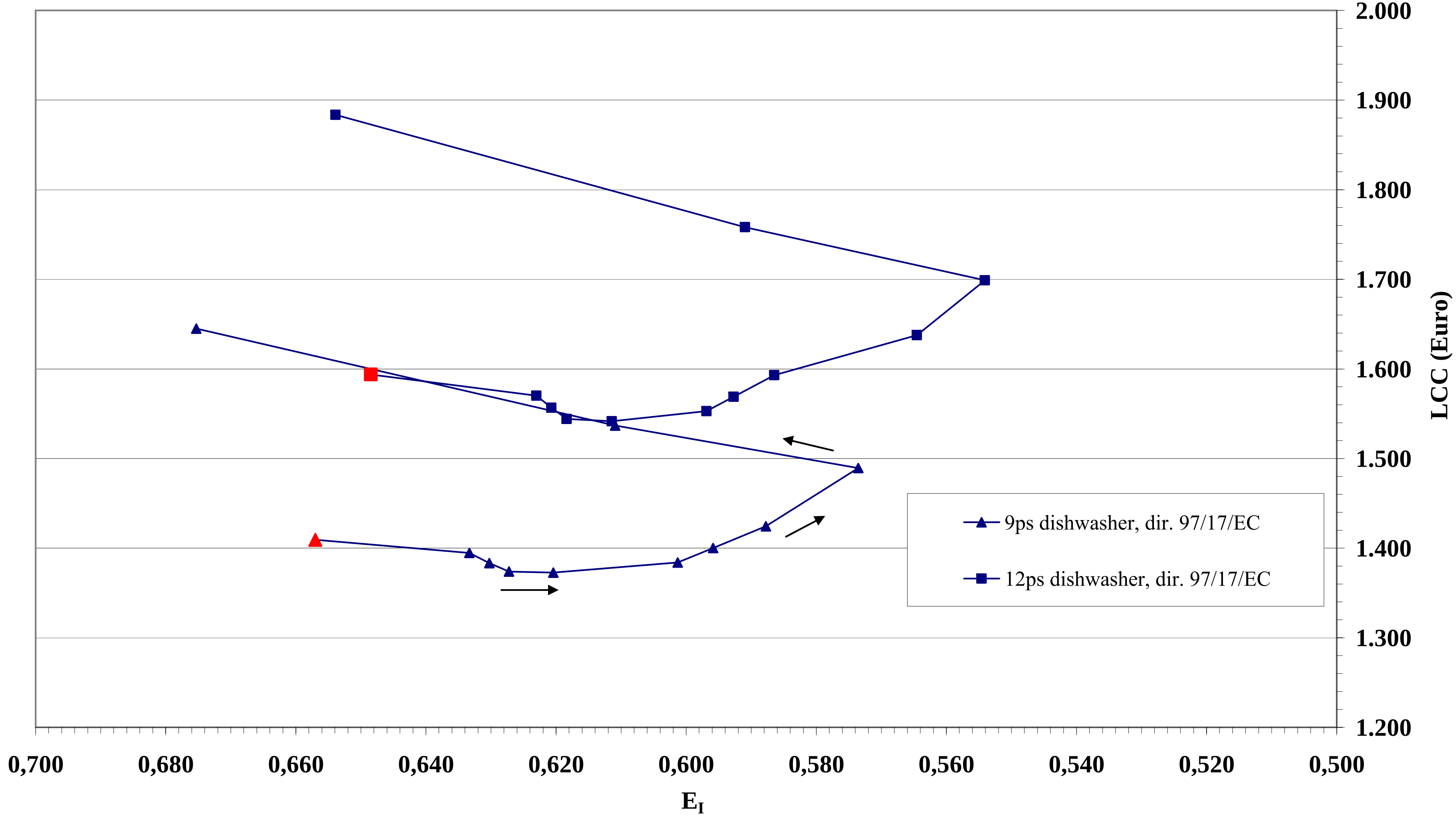


Figure 6.4: Life Cycle Cost (lifetime = 15 years, 280 cycle/year) as a function of the Energy Efficiency Index (EI) in directive 97/17/EC for each dishwasher standard base case. Average standard base cases are the red point on each curve. Appliance base cases are identified by their place setting number. Arrows (on the 9ps machine curve only) show the option application sequence.



b) The results for the standard base case model

When the more traditional LCC analysis is applied, the technological options already applied to the base cases are identified, allowing therefore to define the options which are totally available for application among those included in the initial Technological Option List. The LCC analysis is then run. The resulting predicted improvement in energy/water consumption, energy efficiency and purchasing price are presented in Table 6.15 for each base case model.

The energy and water consumption for the 9ps machine is reduced by 83 Wh/cycle (or 10,0%) and 3,7 litre/cycle (or 27,2%); for the 12ps machine the energy and water consumption is reduced by 112 Wh/cycle (or 10,5%) and 4,6 litre/cycle (or 30,3%). The average E_I at LLCC of the two products are below the threshold of the class A, with an improvement of 10% for the 9ps machine and of 10,5% for the 12ps machine.

The predicted increase in purchase price at LLCC is 8% for the 9ps dishwasher and 7,60% for the 12ps machine. The ratio between the increase in purchase price and the efficiency improvement becomes is:

Appliance	Ratio
9ps	0,80
12ps	0,72

The LCC is also presented in Figure 6.5 for the two base case models. It is worth noting that *Option h.1* and *Option h.2* have been added as the last ones, despite their MNPV, due to the associated increase in the energy consumption of the machines. In the LCC analysis an attempt was made to predict the lowest possible achievable energy consumption before adding the energy consuming options.

The lowest predictable energy consumption for after all options have been added, or the Best Available Technology (BAT) to the base cases is presented in Table 6.16. For dishwashers, three BAT levels can be predicted, due to the fact the options applied to reduce the noise are also increasing the overall energy consumption of the dish-washing cycle. In particular an average machine with a noise level of 41dB(A) consumes about the same as the average machine in 2005, but need the contemporary implementation of several technological options to balance the energy consumption increase due to the added insulation. The options to reduce noise could be applied to any model and at any stage of the technological development pathway, here they are applied as last option to the best available technology model to show more clearly the tradeoffs between energy consumption and noise reduction

The energy consumption for the 9ps machine is reduced by 152 Wh/cycle (or 18,4%) and that of the 12ps machine by 215 Wh/cycle (or 20,1%). The water saving is 4,1 litre/cycle (or 29,9%) for the 9ps category, with a minimum close to 9,5litres; for the 12ps machine the savings is 5 litre/cycle (or 32,6%) with a minimum of 10,2 litres.

When the Life Cycle Cost (lifetime = 15 years, 280 cycles/year) is shown as a function of the energy consumption (kWh/cycle) and the Energy Efficiency Index (E_I) in directive 97/17/EC the curves in Figures 6.6 and 6.7 result.

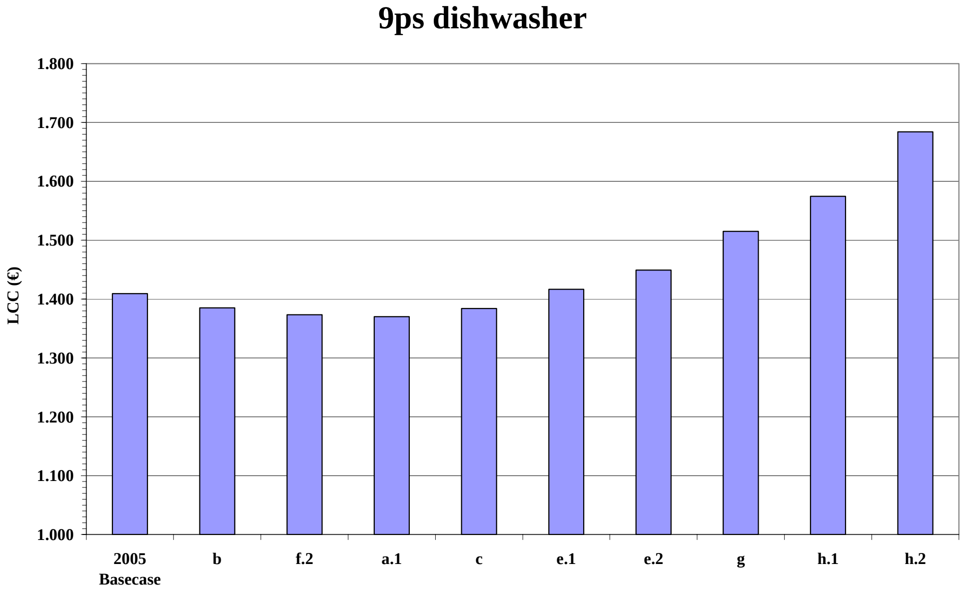
Table 6.15: Energy efficiency index (EEI), energy & water consumption and incremental purchase price for dishwasher Base Case and LLCC for standard base case models

Standard base case	Energy consumption		Water consumption		Energy efficiency Index (dir. 97/17/EC)			Purchase price			LCC (15 years, 280 cycles)	
	Base case (kWh/cycle)	LLCC (kWh/cycle)	Base case (litre/cycle)	LLCC (litre/cycle)	Base case E_I	LLCC E_I	difference (%)	Base case (Euro)	LLCC (Euro)	Increase (%)	Base case (€)	LLCC (€)
9ps dishwashers	0,828	0,745	13,7	9,97	0,657	0,591	10,0	520,0	561,7	8,0	1.409	1.370
12ps dishwashers	1,070	0,958	15,2	10,6	0,648	0,581	10,5	548,4	590,1	7,6	1.594	1.531

Table 6.16: Energy efficiency index (EEI), energy & water consumption and incremental purchase price for dishwasher Base Case and BAT for standard base case models

Standard base case	Energy consumption		Water consumption		Energy efficiency Index (dir. 97/17/EC)			Purchase price			LCC (15 years, 280 cycles)	
	Base case (kWh/cycle)	BAT (kWh/cycle)	Base case (litre/cycle)	BAT (litre/cycle)	Base case E_I	BAT E_I	difference (%)	Base case (Euro)	BAT (Euro)	Increase (%)	Base case (€)	BAT (€)
9ps dishwashers	0,828	0,676	13,7	9,61	0,657	0,536	18,4	520,0	745,0	43,3	1.409	1.515
		0,733		9,61		0,582	11,5		776,2	49,3		1.575
		0,813		9,61		0,645	1,9		846,4	62,8		1.684
12ps dishwashers	1,070	0,855	15,2	10,25	0,648	0,518	20,1	548,4	835,8	52,4	1.594	1.772
		0,937		10,25		0,568	12,4		874,8	59,5		1.801
		1,042		10,25		0,632	2,6		952,8	73,7		1.931

Figure 6.5: Life Cycle Cost (lifetime = 15 years, 280 cycle/year) as a function of the applied technological options for 9ps and 12ps dishwasher standard base case models.



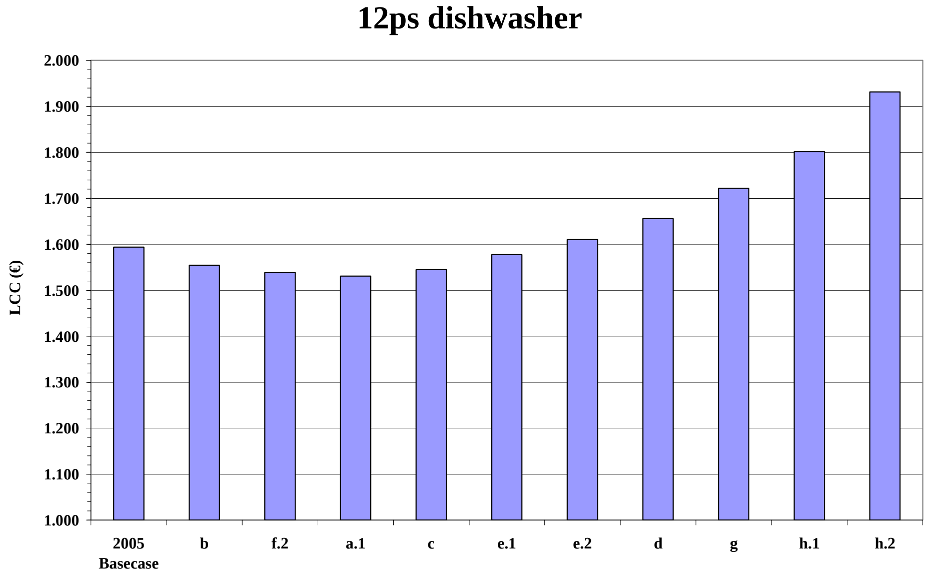


Figure 6.6: Life Cycle Cost (lifetime = 15 years) as a function of the energy consumption for each of the dishwasher standard base case model. Standard base case models are the red point on each curve, the Best Available Technology (BAT), at noise=50 dB(A), in the reference year (2005) is the most right point on each curve (highlighted in pink). Appliance base cases are identified by place settings number. Arrows (on the 12ps machine curve only) show the option application sequence.

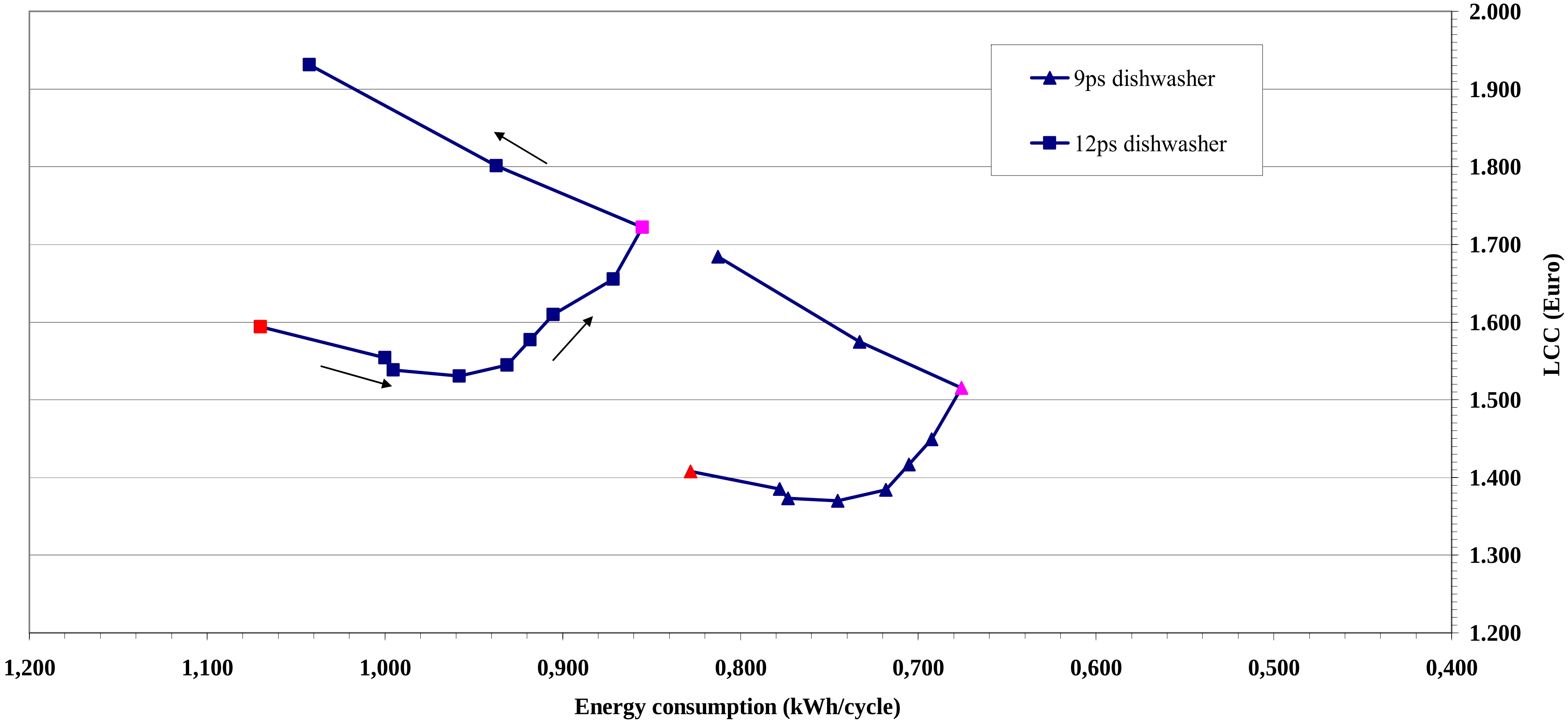
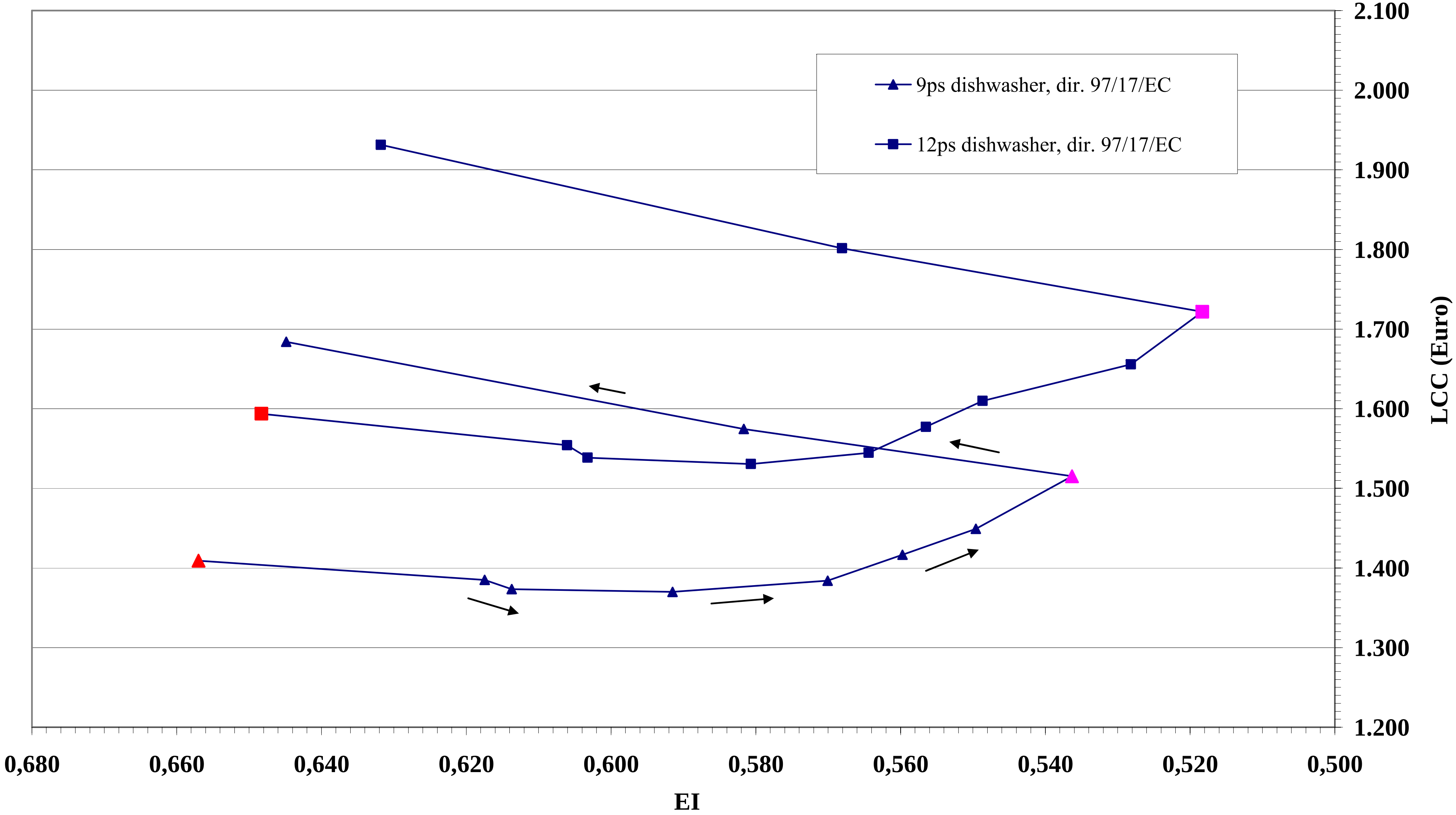


Figure 6.7: Life Cycle Cost (lifetime = 15 years) as a function of the Energy Efficiency Index (EI) in directives 97/17/EC for each of the dishwasher standard base case models. Standard base case models are the red point on each curve, the Best Available Technology (BAT), at noise=50 dB(A), in the reference year (2005) is the most right point on each curve (highlighted in pink). Appliance base cases are identified by place settings number. Arrows (on the 9ps machine curve only) show the option application sequence.



A close agreement can be seen between the results the predicted BAT energy consumption and efficiency index and the actual minimum values of the dishwasher models on the market in 2005/2006 in terms of minimum energy and water consumption for the 12ps machine and the best model in CECED 2005 technical database for the 9ps machine (see Task 5) as shown in Table 6.17.

Table 6.17: Comparison of the minimum energy and water consumption for dishwasher models in 2005/2006 and the results of the LCC for the standard base case models

Category	Min. energy consumption (kWh/cycle)		Min. water consumption (litre/cycle)	
	CECED 2005	LCC	CECED 2005	LCC
9ps dishwasher	0,800	0,813 (41dBA)	10	9,6
12ps dishwasher	0,950 (45dBA) 1,050 (41dBA)	0,937 (44dBA) 1,042 (41dBA)	9	10,3

6.4.2.4 The analysis for the real-life base cases

The real-life base case LCC analysis will be run by applying the technological options identified for the standard base case to the real-life base cases defined in Task 5 on the basis of the consumer analysis described in Task 3. The expected outcome is the evaluation of the savings achievable under real life conditions from the technological improvement of the standard machines.

The evaluation of the Simple Payback Time (SPB) and the Net Present Value (NPV) of the single options when applied to the relevant real-life base cases was run. The results are presented in Table 6.18 for the 9ps and the 12ps machines. NPV is calculated for a lifetime of 15 years and 280 washing cycles.

Table 6.18: Simple payback time and net present value (at 15 years, for 280 cycles/year) for the identified technological options applied to the real-life base cases for dishwashers

Dishwashers categories		9ps machine		12ps machine	
Options (n)	**Technology** (description)	SPB (years)	NPV (€)	SPB (years)	NPV (€)
a.1	Lower wash temperature (54,3°C) longer time	7,37	4,29	5,53	9,23
b	Alternating spraying of water	5,49	24,29	4,24	39,54
c	Heat exchanger (with storage tank)	19,12	-12,48	19,12	-12,48
d	Cross flow heat exchanger			32,77	-42,64
e.1	condenser for drying	54,62	-31,59	54,62	-31,59
e.2	Condenser with fan for drying	54,62	-31,59	54,62	-31,59
f.1	Avoidance/reduction of the cold pre-rinse	0,00	31,82	0,00	31,82
f.2	partly draining and re-filling (of water)	2,18	14,70	1,69	20,08
g	DC brushless motor	53,06	-62,74	53,06	-62,74
h.1	Noise reduction to 44 dB(A) (through better insulation)	-9,36	-65,79	-8,62	-85,94
h.2	Noise reduction to 41 dB(A) (through better insulation)	-16,39	-114,67	-13,66	-137,29

In particular, for *Option a.1* the decrease (i.e. the ΔT) in the washing temperature is kept constant compared to the standard base case. In other words, if the average standard 12ps machine has a wash temperature of 50°C whereof the average real life 12ps machine has an actual washing temperature of 59,3°C (ΔT = +9,3 K), when *Option a.1* is applied the new actual wash temperature under real life conditions is 45+9,3 = 54,3 °C. The energy savings associated with the option application remains the same as in the standard base case simulation.

The results of the aggregated option analysis are presented in Table 6.19, where the applied options, with the order of application, the corresponding marginal net present value (MNPV) and the resulting energy/water consumption values for a 15 year lifetime and 280 cycles per year are given for the average real life base cases.

Table 6.19: Technological options and marginal net present value (MNPV) at 15 years for the aggregated option analysis for average dishwasher real life base cases

9ps dishwasher		Consumption		**12ps dishwasher**		Consumption	
Options (n)	$MNPV_{av}$ (€)	energy (kWh/cycle)	water (litre/cycle)	Options (n)	MNPV (€)	energy (kWh/cycle)	water (litre/cycle)
+b	14,57	0,873	12,40	**+b**	23,73	1,125	13,60
+f.1	11,50	0,869	11,51	**+f.1**	11,40	1,121	12,72
+f.2	9,47	0,865	10,51	**+f.2**	12,99	1,117	11,40
+a.1	1,10	0,857	10,51	**+a.1**	2,52	1,106	11,40
+c	-11,25	0,832	10,51	**+c**	-11,27	1,082	11,40
+e.1	-16,08	0,826	10,51	**+e.1**	-16,07	1,075	11,40
+e.2	-24,17	0,815	10,51	**+e.2**	-24,13	1,064	11,40
+g	-65,01	0,797	10,14	**+d**	-44,38	1,028	11,40
+h.1	-47,53	0,845	10,14	**+g**	-61,12	1,010	10,99
+h.2	-108,45	0,926	10,14	**+h.1**	-59,73	1,072	10,99
				+h.2	-125,85	1,177	10,99

The resulting energy consumption and incremental purchase price for Base Case and average LLCC ($LLCC_{av}$) case when the technological options are applied to the two real-life base cases are presented in Table 6.20. The energy and water consumption for the 9ps machine is reduced by 46 Wh/cycle (or 5,1%) and 3,2 litre/cycle (or 23,4%); for the 12ps machine the energy and water consumption is reduced by 61 Wh/cycle (or 5,2%) and 4,0 litre/cycle (or 26,0%).

The LCC is also presented in Figure 6.8 for the two real-life base cases. It is worth noting that the options increasing the energy consumption have been added as the last ones, despite their MNPV, due to the associated increase in the energy consumption of the machines. In the LCC analysis an attempt was made to predict the lowest possible achievable energy consumption before adding the energy consuming options.

The lowest predictable energy consumption values after all options have been added, or the average Best Available Technology (BAT_{av}) to the base cases are presented in Table 6.21. For dishwashers, three BAT_{av} levels can be predicted due to the fact that some options, as already mentioned, are also increasing the overall energy consumption of the dish-washing cycle. In particular, a machine with a noise level of 41dB(A) consumes more than the average machine in 2005 under real life conditions. When the noise remain unchanged at the average value of 50d(B)A, the energy consumption for the 9ps machine is reduced by 46 Wh/cycle (or 5,1%) with a minimum of 0,857 kWh/cycle and that of the 12ps machine by 61 Wh/cycle (or 5,2%) with a minimum of 1,106 kWh/cycle. The water saving is 3,4 litre/cycle (or 24,5%) for the 9ps category, with a minimum of 10,5 litres; for the 12ps machine the savings is 4 litre/cycle (or 26%) with a minimum of 11,4 litres.

When the Life Cycle Cost (lifetime = 15 years, 280 cycles/year) is shown as a function of the energy consumption (in kWh/cycle) and the Energy Efficiency Index (E_I) in directive 97/17/EC the curves in Figures 6.9 and 6.10 result.

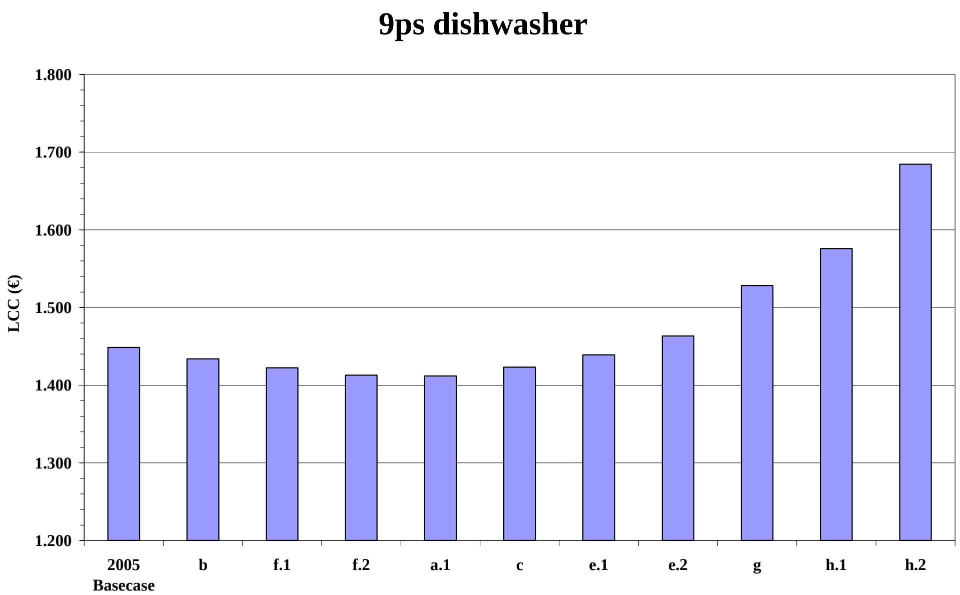
Table 6.20: Energy efficiency index (EEI), energy & water consumption and incremental purchase price for dishwasher Base Case and LLCCav for real-life base cases

Real life base case	Energy consumption		Water consumption		Energy efficiency Index (dir. 97/17/EC)			Purchase price			LCC (15 years, 280 cycles)	
	Base case (kWh/cycle)	$LLCC_{av}$ (kWh/cycle)	Base case (litre/cycle)	$LLCC_{av}$ (litre/cycle)	Base case E_I	$LLCC_{av}$ E_I	difference (%)	Base case (Euro)	$LLCC_{av}$ (Euro)	Increase (%)	Base case (€)	$LLCC_{av}$ (€)
9ps dishwashers	0,903	0,857	13,9	10,5	0,717	0,680	5,1	520,0	542,7	4,4	1.448	1.412
12ps dishwashers	1,167	1,106	15,4	11,4	0,707	0,670	5,2	548,4	571,1	4,1	1.644	1.593

Table 6.21: Energy efficiency index (EEI), energy & water consumption and incremental purchase price for dishwasher Base Case and BATav for real-life base cases

Real life base case	Energy consumption		Water consumption		Energy efficiency Index (dir. 97/17/EC)			Purchase price			LCC (15 years, 280 cycles)	
	Base case (kWh/cycle)	BAT_{av} (kWh/cycle)	Base case (litre/cycle)	BAT_{av} (litre/cycle)	Base case E_I	BAT_{av} E_I	difference (%)	Base case (Euro)	BAT_{av} (Euro)	Increase (%)	Base case (€)	BAT_{av} (€)
9ps dishwashers	0,903	0,797	13,9	10,1	0,717	0,633	11,7	520,0	692,6	33,2	1.448	1.528
		0,845				0,670	6,4		716,6	37,8		1.576
		0,926				0,735	-2,6		784,7	50,9		1.684
12ps dishwashers	1,167	1,010	15,4	11,0	0,707	0,612	13,4	548,4	779,5	42,1	1.644	1.750
		1,072				0,650	8,1		808,8	47,5		1.810
		1,177				0,713	-0,8		882,9	61,0		1.936

Figure 6.8: Life Cycle Cost (lifetime = 15 years, 280 cycle/year) as a function of the applied technological options for 9ps and 12ps dishwasher real-life base cases



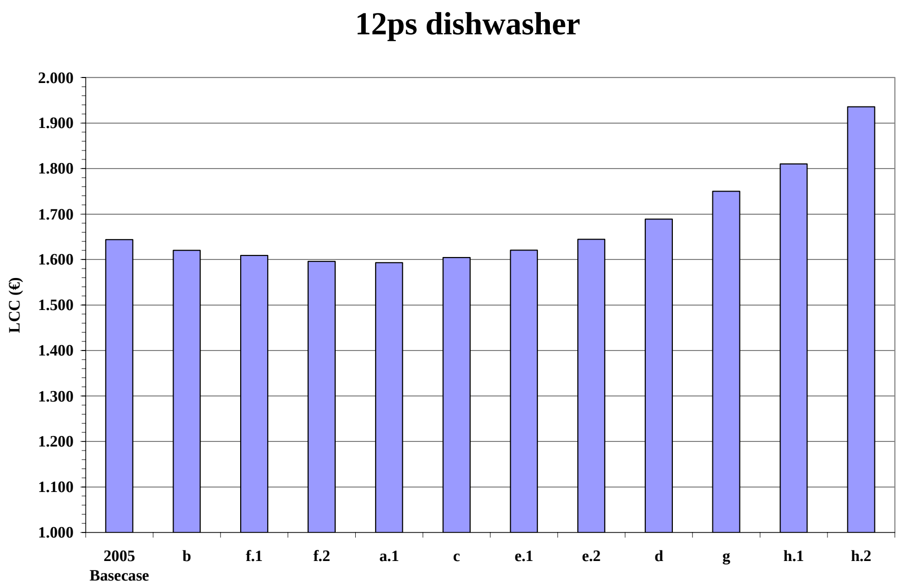


Figure 6.9: Life Cycle Cost (lifetime = 15 years, 280 cycle/year) as a function of the energy consumption for each dishwasher real-life base cases. Real-life base cases are the red point on each curve. Appliance base cases are identified by their place setting number. Arrows (on the 12ps machine curve only) show the option application sequence.

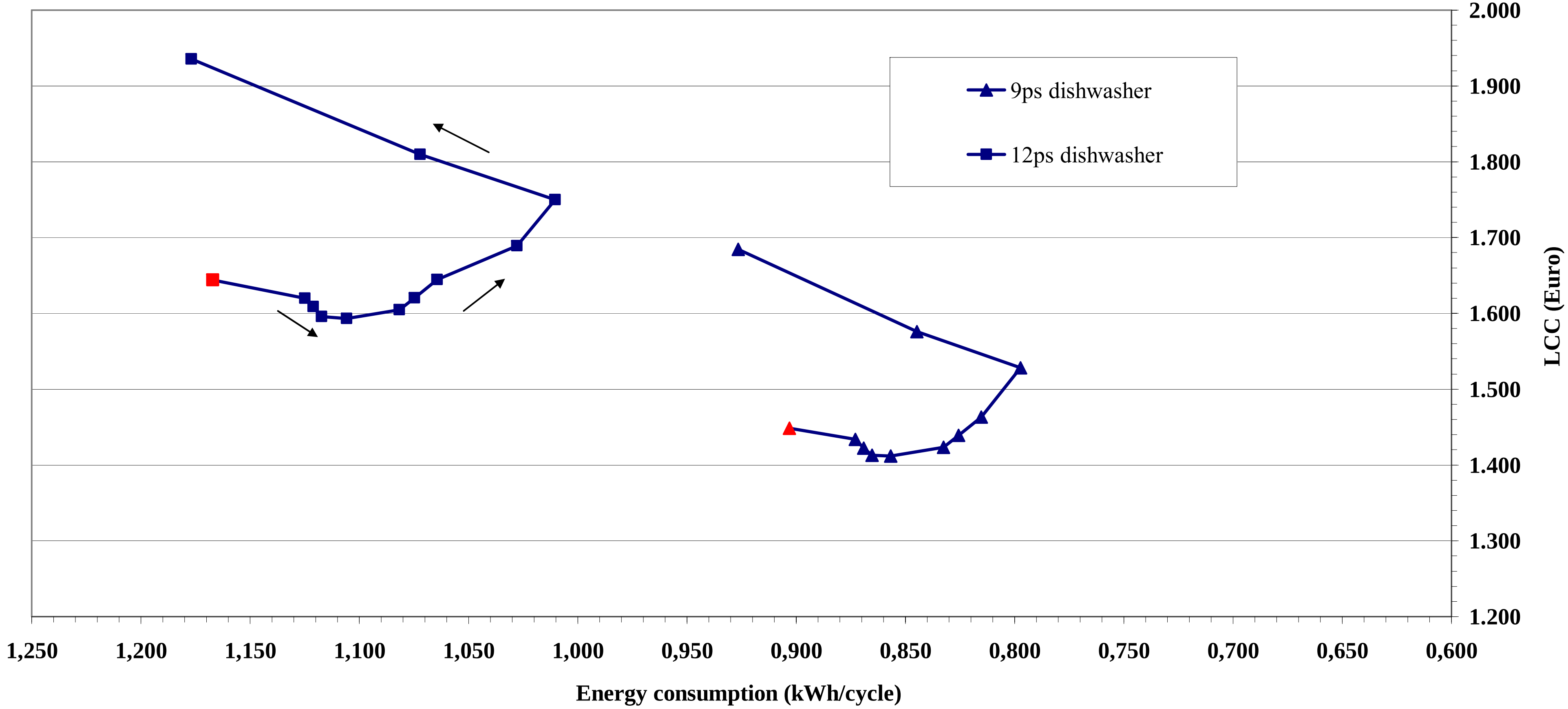
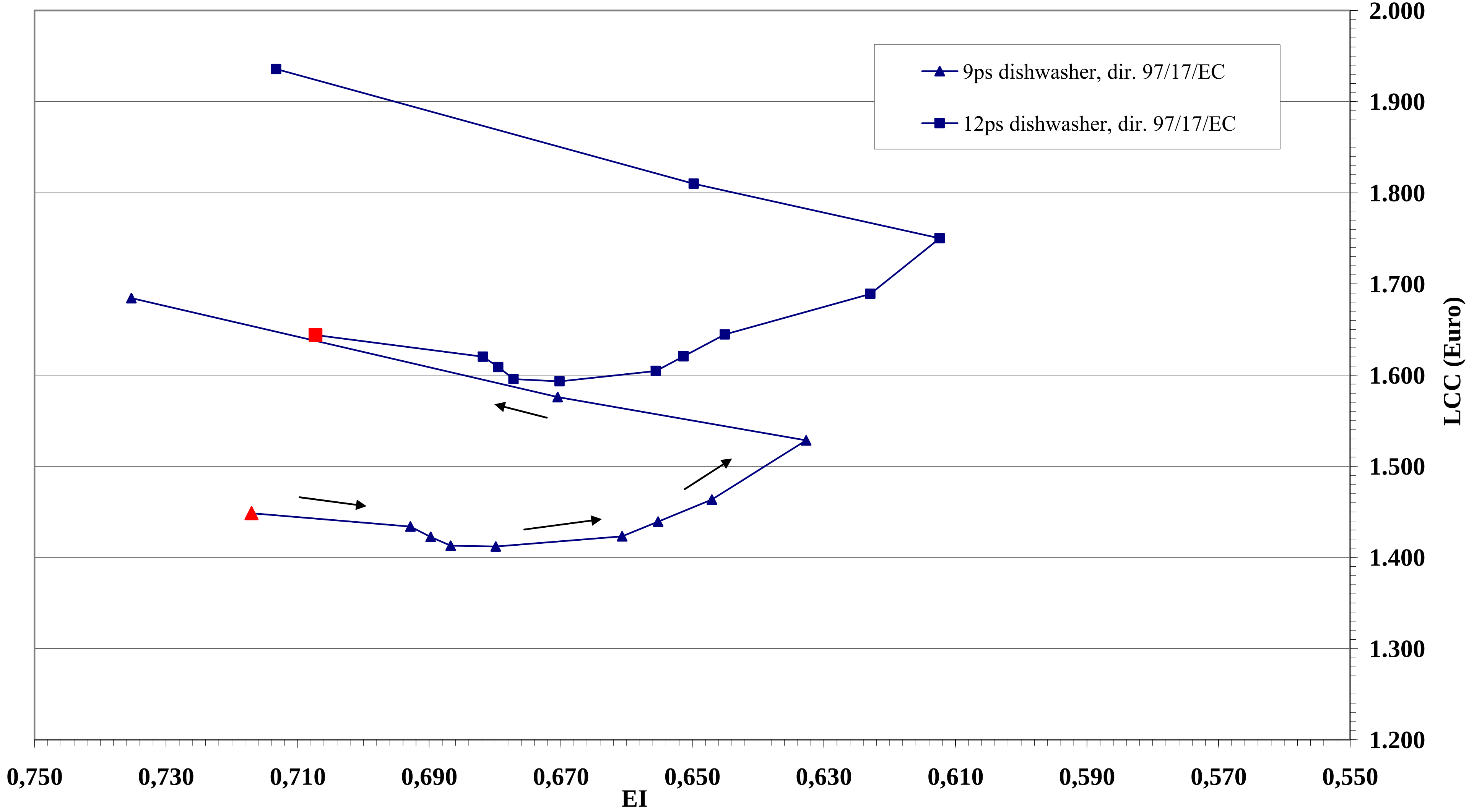


Figure 6.10: Life Cycle Cost (lifetime = 15 years, 280 cycle/year) as a function of the Energy Efficiency Index (EI) in directive 97/17/EC for each dishwasher real-life base cases. Real-life base cases are the red point on each curve. Appliance base cases are identified by their place setting number. Arrows (on the 9ps machine curve only) show the option application sequence.



6.4.2.5 The analysis for the standard base cases with an extended option set

In this analysis, the technological options identified in previous Tables 6.1-6.2 as suitable for the real life will be applied to the standard base cases together with the options already identified as applicable for the standard base cases to evaluate the overall modification of the energy/water consumption when the average machine is used under real-life conditions. This exercise, although simplified through some potentially questionable assumptions, will give indications on the energy/water consumption measured according to a possible revised standard, more adherent to the real life.
Again the evaluation of the Simple Payback Time (SPB) and the Net Present Value (NPV) of the single options when applied to the relevant standard base cases was developed. The results are presented in Table 6.22 for the 9ps and the 12ps machines. NPV is calculated for a lifetime of 15 years and 280 washing cycles.

The results of the aggregated option analysis are presented in Table 6.23, where the applied options, with the order of application, the corresponding marginal net present value (MNPV) and the resulting energy/water consumption values for a 15 year lifetime and 280 cycles per year are given. In particular in the previous analysis *Option a.1* and *Option a.2* have been combined, so that the actual wash temperature drops from 50°C to 40°C in one step; *Option h.1*, *Option h.2* and *Option i* have been added as the last ones, despite their MNPV, due to the associated increase in the energy consumption of the machines. In particular the decision to apply *Option i* (encompassing a hot rinse at 70-75°C) to 20% of the cycles is questionable, but has been included as the last option to evaluate the potential increase in energy consumption in case a final hot rinse would become part of a future standard washing cycle (to solve the hygiene problems). In addition, *Option j.1- electronic sensors for the load soling (50% soiled)* and *Option j.2 - Electronic sensors for the load weight (50% mass)* have been added together (to avoid the need of a separate further LCC analysis), thus simulating a wash cycle with a half load of half soiled tableware, but not necessarily this will happen contemporarily in real life.

Table 6.22: Simple payback time and net present value (at 15 years, for 280 cycles/year) for the extended technological options applied to the average standard base cases for dishwashers

Dishwashers categories		9ps machine		12ps machine	
Options (n)	**Technology** (description)	SPB (years)	NPV (€)	SPB (years)	NPV (€)
a.1	Lower wash temperature (45°C) + longer time	7,37	4,29	5,53	9,23
a.2	Lower wash temperature (40 °C) + longer time	7,37	4,29	5,53	9,23
b	Alternating spraying of water	5,49	24,29	4,24	39,54
c	Heat exchanger (with storage tank)	19,12	-12,48	19,12	-12,48
d	Cross flow heat exchanger			32,77	-42,64
e.1	condenser for drying	54,62	-31,59	54,62	-31,59
e.2	Condenser with fan for drying	54,62	-31,59	54,62	-31,59
f.1	Avoidance/reduction of the cold pre-rinse	0,00	31,82	0,00	37,20
f.2	partly draining and re-filling (of water)	2,18	14,70	1,69	20,08
g	DC brushless motor	53,06	-62,74	53,06	-62,74
h.1	Noise reduction to 44 dB(A) (through better insulation)	-9,36	-65,79	-8,62	-85,94
h.2	Noise reduction to 41 dB(A) (through better insulation)	-16,39	-114,67	-13,66	-137,29
i	Hot rinse at 70-75°C (20% of the cycles)	-0,71	-121,44	-1,04	-85,37
j.1	Electronic sensors for the load soling (50% soiled)	3,49	38,51	3,36	40,66
j.2	Electronic sensors for the load weight (50% mass)	2,31	54,44	2,15	59,82
k	Delay start (3,5 W average power level)	0,00	-0,01	0,00	-0,01

Table 6.23: Marginal net present value (MNPV, 15years) for the aggregated option analysis for the extended technological options applied to the average standard base cases for dishwashers

9ps dishwasher		Consumption		**12ps dishwasher**		Consumption	
Options (n)	$MNPV_{av}$ (€)	energy (kWh/cycle)	water (litre/cycle)	Options (n)	MNPV (€)	energy (kWh/cycle)	water (litre/cycle)
+j.2	43,55	0,732	12,90	**+j.2**	47,85	0,974	14,00
+j.1	19,37	0,679	12,45	**+j.1**	21,23	0,919	13,45
+f.1	10,43	0,654	11,09	**+f.1**	18,57	0,883	11,85
+b	10,26	0,651	10,28	**+b**	11,70	0,880	10,92
+f.2	8,11	0,648	9,38	**+f.2**	10,86	0,877	9,77
+a.1 & a.2	1,39	0,618	9,38	**+a.1 & a.2**	7,36	0,834	9,77
+k	0,00	0,618	9,38	**+k**	0,00	0,834	9,77
+c	-13,81	0,599	9,38	**+c**	-13,38	0,814	9,77
+e.1	-16,39	0,592	9,38	**+e.1**	-16,35	0,808	9,77
+e.2	-25,27	0,584	9,38	**+e.2**	-25,05	0,799	9,77
+g	-67,35	0,570	9,03	**+d**	-47,64	0,769	9,77
+h.1	-42,36	0,607	9,03	**+g**	-64,07	0,756	9,46
+h.2	-99,72	0,671	9,03	**+h.1**	-54,12	0,806	9,46
+i	-25,51	0,720	9,03	**+h.2**	-116,53	0,892	9,46
				+i	-18,37	0,926	9,46

The resulting energy consumption and incremental purchase price for Base Case and average LLCC ($LLCC_{av}$) case when the technological options are applied to the two real-life base cases are presented in Table 6.24. The energy and water consumption for the 9ps machine is reduced by 210 Wh/cycle (or 25,4%) and 4,3 litre/cycle (or 31,4%); for the 12ps machine the energy and water consumption is reduced by 236 Wh/cycle (or 22,1%) and 5,4 litre/cycle (or 31,5%). This significant savings is mainly due to the half load (*Option j.1*) and half soil (*Option j.2*) options. On the other side these results can be presented on the basis of a constant weight and soiled load, where the energy and water consumption should be at least doubled to reach 1,236 kWh/cycle/18,8 litre cycle for the 9ps machine and 1,668 kWh/cycle/19,6 litre/cycle for the 12ps machine. The LCC is also presented in Figure 6.11 for the two average standard base cases. It is worth noting that the options increasing the energy consumption have been added as the last ones, despite their MNPV, due to the associated increase in the energy consumption of the machines. In the LCC analysis an attempt was made to predict the lowest possible achievable energy consumption before adding the energy consuming options.

The lowest predictable energy consumption values after all options have been added, or the average Best Available Technology (BAT_{av}) to the base cases are presented in Table 6.25. For dishwashers, four BAT_{av} levels can be predicted due to the fact that some options, as already mentioned, are also increasing the overall energy consumption of the dish-washing cycle (*Options h.1, h.2, i* and *k*). In particular, the predicted energy consumption for a machine with a noise level of 41dB(A) (third row of each base case) is 0,671 kWh/cycle, still lower than the average standard 9ps machine in 2005, but after the application of a series of consumption reduction options. For the 12ps machine, the consumption is 0,892 kWh/cycle when the noise is reduced to of 41dB(A). When the noise remain unchanged at the average value of 50d(B)A, the energy consumption for the 9ps machine is reduced by 258 Wh/cycle (or 31,2%) with a minimum of 0,570 kWh/cycle and that of the 12ps machine by 178 Wh/cycle (or 16,6%) with a minimum of 0,756 kWh/cycle. The water saving is 4,7 litre/cycle (or 34,3%) for the 9ps category, with a minimum of 9 litres; for the 12ps machine the savings is 5,7 litre/cycle (or 37,5%) with a minimum of 9,5 litres.

When the Life Cycle Cost (lifetime = 15 years, 280 cycles/year) is shown as a function of the energy consumption (in kWh/cycle) and the Energy Efficiency Index (E_I) in directive 97/17/EC the curves in Figures 6.12 and 6.13 result.

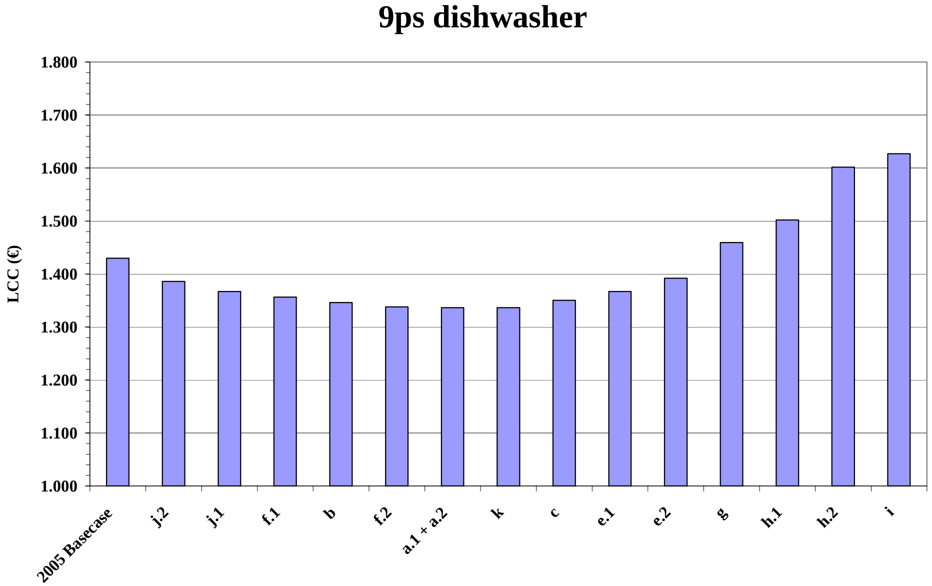
Table 6.24: Energy efficiency index (EEI), energy & water consumption and incremental purchase price for dishwasher Base Case and LLCCav for the extended standard base case analysis

Extended standard base case	Energy consumption		Water consumption		Energy efficiency Index (dir. 97/17/EC)			Purchase price			LCC (15 years, 280 cycles)	
	Base case (kWh/cycle)	$LLCC_{av}$ (kWh/cycle)	Base case (litre/cycle)	$LLCC_{av}$ (litre/cycle)	Base case E_I	$LLCC_{av}$ E_I	difference (%)	Base case (Euro)	$LLCC_{av}$ (Euro)	Increase (%)	Base case (€)	$LLCC_{av}$ (€)
9ps dishwashers	0,828	0,618	13,7	9,4	0,657	0,473	28,0	520,0	577,4	11,0	1.430	1.337
12ps dishwashers	1,070	0,834	15,2	9,8	0,648	0,506	22,0	548,4	605,8	10,5	1.594	1.476

Table 6.25: Energy efficiency index (EEI), energy & water consumption and incremental purchase price for dishwasher Base Case and BATav for the extended standard base case analysis

Extended standard base case	Energy consumption		Water consumption		Energy efficiency Index (dir. 97/17/EC)			Purchase price			LCC (15 years, 280 cycles)	
	Base case (kWh/cycle)	BAT_{av} (kWh/cycle)	Base case (litre/cycle)	BAT_{av} (litre/cycle)	Base case E_I	BAT_{av} E_I	difference (%)	Base case (Euro)	BAT_{av} (Euro)	Increase (%)	Base case (€)	BAT_{av} (€)
9ps dishwashers	0,828	0,570	13,7	9,0	0,657	0,437	33,5	520,0	727,3	39,9	1.430	1.459
		0,607				0,465	29,2		751,3	44,5		1.502
		0,671				0,514	21,7		819,4	57,6		1.601
		0,720				0,551	16,1		821,0	57,9		1.627
12ps dishwashers	1,070	0,756	15,2	9,5	0,648	0,458	29,4	548,4	814,2	48,5	1.594	1.646
		0,806				0,489	24,7		843,5	53,8		1.700
		0,892				0,541	16,6		917,6	67,3		1.817
		0,926				0,561	13,5		919,1	67,6		1.835

Figure 6.11: Life Cycle Cost (lifetime = 15 years, 280 cycle/year) as a function of the applied technological options for 9ps and 12ps dishwasher extended standard base case analysis



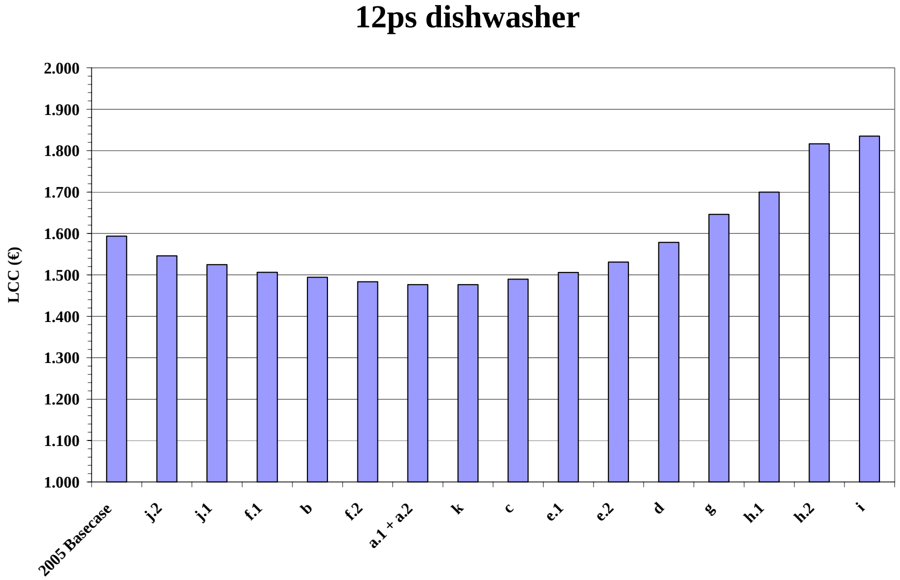


Figure 6.12: Life Cycle Cost (lifetime = 15 years, 280 cycle/year) as a function of the energy consumption for dishwasher extended standard base case analysis. Average standard base cases are the red point on each curve. Appliance base cases are identified by their place setting number. Arrows (on the 12ps machine curve only) show the option application sequence.

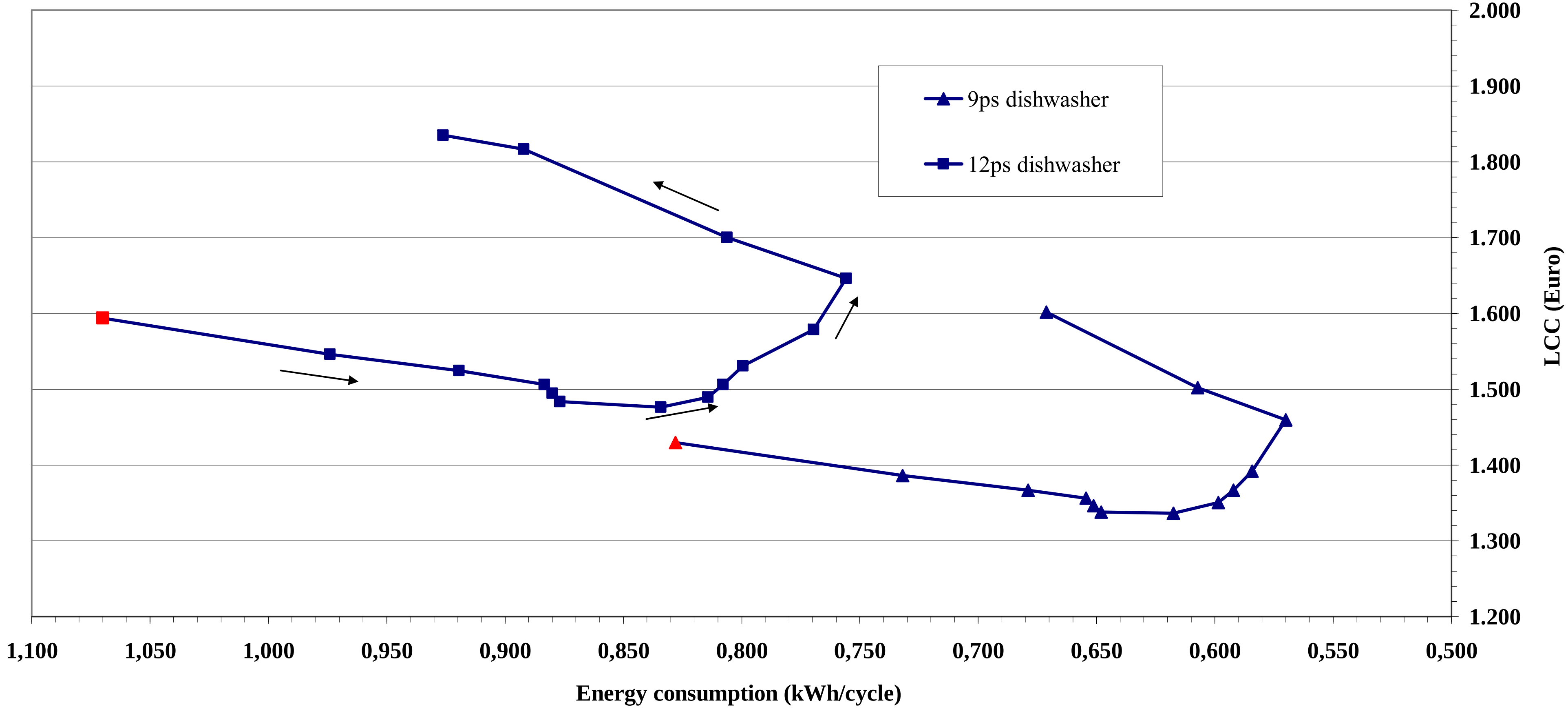
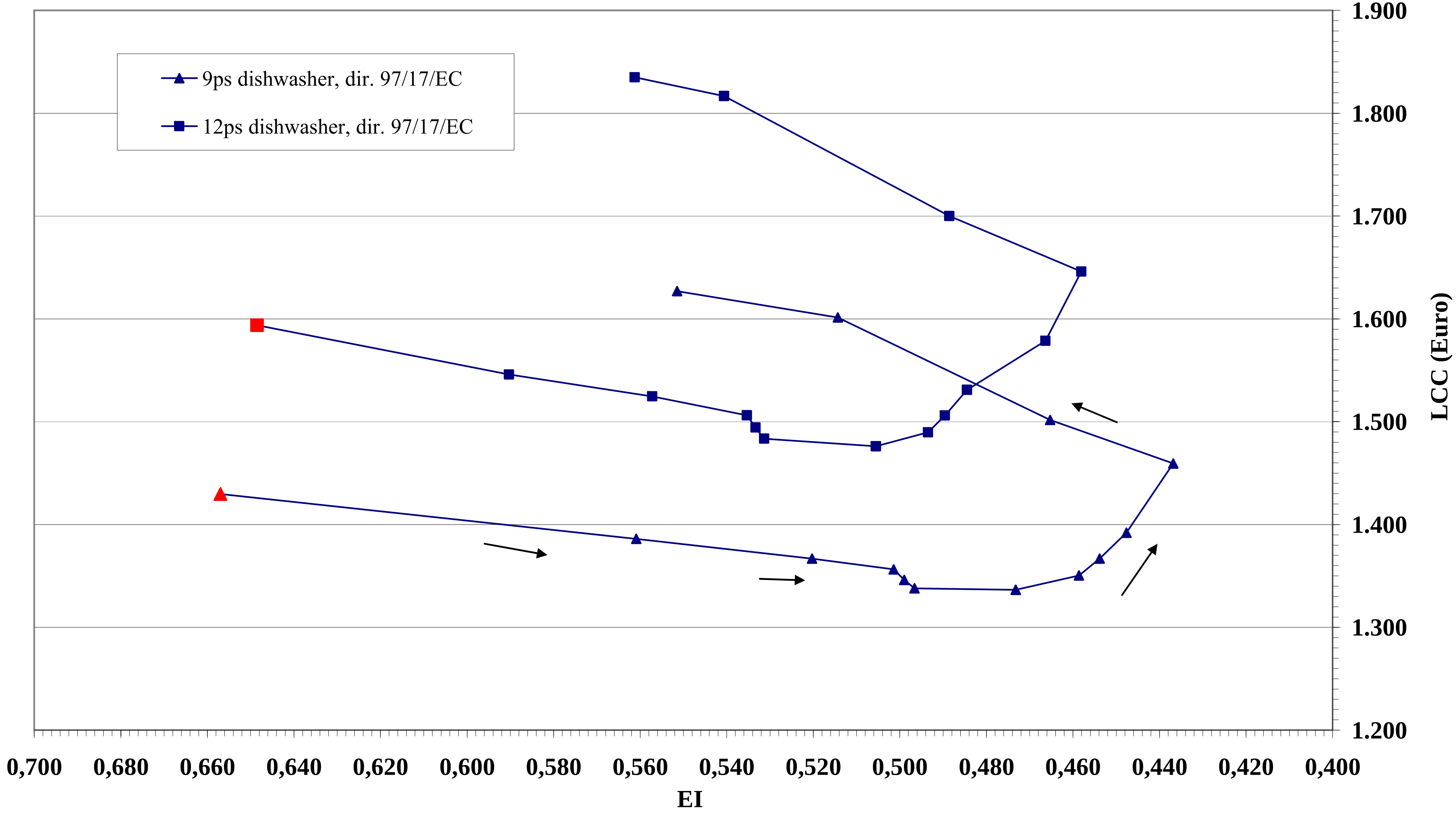


Figure 6.13: Life Cycle Cost (lifetime = 15 years, 280 cycle/year) as a function of the Energy Efficiency Index (EI) in directive 97/17/EC for each dishwasher real-life base cases. Real-life base cases is the first point on each curve. Appliance base cases are identified by their place setting number. Arrows (on the 9ps machine curve only) show the option application sequence.



6.4.2.6 Conclusions of the LCC analysis and results comparison for dishwashers

The LCC is a means of expressing the overall cost of the appliance from the owner's perspective. It includes both the initial purchase price, the operating expenses for electricity, water and chemicals consumption and the other costs (maintenance, repairs, disposal) amortised to the present. In this approach, the net present value of the operating expenses and other costs decrease from one year to the next due to discounting of their current value. Due to the time and budget constraints of the present study, and supported by the analysis of the last available technical database of the dishwasher appliance models produced or imported in the EU market in 2005, only free-standing base cases were simulated.
A summary of the LCC analyses is presented in Table 6.26 for the $LLCC_{av}$ values and in Table 6.27 where the BAT_{av} values are compared. In the two Tables also the values for the Marginal Payback Time (MPB) have been calculated and are shown. Main results are:

a) The **LCC analysis for the standard base cases** shows that:

- for the two average standard base cases the least life cycle cost occurs for appliances that are rated A class (for energy efficiency) with an E_I = 0,62 for the 9ps machine and E_I = 0,61 for the 12ps dishwasher (the threshold for class A is $E_I \leq 0{,}64$) and an energy consumption of 0,782 kWh/cycle and 1,009 kWh/cycle respectively; the water consumption is 10,3 and 11,0 litre/cycle respectively; the standard base cases energy consumption is 0,828 kWh/cycle for the 9ps machine and 1,070 kWh/cycle for the 12ps machine.
- the water consumption at LLCC point is 9,4 litre/cycle for the 9ps dishwasher and 9,8 litre/cycle for the 12ps dishwasher, against a standard base case consumption of 13,7 litre/cycle and 15,2 litre/cycle respectively;
- the payback time at LLCC is quite short: 4 years for the 9ps machine and even lower, at 3,1 years for the 12ps dishwasher;
- the LCC analysis for the standard base case models predicts the energy and water consumption of the best available models on the market in 2005/2006 for the 12ps machine and the best model available in CECED 2005 technical database for the 9ps dishwasher (no data on best models on the market were found for this machine category). The energy efficiency index values for the BAT are respectively E_I=0,536 for the 9ps machine and E_I=0,518 for the 12ps dishwasher when the noise remains at 50d(B)A, corresponding to 0,676 kWh/cycle and 0,855 kWh/cycle; the water consumption decreases to 9,6 and 10,3 litre/cycle respectively. The E_I increases to E_I=0,645 for the 9ps machine and E_I=0,632 for the 12ps machine when the noise is decreased to 41d(B)A, which is the lowest declared value on the market in both 2005 and 2007, with a corresponding energy consumption of 0,813 and 1,042 kWh/cycle;
- the payback time at BAT is longer than the estimated appliance lifetime, being 19,4 years for the 9ps machine and 19,3 years for the 12ps machine when the noise is maintained at 50 dB(A). When the noise decreases to 41 dB(A) the payback time reaches 94,4 years for both machines;
- options aimed at decreasing noise increase the machine energy consumption is all cases. These options are shown as applied at the end to the best available technology models to better illustrate the energy/noise tradeoffs, they could be applied to any model and at any point of the technological development pathway.

b) The **LCC analysis for the real-life base cases** shows that:

- the average real life 12ps machine has an actual washing temperature of 59,3°C, compared to the average standard machine with 50°C;
- for the two average real-life base cases, the least life cycle cost occurs at an energy consumption of 0,857 kWh/cycle and 1,106 kWh/cycle respectively with a water consumption of 10,5 and 11,4 litre/cycle respectively;
- the payback time at LLCC is again 3-4 years for the two dishwasher categories;

- the analysis predicts also an energy and water consumption of the best available models at 0,797 kWh/cycle for the 9ps dishwasher and 1,010 kWh/cycle for the 12ps dishwasher, with a corresponding water consumption of 10,1 and 11 litre/cycle;
- options aimed at decreasing noise increase the machine energy consumption is all cases. These options are shown as applied at the end to the best available technology models to better illustrate the energy/noise tradeoffs, they could be applied to any model and at any point of the technological development pathway;
- the payback time increases to about 19 years (longer than the estimated appliance lifetime) for both dishwashers when noise remains at 50dB(A), and increases rapidly when noise decreases.

c) The **LCC analysis for the extended standard base cases** shows that:

- in this analysis the technological options suitable for the real life will be applied to the standard base cases together with the options already identified for the standard base cases, to evaluate the changes in energy/water consumption when the average machine is used under real-life conditions. A wash cycle with a half load of half soiled tableware has been simulated, but not necessarily this will happen contemporarily in real life;
- for the two extended standard base cases the least life cycle cost occurs at an energy consumption of 0,618 kWh/cycle and 0,834 kWh/cycle respectively with a water consumption of 9,4 and 9,8 litre/cycle respectively, mainly due to the half load/half soiled tableware presence. These results can be presented also on the basis of a constant weight and soiled load, where the energy and water consumption should be at least doubled to reach 1,236 kWh & 18,8 litre per cycle for the 9ps machine and 1,668 kWh & 19,6 litre per cycle for the 12ps machine;
- payback time is the same as for the other cases: 3-4 years for the two machine categories;
- the analysis predicts also an energy and water consumption of the average BAT models (with noise remaining at base case level or 50 dB(A)) at 0,570 kWh/cycle for the 9ps dishwasher and 0,720 kWh/cycle for the 12ps dishwasher, with a water consumption of 9 and 9,5 litre/cycle;
- the payback time is now 12,1 years for the 9ps machine and 12,7 years for the 12ps dishwashers, shorter than the appliance lifetime
- options aimed at decreasing noise increase the machine energy consumption is all cases. These options are shown as applied at the end to the best available technology models to better illustrate the energy/noise tradeoffs, they could be applied to any model and at any point of the technological development pathway. Payback time increases accordingly, but remains at the level of the appliances lifetime when the noise is decreased to 44 dB(A); when noise is further decreased or the high temperature (hygienising) rinse is allowed then the payback time increases to 30 years.

6.4.3 The NPV/MNPV and LCC Analysis for Washing Machines

6.4.3.1 The key technical, economic and financial assumption

The key technical, common economic and financial assumptions (see Task 5) are:

- Product life: 15 years
- Cycles per year: 220
- Discount rate: 5%/year (PWF = 10,38 for 15years)
- Electricity price: 0,17 Euro/kWh
- Water price: 3,7 Euro/m^3
- detergent costs: 0,22 Euro/wash for 139,76 g/wash
- Maintenance & repairs: 5,5 Euro/year
- Disposal & recycling 61 Euro/life (at end of life)
- Machine price: 443,5 Euro.

Table 6.26: Energy efficiency index (EEI), energy & water consumption and incremental purchase price for the dishwasher Base Case and LLCC Case

Base case	Energy consumption		Water consumption		Energy efficiency Index (dir. 97/17/EC)			Purchase price			LCC (15 years, 280 cycles)		
	Base case (kWh/cycle)	LLCC (kWh/cycle)	Base case (litre/cycle)	LLCC (litre/cycle)	Base case E_I	LLCC E_I	difference (%)	Base case (Euro)	LLCC (Euro)	Increase (%)	Base case (€)	LLCC (€)	MPB (years)
9 place settings dishwasher													
Average standard	0,828	0,782	13,7	10,3	0,657	0,620	5,6	520,0	542,7	4,4	1.409	1.373	4,0
Real life	0,903	0,857	13,9	10,5	0,717	0,680	5,1	520,0	542,7	4,4	1.448	1.412	4,0
Extended standard	0,828	0,618	13,7	9,4	0,657	0,473	28,0	520,0	577,4	11,0	1.430	1.337	4,0
12 place settings dishwasher													
Average standard	1,070	1,009	15,2	11,0	0,648	0,611	5,7	548,4	571,1	4,1	1.594	1.542	3,1
Real life	1,167	1,106	15,4	11,4	0,707	0,670	5,2	548,4	571,1	4,1	1.644	1.593	3,2
Extended standard	1,070	0,834	15,2	9,8	0,648	0,506	22,0	548,4	605,8	10,5	1.594	1.476	3,4

Table 6.27: Energy efficiency index (EEI), energy & water consumption and incremental purchase price for the dishwashers Base Case and BAT Case

Base case	Energy consumption		Water consumption		Energy efficiency Index (dir. 97/17/EC)			Purchase price			LCC (15 years, 280 cycles)		
	Base case (kWh/cycle)	BAT (kWh/cycle)	Base case (litre/cycle)	BAT (litre/cycle)	Base case E_I	BAT E_I	difference (%)	Base case (Euro)	BAT (Euro)	Increase (%)	Base case (€)	BAT (€)	MPB (years)
9 place settings dishwasher													
Average standard	0,828	0,723	13,7	9,9	0,657	0,574	12,7	520,0	692,6	33,2	1.409	1.489	19,4
		0,770				0,611	7,0		716,6	37,8		1.537	29,5
		0,851				0,675	-2,8		784,7	50,9		1.645	94,4
Real life	0,903	0,797	13,9	10,1	0,717	0,633	11,7	520,0	692,6	33,2	1.448	1.528	19,3
		0,845				0,670	6,4		716,6	37,8		1.576	29,5
		0,926				0,735	-2,6		784,7	50,9		1.684	94,4
Extended standard	0,828	0,570	13,7	9,0	0,657	0,437	33,5	520,0	727,3	39,9	1.430	1.459	12,1
		0,607				0,465	29,2		751,3	44,5		1.502	15,1
		0,671				0,514	21,7		819,4	57,6		1.601	24,3
		0,720				0,551	16,1		821,0	57,9		1.627	30,1
12 place settings dishwasher													
Average standard	1,070	0,914	15,2	10,6	0,648	0,554	14,6	548,4	779,5	42,1	1.594	1.699	19,0
		0,975				0,591	8,9		808,8	47,5		1.758	28,2
		1,079				0,654	-0,8		882,9	61,0		1.884	77,9
Real life	1,167	1,010	15,4	11,0	0,707	0,612	13,4	548,4	779,5	42,1	1.644	1.750	19,2
		1,072				0,650	8,1		808,8	47,5		1.810	28,7
		1,177				0,713	-0,8		882,9	61,0		1.936	81,6
Extended standard	1,070	0,756	15,2	9,5	0,648	0,458	29,4	548,4	814,2	48,5	1.594	1.646	12,7
		0,806				0,489	24,7		843,5	53,8		1.700	15,9
		0,892				0,541	16,6		917,6	67,3		1.817	25,6
		0,926				0,561	13,5		919,1	67,6		1.835	29,0

In particular:

- number of cycles per year: 200 is the number of washing cycles considered in the energy labelling directive for a four-person household and forecast for 2010 in the WASH-II study. In addition, 220 cycles (the average number of cycles used in the WASH-II study) and 245 cycles (the average number of cycles used in the GEA study) will be considered for the sensitivity analysis;
- the sales weighted average price of the washing machines sold in 2004 according GfK was on average of 443,5 Euro for the 13 EU member stated where GfK collected the market data. In addition the values of 562 Euro in West EU countries and 326 Euro in East EU countries will be considered for the sensitivity analysis;
- temperature setting: standard base case 60°C cotton (40°C cotton cycle will be estimated within the sensitivity analysis).

6.4.3.2 The Simple Payback Time and Net Present Value analysis for the standard base cases

The first step of the analysis is the evaluation of the Simple Payback Time (SPB) and the Net Present Value (NPV) of the single options when applied to the standard base case for washing machines. The results are presented in Table 6.28. NPV is calculated for a lifetime of 15 years and 220 washing cycles.

The same data are ordered in Table 6.29 by simple payback time. In general there is a good agreement between the SPB and the NPV values, where the former increases the latter decreases. Some Options increase the energy/water consumption, and therefore the calculated payback time will be negative. The NPV is positive for four options: the first option tends to better control the temperature (*Option c.3*), the second to the optimisation of the mechanical action (*Option b*) , while the other two are relevant with the water consumption optimisation through a sensor (*Option c.2*) the optimisation of the rinsing phase (*Option d*). The following options have SPB much longer that the average appliance lifetime (15 years) and significantly negative net present values. *Option a.4 - Optimised motor composition* decrease slightly the purchase price of the machine through the optimisation of the composition and the decrease in the motor price.

Table 6.28: Simple payback time and net present value (at 15 years, for 220 cycles/year) for the identified technological options applied to the standard base case for washing machines

Options (n)	**Technology** (description)	**SPB** (years)	**NPV** (€)
a.1	Brushless DC motor (+ control)	32,1	-40,6
a.2	Brushless DC direct drive motor (+ control)	130,3	-179,5
a.3	Three-phase motor	48,1	-70,6
a.4	Optimised motor composition	--	3,0
b	Mechanical action optimisation	0,3	54,2
c.1	Sophisticated unbalance control (+ separate sensors)	--	-22,5
c.2	Analogue water sensor	1,3	40,7
c.3	Temperature control sensor (+ simple unbalance control)	0,3	43,3
d	Rinsing phase optimisation	2,5	48,4
e	Increased load capacity in the same machine	--	-56,7
k	Higher spinning speed (to ≥ 1 600 rpm)	--	-49,37

Table 6.29: Technological options ordered by simple payback time (SPB) and net present value (at 15 years, for 220 cycles/year) for the identified technological options applied to the standard base case for washing machines

Options (n)	Technology (description)	SPB (years)	NPV (€)
b	Mechanical action optimisation	0,3	54,2
c.3	Temperature control sensor (+ simple unbalance control)	0,3	43,26
c.2	Analogue water sensor	1,3	40,72
d	Rinsing phase optimisation	2,5	48,37
a.1	Brushless DC motor (+ control)	32,1	-40,59
a.3	Three-phase motor	48,1	-70,59
a.2	Brushless DC direct drive motor (+ control)	130,3	-179,47
a.4	Optimised motor composition	--	3
c.1	Sophisticated unbalance control (+ separate sensors)	--	-22,5
k	Higher spinning speed (to ≥1 600 rpm)	--	-49,37
e	Increased load capacity in the same machine	--	-56,7

6.4.3.3 The Marginal Net Present Value and the aggregated option LCC analysis

To evaluate the improvement potential of the standard base case, the aggregated option analysis is developed. Also in the case of washing machines this LCC analysis was run for the average standard base-case appliance and for the standard base case model. The former represents the average machine of the reference year and takes into consideration the percentage of application of each technological option to the market, or better the percentage of each option still available for application to the market; for the latter a technological level is specified for the base case and then all the available technological options are applied.

In the first case, the possible average improvement of the overall appliance category is predicted. The second analysis allows to predict the best available technology model, and can be also considered a sort of inner validation of the previous scenario and more in general of the overall calculation model: if the simulation can predict in a technically and economically sound way the development from the base case model to the to the best available model(s) on the market in 2005, then the overall simulation is not only inherently coherent, but also in agreement with the reality.
In addition, an analysis with and without *Option e - increased load capacity in the same machine* will be developed, to evaluate the influence of the an increased load capacity over a technological development pathway.

In Table 6.30 the applied options, with the order of application, the corresponding marginal net present value (MNPV) and the resulting energy/water consumption for a 15 year lifetime and 220 cycles per year are presented for the average standard base cases and the standard base case models. The reasons for the selection of the specific technological pathways (out of the Technological Option List) and the detailed Life Cycle Cost results and calculations for each base case are presented in Annex 1.

The optimum option combination varies whether the LCC analysis was run for the average standard base-case appliance or for the standard base case model, nevertheless some common elements can be drawn from the data presented in Table 6.30:

- the use of the optimised mechanical action is always the most cost-effective design option;
- the same occurs for the optimisation of the rinsing phase and the addition of analogue water sensors;
- the optimised motor composition is slightly cost-effective in both cases;

- the temperature control sensor is cost-effective only for the standard base case;
- any motor improvement is not cost-effective, the less cost-ineffective is the brushless direct drive DC motor (plus the relevant control);
- a more sophisticate unbalance control is the last of the cost-effective options or the first of the non cost-effective depending on the case;
- the increase in spinning speed is also not cost-effective (when the washing machine alone is considered[18]);
- the increase in the load capacity (from 5 to 6 kg) is not cost-effective at the overall machine (energy and water consumption) level, but becomes a positive technological development when evaluate considering the energy and water consumption per unit of load weight.

The resulting energy and water consumption and incremental purchase price for Base Case and LLCC for the average standard base case and the standard base case model are presented in Table 6.31. Also the energy consumption "C" for kg of washed load for the standard 60°C cotton cycle is shown, calculated according to the algorithms of directive 95/12/EC (described in Task 1). The energy and water consumption for the average machine are reduced by 98 Wh/cycle (or 9,8%) and 12 litre/cycle (or 23,7%); the consumption per kg of washed load for the LLCC is 0,168 corresponding to the commercially defined A+ energy efficiency class (A class according to the mentioned directive). For the standard base case model the LLCC model has an energy consumption of 0,889 kWh/cycle (with a savings of 109 Wh or 10,9%) an a water consumption of 37,4 litre/cycle (with a savings of 13,3 litre or 26,2%). The energy efficiency class achievable is again A+ (A class according to the EU labelling directive).

The forecast increase in purchase price is 3,8% for the average standard base case and 4,4% for the standard base case model. The ratio between the predicted increase in purchase price and the efficiency improvement is:

Base case	Ratio
Average standard base case	0,38
Standard base case model	0,44

The LCC is also presented in Figure 6.14 for the two standard base cases. It is worth noting that *Option k* and *Option e* have been added as the last ones, due to the associated increase in the spinning speed (for the former) and in the machine load capacity (for the latter). In the LCC analysis an attempt was made to predict the lowest possible achievable energy consumption before adding this option which modifies the machine technical characteristics.

The lowest predictable energy consumption for after all options have been added, or the Best Available Technology (BAT) to the base case is presented in Table 6.32. For washing machines, three BAT levels can be predicted, due to the fact the last two added options increase the overall energy consumption of the laundry-washing cycle by increasing the spinning speed and the load capacity. The energy consumption for the average standard base case is reduced by 143 Wh/cycle (or 14,3%) to 0,855 kWh/cycle; the water consumption of 12 litre/cycle (or 23,7%), with a minimum of 38,7 litres.
When the Life Cycle Cost (lifetime=15 years, 220 cycles/year) is shown as a function of the energy consumption (kWh/cycle) the curves in Figure 6.15 result.

A close agreement can be seen between the results the predicted BAT energy consumption and energy efficiency class and the actual minimum values of the washing machine models on the

[18] The interaction of the washing machine and the dryer will be briefly analysed in paragraph 1.5.3 System Analysis.

market in 2005/2006 in terms of minimum energy and water consumption and the best model in CECED 2005 technical database (see Task 5) as shown in Table 33.

Table 6.30: Technological options and marginal net present value (MNPV) at 15 years for the aggregated option analysis for washing machine average standard base case and standard base case model

Average standard base case				Consumption		Standard base case model				Consumption	
Options (n)	$MNPV_{av}$ (€)	Noise* (dBA)	Cycle time (min)	energy (kWh/cycle)	water (litre/cycle)	Options (n)	MNPV (€)	Noise* (dBA)	Cycle time (min)	energy (kWh/cycle)	water (litre/cycle)
+b	54,22	53	110	0,918	49,10	**+b**	54,22	53	110	0,898	48,70
+d	37,09	53	98	0,918	43,29	**+d**	45,87	53	95	0,898	41,50
+c.2	32,44	53	98	0,909	39,18	**+c.2**	32,55	53	95	0,889	37,35
+c.3	7,15	53	98	0,900	38,71	**+a.4**	3,00	53	95	0,889	37,35
+a.4	3,00	53	98	0,900	38,71	**+c.1**	-22,50	48	95	0,889	37,35
+c.1	-21,38	53	98	0,900	38,71	**+a.1**	-42,71	45	85	0,844	37,35
+a.1	-42,28	50	88	0,855	38,71	**+k**	-46,39	45	90	0,887	37,35
+k	-23,30	50	92	0,892	38,71	**+e**	-46,56	45	105	0,958	39,56
+e	-23,47	50	103	0,942**	40,32**						

*during the washing cycle;
**for an increased load of 6kg

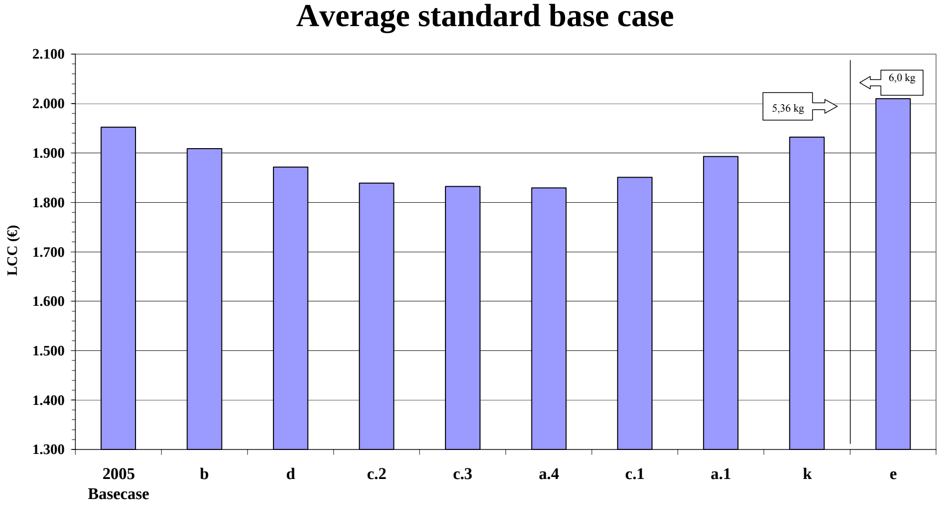
Table 6.30: Technological options and marginal net present value (MNPV) at 15 years for the aggregated option analysis for washing machine standard base case model – continued

Options	Consumption per cycle				Specific consumption				EE class
	energy (kWh/cycle)		water (litre/cycle)		energy (kWh/kg cycle)		water (litre/kg cycle)		
(n)	5kg	6kg	5kg	6kg	5kg	6kg	5kg	6kg	
+b	0,838	--	45,4	--	0,168	--	9,1	--	A+
+d	0,838	--	38,7	--	0,168	--	7,7	--	A+
+c.2	0,829	--	34,8	--	0,166	--	7,0	--	A+
+a.4	0,829	--	34,8	--	0,166	--	7,0	--	A+
+c.1	0,829	--	34,8	--	0,166	--	7,0	--	A+
+a.1	0,788	--	34,8	--	0,158	--	7,0	--	A+
+k	0,827	--	34,8	--	0,165	--	7,0	--	A+
+e	--	0,958	--	39,6	--	0,160	--	6,6	A+

Table 6.31: Energy and water consumption and incremental purchase price for washing machine Base Case and LLCC for average standard base case and standard base case model

Base case	Energy consumption		Water consumption		Specific energy consumption "C" (dir. 95/12/EC)			Purchase price			LCC (15y, 220 cycles)	
	Base case (kWh/cycle)	LLCC (kWh/cycle)	Base case (litre/cycle)	LLCC (litre/cycle)	Base case C	LLCC C	difference (%)	Base case (Euro)	LLCC (Euro)	Increase (%)	Base case (€)	LLCC (€)
Average standard base case	0,998	0,900	50,7	38,7	0,186	0,168	9,8	443,5	459,7	3,7	1.952	1.829
Standard base case model	0,998	0,889	50,7	37,4	0,186	0,166	10,9	443,5	463,0	4,4	1.952	1.816

Figure 6.14: Life Cycle Cost (lifetime = 15 years, 220 cycle/year) as a function of the applied technological options for the washing machine standard base cases



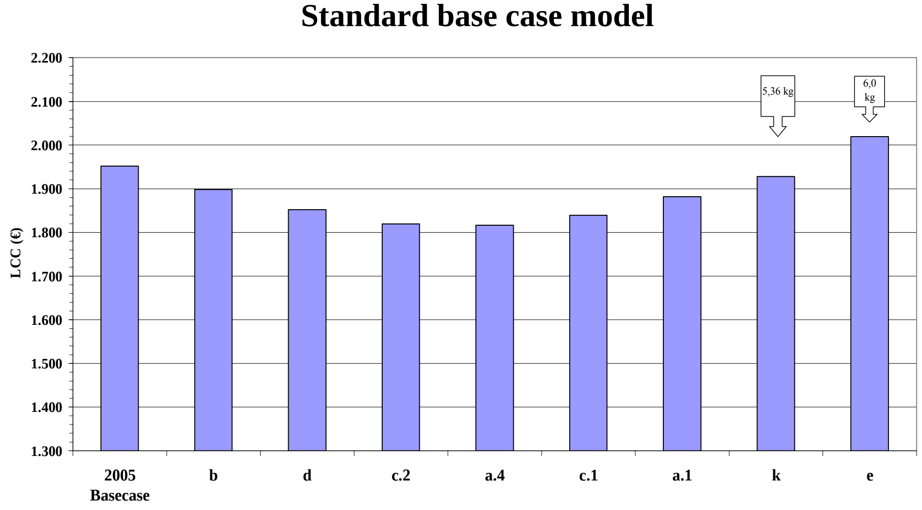


Table 6.32: Energy and water consumption and incremental purchase price for washing machine Base Case and BAT for average standard base case and standard base case model

Base case	Energy consumption		Water consumption		Specific energy consumption "C" (dir. 95/12/EC)			Purchase price			LCC (15y, 220 cycles)	
	Base case (kWh/cycle)	BAT (kWh/cycle)	Base case (litre/cycle)	BAT (litre/cycle)	Base case C	BAT C	difference (%)	Base case (Euro)	BAT (Euro)	Increase (%)	Base case (€)	BAT (€)
Average standard base case	0,998	0,855	50,7	38,7	0,186	0,1596	14,3	443,5	540,8	21,9	1.952	1.893
		0,892		38,7		0,1663	10,7		566,3	27,7		1.932
		0,942		40,3		0,1569	15,7		566,5	27,7		2.010
Standard base case model	0,998	0,844	50,7	37,4	0,186	0,1575	15,4	443,5	545,5	23,0	1.952	1.882
		0,887		37,4		0,1654	11,2		575,5	29,8		1.928
		0,958		39,6		0,1596	14,3		575,8	29,8		2.019

Figure 6.15: Life Cycle Cost (lifetime = 15 years, 220 cycle/year) as a function of the energy consumption for washing machine analysis. Average standard base case and standard base case model are the red point on each curve. Arrows show the option application sequence.

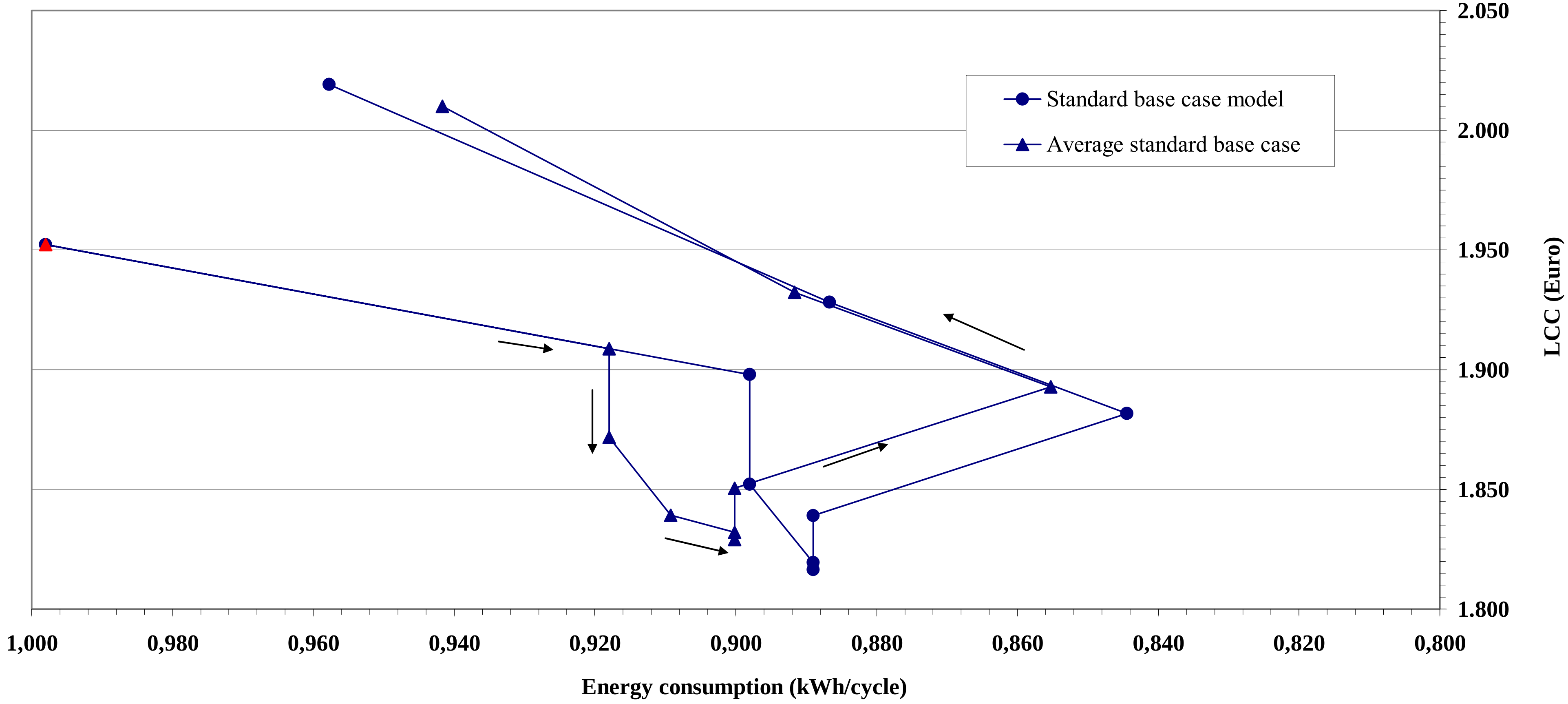


Table 6.33: Comparison of the minimum energy and water consumption for washing machine models in 2005/2006 and the results of the LCC for the standard base case models

Capacity	Min. energy consumption (kWh/cycle)		Min. water consumption (litre/cycle)	
	CECED 2005	LCC	CECED 2005	LCC
5kg	0,830	0,844*	35,0	37,4*
6kg	0,950	0,958	37,0	39,6

*for the 5,36 kg machine

6.4.3.4 The analysis results for the real-life base case

The real-life base case LCC analysis will be run by applying the technological options identified for the standard base case to the real-life base case defined in Task 5 on the basis of the consumer analysis (Task 3). The expected outcome is the evaluation of the savings achievable under real life conditions from the technological improvement of the standard washing machine.

The evaluation of the Simple Payback Time (SPB) and the Net Present Value (NPV) of the single options when applied to the relevant real-life base cases was run. The results are presented in Table 6.34. NPV is calculated for a lifetime of 15 years and 220 washing cycles. The same data are ordered in Table 6.35 by simple payback time. Some Options increase the energy/water consumption, and therefore the calculated payback time will be negative. The NPV is positive for the same four options already described for the standard base case analysis. It is worth noting that the washing temperature is 45,8 °C compared to the 60°C of the standard washing cycle.

The results of the aggregated option analysis are presented in Table 6.36, where the applied options, with the order of application, the corresponding marginal net present value (MNPV) and the resulting energy/water consumption values for a 15 year lifetime and 220 cycles per year are given for the average real life base cases. *Option e* is not applied because there is little scope in simulating an increase in the machine capacity when a reduced load is washed.

Table 6.34: Simple payback time and net present value (at 15 years, for 220 cycles/year) for the identified technological options applied to the real-life base case for washing machine

Washing machines			
Options (n)	**Technology** (description)	SPB (years)	NPV (€)
a.1	Brushless DC motor (+ control)	44,5	-46,02
a.2	Brushless DC direct drive motor (+ control)	180,9	-183,81
a.3	Three-phase motor	66,8	-76,02
a.4	Optimised motor composition	--	3,00
b	Mechanical action optimisation	0,4	41,00
c.1	Sophisticated unbalance control (+ separate sensors)	--	-22,50
c.2	Analogue water sensor	1,6	33,63
c.3	Temperature control sensor (+ simple unbalance control)	0,4	34,28
d	Rinsing phase optimisation	2,9	39,49
e	Increased load capacity in the same machine	--	-44,47
k	Higher spinning speed (≥ 1 600 rpm)	--	-43,96

Table 6.35: Simple payback time and net present value (at 15 years, for 220 cycles/year) for the identified technological options applied to the real-life base case for washing machine

Washing machines			
Options (n)	**Technology** (description)	SPB (years)	NPV (€)
b	Mechanical action optimisation	0,4	41,00
c.3	Temperature control sensor (+ simple unbalance control)	0,4	34,28
c.2	Analogue water sensor	1,6	33,63
d	Rinsing phase optimisation	2,9	39,49
a.1	Brushless DC motor (+ control)	44,5	-46,02
a.3	Three-phase motor	66,8	-76,02
a.2	Brushless DC direct drive motor (+ control)	180,9	-183,81
a.4	Optimised motor composition	--	3,00
c.1	Sophisticated unbalance control (+ separate sensors)	--	-22,50
k	Higher spinning speed (≥ 1 600 rpm)	--	-43,96
e	Increased load capacity in the same machine	--	-44,47

Table 6.36: Technological options and marginal net present value (MNPV) at 15 years for the aggregated option analysis for average washing machine real-life base case

Washing machine Options (n)	$MNPV_{av}$ (€)	Consumption (for 3,4kg actual load) energy (kWh/cycle)	(kWh/kg cycle)	water (litre/cycle)	(litre/kg cycle)
+d	32,80	0,661	0,1945	42,22	12,42
+b	30,22	0,661	0,1945	37,23	10,95
+c.2	26,62	0,655	0,1927	33,69	9,91
+c.3	5,62	0,649	0,1907	33,29	9,79
+a.4	3,00	0,649	0,1907	33,29	9,79
+c.1	-21,38	0,649	0,1907	33,29	9,79
+a.1	-47,15	0,616	0,1812	33,29	9,79
+k	-35,67	0,642	0,1889	33,29	9,79

The resulting energy consumption and incremental purchase price for Base Case and average LLCC case when the technological options are applied to real-life base case are presented in Table 6.37. The energy and water consumption of the machine is reduced by 70 Wh/cycle (or 9,7%) and 10,3 litre/cycle (or 23,6%); the purchase price increase of 3,7%. The lowest predictable energy consumption values after all options have been added, or the average Best Available Technology to the base case are presented in the same Table. For real-life washing machine, two BAT levels can be predicted, due to the fact the last added option increases the overall energy consumption of the laundry-washing cycle by increasing the spinning speed. The energy consumption for the average standard base case is reduced by 103 Wh/cycle (or 14,3%) to 0,616 kWh/cycle; the water consumption of 10,3 litre/cycle (or 23,6%), with a minimum of 33,3 litres.

When the Life Cycle Cost (lifetime=15 years, 220 cycles/year) is shown as a function of the energy consumption (in kWh/cycle) the curves in Figure 6.16 result.

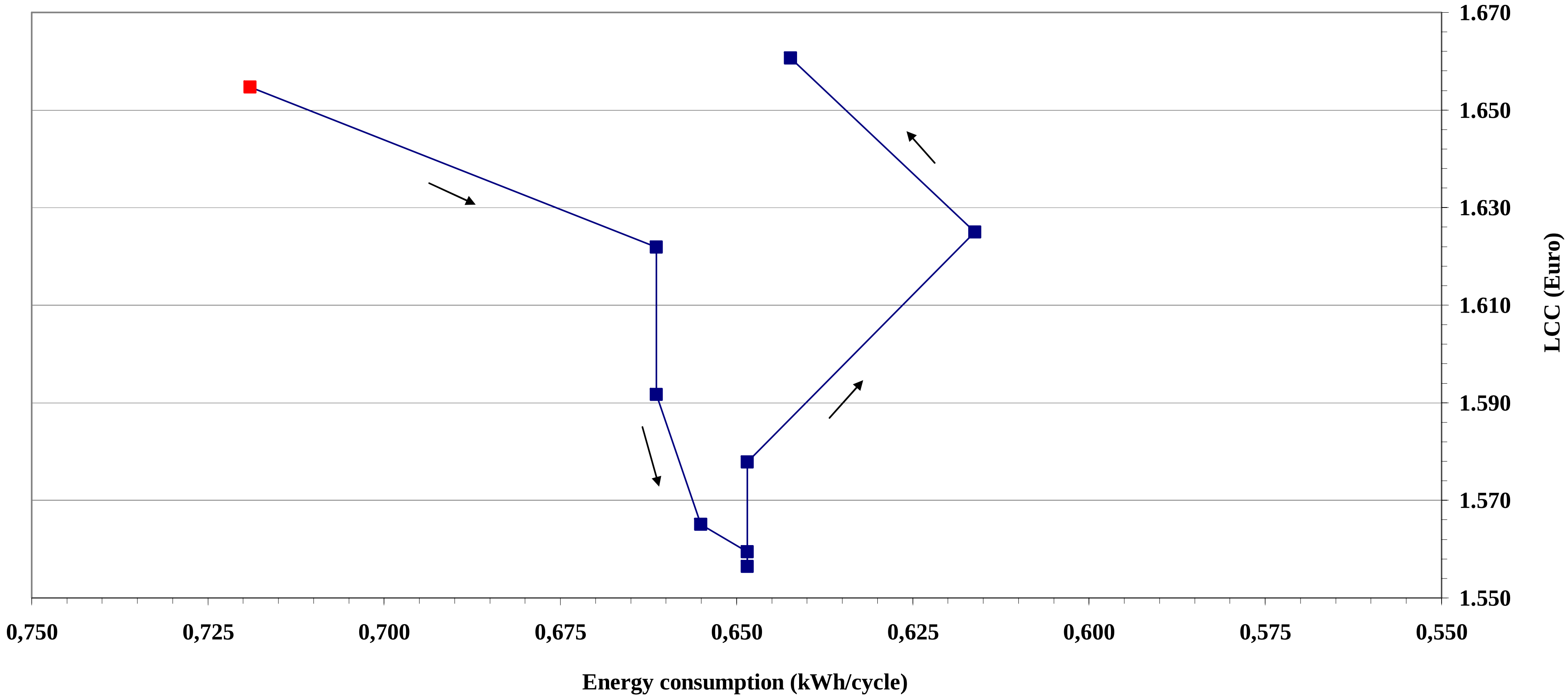
6.4.3.5 The analysis for the standard base cases with an extended option set

As in the case of dishwashers, in this analysis, the technological options identified in previous Table 6.8 as suitable for the real life will be applied to the standard base case (together with the options already identified as applicable for the standard base case itself) to evaluate the overall modification

Table 6.37: Energy and water consumption and incremental purchase price for washing machine Base Case and LLCC for real-life base case

	Energy consumption		Water consumption		Specific energy consumption "C" (dir. 95/12/EC), 3,4kg			Purchase price			LCC (15y, 220 cycles)	
Real-life base case	Base case (kWh/cycle)	LLCC (kWh/cycle)	Base case (litre/cycle)	LLCC (litre/cycle)	Base case C	LLCC C	difference (%)	Base case (Euro)	LLCC (Euro)	Increase (%)	Base case (€)	LLCC (€)
	0,719	0,649	43,6	33,3	0,2115	0,1907	9,8	443,5	459,7	3,7	1.655	1.556
	Base case (kWh/year)	BAT (kWh/year)	Base case (litre/cycle)	BAT (litre/cycle)	Base case C	BAT C	difference (%)	Base case (Euro)	BAT (Euro)	Increase (%)	Base case (€)	BAT (€)
	0,719	0,616	43,6	33,3	0,2115	0,1812	14,3	443,5	540,8	21,9	1.655	1.625
		0,642		33,3		0,1889	10,7		566,3	27,7		1.661

Figure 6.16: Life Cycle Cost (lifetime = 15 years, 220 cycle/year) as a function of the energy consumption for each washing machine real-life base cases. Real-life base case is the red point on the curve. Arrows show the option application sequence.



of the energy/water consumption when the average machine is used under real-life conditions. This exercise will also potentially give indications on the energy/water consumption measurable according to a possible revised standard, more adherent to the real life conditions and usage.

Again the evaluation of the Simple Payback Time (SPB) and the Net Present Value (NPV) of the single options when applied to the standard base case was developed. The results are presented in Table 6.38. NPV is calculated for a lifetime of 15 years and 220 washing cycles. The results of the aggregated option analysis are presented in Table 6.39, where the applied options (with the order of application), the corresponding marginal net present value (MNPV) and the resulting energy/water consumption values for a 15 year lifetime and 220 cycles per year are given. It should be noted that *Options a.1* to *a.3* are alternative motor types; *Option g* and *Option j* are also considered alternatives in the simulation: *Option g* allows the reduction of the energy/water consumption for a reduced load (from 5kg to 3,4kg as stated in Task 3), while *Option j* results in the machine to be filled with a real 5kg load, making Option g useless, at least in the simplified simulation run in this paragraph. Therefore *Option j* will not be simulated. *Option e* is also an alternative to *Option g*: in fact there is little scope to increase the nominal load capacity of a machine and then wash a reduced load, at least from the simulation point of view. In this case two technological pathways will be studied, the first including *Option g* (and considering a reduced load) and the second including *Option e* (and considering an increased load). For the latter, the specific energy consumption in kWh per kg of load per cycle are given to allow the evaluation of the option impact. In addition, *Option a.4* does not decrease the machine energy consumption or the noise, but since the optimisation of the material composition of the motor decreases the motor cost for the manufacturers, the machine price for the consumers and the resources consumption for the environment this Option has been included in the technological development pathway under the overall eco-design approach.

Table 6.38: Simple payback time and net present value (at 15 years, for 220 cycles/year) for the extended technological options applied to the average standard base cases for dishwashers

Washing machines			
Options (n)	**Technology** (description)	**SPB** (years)	**NPV** (€)
a.1	Brushless DC motor (+ control)	32,09	-40,59
a.2	Brushless DC direct drive motor (+ control)	130,35	-179,47
a.3	Three-phase motor	48,13	-70,59
a.4	Optimised motor composition	--	3,00
b	Optimised mechanical action	0,28	54,22
c.1	Sophisticated unbalance control (with separate sensors)	--	-22,50
c.2	Analogue water sensor	1,33	40,72
c.3	Temperature control sensor (and simple unbalance control)	0,35	43,26
d	Rinsing phase optimisation	2,46	48,37
e	Increased load capacity in the same machine	--	-56,70
f.1	high temperature (77°C) water intake (8 litre/cycle)	--	-84,96
f.2	Boiling water/steam cycle (4 litre/cycle)	--	-145,13
k	increase spinning speed, from 1200 to ≥ 1600 rpm	--	-49,37
g	Weight sensors (load control)	3,20	50,46
h	sophisticated electronic controls (fuzzy logic)	27,27	-23,23
i	increased time control: delay start	--	-15,00
j	LCD with actual load display	32,09	-40,59

Table 6.39: Marginal net present value (MNPV, 15years, 220 cycles) for the aggregated option analysis for the extended technological options applied to the average standard base case for washing machines

5kg machine		Consumption		**6kg machine**		Consumption			
Options (n)	MNPV (€)	energy (kWh/cy)	water (litre/cy)	Options (n)	MNPV (€)	energy (kWh/cy)	energy (kWh/kg)	water (litre/cy)	water (litre/kg)
+b	43,37	0,918	49,10	**+b**	43,37	0,918	0,1713	49,10	9,16
+d	37,09	0,918	43,29	**+d**	37,09	0,918	0,1713	43,29	8,08
+c.2	32,44	0,909	39,18	**+c.2**	32,44	0,909	0,1696	39,18	7,31
+g	30,97	0,844	36,40	**+c.3**	7,15	0,900	0,1679	38,71	7,22
+c.3	6,62	0,835	35,96	**+a.4**	3,00	0,900	0,1679	38,71	7,22
+a.4	3,00	0,835	35,96	**+i**	-10,50	0,900	0,1679	38,71	7,22
+i	-10,50	0,835	35,96	**+h**	-12,90	0,893	0,1667	38,33	7,15
+h	-13,32	0,829	35,61	**+c.1**	-21,38	0,893	0,1667	38,33	7,15
+c.1	-21,38	0,829	35,61	**+e**	-33,09	0,944	0,1573*	39,92	6,65*
+a.1	-43,66	0,788	35,61	**+a.1**	-41,44	0,896	0,1494*	39,92	6,65*
+f.1	-67,03	0,956	35,61	**+f.1**	-76,09	1,089	0,1814*	39,92	6,65*
+f.2	-138,46	1,309	35,61	**+f.2**	-157,39	1,490	0,2484*	39,92	6,65*
+k	-47,10	1,365	35,61	**+k**	-50,09	1,554	0,2689*	39,92	6,65*

*for a 6kg load

The resulting energy and water consumption and incremental purchase price for Base Case and $LLCC_{av}$ for the average standard base case are presented in Table 6.40. Also the specific energy consumption "C" for kg of washed load is shown. In the calculation of the LLC also the variation of the detergent dosage due to the modification of the load has been taken into consideration. The energy and water consumption for the average 5kg machine are reduced by 163 Wh/cycle (or 16,4%) to 0,835 kWh/cycle and 14,7 litre/cycle (or 29%) to 36 litre/cycle; the specific consumption per 3,4kg of washed load for the $LLCC_{av}$ is 0,246 (due to the application of *Option g*, which implies also a decrease in the detergent dosage to 110g). When on the contrary the machine load capacity is improved to 6kg (trough the application of *Option e*, which implies also the increase of the detergent dosage to 150g) the $LLCC_{av}$ model has an energy consumption of 0,900 kWh/cycle and a water consumption of 38,7 litre/cycle, with apparently a lower absolute savings compared to the 5kg machine, but the specific energy and water consumption decrease to 0,168 kWh/kg and 7,2 litre/kg respectively for an actual load of 5,36kg. *Option e* is applied after the LLCC point due to its NPV. The forecast increase in purchase price is 9,2% for the 5kg machine and 4,5% for the 6kg machine model. For the latter, the ratio between the predicted increase in purchase price and the efficiency improvement is 0,46.

The LCC is presented in Figure 6.17 for the two machines. The sharp decrease in the life cycle cost between *Option c.2* and *Option g* for the 5kg machine is mainly due to the mentioned decrease in the detergent dosage. When *Option f.1*, *f.2* and *k* are added, due to the associated increase in the washing temperature (the first two options) and the spinning speed (for the latter) also the overall and specific energy consumption increases. In particular, to simplify the analysis, *Option f.1* and *f.2* have been added one after the other, which will hardly happen in real-life.

When the BAT_{av} values are compared (Table 6.41) the influence of the reduced (from 5,36kg to 3,4kg) or increased (from 5,36kg to 6kg) load and the consequent change in the detergent dosage is more evident. It is worth noting that the improved load machine reaches a specific energy consumption of 0,1494 kWh/kg/cycle, which is the "A++" efficiency class machine claimed by some manufacturers (see Task 5). When the Life Cycle Cost (lifetime=15 years, 220 cycles/year) is shown as a function of the energy consumption (kWh/cycle) the curves in Figure 6.18 result. In Figure 6.19 the specific energy consumption of the two machines is presented, to evaluate the affect

Table 6.40: Energy and water consumption and incremental purchase price for washing machine Base Case and LLCCav for the extended standard base case analysis

Extended standard base case	Energy consumption		Water consumption		Specific energy consumption "C" (dir. 95/12/EC)			Purchase price			LCC (15y)	
	Base case (kWh/cycle)	$LLCC_{av}$ (kWh/cycle)	Base case (litre/cycle)	$LLCC_{av}$ (litre/cycle)	Base case C	$LLCC_{av}$ C	difference (%)	Base case (Euro)	$LLCC_{av}$ (Euro)	Increase (%)	Base case (€)	$LLCC_{av}$ (€)
5kg machine	0,998	0,835	50,7	36,0	0,186	0,2456*	-31,9	443,5	480,7	8,4	1.952	1.670
6kg machine	0,998	0,900	50,7	38,7	0,186	0,1679**	9,8	443,5	459,7	3,7	1.952	1.829

*for an actual load of 3,4kg;
**for an actual load of 5,36kg.

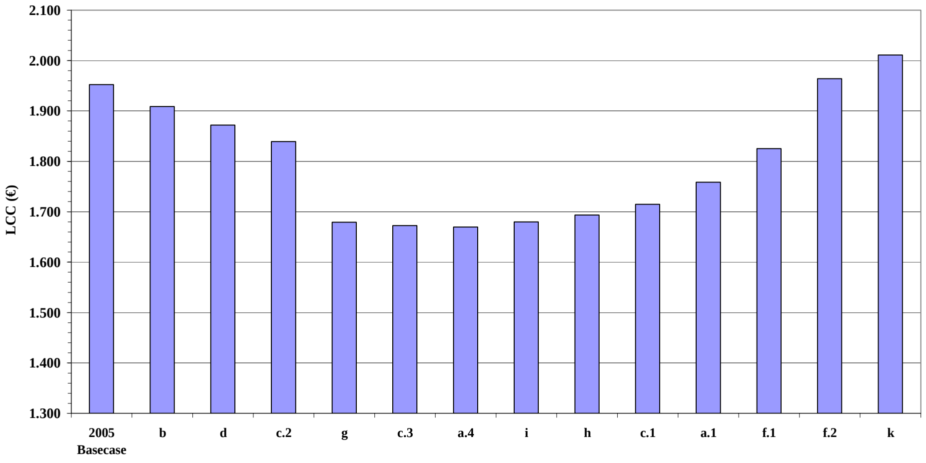
Table 6.41: Energy and water consumption and incremental purchase price for washing machine Base Case and BATav for the extended standard base case analysis

Extended standard base case	Energy consumption		Water consumption		Specific energy consumption "C" (dir. 95/12/EC)			Purchase price			LCC (15y)	
	Base case (kWh/cycle)	BAT_{av} (kWh/cycle)	Base case (litre/cycle)	BAT_{av} (litre/cycle)	Base case C	BAT_{av} C	difference (%)	Base case (Euro)	BAT_{av} (Euro)	Increase (%)	Base case (€)	BAT_{av} (€)
5kg machine	0,998	0,788	50,7	35,6	0,186	0,2317*	-31,9	443,5	588,0	-32,6	1.952	1.758
		0,956				0,2813*	-24,4		589,5	-32,9		1.825
		1,309				0,3851*	-51,1		591,0	-33,3		1.964
		1,365				0,4014*	-106,8		616,5	-39,0		2.011
6kg machine	0,998	0,896	50,7	39,9	0,186	0,1494**	19,8	443,5	570,2	-28,6	1.952	1.993
		1,089				0,1814**	2,6		571,7	-28,9		2.069
		1,490				0,2484**	-33,4		573,2	-29,2		2.226
		1,554				0,2589**	-39,1		598,7	-35,0		2.276

*for an actual load of 3,4kg;
**for an actual load of 6kg.

Figure 6.17: Life Cycle Cost (lifetime = 15 years, 220 cycle/year) as a function of the applied technological options for washing machine extended standard base case analysis

5kg machine



6kg machine

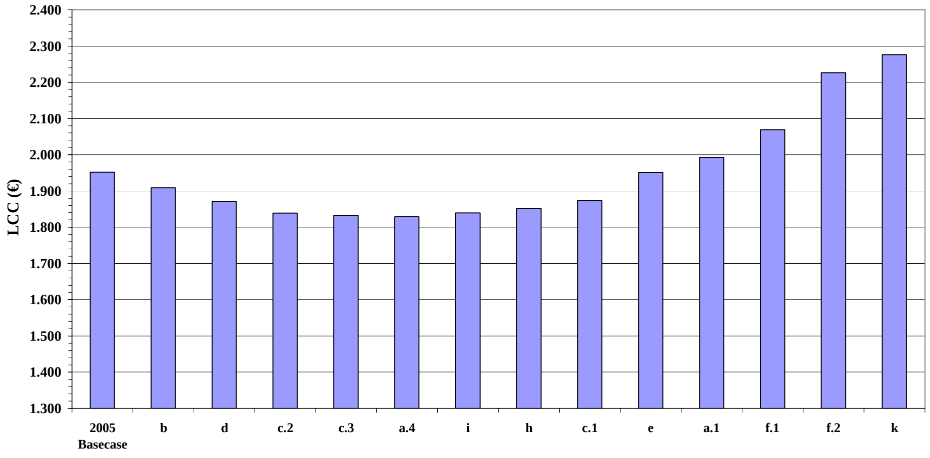


Figure 6.18: Life Cycle Cost (lifetime = 15 years, 220 cycle/year) as a function of the energy consumption for washing machine extended standard base case analysis. Average standard base cases are the first point on each curve where the arrows originate. Appliance base cases are identified by their load capacity. Arrows show the option application sequence.

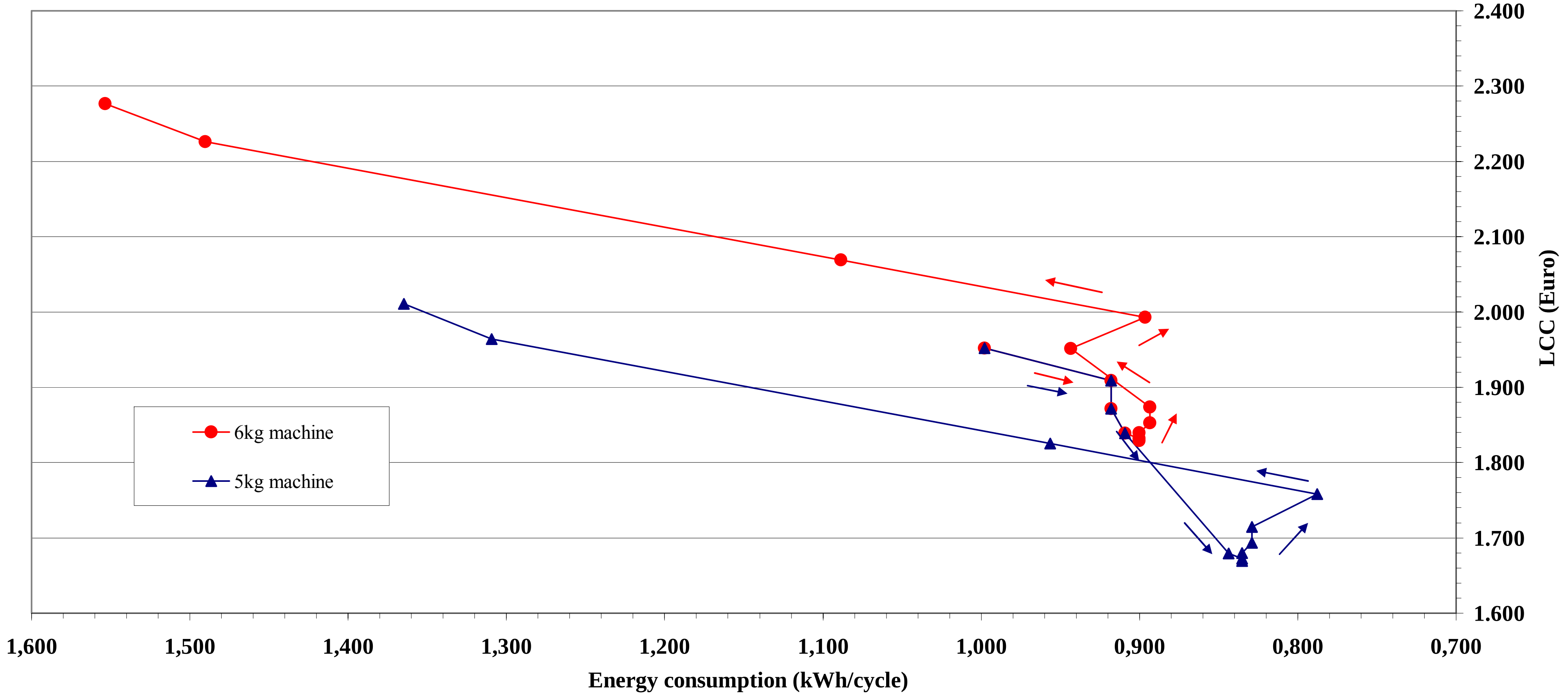
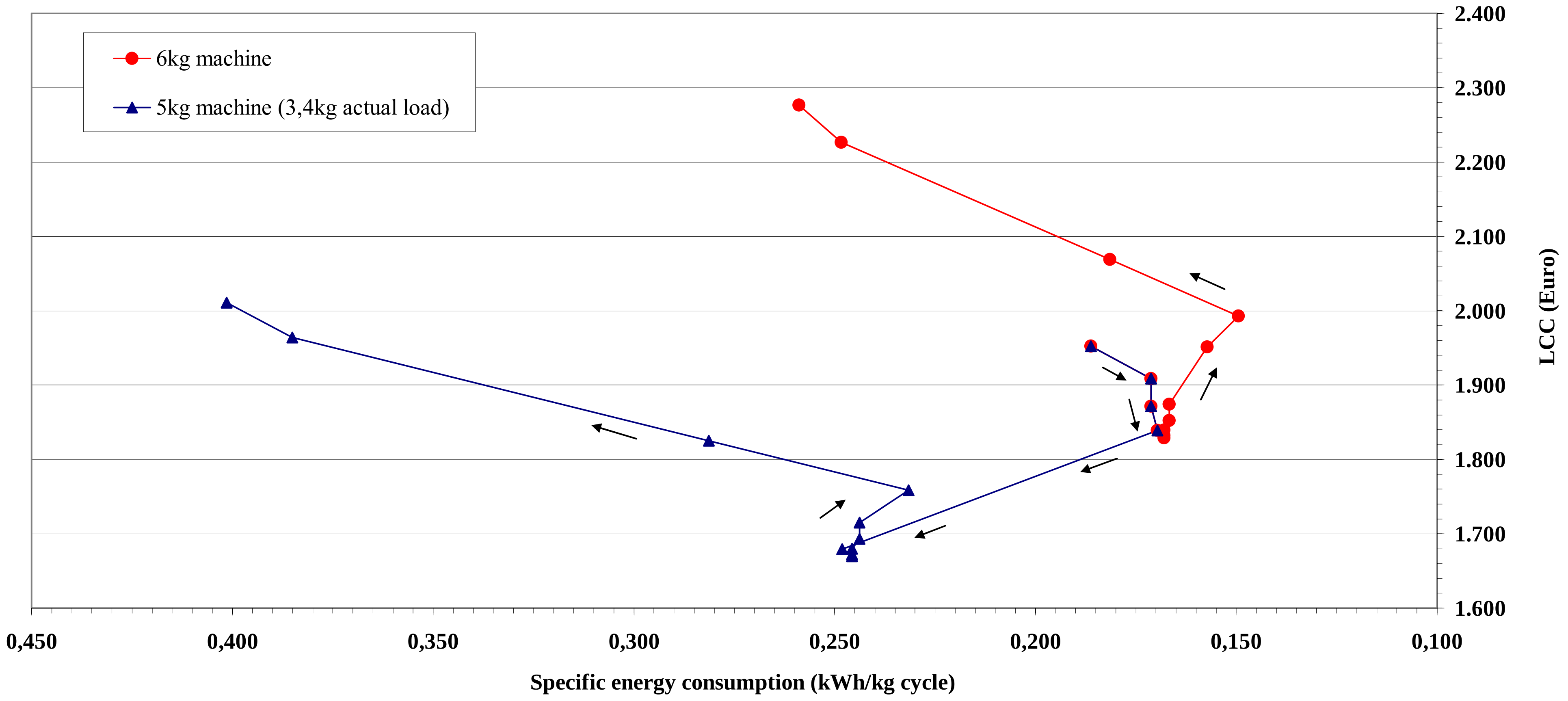


Figure 6.19: Life Cycle Cost (lifetime = 15 years, 220 cycle/year) as a function of the specific energy consumption for washing machine extended standard base case analysis. Average standard base cases are the first point on each curve. Appliance base cases are identified by their load capacity. Arrows show the option application sequence.



of the followed real life technological pathway.

6.4.3.6 Conclusions of the LCC analysis and results comparison for washing machines

The LCC is a means of expressing the overall cost of the appliance from the owner's perspective. It includes both the initial purchase price, the operating expenses for electricity, water and chemicals consumption and the other costs (maintenance, repairs, disposal) amortised to the present. In this approach, the (marginal) net present value of the operating expenses and other costs decrease from one year to the next due to discounting of their current value. Due to the time and budget constraints of the present study, and supported by the analysis of the last available technical database of the washing machine appliance models in 2005, only free-standing base cases were simulated.

A summary of the LCC analyses is presented in Table 6.42 for the $LLCC_{av}$ values and in Table 6.43 where the BAT_{av} values are compared. In the two Tables also the values for the Marginal Payback Time (MPB) have been calculated and are shown. Main results are:

a) The **LCC analysis for the standard base cases** shows that:
- for the average standard base case the LLCC occurs for appliances that are rated "A+" class (for energy efficiency) with C = 0,168 for the 5,36kg machine (the energy efficiency threshold for class A+ in CECED commercial agreement is C ≤ 0,17) and an energy consumption of 0,900 kWh/cycle; the water consumption is 38,7 litre/cycle, 12 litres below the 2005 average; the payback time is 1,2 years;
- the LCC analysis for the standard base case model predicts the energy and water consumption of the best available 6kg washing machine model on the market in 2005/2006 and the best 5kg model available in CECED 2005 technical database both in terms of energy and water consumption. The energy efficiency values for the BAT is C = 0,158 with a noise decreasing to 45d(B)A in washing (from the 53 dB(A) of the standard base case), corresponding to 0,855 kWh/cycle; the water consumption decreases to 37,4 litre/cycle. The value of C increases when the spinning speed is increased to 1 600 rpm, with a corresponding energy consumption of 0,892 kWh/cycle, with no influence on the water consumption and an increase of the spinning noise of 5dB(A);
- the payback time is 6,4 years when the spinning speed is not improved, but raises to 8,9 years when the spinning speed becomes 1 600 rpm, and to 11,6 years when the nominal load capacity of the machine is improved to 6kg;
- the increase in the nominal load capacity (from 5 to 6 kg) is not cost-effective at the overall machine (energy and water consumption) level, but becomes a positive technological development when evaluate considering the specific energy and water consumption (per unit of load weight).

b) The **LCC analysis for the real-life base cases** show that:
- for the LCC analysis of real life base case only the average base case is taken into consideration;
- the average real life machine has an actual washing temperature of 45,8°C, compared to the average standard machine with 60°C;
- for the average real-life base case the least life cycle cost occurs at an energy consumption of 0,649 kWh/cycle and with a water consumption of 33,3 litre/cycle for an actual load of 3,4kg; the payback time is 1,5 years;
- the analysis predicts also an energy and water consumption of the best available models at 0,616 kWh/cycle with a corresponding water consumption of 33,3 litre/cycle for the same 3,4kg load, and a payback time of 8,0 years that become 10,6 when the spinning speed is improved to 1 600 rpm with a contemporary increase of the energy consumption to 0,642 kWh/kg.

c) The **LCC analysis for the extended standard base cases** show that:
- in this analysis, the technological options identified as suitable for the real life will be applied to

the standard base cases (together with the options already identified as applicable for the standard base cases) to evaluate the overall modification of the energy/water consumption when the average machine is used under real-life conditions; a wash cycle with a 64% load (3,4kg) load has been simulated as result of the consumer analysis; a second simulation was run with an increase load capacity of 6kg, to evaluate also the effect of a larger capacity machine; in this case the option allowing the reduced load has not been applied;

- the increase in washing temperature due to a high temperature (77°C) water intake and a boiling water steam cycle have been applied, but not necessarily this will happen contemporarily in real life;
- for the extended standard base case encompassing a load capacity reduction, the least life cycle cost occurs at an energy consumption of 0,835 kWh/cycle with a water consumption of 36 litre/cycle, mainly due to the application of the partial load option, but the specific energy and water consumption is 0,246k Wh/kg/cycle and 10,6 litre/kg/cycle, with a payback time of 1,9y;
- the BAT occurs at an energy consumption of 0,788 kWh/cycle and a water consumption of 35,6 litre/cycle (payback time 7,2 years), which increases to 0,956 kWh/cycle when a high temperature water intake is used for hygiene purposes, with a payback time of 10,6 years. The application of the other options (steam cycle and improved spin speed) increase the energy consumption (but not the water consumption) to a level when the payback time is a nonsense;
- for the extended standard base case with a load increase to 6kg, the LLCC occurs before the improved load capacity option is applied due to its NPV; the payback time is 1,2 years;
- the BAT analysis predicts also the energy and water consumption of the best available model on the market in 2005/2006, which is claimed to reach an A++ energy efficiency class, with a specific energy consumption of 0,1494 kWh/kg/cycle (the claimed threshold of the A++ is below 0,15 kWh/kg/cycle); the payback time of this level is 10,1 years. When other options are added the energy consumption increases to values far above the base case payback time becomes meaningless.

6.4.4 Sensitivity Analysis

The life-cycle cost analysis presented in previous paragraph assumed EU average values for wash appliance prices, lifetime, electricity tariffs and discount rates. As all of these parameters will vary at the Member State level, a sensitivity analysis was performed to determine if the efficiency level associated with the least life-cycle cost might occur at a different level depending on the Member State concerned.

6.4.4.1 The key technical, economic and financial assumption

The key parameters used in the sensitivity analysis for dishwashers and washing machines are:

- <u>Lifetime</u>: 10y, 12y and 17y in addition to the average 15y
- <u>Electricity price</u>: 0,25 €/kWh and 0,10 €/kWh, in addition to the average 0,17 €/kWh
- <u>Water prices</u>: 3,7 Euro/m^3 ±30% or 4,8 Euro/m^3 and 2,6 Euro/m^3
- <u>Discount rate</u>: 4% and 6%, in addition to the average value of 5%
- <u>Cycles per year</u>: 200 and 220 cycle are considered in addition to the 280 used in the LCC for dishwashers
- <u>Average 12ps dishwasher price</u>: 552 € in West EU and 464 € in East EU (average 548,4 €). No price differentiation is possible for 9ps machines, therefore the sensitivity for price was not run
- <u>Cycles per year</u>: 200 and 245 cycle are considered in addition to the 220 used in the LCC for washing machines
- <u>Washing temperature</u>: 40°C cycle will be estimated for washing machines
- <u>Average washing machine price</u>: 562 Euro in West EU and 326 Euro in East EU.
- <u>Disposal and recycling costs</u>: 10€ in addition to the 61€.

Table 6.42: Energy efficiency, energy & water consumption and incremental purchase price for the washing machine Base Case and LLCCav Case

Base case	Energy consumption		Water consumption		Specific energy consumption "C" (dir. 95/12/EC)			Purchase price			LCC (15 years, 220 cycles)		
	Base case (kWh/cycle)	$LLCC_{av}$ (kWh/cycle)	Base case (litre/cycle)	$LLCC_{av}$ (litre/cycle)	Base case C	$LLCC_{av}$ C	difference (%)	Base case (Euro)	$LLCC_{av}$ (Euro)	Increase (%)	Base case (€)	$LLCC_{av}$ (€)	MPB (years)
5kg machine (5,36 kg load)													
Average standard	0,998	0,900	50,7	38,7	0,186	0,168	9,8	443,5	459,7	3,7	1.952	1.829	1,2
Real life	0,719	0,649	43,6	33,3	0,2115	0,1907	9,8	443,5	459,7	3,7	1.655	1.556	1,5
Extended standard	0,998	0,835	50,7	36,0	0,186	0,2456*	-31,9	443,5	480,7	8,4	1.952	1.670	1,9
6kg machine													
Extended standard	0,998	0,900	50,7	38,7	0,186	0,1679**	9,8	443,5	459,7	3,7	1.952	1.829	1,2

*for an actual load of 3,4kg;
**for an actual load of 5,36kg.

Table 6.43: Efficiency, energy & water consumption and incremental purchase price for the washing machine Base Case and BATav Case

Base case	Energy consumption		Water consumption		Specific energy consumption "C" (dir. 95/12/EC)			Purchase price			LCC (15 years, 220 cycles)		
	Base case (kWh/cycle)	BAT_{av} (kWh/cycle)	Base case (litre/cycle)	BAT_{av} (litre/cycle)	Base case C	BAT_{av} C	difference (%)	Base case (Euro)	BAT_{av} (Euro)	Increase (%)	Base case (€)	BAT_{av} (€)	MPB (years)
5kg machine													
Average standard	0,998	0,855	50,7	38,7	0,186	0,1596	14,3	443,5	540,8	21,9	1.952	1.893	6,4
		0,892		38,7		0,1663	10,7		566,3	27,7		1.932	8,9
		0,942		40,3		0,1569	15,7		566,5	27,7		2.010	11,6
Real life	0,719	0,616	43,6	33,3	0,2115	0,1812	14,3	443,5	540,8	21,9	1.655	1.625	8,0
		0,642		33,3		0,1889	10,7		566,3	27,7		1.661	10,9
Extended standard	0,998	0,788	50,7	35,6	0,1862	0,2317*	-31,9	443,5	588,0	-32,6	1.952	1.758	7,2
		0,956				0,2813*	-24,4		589,5	-32,9		1.825	10,6
		1,309				0,3851*	-51,1		591,0	-33,3		1.964	--
		1,365				0,4014*	-106,8		616,5	-39,0		2.011	--
6kg machine													
Extended standard	0,998	0,896	50,7	39,9	0,1862	0,1494**	19,8	443,5	570,2	-28,6	1.952	1.993	10,1
		1,089				0,1814**	2,6		571,7	-28,9		2.069	23,8
		1,490				0,2484**	-33,4		573,2	-29,2		2.226	--
		1,554				0,2589**	-39,1		598,7	-35,0		2.276	--

*for an actual load of 3,4kg;
**for an actual load of 6kg.

In particular:

- number of washing cycles per year: the value of 208 cycle/year has been kept for sake of comparison with previous results, 220 cycle/year is used is the labelling directive, 280 cycle/year was found in a German study made by STIWA in 2003;
- the sales weighted average price of the dishwashers sold in 2004 according GfK was 552 Euro in West EU countries and 464 Euro in East EU countries, with an average of 548,4 Euro for the 13 EU member stated where GfK collected the market data. The 9ps machine price is estimated in 520 Euro;
- the number of cycles per year in a washing machine: 200 is the number of washing cycles considered in the energy labelling directive for a four-person household and forecast for 2010 in the WASH-II study; 222 is the number of cycles used in the WASH-II study; 245 is the number of cycles used in GEA study;
- the sales weighted average price of the washing machines sold in 2004, according GfK, was 562 Euro in West EU countries and 326 Euro in East EU countries, with an average of 443,5 Euro for the 13 EU member stated where GfK collected the market data;
- additional data from literature (Table 6.44) about washing machines lifetime and number of washing cycles were collected by ÖKÖ Institute in 2004[19]. In addition, the scenario analysis (Chapter 9) of the WASH-II study, considered a number of cycles per washing machine around 240-245 per year for the EU. This is not to be confused with the number of cycles per household, which is a bit over 220 cycle/year (not every household owns a washing machine). Both the number of cycles per household and per machine are dropping very slowly. However, the number of wash cycles per capita is rising.

Table 6.44: Washing machine lifetime and number of washing cycles in literature

Study	Materials	Manufacturing	Distribution	Use phase	CED (use phase)/cycle	End of life
Current study [Rüdenauer et al. 2004]	Manufacturer data	Manufacturer data	170 km train 170 km truck	11,4 years life-span with 175 washing cycles per year; 2.000 washing cycles per lifespan	Mix of programs and loading, see section 3.7.2.6	Credits for recycling of materials
Behrendt et al. 2004	Dismantled washing machine	Not specified	750 km train 300 km big truck 30 km small truck	10 years life-span with 240 washing cycles per year; 2.400 washing cycles per life span	Cotton 60°C 5 kg loading (EPD 2001)	Redistribution 150 km train 300 km big truck 30 km small truck
Szczepanowki 2001	Dismantled washing machine	Manufacturer data	Not specified	15 years life-span with 209 washing cycles per year; 3.135 washing cycles per life span	Cotton 60°C (according to European union eco-labelling directive)	Redistribution, shredding, landfill
Ebersperger 1996	Dismantled washing machine	Not specified	Not specified	10 years life-span with 172 washing cycles per year; 1.720 washing cycles per life span	Mix of programs and loading, not specified repair, sewage treatment	Redistribution, shredding and sortation, landfill
Strubel und Gensch 1996	Manufacturer data Multiplied by factor 2 for rejections etc.	Included in materials	150 km train 300 km big truck 30 km small truck	15 years life-span with 180 washing cycles per year; 2.700 washing cycles per life span	Cotton 60°C 4 kg loading	Redistribution, assumptions equal to distribution
Durrant et al. 1991	Manufacturer data	5% of material production (estimation of manufacturers)	300 km truck	14 years life-span with 250 washing cycles per year; 3.500 washing cycles per life span	Mix of hot and economy wash	Shredding (EMPA 1984)

[19] source: ÖKÖ Insitute eV, Eco-Efficiency Analysis of Washing machines – Life Cycle Assessment and determination of optimal life span, Freiburg, November 2nd, 2004, page 51.

6.4.4.2 The sensitivity analysis for dishwashers

The Life Cycle Cost sensitivity analysis has been developed only for the two average standard base cases. The technical and financial assumptions defined in Task 5, were modified, one at time, to evaluate the impact on the LCC output values. It is worth highlighting that in the sensitivity analysis the application order of the technological options is that resulting as the most profitable for the consumers according to the MNPV analysis for the average standard base case and the basic technical and financial assumptions. The variation of parameters such as the energy and water price and the number of cycles per year might have an influence on the optimum technological option combination (corresponding to the LLCC) and more in general to the options application order, but this more sophisticated sensitivity analysis was not compatible with the time and budget constraints of the study.

In Table 6.45 the LCC analyses of the **9ps dishwashers** are presented for the three different values of the annual washing cycle number.

The most important result is that in practice the Least Life Cycle Cost point occurs at the technological option combination (b+f.1+f.2+a.1) for the variation of all the investigated parameters. In fact, only when electricity price is considered 0,10 €/kWh (or 58% of the initial value of 0,17 €/kWh) and the number of washing cycles is 208 then the LLCC occurs for the option combination (b+f.1+f.2) but with a difference of 1 Euro over 15years; the same occurs for a lifetime of 10 years and 220 cycles/year. As expected, there is no effect on the overall LCC results robustness when the disposal and recycling costs are decreased from 61 € to 10 €.

The second most important outcome of the sensitivity analysis is the large variation of the LCC at the LLCC point due to the combination of technical and economical factors: when 208 washing cycles are run per year, the life cycle cost over a lifetime of 10 years is 1.033 Euro; on the contrary when the electricity price is 0,25 €/kWh, the life cycle cost over a lifetime of 17 years is 1.554 Euro, with a difference of 521 Euro.

The same data are presented in Figures 6.20-6.22, respectively for 208, 220 and 280 washing cycles per year, using the same scale for the LCC to allow an immediate comparison of the differences due to the consumer behaviour.

In Table 6.46 the LCC analyses of the **12ps dishwasher**s are presented for the three different values of the annual washing cycle number.

The most important result is that the Least Life Cycle Cost point occurs again at the technological option combination (b+f.1+f.2+a.1) for the variation of all the investigated parameters. As expected, there is no effect on the overall LCC when the disposal and recycling costs are varied from 61€ to 10€. The second most important outcome of the sensitivity analysis is also the large variation of the LCC at the LLCC point due to the combination of technical and economical factors: when 208 washing cycles are run per year, the life cycle cost over a lifetime of 10 years is 1.139 Euro; on the contrary when the electricity price is 0,25 €/kWh, the life cycle cost over a lifetime of 17 years is 1.776 Euro, with a difference of 635 €.
The same data are presented in Figures 6.23-6.25, respectively for 208, 220 and 280 washing cycles per year, using the same scale for the LCC to allow an immediate comparison of the differences due to the consumer behaviour.

To allow an easier understanding of the overall LCC analysis results, the output for the different

Table 6.45: Sensitivity analysis results for the LCC of 9ps dishwashers average standard base case

Technological options			2005	+b	+f.1	+f.2	+a.1	+c	+e.1	+e.2	+g	+h.1	+h.2
cycles per year	Investigated parameters and variations		Base case	Alternating spraying of water	Avoidance/ reduction of the cold pre-rinse	partly draining and refilling of water	Lower wash temperature (45°C) & longer time	Heat exchanger (with sto-rage tank)	condenser for drying	Condenser with fan for drying	DC brushless motor	Noise reduction, level 44 dB(A)	Noise reduction, level 41 dB(A)
LCC results for basic technical and financial assumptions		kWh/cycle litre/cycle g/cycle	0,828 13,7 51	0,798 12,2 51	0,794 11,3 51	0,790 10,3 51	0,782 10,3 51	0,758 10,3 51	0,751 10,3 51	0,741 10,3 51	0,723 9,9 51	0,770 9,9 51	0,851 9,9 51
208	lifetime	10y	1.043	1.043	1.036	1.033	**1.033**	1.050	1.068	1.094	1.165	1.202	1.292
208	lifetime	12y	1.112	1.109	1.101	1.096	1.097	1.113	1.130	1.156	1.226	1.265	1.358
208	lifetime	**15y**	**1.203**	**1.196**	**1.188**	**1.181**	**1.181**	**1.196**	**1.213**	**1.238**	**1.307**	**1.348**	**1.446**
208	lifetime	17y	1.256	1.248	1.238	1.231	1.231	1.245	1.261	1.287	1.354	1.397	1.497
208	water price	€ 4,8	1.235	1.225	1.215	1.206	1.206	1.220	1.237	1.263	1.330	1.372	1.470
208	water price	€ 2,6	1.170	1.167	1.161	1.157	1.157	1.171	1.188	1.214	1.283	1.324	1.422
208	electricity price	€ 0,25	1.346	1.334	1.325	1.318	1.317	1.327	1.343	1.366	1.432	1.481	1.593
208	electricity price	€ 0,10	1.078	1.076	1.068	1.062	1.063	1.081	1.099	1.126	1.198	1.232	1.317
208	discount rate	4%	1.254	1.246	1.236	1.230	1.229	1.243	1.260	1.285	1.353	1.395	1.495
208	discount rate	6%	1.157	1.152	1.144	1.138	1.138	1.153	1.170	1.196	1.265	1.305	1.401
208	disposal&recycling	€ 10	1.178	1.172	1.163	1.157	1.157	1.171	1.188	1.214	1.282	1.324	1.421
220	lifetime	10y	1.069	1.067	1.061	1.056	1.057	1.073	1.091	1.117	1.188	1.225	1.317
220	lifetime	12y	1.141	1.137	1.129	1.124	1.124	1.139	1.157	1.182	1.252	1.291	1.386
220	lifetime	15y	**1.237**	**1.229**	**1.220**	**1.214**	**1.213**	**1.227**	**1.244**	**1.269**	**1.337**	**1.379**	**1.479**
220	lifetime	17y	1.293	1.283	1.274	1.266	1.266	1.279	1.295	1.320	1.387	1.431	1.533
220	water price	€ 4,8	1.272	1.260	1.249	1.239	1.239	1.253	1.270	1.295	1.362	1.404	1.504
220	water price	€ 2,6	1.203	1.199	1.192	1.188	1.187	1.201	1.218	1.243	1.312	1.355	1.454
220	electricity price	€ 0,25	1.388	1.375	1.365	1.358	1.356	1.366	1.381	1.405	1.469	1.520	1.635
220	electricity price	€ 0,10	1.105	1.102	1.093	1.087	1.088	1.106	1.124	1.151	1.222	1.256	1.343
220	discount rate	4%	1.291	1.281	1.271	1.264	1.264	1.277	1.293	1.318	1.386	1.429	1.531
220	discount rate	6%	1.189	1.183	1.174	1.168	1.168	1.183	1.200	1.225	1.294	1.335	1.432
220	disposal&recycling	€ 10	1.213	1.205	1.196	1.189	1.189	1.203	1.220	1.245	1.313	1.355	1.455
280	lifetime	10y	1.197	1.190	1.182	1.176	1.176	1.190	1.207	1.232	1.301	1.342	1.440
280	lifetime	12y	1.288	1.278	1.268	1.261	1.260	1.273	1.290	1.315	1.382	1.426	1.528
280	lifetime	15y	**1.409**	**1.395**	**1.383**	**1.374**	**1.373**	**1.384**	**1.400**	**1.424**	**1.489**	**1.537**	**1.645**
280	lifetime	17y	1.480	1.463	1.451	1.440	1.439	1.449	1.465	1.489	1.553	1.602	1.713
280	water price	€ 4,8	1.453	1.434	1.419	1.407	1.406	1.417	1.433	1.457	1.521	1.568	1.677
280	water price	€ 2,6	1.365	1.356	1.347	1.341	1.340	1.351	1.367	1.391	1.458	1.505	1.613
280	electricity price	€ 0,25	1.602	1.580	1.568	1.558	**1.554**	1.560	1.575	1.597	1.657	1.716	1.843
280	electricity price	€ 0,10	1.241	1.232	1.222	1.213	1.214	1.230	1.247	1.274	1.342	1.380	1.472
280	discount rate	4%	1.475	1.458	1.446	1.436	1.434	1.445	1.461	1.484	1.549	1.597	1.709
280	discount rate	6%	1.350	1.337	1.327	1.318	1.317	1.329	1.346	1.370	1.436	1.482	1.588
280	disposal&recycling	€ 10	1.385	1.370	1.359	1.349	1.348	1.359	1.376	1.400	1.465	1.512	1.620

Figure 6.20: Life Cycle Cost (lifetime = 15 years, 208 cycle/year) as a function of the technological options for 9ps dishwasher sensitivity analysis. Parameters variation is indicated for each curve

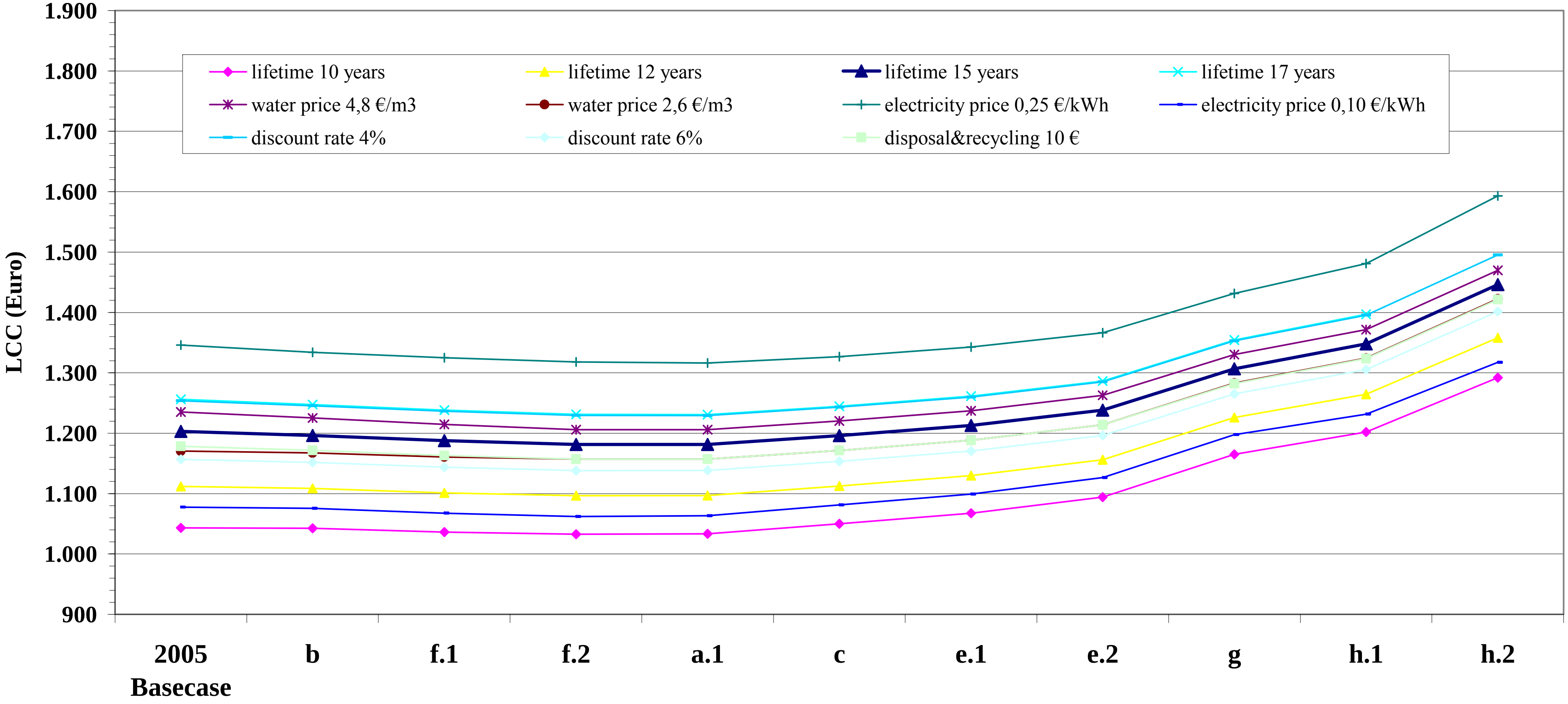


Figure 6.21: Life Cycle Cost (lifetime = 15 years, 220 cycle/year) as a function of the technological options for 9ps dishwasher sensitivity analysis. Parameters variation is indicated for each curve

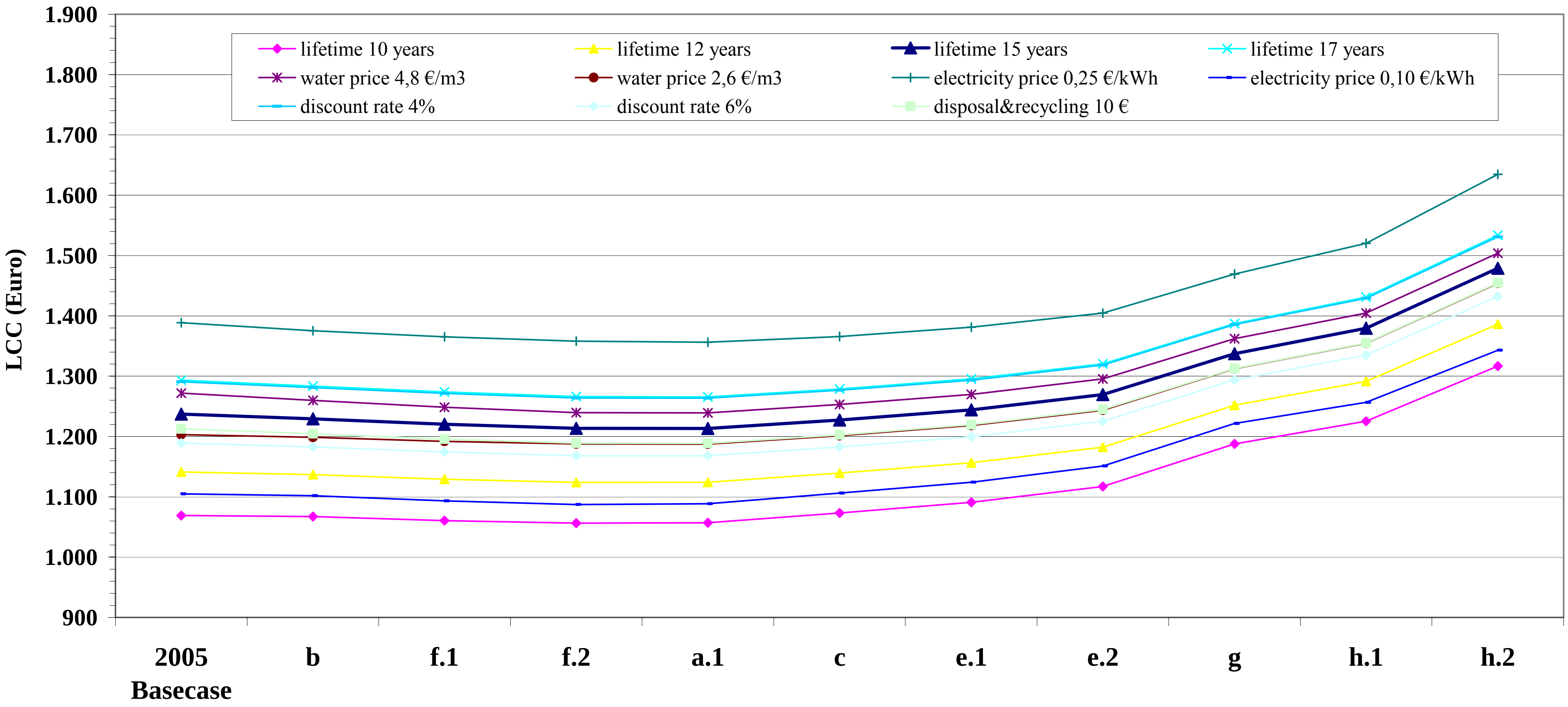


Figure 6.22: Life Cycle Cost (lifetime = 15 years, 280 cycle/year) as a function of the technological options for 9ps dishwasher sensitivity analysis. Parameters variation is indicated for each curve

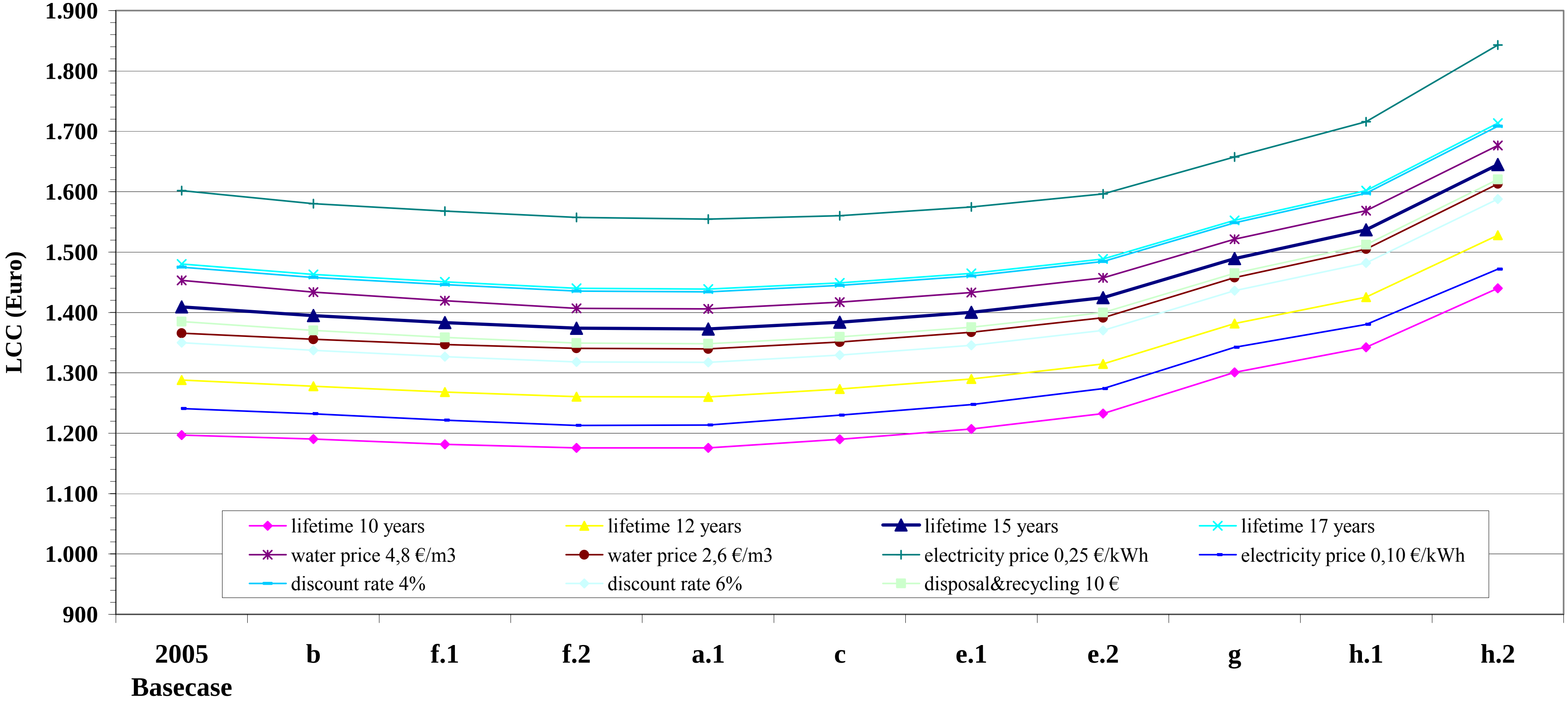


Table 6.46: Sensitivity analysis results for the LCC of 12ps dishwashers average standard base case

Technological options			**2005**	**+b**	**+f.1**	**+f.2**	**+a.1**	**+c**	**+e.1**	**+e.2**	**+d**	**+g**	**+h.1**	**+h.2**
cycles per year	Investigated parameters and variations		**Base case**	Alterna-ting spraying of water	Avoidance/ reduction of the cold pre-rinse	partly draining and refilling of water	Lower wash temperature (45°C) & longer time	Heat exchanger (with sto-rage tank)	Conden-ser for drying	Condenser with fan for drying	Cross flow heat exchanger	DC brushless motor	Noise reduction, level 44 dB(A)	Noise reduction, level 41 dB(A)
LCC results for basic technical and financial assumptions		kWh/cycle litre/cycle g/cycle	1,070 15,2 54	1,028 13,4 54	1,024 12,3 54	1,020 11,0 54	1,009 11,0 54	0,985 11,0 54	0,978 11,0 54	0,968 11,0 54	0,931 11,0 54	0,914 10,6 54	0,975 10,6 54	1,079 10,6 54
208	lifetime	10y	1.158	1.152	1.145	1.139	**1.139**	1.156	1.174	1.200	1.253	1.320	1.365	1.468
208	lifetime	12y	1.239	1.230	1.222	1.215	1.214	1.230	1.247	1.273	1.324	1.390	1.439	1.545
208	lifetime	**15y**	**1.347**	**1.334**	**1.324**	**1.315**	**1.314**	**1.329**	**1.346**	**1.371**	**1.420**	**1.485**	**1.536**	**1.649**
208	lifetime	17y	1.410	1.394	1.384	1.374	1.373	1.386	1.403	1.428	1.476	1.540	1.593	1.709
208	water price	€ 4,8	1.383	1.366	1.353	1.341	1.340	1.355	1.372	1.397	1.446	1.510	1.562	1.674
208	water price	€ 2,6	1.311	1.302	1.295	1.289	1.288	1.302	1.319	1.345	1.394	1.459	1.511	1.623
208	electricity price	€ 0,25	1.532	1.511	1.501	1.491	1.488	1.499	1.514	1.538	1.581	1.643	1.705	1.835
208	electricity price	€ 0,10	1.185	1.178	1.169	1.161	1.162	1.180	1.198	1.225	1.279	1.347	1.389	1.485
208	discount rate	4%	1.406	1.391	1.380	1.371	1.370	1.383	1.400	1.425	1.473	1.537	1.590	1.705
208	discount rate	6%	1.294	1.282	1.273	1.265	1.264	1.279	1.296	1.322	1.372	1.437	1.487	1.597
208	dw price WEU	€ 552	1.351	1.337	1.328	1.319	1.318	1.332	1.349	1.375	1.424	1.488	1.540	1.652
208	dw price EEU	€ 464	1.263	1.249	1.240	1.231	1.230	1.244	1.261	1.287	1.336	1.400	1.452	1.564
208	disposal&recycling	€ 10	1.189	1.182	1.174	1.168	1.168	1.184	1.201	1.228	1.280	1.346	1.393	1.497
220	lifetime	10y	1.189	1.182	1.174	1.168	1.168	1.184	1.201	1.228	1.280	1.346	1.393	1.497
220	lifetime	12y	1.274	1.264	1.255	1.247	1.247	1.262	1.279	1.305	1.355	1.421	1.470	1.579
220	lifetime	**15y**	**1.388**	**1.373**	**1.363**	**1.353**	**1.352**	**1.366**	**1.383**	**1.408**	**1.456**	**1.520**	**1.573**	**1.688**
220	lifetime	17y	1.455	1.437	1.426	1.415	1.414	1.427	1.443	1.468	1.516	1.579	1.634	1.751
220	water price	€ 4,8	1.426	1.407	1.394	1.381	1.380	1.394	1.411	1.436	1.484	1.547	1.600	1.714
220	water price	€ 2,6	1.350	1.339	1.332	1.326	1.324	1.338	1.355	1.380	1.429	1.494	1.547	1.661
220	electricity price	€ 0,25	1.584	1.561	1.550	1.540	1.536	1.546	1.561	1.585	1.627	1.687	1.751	1.885
220	electricity price	€ 0,10	1.217	1.209	1.199	1.190	1.191	1.209	1.226	1.253	1.307	1.374	1.417	1.515
220	discount rate	4%	1.450	1.433	1.422	1.412	1.410	1.423	1.440	1.465	1.512	1.576	1.630	1.747
220	discount rate	6%	1.332	1.319	1.309	1.301	1.300	1.314	1.331	1.357	1.406	1.471	1.522	1.634
220	dw price WEU	€ 552	1.392	1.377	1.366	1.357	1.356	1.370	1.386	1.412	1.460	1.524	1.577	1.691
220	dw price EEU	€ 464	1.304	1.289	1.278	1.269	1.268	1.282	1.298	1.324	1.372	1.436	1.489	1.603
220	disposal&recycling	€ 10	1.364	1.349	1.338	1.329	1.328	1.341	1.358	1.384	1.432	1.496	1.549	1.663
280	lifetime	10y	1.342	1.328	1.318	1.310	1.308	1.323	1.340	1.365	1.414	1.479	1.531	1.643
280	lifetime	12y	1.450	1.432	1.420	1.410	1.408	1.421	1.438	1.463	1.510	1.573	1.628	1.746
280	lifetime	**15y**	**1.594**	**1.570**	**1.557**	**1.544**	**1.542**	**1.553**	**1.569**	**1.593**	**1.638**	**1.699**	**1.758**	**1.884**
280	lifetime	17y	1.678	1.651	1.637	1.622	1.619	1.630	1.646	1.669	1.712	1.772	1.834	1.964

Technological options				+b	+f.1	+f.2	+a.1	+c	+e.1	+e.2	+d	+g	+h.1	+h.2
cycles per year	Investigated parameters and variations		**2005 Base case**	Alterna-ting spraying of water	Avoidance/ reduction of the cold pre-rinse	partly draining and refilling of water	Lower wash temperature (45°C) & longer time	Heat exchanger (with sto-rage tank)	Conden-ser for drying	Condenser with fan for drying	Cross flow heat exchanger	DC brushless motor	Noise reduction, level 44 dB(A)	Noise reduction, level 41 dB(A)
280	water price	€ 4,8	1.642	1.613	1.596	1.579	1.577	1.588	1.604	1.628	1.673	1.733	1.792	1.918
280	water price	€ 2,6	1.545	1.527	1.517	1.509	1.506	1.518	1.534	1.558	1.602	1.665	1.724	1.850
280	electricity price	€ 0,25	1.843	1.809	1.795	1.781	**1.776**	1.782	1.796	1.818	1.854	1.911	1.985	2.135
280	electricity price	€ 0,10	1.376	1.361	1.348	1.336	1.336	1.352	1.370	1.396	1.448	1.513	1.560	1.664
280	discount rate	4%	1.671	1.644	1.630	1.616	1.613	1.623	1.639	1.663	1.706	1.767	1.828	1.957
280	discount rate	6%	1.525	1.503	1.491	1.479	1.477	1.489	1.505	1.530	1.576	1.638	1.695	1.817
280	dw price WEU	€ 552	1.597	1.574	1.560	1.548	1.545	1.556	1.573	1.597	1.641	1.702	1.762	1.887
280	dw price EEU	€ 464	1.509	1.486	1.472	1.460	1.457	1.468	1.485	1.509	1.553	1.614	1.674	1.799
280	disposal&recycling	€ 10	1.569	1.546	1.532	1.519	1.517	1.528	1.544	1.569	1.613	1.674	1.734	1.859

Figure 6.23: Life Cycle Cost (lifetime = 15 years, 208 cycle/year) as a function of the technological options for 12ps dishwasher sensitivity analysis. Parameters variation is indicated for each curve

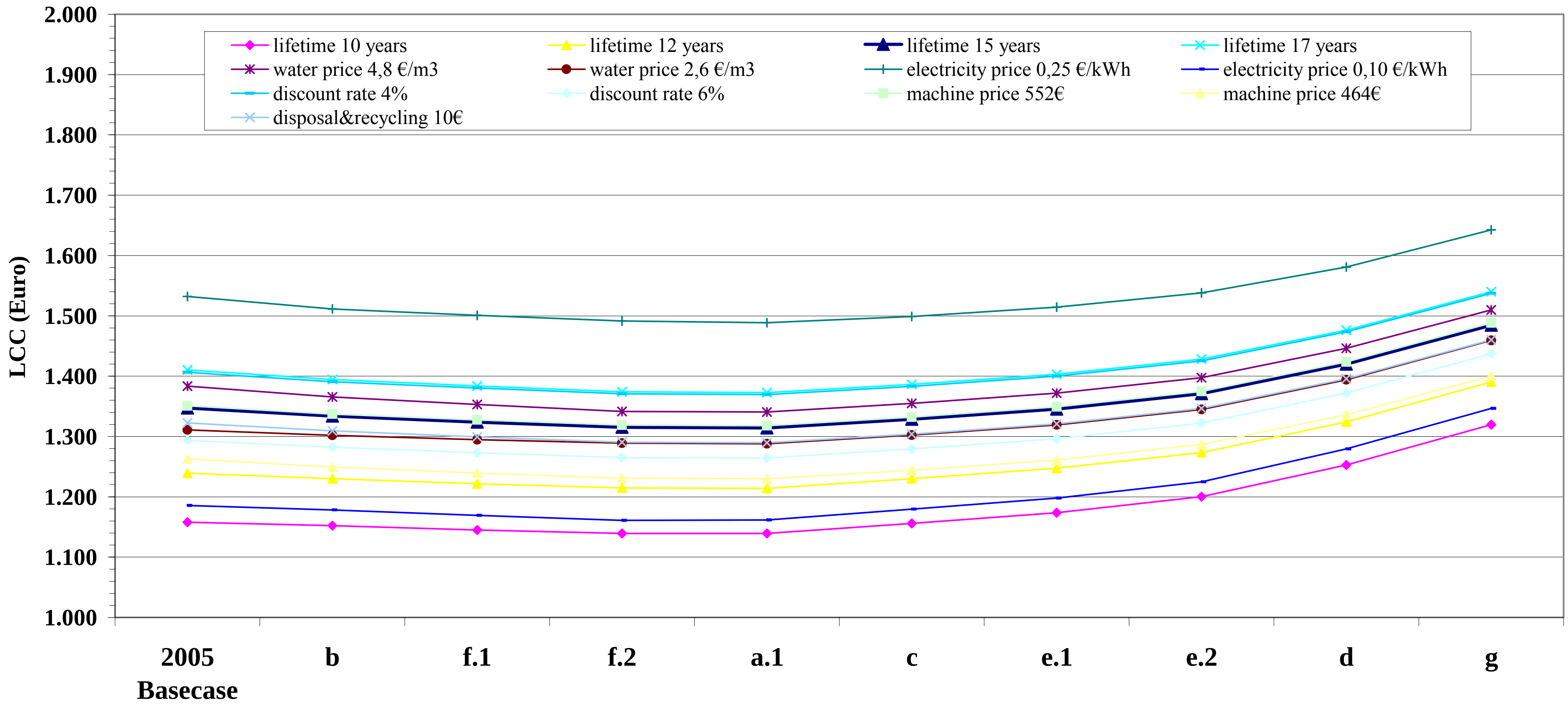


Figure 6.24: Life Cycle Cost (lifetime = 15 years, 220 cycle/year) as a function of the technological options for 12ps dishwasher sensitivity analysis. Parameters variation is indicated for each curve

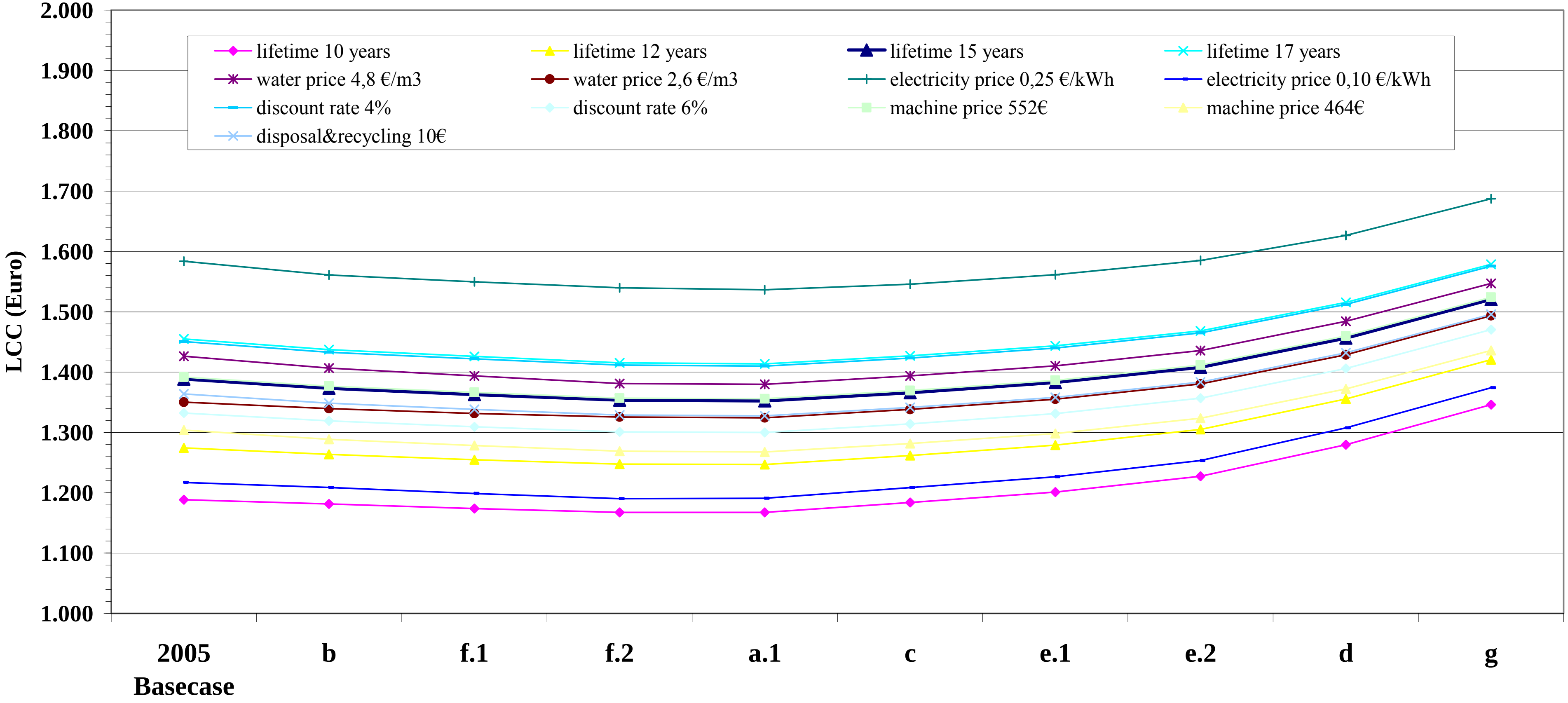
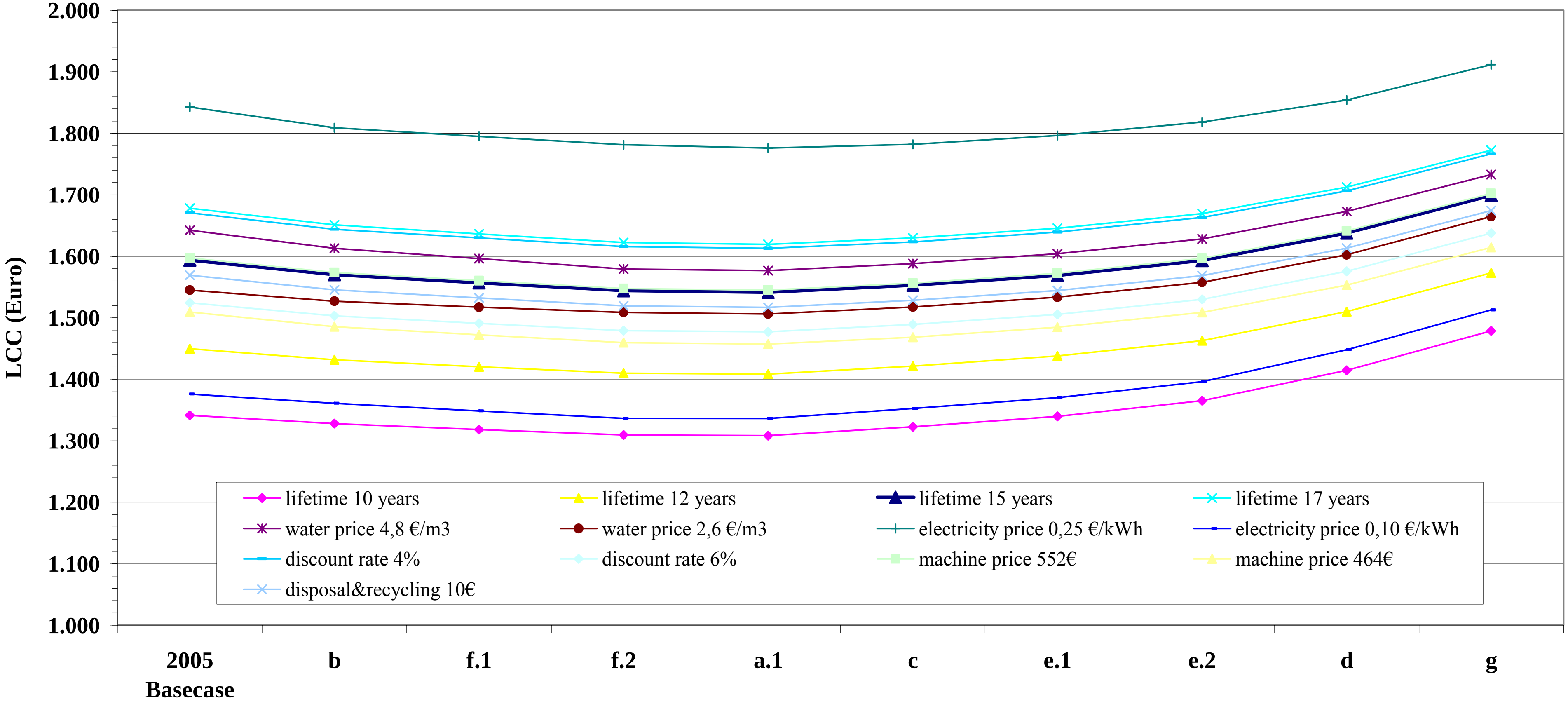


Figure 6.25: Life Cycle Cost (lifetime = 15 years, 280 cycle/year) as a function of the technological options for 12ps dishwasher sensitivity analysis. Parameters variation is indicated for each curve



number of washing cycles per year and lifetimes are compared in Table 6.47 for the 9ps machine. The standard base case, the $LLCC_{av}$, and the BAT_{av} case with noise values of 50 dB(A), 44 dB(A) and 41 dB(A) are presented. Table 6.48 shows the derived annual savings to the average standard base case for the 9ps dishwashers at a different number of washing cycles per year with an energy price of 0,17 €/kWh and a water price of 3,7 €/m^3. The energy savings going from the average standard base case to the $LLCC_{av}$ are in the range 1,6-2,2 €/year depending on the annual washing cycles, the water savings in the range 2,6-3,6 €/year, for a total of 4,2-5,7 €/year against an increase in purchase price of 23 Euro; the energy savings going from the average standard base case to the BAT_{av} at 50 dB(A) are in the range 3,7-5,0 €/year and the water savings in the range 2,8-3,8 €/year, for a total of 6,6-8,8 €/year against an increase in purchase price of 173 Euro. When the noise is decrease to 41 dB(A) there is a slight increase of the energy expenses (-0,8-1,1 €/year), while the water savings are in the range 2,8-3,8 €/year, with a price increase of 265 €.

The same analysis is given in Tables 6.49 and 6.50 for the 12ps machine. The energy savings going from the average standard base case to the $LLCC_{av}$ are in the range 2,2-2,9 €/year depending on the annual washing cycles, the water savings in the range 3,2-4,4 €/year, for a total of 5,4-7,3 €/year against an increase in purchase price of 23 €; the energy savings going from the average standard base case to the BAT_{av} at 50 dB(A) are in the range 5,5-7,4 €/year depending on the annual washing cycles and the water savings in the range 3,5-4,8 €/year, for a total of 9,1-12,2 €/year against an increase in purchase price of 231 €. When the noise is decrease to 41 dB(A) there is no energy savings, while the water savings are in the range 3,5-4,8 €/year, with a price increase of 335 €.

6.4.4.3 The sensitivity analysis for washing machines

a) The 60 °C washing temperature cycle

In Table 6.51 the LCC analyses of the 5,36 washing machine are presented for the three different values of the annual washing cycle number. The most important result is that the Least Life Cycle Cost point occurs at the technological option combination (b+d+c.2+c.3+a.4) for the variation of all the investigated parameters. As in the case of dishwashers, there is no effect on the overall LCC when the disposal and recycling costs are varied up to negative values (costs turned into profits). The second most important outcome of the sensitivity analysis is the large variation of the LCC at the LLCC point due to the combination of technical and economical factors: when 200 washing cycles are run per year, the life cycle cost over a lifetime of 10 years is 1.411 €; on the contrary when the electricity price is 0,25 €/kWh, the life cycle cost over a lifetime of 17 years is 2.162 Euro, with a difference of 751 €. The same data are presented in Figures 6.26-6.28, respectively for 200, 220 and 245 washing cycles per year, using the same scale for the LCC to allow an immediate comparison of the differences due to the consumer behaviour.

LCC analysis output for the different amounts of washing cycles per year and lifetimes are compared in Table 6.52. The Standard base case, the $LLCC_{av}$, and the BAT_{av} for 5,36kg and 6kg load are presented as well as for the machine with a spin speed of 1 600 rpm. Table 6.53 presents the annual energy and water savings over the average standard base case. The energy savings for the $LLCC_{av}$ are in the range 3,3-4,1 €/year depending on the annual washing cycles, the water savings[20] in the range 8,9-10,9 €/year, for a total of 12,2-15,0 €/year against an increase in purchase price of 16 € the energy savings going from the average standard base case to the BAT_{av} are in the range 4,95-6,0 €/year and the water savings in the range 8,9-10,9 €/year, for a total of 13,7-16,8 €/year against an increase in purchase price of 97 €. When the spin speed is increased to 1 600 rpm or when the capacity increases to 6kg the savings decrease and the price increase of 123 €.

[20] the modification of the rinsing performance (if any) due to the decrease of the water consumption is not known.

Table 6.47: Comparison of the Life Cycle Costs for 9ps dishwashers

Washing cycles per year (n)	Consumer price (€)	Energy consumption (kWh/cycle)	Energy costs (€/year)	Water consumption (litre/cycle)	Water costs (€/year)	Chemicals costs (€/year)	LCC at 10 years (€)	LCC at 12 years (€)	LCC at 15 years (€)	LCC at 17 years (€)
9ps average standard base case										
208	520	0,828	29,28	13,70	10,54	17,63	1.044	1.112	1.203	1.256
220	520	0,828	30,97	13,70	11,15	18,65	1.069	1.141	1.237	1.294
280	520	0,828	39,41	13,70	14,19	23,74	1.197	1.288	1.409	1.481
$LLCC_{av}$										
208	542,7	0,782	27,65	10,3	7,93	17,63	1.034	1.097	1.181	1.231
220	542,7	0,782	29,25	10,3	8,38	18,65	1.057	1.124	1.213	1.266
280	542,7	0,782	37,22	10,3	10,67	23,74	1.176	1.260	1.373	1.439
BAT_{av}, 50dB(A)										
208	692,6	0,723	25,57	9,9	7,70	17,63	1.165	1.226	1.307	1.354
220	692,6	0,723	27,04	9,9	8,14	18,65	1.188	1.252	1.337	1.387
280	692,6	0,723	34,41	9,9	10,36	23,74	1.301	1.382	1.489	1.552
BAT_{av}, 44 dB(A)										
208	716,6	0,770	27,23	9,9	7,70	17,63	1.202	1.264	1.348	1.397
220	716,6	0,770	28,80	9,9	8,14	18,65	1.225	1.291	1.379	1.431
280	716,6	0,770	36,65	9,9	10,36	23,74	1.342	1.425	1.536	1.602
BAT_{av}, 41 dB(A)										
208	784,7	0,851	30,09	9,9	7,70	17,63	1.292	1.358	1.446	1.497
220	784,7	0,851	31,83	9,9	8,14	18,65	1.317	1.386	1.479	1.533
280	784,7	0,851	40,51	9,9	10,36	23,74	1.440	1.528	1.644	1.713

Table 6.48: Savings to the average standard base case for the 9ps dishwashers at different values of lifetime and washing cycles per year

Washing cycles per year (n)	Difference in consumer price (€)	Energy savings (kWh/cycle)	Energy savings (€/year)	Water savings (litre/cycle)	Water savings (€/year)	Chemicals cost savings (€/year)	Δ_{LCC} at 10 years (€)	Δ_{LCC} at 12 years (€)	Δ_{LCC} at 15 years (€)	Δ_{LCC} at 17 years (€)
$LLCC_{av}$										
208	-22,70	0,046	1,63	3,4	2,61	--	10	15	22	25
220	-22,70	0,046	1,72	3,4	2,77	--	12	17	24	28
280	-22,70	0,046	2,19	3,4	3,52	--	21	28	36	42
BAT_{av}, 50dB(A)										
208	-172,60	0,105	3,71	3,8	2,84	--	-121	-114	-104	-98
220	-172,60	0,105	3,93	3,8	3,01	--	-119	-111	-100	-93
280	-172,60	0,105	5,00	3,8	3,83	--	-104	-94	-80	-71
BAT_{av}, 44 dB(A)										
208	-196,60	0,058	2,05	3,8	2,84	--	-158	-152	-145	-141
220	-196,60	0,058	2,17	3,8	3,01	--	-156	-150	-142	-137
280	-196,60	0,058	2,76	3,8	3,83	--	-145	-137	-127	-121
BAT_{av}, 41 dB(A)										
208	-264,70	-0,023	-0,81	3,8	2,84	--	-248	-246	-243	-241
220	-264,70	-0,023	-0,86	3,8	3,01	--	-248	-245	-242	-239
280	-264,70	-0,023	-1,10	3,8	3,83	--	-243	-240	-235	-232

Table 6.49: Comparison of the Life Cycle Costs for 12ps dishwashers

Washing cycles per year (n)	Consumer price (€)	Energy consumption (kWh/cycle)	Energy costs (€/year)	Water consumption (litre/cycle)	Water costs (€/year)	Chemicals costs (€/year)	LCC at 10 years (€)	LCC at 12 years (€)	LCC at 15 years (€)	LCC at 17 years (€)
12ps average standard base case										
208	548,4	1,070	37,84	15,20	11,70	19,09	1.158	1.239	1.347	1.411
220	548,4	1,070	40,02	15,20	12,37	20,20	1.189	1.274	1.388	1.455
280	548,4	1,070	50,93	15,20	15,75	25,70	1.342	1.450	1.594	1.679
$LLCC_{av}$										
208	571,1	1,009	35,68	11,0	8,47	19,09	1.139	1.214	1.314	1.373
220	571,1	1,009	37,74	11,0	8,95	20,20	1.167	1.247	1.352	1.414
280	571,1	1,009	48,03	11,0	11,40	25,70	1.308	1.408	1.541	1.619
BAT_{av}, 50dB(A)										
208	779,5	0,914	32,32	10,6	8,16	19,09	1.319	1.390	1.484	1.540
220	779,5	0,914	34,18	10,6	8,63	20,20	1.346	1.421	1.520	1.578
280	779,5	0,914	43,51	10,6	10,98	25,70	1.479	1.573	1.698	1.772
BAT_{av}, 44 dB(A)										
208	808,8	0,975	34,48	10,6	8,16	19,09	1.365	1.439	1.536	1.593
220	808,8	0,975	36,47	10,6	8,63	20,20	1.393	1.470	1.573	1.634
280	808,8	0,975	46,41	10,6	10,98	25,70	1.530	1.628	1.758	1.834
BAT_{av}, 41 dB(A)										
208	882,9	1,079	38,15	10,6	8,16	19,09	1.468	1.545	1.648	1.709
220	882,9	1,079	40,35	10,6	8,63	20,20	1.497	1.579	1.687	1.751
280	882,9	1,079	51,36	10,6	10,98	25,70	1.643	1.746	1.883	1.964

Table 6.50: Savings to the average standard base case for the 12ps dishwashers at different values of lifetime and washing cycles per year

Washing cycles per year (n)	Difference in consumer price (€)	Energy savings (kWh/cycle)	Energy savings (€/year)	Water savings (litre/cycle)	Water savings (€/year)	Chemicals cost savings (€/year)	Δ_{LCC} at 10 years (€)	Δ_{LCC} at 12 years (€)	Δ_{LCC} at 15 years (€)	Δ_{LCC} at 17 years (€)
$LLCC_{av}$										
208	-22,70	0,061	2,16	4,2	3,23	--	19	25	33	38
220	-22,70	0,061	2,28	4,2	3,42	--	22	27	36	41
280	-22,70	0,061	2,90	4,2	4,35	--	34	42	53	60
BAT_{av}, 50dB(A)										
208	-231,10	0,156	5,52	4,6	3,54	--	-161	-151	-137	-129
220	-231,10	0,156	5,84	4,6	3,74	--	-157	-147	-132	-123
280	-231,10	0,156	7,42	4,6	4,77	--	-137	-123	-104	-93
BAT_{av}, 44 dB(A)										
208	-260,40	0,095	3,36	4,6	3,54	--	-207	-200	-189	-182
220	-260,40	0,095	3,55	4,6	3,74	--	-204	-196	-185	-179
280	-260,40	0,095	4,52	4,6	4,77	--	-188	-178	-164	-155
BAT_{av}, 41 dB(A)										
208	-334,50	-0,009	-0,31	4,6	3,54	--	-310	-306	-301	-298
220	-334,50	-0,009	-0,33	4,6	3,74	--	-308	-305	-299	-296
280	-334,50	-0,009	-0,43	4,6	4,77	--	-301	-296	-289	-285

Table 6.51: Sensitivity analysis results for the LCC of washing machine average standard base case

Technological options				+b	+d	+c.2	+c.3	+a.4	+c.1	+a.1	+k	+e
cycles per year	Investigated parameters and variations		**2005 Base case**	Optimised mechanical action	Rinsing phase optimisation	Analogue water sensor	Temperature control sensor (and simple unbalance control)	Optimised motor composition	Sophisticated unbalance control (with separate sensors)	Brushless DC motor (+ control)	increase spinning speed, from 1200 to 1600 rpm	Increased load capacity in the same machine
LCC results for basic technical and financial assumptions		kWh/cycle litre/cycle g/cycle	0,998 50,7 139,76	0,918 49,1 139,76	0,918 43,3 139,76	0,909 39,2 139,76	0,900 38,7 139,76	0,900 38,7 139,76	0,900 38,7 139,76	0,855 38,7 139,76	0,898 38,7 139,76	0,948 40,3 150,0
200	lifetime	10y	1.456	1.435	1.415	1.410	1.407	1.428	1.476	1.511	1.564	1.456
200	lifetime	12y	1.596	1.570	1.546	1.541	1.538	1.559	1.605	1.642	1.702	1.596
200	lifetime	**15y**	**1.784**	**1.751**	**1.722**	**1.715**	**1.712**	**1.734**	**1.778**	**1.816**	**1.887**	**1.784**
200	lifetime	17y	1.893	1.857	1.825	1.818	1.815	1.836	1.878	1.918	1.995	1.893
200	water price	€ 4,8	1.896	1.850	1.811	1.804	1.801	1.822	1.866	1.904	1.979	1.896
200	water price	€ 2,6	1.671	1.652	1.632	1.627	1.624	1.645	1.689	1.728	1.795	1.671
200	electricity price	€ 0,25	1.936	1.903	1.873	1.865	1.862	1.883	1.920	1.964	2.043	1.936
200	electricity price	€ 0,10	1.650	1.617	1.590	1.585	1.582	1.603	1.653	1.686	1.750	1.650
200	discount rate	4%	1.881	1.845	1.814	1.807	1.804	1.825	1.868	1.907	1.983	1.881
200	discount rate	6%	1.695	1.666	1.639	1.633	1.630	1.651	1.696	1.734	1.800	1.695
200	wm price WEU	€ 562	1.902	1.869	1.840	1.834	1.831	1.852	1.896	1.935	2.005	1.902
200	wm price EEU	€ 326	1.666	1.633	1.604	1.598	1.595	1.616	1.660	1.699	1.769	1.666
200	disposal&recycling	€ 10	1.798	1.759	1.726	1.697	1.691	1.688	1.709	1.753	1.791	1.862
220	lifetime	10y	1.549	1.525	1.502	1.497	1.494	1.515	1.562	1.598	1.656	1.549
220	lifetime	12y	1.703	1.673	1.647	1.640	1.637	1.659	1.704	1.741	1.808	1.703
220	lifetime	**15y**	**1.909**	**1.872**	**1.839**	**1.832**	**1.829**	**1.850**	**1.893**	**1.932**	**2.010**	**1.909**
220	lifetime	17y	2.029	1.988	1.952	1.944	1.941	1.963	2.003	2.044	2.128	2.029
220	water price	€ 4,8	2.032	1.980	1.938	1.929	1.926	1.948	1.990	2.030	2.111	2.032
220	water price	€ 2,6	1.785	1.763	1.741	1.735	1.732	1.753	1.795	1.835	1.909	1.785
220	electricity price	€ 0,25	2.076	2.039	2.005	1.997	1.994	2.015	2.049	2.095	2.182	2.076
220	electricity price	€ 0,10	1.762	1.725	1.694	1.688	1.685	1.707	1.756	1.790	1.859	1.762
220	discount rate	4%	2.015	1.975	1.940	1.932	1.929	1.950	1.991	2.032	2.115	2.015
220	discount rate	6%	1.813	1.779	1.749	1.742	1.739	1.760	1.804	1.842	1.915	1.813
220	wm price WEU	€ 562	2.027	1.990	1.958	1.951	1.948	1.969	2.011	2.051	2.128	2.027
220	wm price EEU	€ 326	1.791	1.754	1.722	1.715	1.712	1.733	1.775	1.815	1.892	1.791
220	disposal&recycling	€ 10	1.928	1.884	1.847	1.815	1.808	1.805	1.826	1.868	1.908	1.985
245	lifetime	10y	1.666	1.637	1.611	1.605	1.602	1.624	1.669	1.706	1.770	1.666
245	lifetime	12y	1.837	1.802	1.772	1.765	1.762	1.783	1.826	1.865	1.939	1.837
245	lifetime	**15y**	**2.065**	**2.023**	**1.986**	**1.978**	**1.975**	**1.996**	**2.037**	**2.078**	**2.164**	**2.065**

Technological options			2005 Base case	+b Optimised mechanical action	+d Rinsing phase optimisation	+c.2 Analogue water sensor	+c.3 Temperature control sensor (and simple unbalance control)	+a.4 Optimised motor composition	+c.1 Sophisticated unbalance control (with separate sensors)	+a.1 Brushless DC motor (+ control)	+k increase spinning speed, from 1200 to 1600 rpm	+e Increased load capacity in the same machine
cycles per year	Investigated parameters and variations											
LCC results for basic technical and financial assumptions		kWh/cycle	0,998	0,918	0,918	0,909	0,900	0,900	0,900	0,855	0,898	0,948
		litre/cycle	50,7	49,1	43,3	39,2	38,7	38,7	38,7	38,7	38,7	40,3
		g/cycle	139,76	139,76	139,76	139,76	139,76	139,76	139,76	139,76	139,76	150,0
245	lifetime	17y	2.199	2.152	2.111	2.103	2.100	2.121	2.160	2.202	2.296	2.199
245	water price	€ 4,8	2.203	2.144	2.095	2.086	2.083	2.105	2.145	2.186	2.277	2.203
245	water price	€ 2,6	1.928	1.902	1.876	1.870	1.867	1.888	1.928	1.969	2.051	1.928
245	electricity price	€ 0,25	2.252	2.209	2.171	2.161	**2.158**	2.179	2.211	2.259	2.356	2.252
245	electricity price	€ 0,10	1.902	1.859	1.824	1.818	1.815	1.836	1.884	1.919	1.997	1.902
245	discount rate	4%	2.183	2.136	2.097	2.088	2.085	2.106	2.145	2.188	2.280	2.183
245	discount rate	6%	1.959	1.920	1.886	1.878	1.875	1.897	1.938	1.979	2.059	1.959
245	wm price WEU	€ 562	2.184	2.141	2.104	2.096	2.093	2.115	2.155	2.196	2.283	2.184
245	wm price EEU	€ 326	1.948	1.905	1.868	1.860	1.857	1.879	1.919	1.960	2.047	1.948
245	disposal&recycling	€ 10	2.089	2.041	1.998	1.961	1.953	1.950	1.972	2.012	2.053	2.140

Figure 6.26: Life Cycle Cost as a function of the technological options for washing machine sensitivity analysis. Parameters variation is indicated for each curve. Base: lifetime = 15 years, 200 cycle/year.

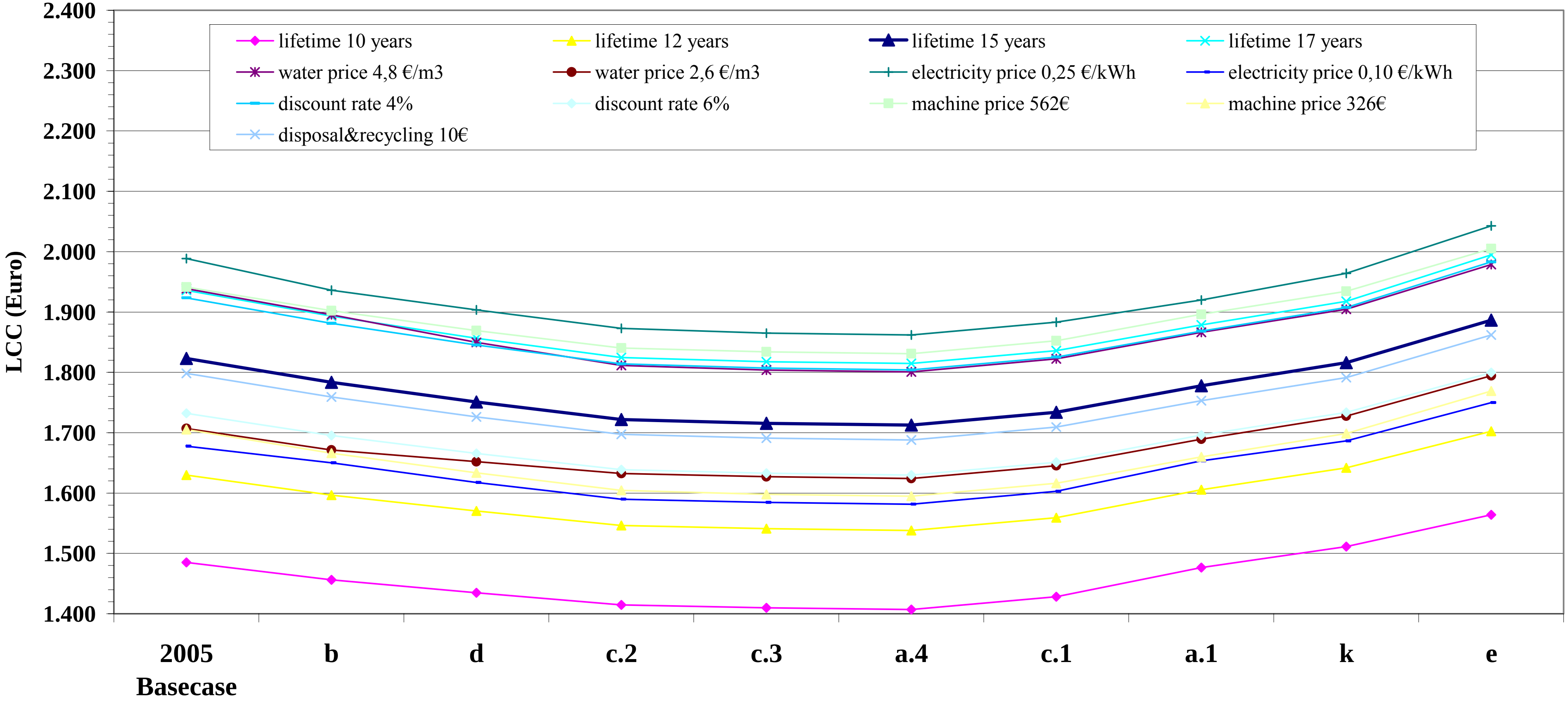


Figure 6.27: Life Cycle Cost as a function of the technological options for washing machine sensitivity analysis. Parameters variation is indicated for each curve. Base: lifetime = 15 years, 220 cycle/year.

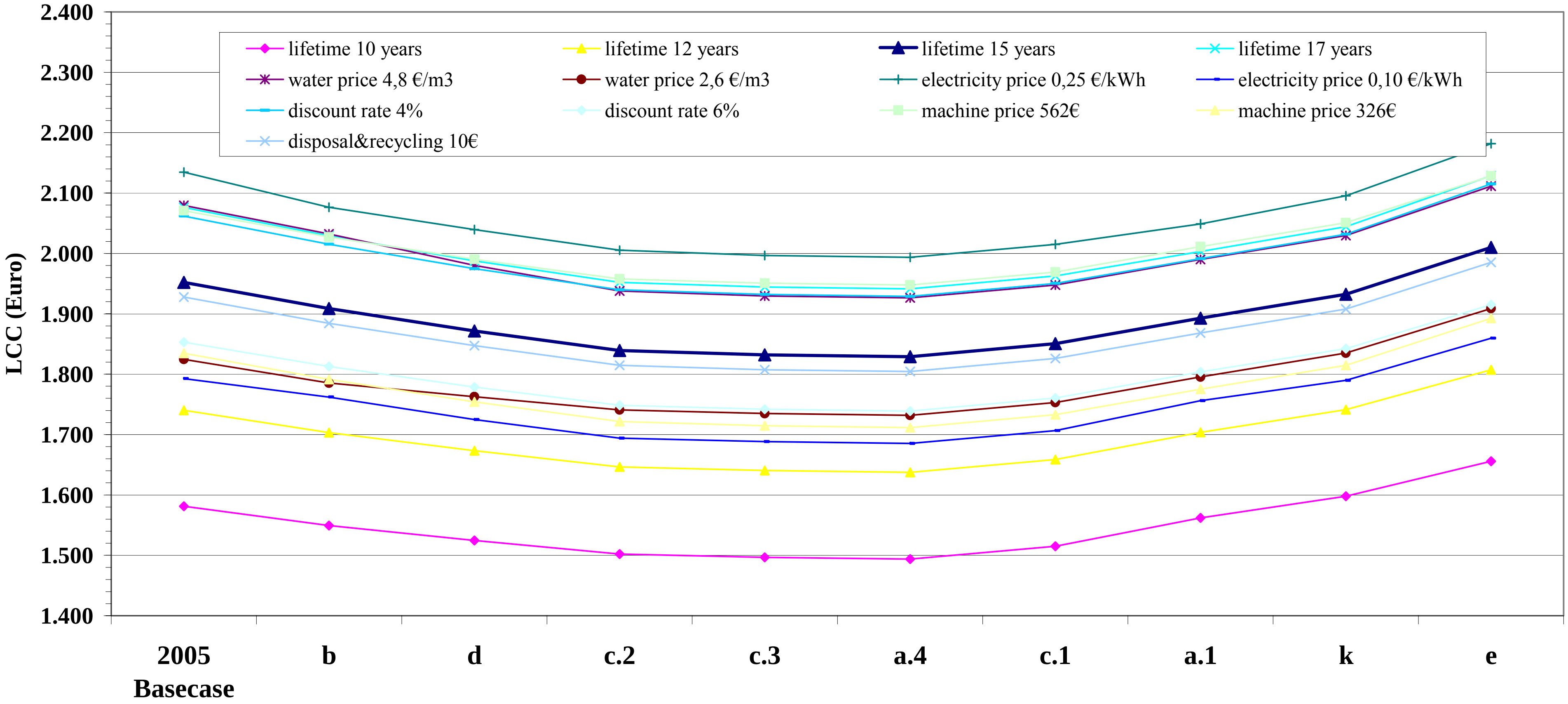


Figure 6.28: Life Cycle Cost as a function of the technological options for washing machine sensitivity analysis. Parameters variation is indicated for each curve. Base: lifetime = 15 years, 245 cycle/year.

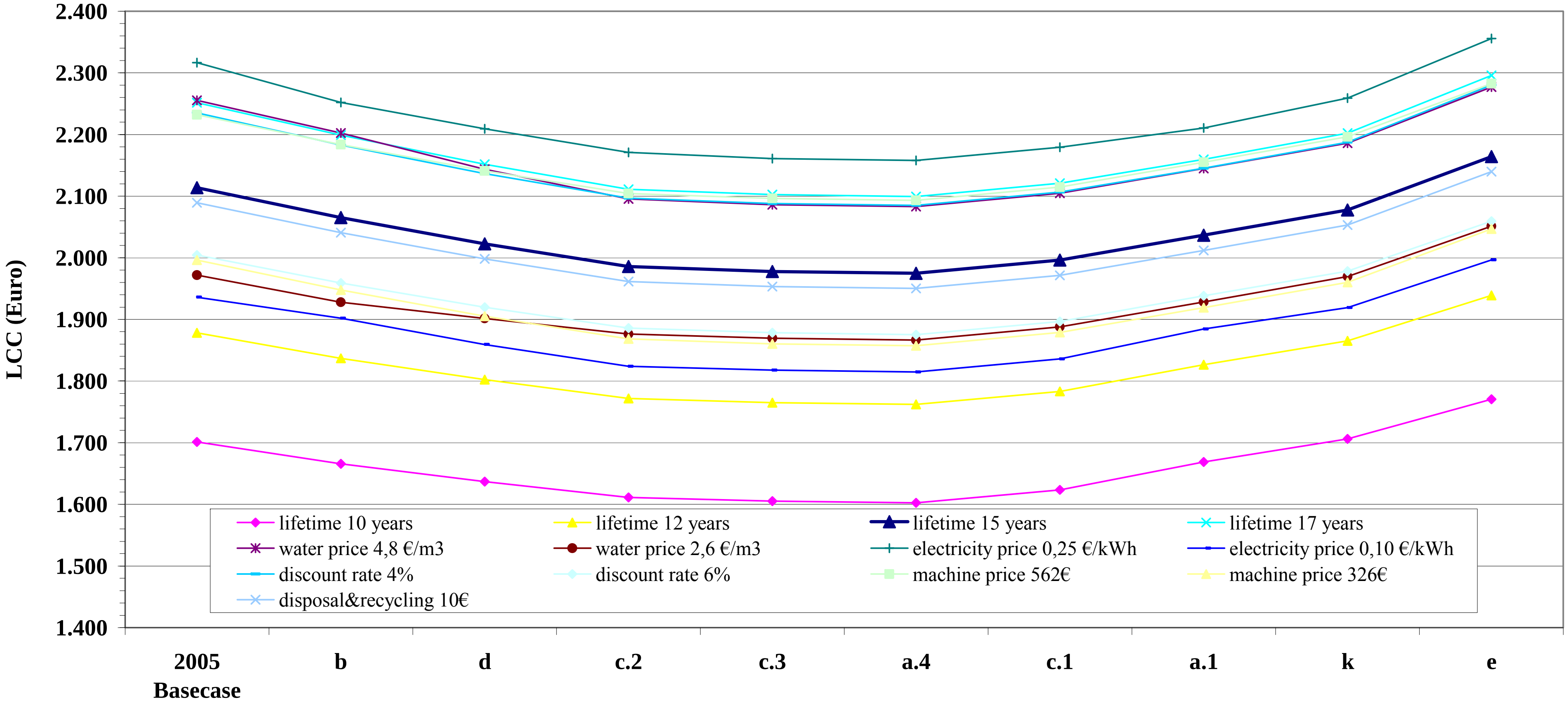


Table 6.52: Comparison of the Life Cycle Costs for the washing machines. Washing temperature 60°C

Washing cycles per year (n)	Consumer price (€)	Energy consumption (kWh/cycle)	Energy costs (€/year)	Water consumption (litre/cycle)	Water costs (€/year)	Chemicals costs (€/year)	LCC at 10 years (€)	LCC at 12 years (€)	LCC at 15 years (€)	LCC at 17 years (€)
Average standard base case (5,36 kg)										
200	443,5	0,998	33,93	50,7	37,52	53,11	1.485	1.630	1.823	1.936
220	443,5	0,998	37,33	50,7	41,27	58,42	1.581	1.741	1.952	2.077
245	443,5	0,998	41,57	50,7	45,96	65,06	1.702	1.879	2.114	2.252
$LLCC_{av}$										
200	459,7	0,900	30,60	38,7	28,64	53,11	1.407	1.538	1.712	1.815
220	459,7	0,900	33,66	38,7	31,50	58,42	1.494	1.638	1.829	1.942
245	459,7	0,900	37,49	38,7	35,08	65,06	1.602	1.762	1.975	2.100
BAT_{av}										
200	540,8	0,855	29,07	38,7	28,64	53,11	1.476	1.606	1.777	1.879
220	540,8	0,855	31,98	38,7	31,50	58,42	1.562	1.704	1.892	2.004
245	540,8	0,855	35,61	38,7	35,08	65,06	1.669	1.827	2.036	2.160
BAT_{av}, 1 600 rpm										
200	566,3	0,892	30,53	38,7	28,64	53,11	1.512	1.642	1.816	1.918
220	566,3	0,892	33,59	38,7	31,50	58,42	1.598	1.742	1.932	2.045
245	566,3	0,892	37,40	38,7	35,08	65,06	1.706	1.866	2.078	2.203
BAT_{av}, 6kg										
200	566,5	0,942	32,23	40,3	29,82	57,00	1.564	1.703	1.887	1.995
220	566,5	0,942	35,46	40,3	32,80	62,70	1.656	1.808	2.010	2.129
245	566,5	0,942	39,48	40,3	36,53	69,83	1.771	1.940	2.164	2.297

Table 6.53: Savings to the average standard base case for the washing machines at different values of lifetime and washing cycles per year. Washing temperature 60°C

Washing cycles per year (n)	Difference in consumer price (€)	Energy savings (kWh/cycle)	Energy savings (€/year)	Water savings (litre/cycle)	Water savings (€/year)	Chemicals cost savings (€/year)	Δ_{LCC} at 10 years (€)	Δ_{LCC} at 12 years (€)	Δ_{LCC} at 15 years (€)	Δ_{LCC} at 17 years (€)
$LLCC_{av}$										
200	-16,20	0,098	3,33	12,0	8,88	--	78	92	111	121
220	-16,20	0,098	3,67	12,0	9,77	--	87	103	123	135
245	-16,20	0,098	4,08	12,0	10,88	--	100	117	139	152
BAT_{av}										
200	-97,30	0,143	4,86	12,0	8,88	--	9	24	46	57
220	-97,30	0,143	5,35	12,0	9,77	--	19	37	60	73
245	-97,30	0,143	5,96	12,0	10,88	--	33	52	78	92
BAT_{av}, 1 600 rpm										
200	-122,80	0,106	3,40	12,0	8,88	--	-27	-12	7	18
220	-122,80	0,106	3,74	12,0	9,77	--	-17	-1	20	32
245	-122,80	0,106	4,17	12,0	10,88	--	-4	13	36	49
BAT_{av}, 6kg										
200	-123,00	0,056	1,70	10,4	7,70	--	-79	-73	-64	-59
220	-123,00	0,056	1,87	10,4	8,47	--	-75	-67	-58	-52
245	-123,00	0,056	2,09	10,4	9,43	--	-69	-61	-50	-45

b) The 40 °C washing temperature cycle

For the simulation of the washing cycle at 40°C an average consumption value of 0,550 kWh/cycle was considered for the average 5,36kg machine. All the other technical and financial parameters of the LCC analysis remained unchanged, as well as the energy and water percentage savings of the applicable technological options with the exclusion of *Option k – higher spin speed*, where 10% savings is considered.

To calculate the energy consumption of the standard base case machine at 40°C, the average of the energy consumption increase between 40 and 60 °C nominal wash temperature found in the German "Wash diary" study (see Task 3), the AISE stock model[21] for EU15, the Stiftung Warentest[22] and the round robin test conducted in 2004 involving 25 European laboratories in the framework of the CENELEC TC59X WG1 activity[23] were considered. Averaging all the available data a value of 0,0224 kWh/K results, leading to a predicted energy consumption of the average standard base case at 40°C of 0,590 kWh/cycle for 5,36kg load.

The simple payback time and the net present value of the applicable technological options are given in Table 6.54. Options are ordered by their SPB.

Table 6.54: Technological options ordered by simple payback time (SPB) and net present value (at 15 years, for 220 cycles/year) for technological options applied to the standard base case for a 40°C washing cycle

Options (n)	**Technology** (description)	**SPB** (years)	**NPV** (€)
b	Mechanical action optimisation	0,4	38,35
c.3	Temperature control sensor (+ simple unbalance control)	0,4	35,32
c.2	Analogue water sensor	1,4	39,13
d	Rinsing phase optimisation	2,5	48,37
a.1	Brushless DC motor (+ control)	54,3	-48,53
a.3	Three-phase motor	81,4	-78,53
a.2	Brushless DC direct drive motor (+ control)	220,5	-185,82
a.4	Optimised motor composition	--	3,00
c.1	Sophisticated unbalance control (+ separate sensors)	--	-22,50
k	Higher spin speed (up to ≥ 1 600 rpm)	--	-52,90
e	Increased load capacity in the same machine	--	-44,01

Comparing SPB and NPV in Table 6.54 with the values for the same option in Table 6.29 options encompassing an energy saving become less important than options leading to a water saving, and more in general all options are less attractive (have a higher SPB and a lower NPV), which is due to the lower potentially achievable energy savings.

To evaluate the improvement potential of the standard base case, the aggregated option analysis has been developed. This LCC analysis was run for the average standard base-case appliance only, to evaluate the potential average savings achievable through technological development in the light of a possible modification of the washing test methods including a standard 40°C washing cycle. In

[21] AISE Code of Good Environmental Practice: Final report to the European Commission 1996-2001, Annex 5 (www.aise.com)

[22] Communication to CENELEC TC59X, WG1, SG1.6

[23] The main results of the round robin test 2004 were described in the document: Gundula Czyzewski, *Updating the European performance standard for washing machines*, presented at the EEDAL06

Table 6.55 the applied options, with the order of application, the corresponding marginal net present value (MNPV) and the resulting energy/water consumption for a 15 year lifetime and 220 cycles per year are presented.

Table 6.55: Marginal net present value (MNPV, 15years, 220 cycles) for the aggregated option analysis for the average standard base case washing machine at 40°C

Options (n)	$MNPV_{av}$ (€)	Noise* (dBA)	Cycle time (min)	Consumption energy (kWh/cycle)	Consumption water (litre/cycle)
+d	38,69	53	98	0,590	44,70
+c.2	32,36	53	98	0,584	40,45
+b	27,77	53	98	0,538	39,18
+c.3	5,71	53	98	0,532	38,71
+a.4	3,00	53	98	0,532	38,71
+c.1	-21,38	53	98	0,532	38,71
+a.1	-49,40	50	88	0,506	38,71
+k	-42,18	50	92	0,549	38,71
+e	-25,71	50	103	0,579	40,32*

*during the washing cycle.

The resulting energy and water consumption and incremental purchase price for Base Case and LLCC for the average standard base case are presented in Table 6.56, compared to the same values for the 60°C. Also the energy consumption "C" for kg of washed load for the 40°C cycle is shown, calculated according to the algorithms of directive 95/12/EC. The energy and water consumption for the average machine are reduced by 58 Wh/cycle (or 9,8%) to 0,532 kWh/cycle and 12 litre/cycle (or 23,7%) to 39,7 litre/cycle; the consumption per kg of washed load for the LLCC is 0,0993, which has no correspondence in directive 95/12/EC. For the 60°C cycle the energy saving was 98 Wh/cycle.

The forecast increase in purchase price is 3,7%, while the decreasing in LCC is 108 € (it is 123 € for the 60°C cycle). The LCC is also presented in Figure 6.29. It is worth noting that *Option k* and *Option e* have been added as the last ones, due to the associated increase in the spinning speed (for the former) and in the machine load capacity (for the latter). In the LCC analysis an attempt was made to predict the lowest possible achievable energy consumption before adding this option which modifies the machine technical characteristics. In Figure 6.30 a comparison of the results for the three values of the washing cycles per year is presented, along with the variation in the cycle time.

The lowest predictable energy consumption for after all options have been added, or the average Best Available Technology (BAT_{av}) to the base case is presented in Table 6.57. For washing machines, three BAT levels can be predicted at 40°C, due again to the fact the last two added options increase the overall energy consumption of the laundry-washing cycle by increasing the spinning speed and the load capacity. The lowest predictable energy consumption for the average standard base case is 0,506 kWh/cycle, with a reduction of 84 Wh/cycle (or 14,3%) against the 143 Wh/cycle at 60°C; the water consumption of 12 litre/cycle (or 23,7%), with a minimum of 38,7 litres, unchanged compared to the $LLCC_{av}$ point and the 60°C cycle. The predicted increase in purchase price is 22% for both 40°C and 60°C.

When the Life Cycle Cost (lifetime=15 years) is shown as a function of the energy consumption (kWh/cycle) the curves in Figure 6.31 result. The technological development pathway at 60°C and at 40°C can be compared in the Figure.

Table 6.56: Energy and water consumption and incremental purchase price for washing machine Base Case and LLCC for average standard base case and standard base case model

Base case	Energy consumption		Water consumption		Specific energy consumption "C" (dir. 95/12/EC)			Purchase price			LCC (15y, 220 cycles)	
	Base case (kWh/cycle)	$LLCC_{av}$ (kWh/cycle)	Base case (litre/cycle)	$LLCC_{av}$ (litre/cycle)	Base case C	$LLCC_{av}$ C	difference (%)	Base case (Euro)	$LLCC_{av}$ (Euro)	Increase (%)	Base case (€)	$LLCC_{av}$ (€)
Average standard base case 60°C	0,998	0,900	50,7	38,7	0,186	0,168	9,8	443,5	459,7	3,7	1.952	1.829
Average standard base case 40C	0,590	0,532	50,7	38,7	0,110	0,0993	9,8	443,5	459,7	3,7	1.794	1.686

Figure 6.29: Life Cycle Cost (lifetime = 15 years, 220 cycle/year) as a function of the applied technological options for the washing machine standard base case at 40°C

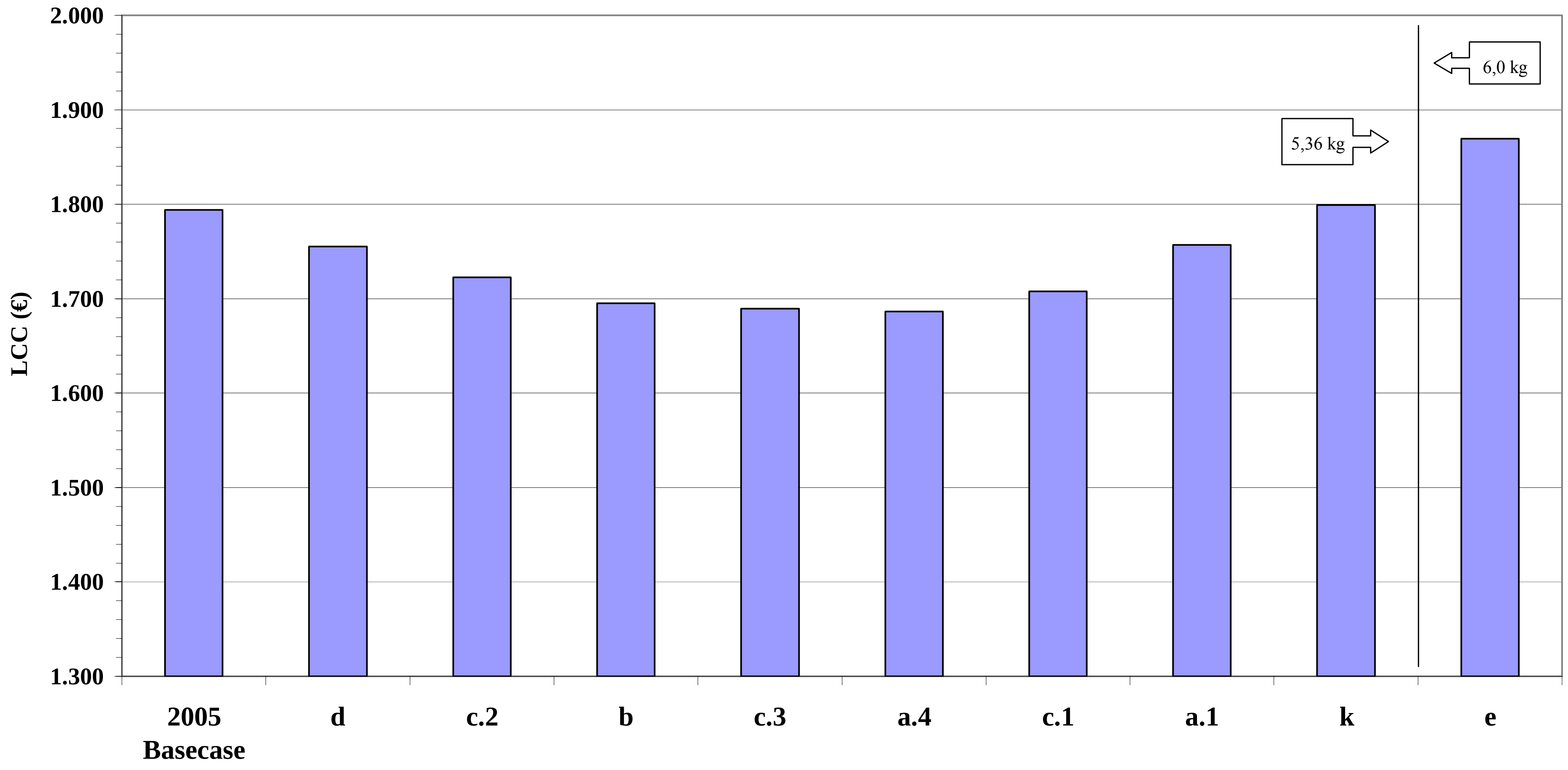


Figure 6.30: LCC (lifetime = 15 years) for 200, 220 and 245 cycle/year as a function of the applied technological options for the washing machine standard base case at 40°C

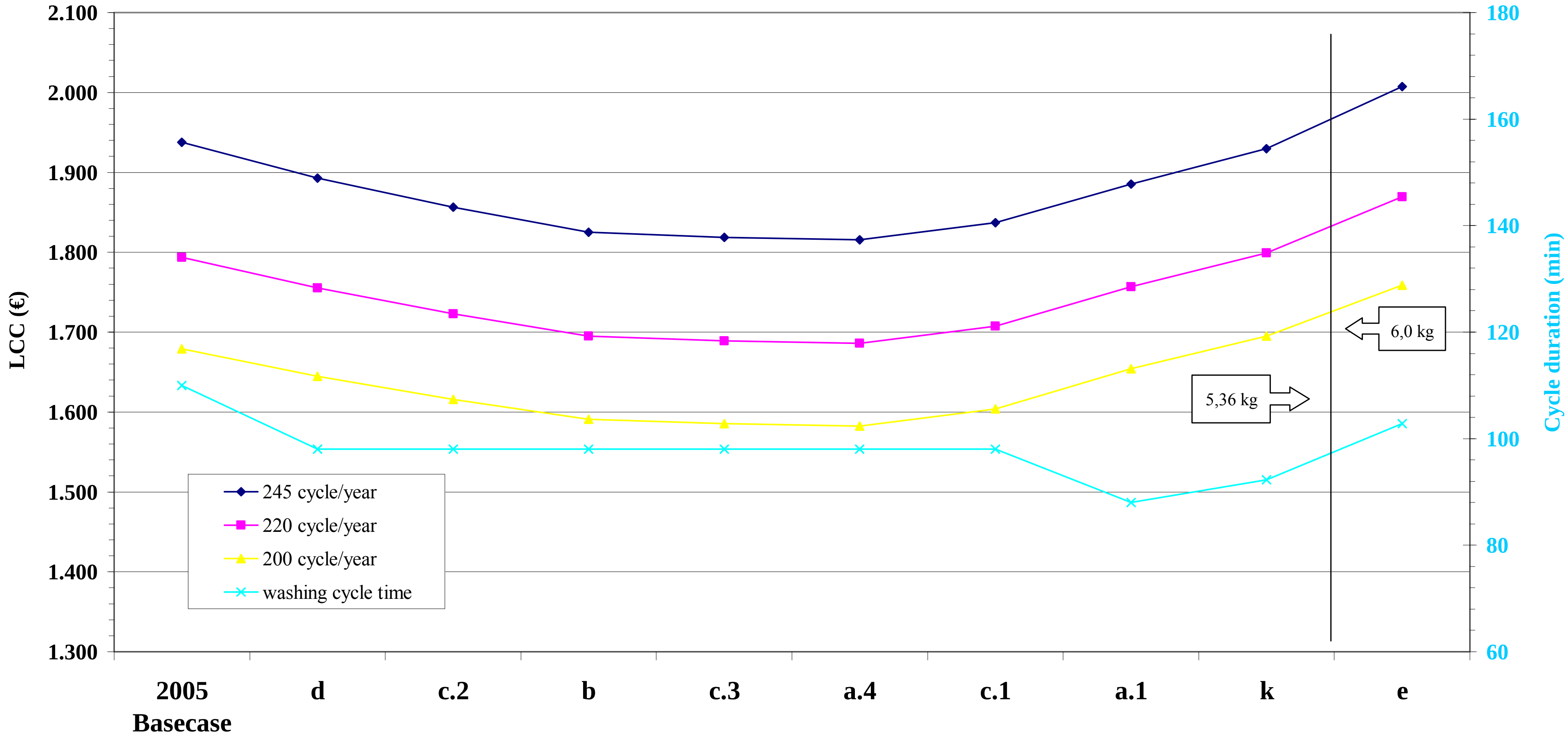
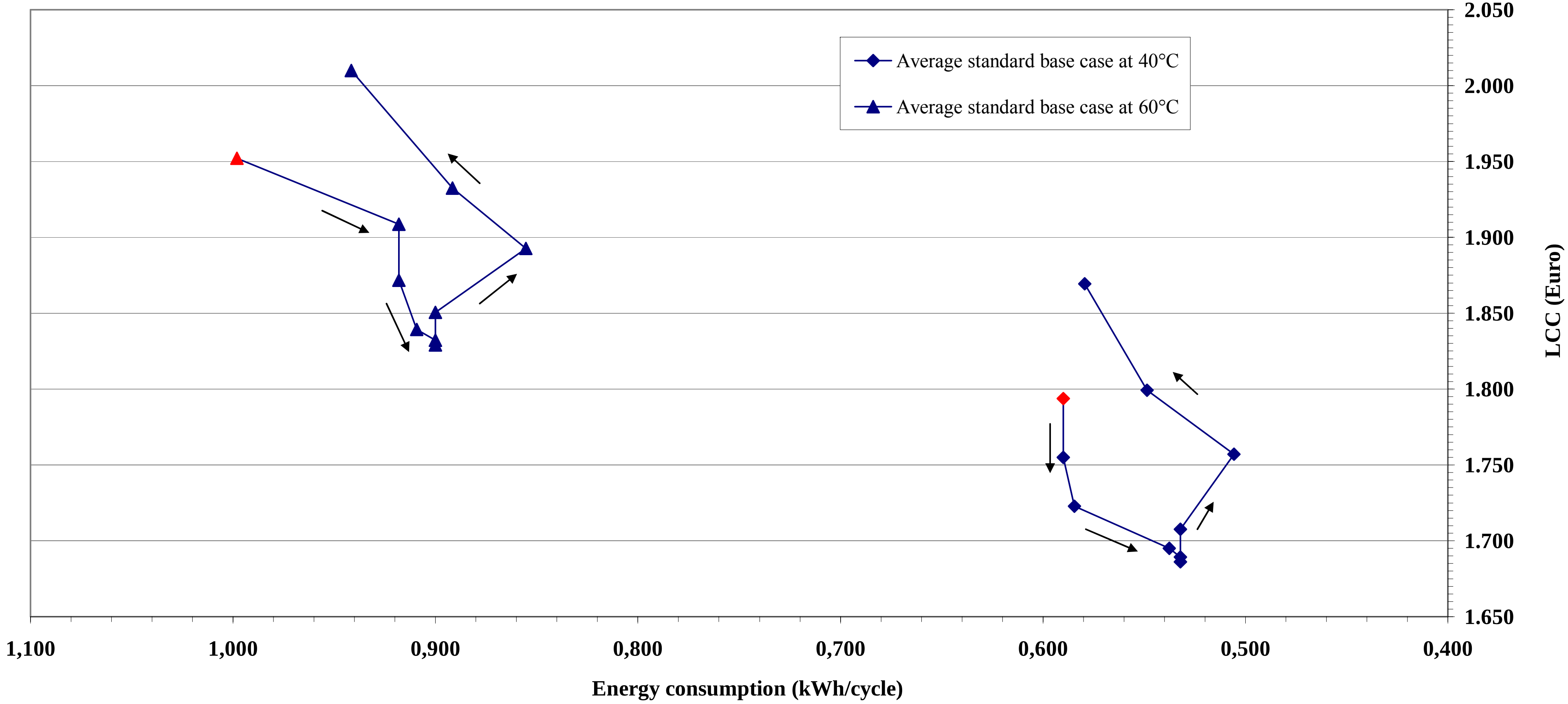


Table 6.57: Energy and water consumption and incremental purchase price for washing machine Base Case and BAT for average standard base case at 60°C and 40°C cycle

Base case	Energy consumption		Water consumption		Specific energy consumption "C" (dir. 95/12/EC)			Purchase price			LCC (15y, 220 cycles)	
	Base case (kWh/cycle)	BAT_{av} (kWh/cycle)	Base case (litre/cycle)	BAT_{av} (litre/cycle)	Base case C	BAT_{av} C	difference (%)	Base case (Euro)	BAT_{av} (Euro)	Increase (%)	Base case (€)	BAT_{av} (€)
Average standard base case 60°C	0,998	0,855	50,7	38,7	0,186	0,1596	14,3	443,5	540,8	21,9	1.952	1.893
		0,892		38,7		0,1663	10,7		566,3	27,7		1.932
		0,942		40,3		0,1569	15,7		566,5	27,7		2.010
Average standard base case 40°C	0,590	0,506	50,7	38,7	0,110	0,0943	14,3	443,5	540,8	21,9	1.794	1.757
		0,549		38,7		0,1024	7,02		566,3	27,7		1.799
		0,579		40,3		0,0966	12,3		566,5	27,7		1.869

Figure 6.31: Life Cycle Cost (lifetime = 15 years, 220 cycle/year) as a function of the energy consumption for washing machine analysis. Average standard base cases are the red point on each curve. Arrows show the option application sequence.



To allow an easier understanding of the overall LCC analysis results, the output for the different number of washing cycles per year and lifetimes are compared in Table 6.58. The Standard base case, the $LLCC_{av}$, and the BAT_{av} for 5,36kg and 6kg load are presented as well as for the machine with a spin speed of 1 600 rpm.

Table 6.59 presents the derived annual energy and water savings over the average standard base case at a different number of washing cycles per year with an energy price of 0,17 €/kWh and a water price of 3,7 €/m^3. The energy savings for the $LLCC_{av}$ are in the range 2,0-2,4 €/year depending on the annual washing cycles, the water savings in the range 8,9-10,9 €/year, for a total of 10,9-13,3 €/year against an increase in purchase price of 16 €; the energy savings going from the average standard base case to the BAT_{av} are in the range 2,9-3,5 €/year and the water savings in the range 8,9-10,9 €/year, for a total of 11,7-14,4 €/year against an increase in purchase price of 97 €. When the spin speed in increased to 1.600 rpm there is a slight decrease in the energy savings (1,4-1,7 €/year), while the water savings are in the same range 8,9-10,9 €/year, with a total of 10,3-12,6 €/years against a price increase of 123 €. Finally, when the load capacity is increased to 6kg, the energy savings (compared to the 5,36kg load machine and keeping the number of cycles constant) are on the range of 37-47 €cent/year and the water savings in the same range 7,7-9,4 €/year with a total of 8,1-9,9 €/year against a price increase of 123 €.

6.5 Subtask 6.3: Long Term Targets (BNAT) and System Analysis

6.5.1 Long Term Targets in Previous Studies for Wash Appliances

Long term targets were described in the GEA study in 1995 as forecast after 2000-2005. These options are here reported more for sake of completeness of the background historical information than on an actual applicability of the highlighted technological development:

- <u>insulated water storage tank</u>: beside the reduction of water consumption it might also be possible t reduce the energy consumption for heating if the hot rinsing water is store in a thermally insulated vessel. It is possible (at low cost) to insulate the water storage tank in such a way that the heat loss does not exceed the 15W (currently available as electric boiler with storage capacity of 5 litres with gross volume of 15 litres). The average time between two cycles is 40 hours, that means that the water has cooled down to 25°C at the beginning of the next cycle, the savings are therefore about 35 Wh/cycle (0,95 Ecu/year);
- <u>storage tank with phase change material</u>: as a substitute for the insulated water storage tank described in the previous option the dishwasher can be equipped with a storage tank containing a phase change material. Phase change materials are materials that feature a high melting heat at a temperature that is within the range of temperatures of the ingoing and drain water. Both fluids are led thorough a tank containing phase change material. The drain water is used to melt the phase change material, the fresh ingoing water again makes it be solid again. With phase change materials a lot of energy can be stored in a very compact container.
- <u>differentiation of the water level for each phase of the washing cycle</u>: one of the determining factors for the total amount of water needed is the water that is moving through the air or flowing down from the load. The amount of water in this process is depending on the recirculation flow: an increased flow means more water, a decreased flow means less. The total amount of water travelling was estimated in 0,75 litre. If it is possible to reduce water flow in certain phases of the wash cycle, the total amount of water needed in this phase will be less too, leading to lower water consumption and if applicable in the wash or hot rinse phase, to a lower heating consumption. If, for instance during the hot rinse phase, the water flow is reduced to half the amount, the water level could be reduced with 0,75 litres. The related energy saving

Table 6.58: Comparison of the Life Cycle Costs for the washing machines. Washing temperature 40°C

Washing cycles per year (n)	Consumer price (€)	Energy consumption (kWh/cycle)	Energy costs (€/year)	Water consumption (litre/cycle)	Water costs (€/year)	Chemicals costs (€/year)	LCC at 10 years (€)	LCC at 12 years (€)	LCC at 15 years (€)	LCC at 17 years (€)
Average standard base case (5,36 kg)										
200	443,5	0,590	20,06	50,7	37,52	53,11	1.378	1.507	1.679	1.780
220	443,5	0,590	22,07	50,7	41,27	58,42	1.464	1.605	1.794	1.905
245	443,5	0,590	24,57	50,7	45,96	65,06	1.570	1.728	1.937	2.061
$LLCC_{av}$										
200	459,7	0,532	18,09	38,7	28,64	53,11	1.311	1.427	1.582	1.674
220	459,7	0,532	19,90	38,7	31,50	58,42	1.388	1.516	1.686	1.786
245	459,7	0,532	22,16	38,7	35,08	65,06	1.484	1.626	1.816	1.927
BAT_{av}										
200	540,8	0,506	17,20	38,7	28,64	53,11	1.385	1.501	1.654	1.745
220	540,8	0,506	18,92	38,7	31,50	58,42	1.461	1.588	1.757	1.857
245	540,8	0,506	21,07	38,7	35,08	65,06	1.557	1.698	1.885	1.996
BAT_{av}, 1 600 rpm										
200	566,3	0,549	18,67	38,7	28,64	53,11	1.422	1.539	1.695	1.787
220	566,3	0,549	20,53	38,7	31,50	58,42	1.499	1.628	1.799	1.900
245	566,3	0,549	22,87	38,7	35,08	65,06	1.596	1.739	1.929	2.042
BAT_{av}, 6kg										
200	566,5	0,579	19,69	40,30	29,82	57,00	1.469	1.593	1.758	1.856
220	566,5	0,579	21,65	40,30	32,80	62,70	1.551	1.688	1.869	1.976
245	566,5	0,579	24,12	40,30	36,53	69,83	1.654	1.806	2.007	2.126

Table 6.59: Savings to the average standard base case for the washing machines at different values of lifetime and washing cycles per year. Washing temperature 40°C

Washing cycles per year (n)	Difference in consumer price (€)	Energy savings (kWh/cycle)	Energy savings (€/year)	Water savings (litre/cycle)	Water savings (€/year)	Chemicals cost savings (€/year)	Δ_{LCC} at 10 years (€)	Δ_{LCC} at 12 years (€)	Δ_{LCC} at 15 years (€)	Δ_{LCC} at 17 years (€)
$LLCC_{av}$										
200	-16,20	0,058	1,97	12,0	8,88	--	67	80	96	106
220	-16,20	0,058	2,17	12,0	9,77	--	76	90	108	118
245	-16,20	0,058	2,41	12,0	10,88	--	86	102	122	134
BAT_{av}										
200	-97,30	0,084	2,86	12,0	8,88	--	-7	7	25	35
220	-97,30	0,084	3,15	12,0	9,77	--	3	17	37	48
245	-97,30	0,084	3,50	12,0	10,88	--	13	30	52	65
BAT_{av}, 1 600 rpm										
200	-122,80	0,041	1,39	12,0	8,88	--	-44	-32	-16	-7
220	-122,80	0,041	1,54	12,0	9,77	--	-35	-23	-5	5
245	-122,80	0,041	1,70	12,0	10,88	--	-26	-11	8	19
BAT_{av}, 6kg										
200	-123,00	0,011	0,37	10,4	7,70	--	-91	-86	-80	-76
220	-123,00	0,011	0,42	10,4	8,47	--	-87	-82	-75	-71
245	-123,00	0,011	0,45	10,4	9,43	--	-84	-78	-70	-65

amounts to 45 Wh/cycle. A reduced water level will certainly have impact on rinsing performance because of reduced mechanical action and a reduced flow. Therefore it might be necessary to prolong the rinse phase. This again results in additional motor energy, but whereas this only amounts to 2Wh/min it might be a trade-off worth investigating.

- cold last rinse: when the last rinse is performed without additional heating, the temperature of the load is till not down to 20°C at the beginning of the drying phase. The temperature will be around 30°C. That means that, if more time is available for the drying process, no heat at all has to be fed to the load for a good drying result. To speed up the drying process it is possible to use a small silent fan, at the cost of some motor energy. Even if the drying process would take the rest of the night after a regular wash cycle, say 7 hours, the energy consumption of a 5W fan would only be 35 Wh. Yet another possibility is to omit the heating of the last rinse phase and instead heat up the load (and inevitably the machine) up to 65°C after the last rinsing water has been drained. If we assume that in a normal cycle the last rinse phase is used only to increase the temperature of the load, the alternative of heating load only definitely makes sense: in this way the last rinse water is drained at a much lower temperature. The energy need for the following drying phase would be 350 Wh.

No long term targets were hypothesised for washing machines in the WASH-2 study.

6.5.2 BNAT and Long Term Targets for Wash Appliances in 2005

6.5.2.1 Long Term and BNAT for dishwashers and washing machines

In addition to long term and BNA Technologies for dishwashers and for washing machines, the following new technologies apply for long term targets:

- ***Washing dishes without water***[24]: this concept unit is a bit out of the design box. The dishwasher, developed by students from the University of New South Wales, Australia, won the top prize at the Electrolux Design Laboratory 2004 competition in New York, U.S. The winning concept combines a sophisticated waterless cleaning technology with a simple user interface. Carbon dioxide is used in a closed-loop operation to clean the dishes.

- ***Electronic control for washing machine motors***: to agitate and brake the motor in washing machines. A very fast CPU with DSP capability, and a fast and accurate ADC, is needed for these software and agitation method changes[25].
- ***Washing laundry without water***[26]: "Airwash" (Figure 6.32) is a waterless washing machine for the home of 2020 from Electrolux. Eliminating the use of detergent and water resources,

[24] Source: "Washing dishes without water", Appliance, February 2005.
[25] Source: Moving Forward - Motor Technology, Appliance, January 2007

it cleans clothes with pressurized air and negative ions. The form is inspired by the waterfall and has a touch-light interface.

Figure 6.32: Airwash waterless washing machines from Electorlux

- ***Washing laundry with ozone and recycled (bath) water***: in March 2007 SANYO Electric Co., Ltd.[27] announced starting April 2007 the marketing of an improved version of the 'AQUA' washer-dryer (model AWD-AQ2000) with a rated capacity of 9kg in washing and 6kg in drying.
  This improved machine includes the "*Air Wash Wide*" function (an expanded application of the previous *Air Wash* function) able to disinfect (tests conducted by Japan Food Research Laboratories/testing methods agar plate cultural method, bacteria elimination using ozone), deodorize and remove light stains from items previously un-washable or temperature-sensitive such as shoes, gloves, leather jackets, blouses, ties, silk) through the power of ozone. This function can treat contents under 2 kg, and some metal/fur items can not be used; in addition not all dirt and stains will be removed as ozone is not a substitute for bleach.
  Through the power of ozone, the 'Aqualoop' water recycle function has evolved to become the 'Aqualoop Wide' which is able to purify and disinfect bath water. The 'Aqualoop Wide' cleans the bathwater using ozone inside of the storage tank: water absorbed by the water hose from the bath is first filtered through an antimicrobial filter to remove larger items such as hair and other items, and is then sent to the storage tank; ozone enters the pipe and is injected into the storage tank before water is filled in; the water that then enters the tank is circulated through the ozone and disinfected. When using the 'water recycle/bathwater' setting, the recycled bathwater is used in the fabric softener cycle. The result is that for one single load of laundry, from wash to dry, the machine only uses 8 litres of fresh tap water, the rest of the water being recycled from the bath.
  The machine allows the traditional use of fresh tap water for all cycles, consuming 78 litres of water for a 9kg load, or for only the final rinse cycle and users can select the setting of 'Aqualoop' that meets their individual need. The machines uses 76 litres of pure tap water (of which 70 litres can be substituted by purified bath water) for the 6kg load cycle.

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[26] Source: ELECTROLUX Airwash system, see: http://www.electrolux.com/node49.aspx?Assid=10865&FolderID=20806&Page=1
[27] Source: SANIO news release, see : http://www.sanyo.co.jp/koho/hypertext4-eng/0703/0327-2e.html#02

According to the manufacturer press release, the product is sold in Japan. An overseas launch of this product is as yet undecided.

- ***Washing laundry with steam***: due to the very high temperature steam (100°C water vapour) is used by for (laundry and machine) specific hygiene at the end of a washing cycle, as already discussed in paragraph 6.3.3.3. But some manufacturers have also started to include steam in specific garment refreshing short (about 20 minutes) programmes or in washing cycles together with water. For the latter, the energy and water savings claimed in a 60°C cotton washing cycle are explained by the fact steam heats the whole machine drum (and laundry), consuming only a small amount of water and more effectively than hot water, allowing the load to reach the optimal temperature faster and reducing the energy and water consumption. At present this system is applied only to one large 8kg capacity machines sold on the UK market (see Table 5.22 for the technical data). It is not clear if the same savings will be achieved in smaller 5-6 kg machines (which use a lower amount of hot water in the washing cycle) or in washing cycles at temperature lower than 60°C (where the overall heat amount and heat transfer are lower).

6.5.2.2 BNAT potential analysis for dishwashers

Hypothesised costs and savings for BNAT and long term technologies (known technologies but whose application to the market is considered to happen in the long term) for **dishwashers** are presented in Tables 6.60 and 6.61 for the 9ps and the 12ps standard base cases.

Since Option BNAT1 is alternative to Option f.1, and this latter have been already applied to the standard base cases, BNAT1 will not be further considered in the long term analysis; Option BNAT3 is not applicable to 9ps machines. To evaluate the effect of Options BNAT5 and BNAT6, where an increase of 5W in the standby power is foreseen, the increased power consumption has been converted into energy consumption under the hypotheses that the 5W power is consumed for 8 760 hours/year with the machine being always plugged in and there is no increase in power consumption when the specific function is working (interned connected or the machine responding to vocal commands). This means that 43,8 kWh are added per year for each option, or - for dishwashers - 156,4 Wh/cycle considering 280 washing cycles; for a 12ps machine this equals to 13,8% of the standard base case consumption (1,070 kWh/cycle), for a 9ps dishwasher to 18,9% of the standard base case consumption (0,828 kWh/cycle).

The simple payback time and the net present value of the BNAT options for 9ps and 12ps dishwashers when applied to the BAT_{av} machines with a noise of 50 dB(A), or $BAT_{av,50}$, are given in Table 6.62; the washing cycle time is 97 min and 107 min respectively for the two cases and is assumed to remain unchanged (no hypothesis on the impact of the BNATs on washing time was done). Option BNAT2, reducing the hot rinse temperature to 55°C is the most effective on the machine energy consumption, followed by Option BNAT4, where energy and water are saved.

The aggregated option analysis allows to estimate the improvement potential when the BNATs are applied to the $BAT_{av,50}$ case, the aggregated option analysis has been developed. This LCC analysis was run for the average standard base case appliance only, to evaluate the potential average savings achievable through not yet available technological development. Due to the fact that *Option BNAT2 - Hot rinse at 55°C* and *Option BNAT4 - Direct heating of the load (avoid last hot rinse)* are mutually exclusive, two technological pathways were identified:

- pathway 1: including the application of Options BNAT2, 5 and 6 for the 9ps dishwasher case and BNAT2, 3, 5 and 6 for the 12ps dishwasher case
- pathway 2: including the application of Options BNAT4, 5 and 6 for the 9ps dishwasher case Options BNAT4, 3, 5 and 6 for the 12ps dishwasher case.

Table 6.60: Technological Option List, improvement in cost/price and energy/water savings for BNAT for 9ps dishwasher standard base case

Options		Application to the market	Unit production		Savings				Cycle time variation	Increase in consumer price	Notes
			cost	price	Electricity		Water				
No	Description	(%)	(€)	(€)	(Wh/cycle)	(%)	(litre/cycle)	(%)	(± min)	(€)	
BNAT1	(Partly) reuse of last rinsing water	0	8	10,4	-7	-0,0085	-2,5	-0,1825	0	31,2	alternative to Option f.1
BNAT2	Hot rinse at 55°C	0	0	0	-230	-0,2778	0	0	0	0	never used in dishwashers, need redesign of drying phase, critical application. Present rinse aid will not work at 55°C.
BNAT3	Insulated water tank										Not feasible for 9ps
BNAT4	Direct heating of the load (avoid last hot rinse)	0	25	32,5	-124,2	-0,15	-1,03	-0,075	0	97,5	lack of suitable technology today
BNAT5	Internet connectivity	0	30	39	+5W* (+156,4)	+0,189	0	0	0	117	increase consumption in low-power modes, long term technology
BNAT6	Voice controlled appliances	0	30	39	+5W* (+156,4)	+0,189	0	0	0	117	increase consumption in low power modes; long term development, even if known technology

*standby power

Table 6.61: Technological Option List, improvement in cost/price and energy/water savings for the BNAT for 12ps dishwasher standard base case

Options		Application to the market	Unit production		Savings				Cycle time variation	Increase in consumer price	Notes
			cost	price	Electricity		Water				
No	Description	(%)	(€)	(€)	(Wh/cycle)	(%)	(litre/cycle)	(%)	(± min)	(€)	
BNAT1	(partly) reuse of last rinsing water	0	10	13	-10	-0,0935	-3,5	-0,2303	0	39	alternative to Option f.1
BNAT2	Hot rinse at 55°C	0	0	0	-250	-0,2336	0	0	0	0	never used in dish-washers, need re-design of drying phase, critical application. Present rinse aid will not work at 55° C
BNAT3	Insulated water tank	0	7	9,1	-26,75	-0,025	0	0	0	27,3	considered not feasible due to hygiene of the long stored water
BNAT4	Direct heating of the load (avoid last hot rinse)	0	25	32,5	-160,5	-0,15	1,14	-0,075	0	97,5	lack of suitable technology today
BNAT5	Internet connectivity	0	30	39	+5W* (+156,4)	+0,146	0	0	0	117	increase consumption in low-power modes, long term technology
BNAT6	Voice controlled appliances	0	30	39	+5W* (+156,4)	+0,146	0	0	0	117	increase consumption in low power modes; long term develop-ment, even if known technology

*standby power

Table 6.62: BNA Technological options ordered by simple payback time (SPB) and net present value (at 15 years, for 280 cycles/year) for 9ps and 12ps BATav,50 dishwashers with 50dB(A) noise

Options (n)	**Technology** (description)	9ps dishwasher **SPB** (years)	9ps dishwasher **NPV** (€)	12ps dishwasher **SPB** (years)	12ps dishwasher **NPV** (€)
BNAT1	(Partly) reuse of last rinsing water	14,43	-8,75	13,29	-8,53
BNAT2	Hot rinse at 55°C	0	99,23	0	105,51
BNAT3	Insulated water tank	--	--	25,10	-16,01
BNAT4	Direct heating of the load (avoid last hot rinse)	16,44	-35,93	13,27	-21,21
BNAT5	Internet connectivity	n.a.	-184,49	n.a.	-183,02
BNAT6	Voice controlled appliances	n.a.	-184,49	n.a.	-183,02

In Table 6.63 the applied options, with the order of application, the corresponding MNPV and LCC for a 15 year lifetime and 280 cycles per year, the resulting energy/water consumption and the new purchase price are presented for the 9ps and the 12ps $BAT_{av,50}$ machine are given. The energy and water consumption for the $BAT_{av,50}$ 9ps machine are reduced by 201 Wh/cycle (or 27,8%) to 0,522 kWh/cycle (E_I = 0,41) for the first technological pathway and by 108 Wh/cycle (or 15%) to 0,615 kWh/cycle E_I = 0,49) for the second technological pathway where also the water is reduced from 9,9 to 9,2 litre/cycle. The LCC has a minimum when Option BNAT2 is applied in technological pathway 1, while for the second technological pathway the LCC always increases. For the 12ps $BAT_{av,50}$ dishwasher, the energy and water consumption are reduced by 231 Wh/cycle (or 25,3%) to 0,683 kWh/cycle (E_I = 0,41) for the first technological pathway and by 157 Wh/cycle (or 17,1%) to 0,757 kWh/cycle (E_I = 0,46) for the second technological pathway where also the water consumption is reduced from 10,6 to 9,8 litre/cycle.

Table 6.63: Marginal net present value (MNPV, 15years, 280 cycles) for the aggregated option analysis for the BATav,50 base case 9ps and 12ps dishwasher (noise 50dB(A))

Options (n)	Economic values $MNPV_{av}$ (€)	Price (€)	LCC (€)	Consumption energy (kWh/cycle)	E_I	water (litre/cycle)
9ps $BAT_{av,50}$	--	692,6	1.489	0,723	0,574	9,9
Technological pathway 1						
+BNAT2	99,23	692,6	1.390	0,522	0,414	9,9
+BNAT5	-165,74	809,6	1.556	0,621	0,493	9,9
+BNAT6	-174,95	926,6	1.731	0,738	0,586	9,9
Technological pathway 2						
+BNAT4	-35,93	790,1	1.525	0,615	0,488	9,2
+BNAT5	-174,36	907,1	1.699	0,731	0,580	9,2
+BNAT6	-185,20	1.024,1	1.885	0,869	0,689	9,2
12ps $BAT_{av,50}$	--	779,5	1.699	0,914	0,554	10,6
Technological pathway 1						
+BNAT2	105,51	779,5	1.593	0,700	0,425	10,6
+BNAT3	-18,65	806,8	1.611	0,683	0,414	10,6
+BNAT5	-166,33	923,8	1.778	0,783	0,474	10,6
+BNAT6	-173,54	1.040,8	1.951	0,897	0,544	10,6
Technological pathway 2						
+BNAT4	-21,21	877,0	1.720	0,777	0,471	9,8
+BNAT3	-17,70	904,3	1.737	0,757	0,459	9,8
+BNAT5	-171,71	1.021,3	1.909	0,868	0,526	9,8
+BNAT6	-179,71	1.138,3	2.089	0,995	0,603	9,8

When a BAT_{av} machine with a lower noise at 41 dB(A) is considered, the base case energy consumption and purchase price increase to 0,851 kWh/cycle (E_I = 0,675) for the 9ps machine and to 1,079 kWh/cycle (E_I=0,65) for the 12ps machine. Therefore also the energy consumption and the life cycle cost of the models with the BNATs increase correspondingly.

Simulation results are presented in Table 6.64. The energy and water consumption for the $BAT_{av,41}$ 9ps machine are reduced to 0,615 kWh/cycle (E_I = 0,48) for the first technological pathway and to 0,723 kWh/cycle E_I = 0,57) for the second technological pathway where also the water is reduced from 9,9 to 9,2 litre/cycle. The LCC has a minimum when Option BNAT2 is applied in technological pathway 1, while for the other technological pathway the LCC always increases. For the 12ps dishwasher, the energy consumption is reduced to 0,806 kWh/cycle (E_I = 0,49) for the first technological pathway and to 0,894 kWh/cycle (E_I=0,54) for the second technological pathway where also the water consumption is reduced from 10,6 to 9,8 litre/cycle.

Table 6.64: Marginal net present value (MNPV, 15years, 280 cycles) for the aggregated option analysis for the BATav base case 9ps and 12ps dishwasher (noise 41dB(A))

Options	Economic values			Consumption		
	$MNPV_{av}$	Price	LCC	energy		water
(n)	(€)	(€)	(€)	(kWh/cycle)	E_I	(litre/cycle)
9ps $BAT_{av,41}$	--	784,7	1.645	0,851	0,675	9,9
Technological pathway 1						
+BNAT2	116,79	784,7	1.528	0,615	0,488	9,9
+BNAT5	-174,37	901,7	1.702	0,731	0,580	9,9
+BNAT6	-185,21	1.018,7	1.887	0,869	0,690	9,9
Technological pathway 2						
+BNAT4	-26,45	882,2	1.671	0,723	0,574	9,2
+BNAT5	-184,52	999,2	1.855	0,860	0,683	9,2
+BNAT6	-197,27	1.116,2	2.053	1,022	0,811	9,2
12ps $BAT_{av,41}$	--	882,9	1.884	1,079	0,654	10,6
Technological pathway 1						
+BNAT2	124,56	882,9	1.759	0,827	0,501	10,6
+BNAT3	-17,09	910,2	1.776	0,806	0,489	10,6
+BNAT5	-175,23	1.027,2	1.951	0,924	0,560	10,6
+BNAT6	-183,75	1.144,2	2.135	1,059	0,642	10,6
Technological pathway 2						
+BNAT4	-8,99	980,4	1.892	0,917	0,556	9,8
+BNAT3	-15,97	1.007,7	1.908	0,894	0,542	9,8
+BNAT5	-181,59	1.124,7	2.090	1,025	0,621	9,8
+BNAT6	-191,03	1.241,7	2.281	1,175	0,712	9,8

6.5.2.3 BNAT potential analysis for washing machines

Hypothesised costs and savings for BNAT and long term technologies for **washing machine**s are presented in Tables 6.65 for the standard base case. For this appliance only the application of *Option BNAT1 - Internet connectivity* and *Option BNAT2 - Voice controlled appliances* be evaluated. Mixed appliances or alternative washing systems encompass in fact a different product archetype compared with the washing machine standard base case or BAT_{av}.

Table 6.65: Technological Option List, improvement in cost/price and energy/water savings for BNAT for washing machine standard base case

Options (No)	(description)	Application to the market (%)	Unit production cost (€)	Unit production price (€)	Savings: Electricity (Wh/cycle)	Savings: Electricity (%)	Savings: Water (litre/cycle)	Savings: Water (%)	Noise (dBA)	Cycle time variation (± min)	Increase in consumer price (€)	Notes
BNAT 1	Internet connectivity	0,1	57,7	75	+5W* (+199)	+0,1994	0	0	0	0	225	increase consumption in low power modes, long term technology
BNAT 2	Voice controlled appliances	0	30	39	+5W* (+199)	+0,1994	0	0	0	0	117	increase consumption in low power modes; long term develop-ment, even if known technology
BNAT 3	Mixed appliances	--	--	--	--	--	--	--	--	--	--	comparison with the traditional washing machine to be studied
BNAT 4	Alternative washing systems	--	--	--	--	--	--	--	--	--	--	comparison with the traditional washing machine to be studied

*standby power

When Options BNAT1 and BNAT2 are applied to the BAT_{av} washing machine, an increase of 5W in the standby power is foreseen for each option; the increased power consumption is again converted into energy consumption under the hypotheses that the 5W power is consumed for 8 760 hours/year with the machine always plugged in and there is no increase in power consumption when the specific function is working (interned connected or the machine responding to vocal commands). This means that 43,8 kWh are added per year for each option, considering 220 washing cycles per year, which is 199 Wh/cycle or 19,9% of the standard base case consumption (0,998 kWh/cycle).

When the two options are applied to the BAT_{av} machine with a load capacity of 5,36 kg or $BAT_{av,5,36kg}$ (the washing cycle time is 88 min and the noise during washing 53dB(A) and are assumed to remain unchanged), the LCC analysis results show (Table 6.66) always a negative MNPV and the energy consumption increases; the water consumption (38,7 litre/cycle) is not affected by the applied BNATs. The same occurs when BNAT1 and BNAT2 are applied to the BAT_{av} machine with a higher spin speed at 1 600rpm or $BAT_{av,1600rpm}$ (the washing cycle time is 92 min and the noise during washing 53dB(A)) and to the larger capacity machine or $BAT_{av,6kg}$ (the washing cycle time is 103 min and the noise during washing 53dB(A).

Table 6.66: Marginal net present value (MNPV, 15years, 220 cycles) for the aggregated option analysis for the BATav cases for washing machines

Options	Economic values			Consumption		
	$MNPV_{av}$	Price	LCC	energy		water
(n)	(€)	(€)	(€)	(kWh/cycle)	(kWh/kg)	(litre/cycle)
$BAT_{av,5,36kg}$	--	540,8	1.893	0,855	0,1596	38,7
+BNAT1	-183,18	657,8	2.076	1,025	0,1913	38,7
+BNAT2	-304,38	882,8	2.380	1,230	0,2295	38,7
$BAT_{av,1600rpm}$	--	566,3	1.932	0,892	0,1663	38,7
+BNAT1	-186,05	683,3	2.118	1,070	0,1996	38,7
+BNAT2	-307,81	908,3	2.426	1,283	0,2394	38,7
$BAT_{av,6kg}$	--	566,5	2.010	0,942	0,1569	40,3
+BNAT2	-189,92	683,5	2.200	1,130	0,1883	40,3
+BNAT1	-312,46	908,5	2.512	1,355	0,2259	40,3

6.5.2.4 Conclusions of the BNAT analysis

The analysis of the potential impact of the BNAT for wash appliances showed that, in the long run, a further decrease of the energy consumption could be possible for **dishwashers**, mainly provided the temperature of the final hot rinse is decreased, or this phase avoided and wet tableware are dried through a different system (although not yet known). In the latter case also few more water can be saved.

The Marginal Net Present Value is positive (and the LCC lower than the starting case) only for the hot rinse temperature decrease at 55°C. The energy efficiency index E_I can reach 0,41 for both 9ps and 12ps machines (corresponding to 0,522 kWh/cycle for the 9ps dishwasher and to 0,683 kWh/cycle for the 12ps dishwasher) for the former when the last hot rinse temperature is set at 55°C, for the latter when also an insulated water tank is added. When an alternative drying system is used the energy consumption decreases less, but some water is saved.

When “communication” technology is added to the machines through the possibility of internet connection or to respond to vocal commands the energy consumption increases, but positive features for consumers - particularly for elder and disable people - are also added (see paragraph 1.3.2.1).

For **washing machines** no further technological improvement is likely possible without the modification of the product archetype through the use of mixed appliances or alternative washing systems. However, those new systems need to be studied more in detail before any conclusions could be drawn about their actual effectiveness and impact.

Also for this product type, when more “communication” technology is added to the machines through the possibility of internet connection or to respond to vocal commands the energy consumption increases, with indeed positive effects for consumers - particularly for elder and disable people.

Although feasible in principle, and practically applied in some countries (Japan), the re-use of purified bath water into the washing machine should be considered in the light of a potentially different “hygiene sensibility” of western consumers towards this practice and, more practically, the spreading use of the shower as a recommended water saving alternative to the bath in western countries. The energy consumption for the ozone purification of bath water should also be considered.

6.5.3 System Analysis

In addition to the product system analysis developed in Task 4, some specific aspects will be dealt in this paragraph, mainly for washing machines:
1. the standby definition for washing machines and dishwashers
2. the trade-off between washed load amount and nominal washing machine capacity
3. the impact of the energy used in detergent production
4. the trade-off between washing machine spin speed and the use of a (tumble) dryer (methodological analysis).

6.5.3.1 The “standby” for wash appliances

a) The standby definition issue

Standby power is a term used widely and loosely in policy circles, and although intuitively understandable and generally referring to the power consumption in one or several low power consumption modes, the lack of an univocal definition (or a set of definitions) is the major barrier to a successful implementation of relevant policy measures for wash (and other) appliances. This ambiguity is still partially persisting, despite the efforts of international stakeholders such as the international standardisation bodies and the European Commission.

After a series of initiatives enforced by single countries (Australia, Denmark, Switzerland, etc.) and the International Energy Agency, the IEC started to address the “standby” definition issue at worldwide level (see Task 1). At present, the standard IEC 60301, Ed.1: 2005 “*Household Electrical Appliances – measurement of the standby power* and the corresponding EN 60301 defines standby mode as:

- *standby mode*: the lowest power consumption mode which cannot be switched off (influenced) by the user and that may persist for an indefinite time when an appliance is connected to the main electricity supply and used in accordance with the manufacturer’s instructions. The standby mode is usually a non-operational mode when compared to the intended use of the appliance's primary function.

A number of changes to the definitions and test conditions of IEC 62301 are under preparation by TC 59/WG 9 - "Measurement of standby power", **to better reflect the normal range of low power modes found in many products**, which were only partially known when this Task Report was prepared.

The European standard EN 60301:2005 includes the same definition(s) and will follow the modifications of the corresponding IEC standard in due course.

As far as the specific wash appliances are concerned, the June 2007 draft of IEC 60456 "*Clothes washing machines for household use - Methods for measuring the performance*" 5th Edition[28] defines:

- *off mode*: is where the product is switched off using appliance controls or switches that are accessible and intended for operation by the user during normal use to attain the lowest power consumption that may persist for an indefinite time while connected to a mains power source and used in accordance with the manufacturer's instructions. Where there are no controls, the washing machine is left to revert to a steady state power consumption of its own accord;
- *left on mode*: is the lowest power consumption mode that may persist for an indefinite time after the completion of the programme and unloading of the machine without any further intervention of the user. In some products this mode may be an equivalent power to off mode.

For dishwashers the standby issues is not addressed in the current IEC 60346:2004 "*Electric dishwashers for household use - Methods for measuring the performance*" or the corresponding EN 50242 Ed. 2/EN 60346, but will be considered for inclusion in a new standards Edition, very likely following the outcome of washing machines.

The European Commission recently addressed the standby issue within the preparatory studies for eco-design requirements for EuPs, with the study "Lot 6-Standby and Off-mode losses of EuPs"[29]. The declared approach followed by this study[30] is to achieve a broad coverage of standby issues by structuring the energy uses by functions offered during standby. Standby energy consumption is understood not as an energy loss, but as a service offered to the user, which should be supplied as efficiently as possible. Off-mode losses are a separate issue, in that energy is consumed without delivering a function. In cases, where valid reasons for off-mode energy consumption exists, the energy level in the off-mode should be as low as possible. The definition of Lot 6 standby and off-mode losses follows a stringent differentiation of functions and their allocation to defined modes. This distinction is based on a hierarchy of energy demand and reflects also predefined or user defined time durations, in which a function is provided.

In Task 1 of Lot 6 study seven modes (operating conditions or states in which a product provides a certain spectrum of functions, a single functions or no function at all) are identified:

1. Disconnected mode
2. 0 Watt off-mode
3. Off-mode with losses
4. Lot 6 passive standby mode
5. Lot 6 networked standby mode

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[28] See document: 59D/336/INF, at http://www.iec.ch .
[29] See: http://www.ecostandby.org .
[30] Source: Standby and Off-mode Losses (Lot 6), Public Report for Task 1 (draft final status before stakeholder meeting), Berlin, 20 April 2007.

6. Transition to standby and off-mode
7. Active mode.

These modes are defined as:

Description	Mode
This mode defines the status in which all connections to power source of the EuP are removed or interrupted. The common terms "unplugged" or "cut off form the mains" may apply to this definition as well.	Disconnected
This mode defines the status in which the EuP is connected to a power source but not drawing energy. The common terms "hard-off" or "galvanically switched off" may apply to this definition as well.	0 Watt off-mode
This mode defines the status in which the EuP is connected to a power source but is drawing energy although not providing any function (for completeness a switch on the main part of the EuP has to be allowed). All energy drawn from the energy supply during that time shall be considered as off-mode losses. The common term "lowest power consumption" could apply to this definition as well, although it should preferably be differentiated between "*lowest mode offering no function*" and "*lowest mode offering a function*". Another common term is "soft off".	Off-mode with losses
This mode defines the status in which the EuP is connected to a power source, drawn energy and offers a selection of the following reactivation and continuity functions: reactivation function provided by soft or hard switch, remote control, internal sensor, timer or network command; continuity function (information storage, sensor-based safety functions); network functions limited to network integrity communication. When at least one network function is available (reactivation via network command or network integrity communication) the mode is called "*Lot 6 networked standby*", otherwise "*Lot 6 passive standby*". This set of functions is defining the spectrum of Lot 6 standby and the associated energy consumption. The common term "passive standby" and "active standby low" may apply to this definition as well.	Lot 6 passive standby mode Lot 6 networked standby mode
This mode defines the status in which the EuP is connected to a power source, has been activated previously by any means (switch, remote control, timer, etc.) and has been manually or automatically switched to a reduced set of functions, in order to either be reactivated soon after or to traverse into lower power modes after some time. Transitional modes are handled according to the above definition: when only "Lot 6 standby functions" are active, the product is considered in standby mode, otherwise the transitional model is still part of the active operation. The EuP should however switch as fast as possible to standby or off-mode. The common terms "energy save mode", "ready", "idle", "sleep" may apply to this mode as well.	Transition to standby and off-mode
This mode defines the status in which the EuP is connected to a power source and provides one or more main functions. The common terms "on", "in-use", "normal operation" may apply to this definition as well.	Active mode

The strict separation between 'disconnected' and '0 off mode' (both consume no energy) and between '0 W off mode' and 'off mode with losses' (both supply no function) is not always necessary, but adds clarity when describing the mode durations.

In addition Lot 6 defines "sensor-based safety functions" as a continuously running sensor circuitry necessary to monitor safety related status of the product or the environment (unless the sensing is the main function of the EuP). Examples are: heat sensor to warn against hot cooking plates or water leak sensor in washing machines.
Finally Lot 6 concludes that the status is that globally harmonised understanding of standby and off-modes is necessary but not yet reachable. It is outside the scope of this study to achieve this harmonisation. The goal of this study is to investigate the significance of standby use and off-mode losses within the European Union and to develop the framework for promoting or regulating ecodesign in this area.

b) Comparison of standby definitions in Lot 6 and draft IEC 60456 5th Ed.

Comparing the latest IEC 60456 5th Ed. 'left-on-mode' and 'off-mode' definitions with the definitions of the Lot 6 study, there is a certain correspondence with the 'Lot 6 standby' or 'Lot 6 off-mode', but the specific washing machine modes cannot be allocated more precisely, as the knowledge of the function(s) provided in these modes needs to be analysed per model and per mode.

The result of the application of Lot 6 definitions to wash appliances is illustrated in Figure 6.33, while in Figure 6.34 the IEC 60456 definitions are shown.

Figure 6.33: Wash appliance modes distinction and relevant functions according to Lot 6 definition

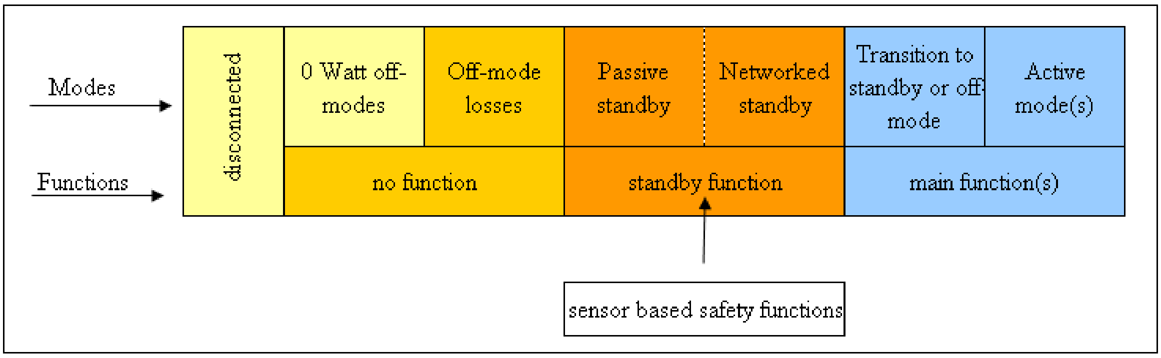
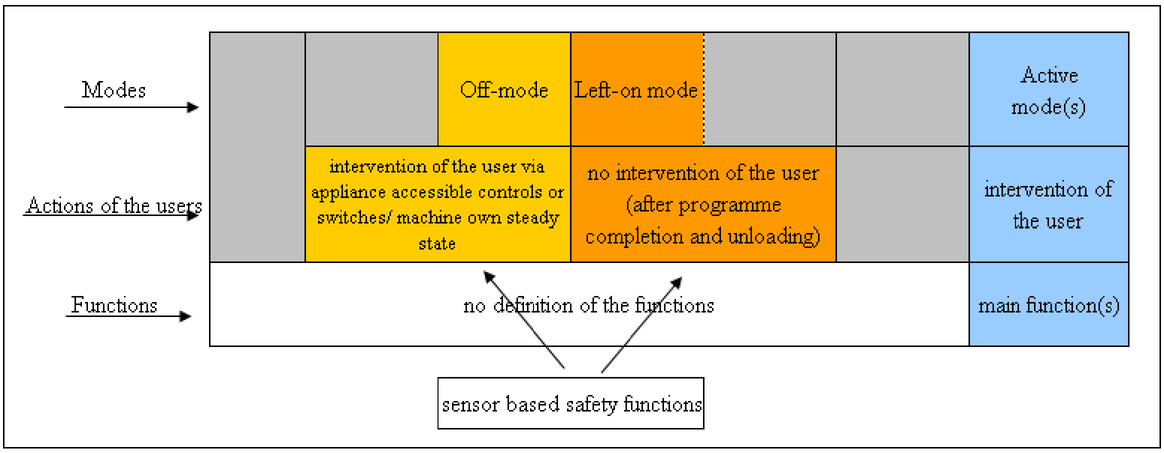


Figure 6.34: Wash appliance modes distinction and relevant functions according to draft IEC 60456 5th Ed. definition



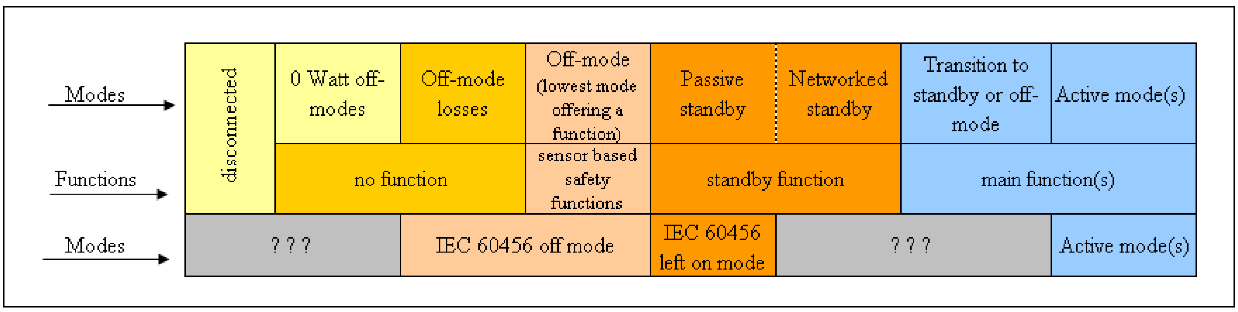
The major problem with the application of the Lot 6 study definitions to wash appliances is that 'off-mode' losses per definition (no function) can not be correlated with a functional unit, and safety functions are considered among reactivation and continuity functions of a functional unit activated when the EuP is in 'Lot 6 standby mode'. However, non primary (from the point of view of a wash appliance, whose primary function is to wash textiles or tableware) safety functions (sensor-based safety functions against water leakage and backsiphonage[31]) are intuitively useful for the consumer but also generally transparent to him/her (not intended to be voluntarily activated when the machine is plugged in) being considered granted features of a wash appliance.

If the sensor based safety functions are included in 'Lot 6 passive standby', then they will be deactivated when a machine reverts (of its own) or is switched (using appliance controls or switches) to 'Lot 6 off-mode' because no functions are associated to this mode, and the appliance will be – at least potentially – "unsafe". Under this hypothesis, to have sensor based safety functions working the machine should – through a reactivation function provided by soft or hard switch, remote control, internal sensor, timer or network command – be entered into 'Lot 6 passive standby' mode.

One might argue that consumers, once informed about the energy consumption of the sensor based safety functions, should decide about having a "less safe" machine with the lowest possible or no energy losses or a "more safe" machine with a Lot 6 standby consumption, and willingly activate the energy consuming safety functions, provided this is possible in their machine model. However, the danger is that consumers will then leave their own machine always in Lot 6 standby mode just to be on the safer side, or will complain with the machine manufacturer after having suffered a water leakage just because they forgot to activate the safety functions. Another negative element of this hypothesis is that since 'Lot 6 passive standby' mode is not defined in any current or under preparation IEC/EN standards for wash appliances, it could not be rapidly included in an implementing measure, unless defined by the legislator under its own responsibility.

For wash appliances, the definition of an additional "off-mode" as the "*lowest mode offering a function*" (Figure 6.35) is probably the most appropriate solution, but if a (useful) function is offered (and safety is intuitively useful), than the associated energy consumption is not a loss, and this contradicts the definition of 'Lot 6 off-mode'. Although not perfect, this compromise solution allows to harmonise Lot 6 and IEC standard definitions for washing machines.

Figure 6.35: Possible harmonisation of Lot 6 and draft IEC 60456 5th Ed. definitions for wash appliance modes



[31] For the protection against flooding from any machine component or water pipe and the prevention of the backflow of non-potable water into the water mains and working not only during normal functioning (as addressed in the International Standard IEC 61770:1999 "*Electric appliances connected to the water mains – avoidance of backsiphonage and failure of the hose-set*"), but also when the machine is switched off.

c) The standby for washing machines and dishwashers

As conclusion, **the definitions of "off-mode" and "left-on-mode" as given in IEC 60456, 5th edition draft are seen here as being more appropriate for washing machines**, considering that they will in a short time the be included also in the new edition of the EN 60456 standard. These definitions will be therefore used in Task 7 for the proposal of standby policy measures specific for washing machines and dishwashers.

A compromise solution for an acceptable harmonisation of Lot 6 and the draft IEC 60456 5th Ed. definitions had also been developed.

6.5.3.2 The trade-off between load amount and nominal washing machine capacity

a) The methodological approach

In the past, washing machines had few operating options, or washing programs, rarely combined with the possibility to select among saving programs. The energy and water consumptions per washing cycle were approximately fixed and users didn't care too much about such a kind of problems. This behaviour, along with the common unawareness on environmental resource consumption went so deeply in the imagination of people that for a long time nobody cared about savings. Though in the last 10-20 years experts put a precious effort to develop new technologies for saving resources, the market was main concerned with the nominal working conditions in order to assess the efficiency and efficacy of a single machine. The same things happened with the standards as if the test washing cycle was really adopted by all users in normal life. This has never been true, but this problem has been always demanded to the responsibility of the user.

In case of a different use of the appliance, or different testing conditions, one must expect a change in energy/water consumption, energy efficiency and performance compared to the results under nominal conditions.

By switching from the point of view of the single machine to that of an holistic system that includes the users of wash appliances – with their habits and needs for textile washing – a new scenario arises in which washing machine efficiency/performance should also be assessed *inter alia* against a partial loading and/or reduced temperature washing programmes.

In the last years, a better knowledge and consideration of the actual consumers behaviour and the overall environmental issue pushed the technological progress toward the design of new and more flexible machines, able to reduce the energy and water consumption according to the real washing conditions. Modern machines allow selecting a full range of washing temperatures and adapt the energy/water consumption to different loads, thus performing a large set of different working cycles. At the same time, even larger machines are manufactured, to target families with a large number of persons of specific washing needs..

The actual consumption of the whole set of washing appliances doesn't just depend on the efficiency or performance in the standard washing programme, but only this specific cycle is addressed in European standards and EU policy measures.

On the other side, a complex scenario should be hypothesised and analysed in order to appreciate the overall behaviour of the 'machine and user system' under different behaviour conditions. .

The objective of the present analysis is to understand the interaction between the two system components, in order to establish an evaluation framework that can be finally adopted to assess the “trade-off” between washing machine technical characteristics on one side and the actual consumer needs on the other side.

Analysing the saving potential of technical options from an almost theoretical point of view and accounting for differences in maximum load size, washing programmes, and other functionalities could be an amazing combinatorial problem, but the interpretation of the results could even be questionable. To evaluate the ‘machine and user system’ a simple but effective model should be created. Thus, from a practical point of view, a small set of theoretical machine types are herewith hypothesised, mainly differing in their maximum load sizes and energy consumption. Users’ habits are also simplified, in order to develop an easily understandable model, whose statistical variables represent a clear cut of the real life, as assessed in the consumers analysis in Task 3.

The presented evaluation methodology could also be seen as a framework for more refined analyses, keeping into account data coming from extended machine tests and more detailed investigations of consumer habits, along with their interaction with technical and logistic constraints.

b) Saving characteristics of the washing machines

The main scope of this analysis is to estimate the impact of larger sized machines on the resources consumption, taking into account the user habits.

One can easily expect that - for a fixed load amount - larger washing machines working at partial load will not have the same efficiency than smaller machines working at nominal load, because the latter have been optimised through the years for that load.

Larger load capacity machines present a lower specific consumption levels: to wash, for example, 10 kg of laundry, a 10kg washing machine will very likely need less energy and water than washing the same amount of laundry in a 5 kg machine for two times. But on the contrary, if only 5kg of laundry have to be washed a larger energy/water consumption is expected when a 10kg machine is used at half load, compared again with a 5kg machine working at nominal load capacity. This expected outcome derives from the fact that all the components in both machines are optimized for the nominal load and the same technological levels for energy management are implemented.

Unfortunately, no comprehensive data on energy and water consumption by load and washing temperature are available, mainly because tests at different load and temperature conditions are not fully covered by the worldwide standards. Therefore, in this analysis theoretical characteristics are assumed for a virtual machine.

When a machine is partially loaded, the resources consumption is not linearly reduced: its (energy and water) efficiency decreases, the appliance being featured for the full-load. So far, if the consumption is fixed and independent from the load, the specific consumption (consumption per load unit) would increase with an hyperbolic trend by reducing the load.

Although the general efficiency of washing appliances has been largely improved in the last decade, due to the introduction of more sophisticated components (motors, pumps, electro valves, etc.) with a higher intrinsic efficiency, as well as better control (electronic) devices, such components can’t avoid to waste energy at null-load, neither afford to preserve their efficiency when required to handle less energy or less water, than the nominal ones. Some experimental tests can confirm these assumptions, as reported in Table 6.67-6.68. Data on specific energy (energy per load unit), and specific amount of water (water per load unit) consumptions are respectively shown in Figures 6.36-6.37. Correspondingly, energy and water consumptions per cycle are presented Figures 6-38-6.39.

Specific energy consumption by load			
Load [(kg)	Load (%)	Specific consumption (kWh/kg)	Consumption. per cycle (kWh)
6,00	100%	0,18	1,08
4,50	75%	0,23	1,04
3,00	50%	0,32	0,96
1,50	25%	0,57	0,86

Table 6.67: Specific energy and energy per cycle consumed by some tested washing machines.

Specific water consumption by load			
Load [(kg)	Load (%)	Specific consumption (kWh/kg)	Consumption. per cycle (kWh)
6,00	100%	9,86	59,2
4,50	75%	12,00	54,0
3,00	50%	15,23	45,7
1,50	25%	23,24	34,9

Table 6.68: Specific water and water per cycle consumed by some tested washing machines.

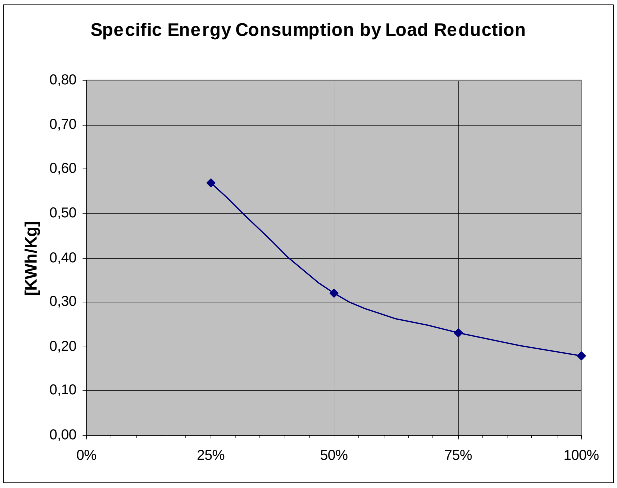


Figure 6.36: Experimental data on specific energy consumption against load reduction

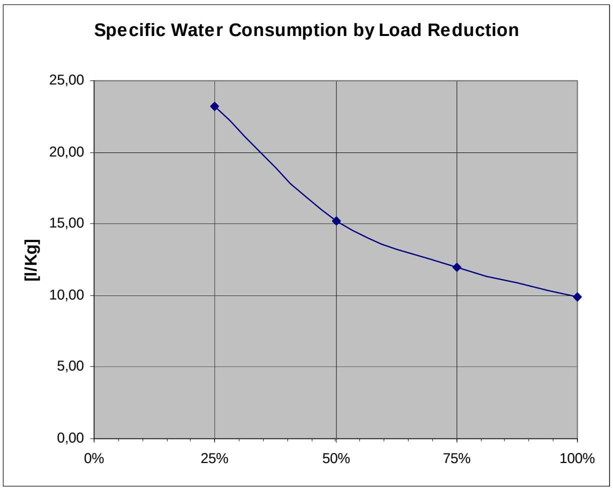


Figure 6.37: Experimental data on specific water consumption against load reduction

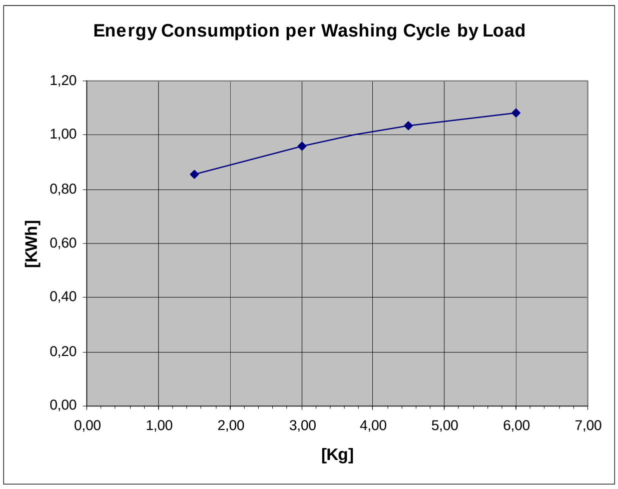


Figure 6.38: Experimental data on energy consumption per washing cycle against load reduction

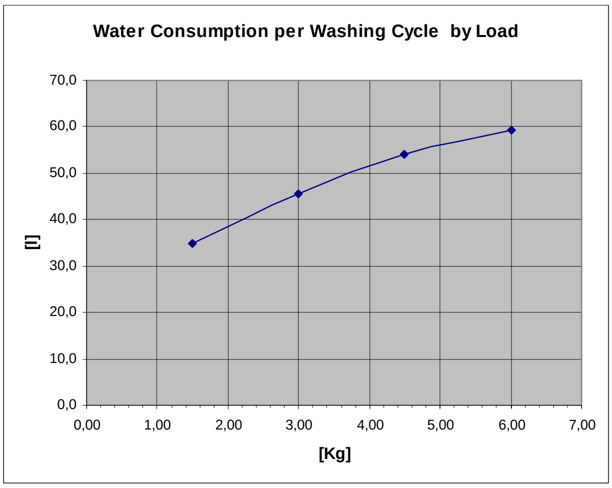


Figure 6.39: Experimental data on water consumption per washing cycle against load reduction

Although these data reflect the performance of real machines, the following analysis will be focussed on the trend more than on absolute value. Direct comparison between two machines belonging to different load capacity categories would have no meaning, since - for different reasons - higher load capacity machines are able to manage the resources (energy, water, detergent) better than smaller load capacity machines, due to a well known scale effect, already happening for other household appliances. It would be also worthless to compare average machines, representing the average features of the real machines in each load capacity category. The present analysis is in fact aimed at enhancing the efficiency and performance of washing machines in each load category, given that the best components and control systems are installed.

In addition, due to the lack of standard data (limited to tests driven at full-load and standard temperatures) and the different consumer habits (in terms of used washing temperatures and loads) suitable interpolations and extrapolations for the available data are needed, so that a theoretical model is necessary.

A mathematical model has been defined, to approximate the saving characteristics over a feasible range of values for the independent variables. Given a set of boundary data (no matter if experimental, or estimated), which represent the consumption levels for both idle (i.e. null load), and full-loaded cycles at different washing temperatures, a set of theoretical curves, representing the resources (energy and water) consumption, have been set - through an interpolation - as function of he load, and in case of the energy consumption as function of the washing temperature, according to the following definitions:

$$W_{l,t} = W_{t,i} + \left(W_{t,f} - W_{t,i}\right) \times \left(\frac{l}{l_f}\right)^n$$

where:

- $W_{l,t}$ is the variable resource consumption level at load l and temperature t;
- $W_{t,i}$ is the resource consumption level for the null load washing cycle (idle);
- $W_{t,f}$ is the resource consumption level for the full-load washing cycle (nominal size);
- l is the variable load;
- l_f is the machine nominal load capacity;
- $n = 0{,}7$

The mathematical model exactly fits the boundary data $W_{t,i}$ and $W_{t,f}$.
Two appliance categories that differ by just 1 kg are defined to be “adjacent”.

This mathematical model represents the energy consumption of an ideal, best performing, theoretical machine – herewith named “archetype” – supposed to be available for each load category and representing its category. Each archetype is also defined as having the possibility to select among six differ washing temperatures and having been optimized for the nominal load capacity (i.e. the same maximum technological level is considered for all categories).

Resulting numerical values of the energy consumption are reported in Tables 6.69-6.72 related to four different archetypes: 5 kg, 6 kg, 7 kg, and 8 kg nominal load. Trend curves are plotted for each characteristic in Figures 6.40-6.43. The characteristics of the different archetypes are extrapolated from each other by means of a multiplying coefficient: an estimated but optimistic 5% increase in the energy consumption between two adjacent categories is assumed, consistently with the mathematical models of each archetype.

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kg	**Energy per cycle** (kWh)					
T	20°C	30°C	40°C	50°C	60°C	90°C
0	0,092	0,235	0,36	0,49	0,59	0,85
1	0,19	0,35	0,50	0,66	0,79	1,06
2	0,25	0,43	0,59	0,76	0,91	1,19
3	0,31	0,49	0,67	0,85	1,02	1,30
4	0,36	0,55	0,74	0,93	1,11	1,41
5	0,40	0,60	0,80	**1,00**	1,20	1,50

Table 6.69: Energy consumption per cycle for the 5 kg archetype

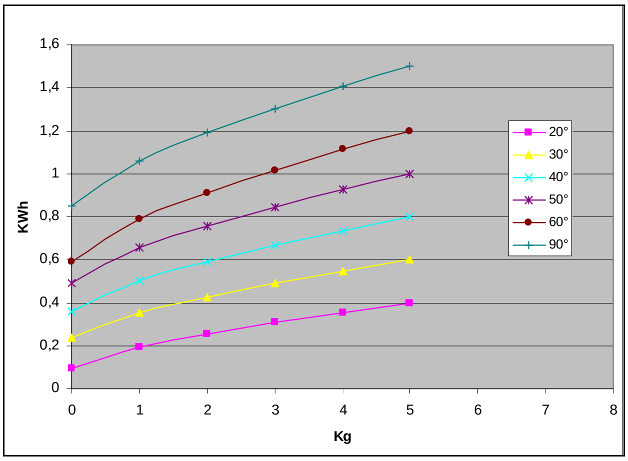


Figure 6.40: Energy consumption per cycle for the 5 kg archetype

kg	**Energy per cycle** (kWh)					
T	20°C	30°C	40°C	50°C	60°C	90°C
0	0,10	0,25	0,38	0,51	0,62	0,89
1	0,20	0,37	0,53	0,69	0,83	1,11
2	0,27	0,45	0,62	0,80	0,96	1,25
3	0,32	0,51	0,70	0,89	1,07	1,37
4	0,37	0,57	0,77	0,97	1,17	1,48
5	0,42	0,63	0,84	1,05	1,26	1,58
6	0,46	0,68	0,90	**1,12**	1,35	1,67

Table 6.70: Energy consumption per cycle for the 6 kg archetype

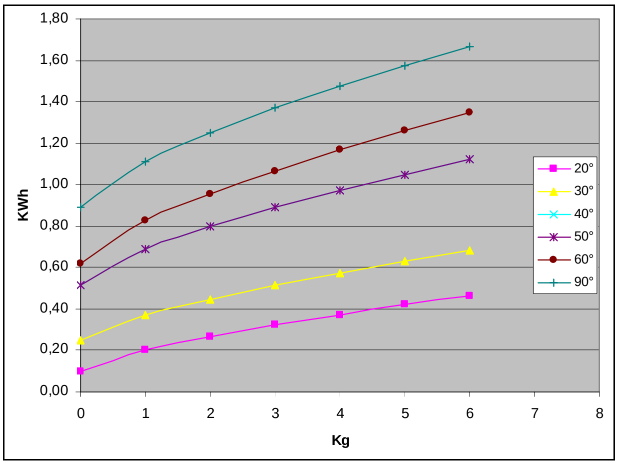


Figure 6.41: Energy consumption per cycle for the 6 kg archetype

kg	**Energy per cycle (kWh)**					
T	20°C	30°C	40°C	50°C	60°C	90°C
0	0,10	0,26	0,40	0,54	0,65	0,94
1	0,21	0,39	0,55	0,72	0,87	1,17
2	0,28	0,47	0,65	0,84	1,00	1,31
3	0,34	0,54	0,74	0,93	1,12	1,44
4	0,39	0,60	0,81	1,02	1,23	1,55
5	0,44	0,66	0,88	1,10	1,32	1,65
6	0,49	0,72	0,95	1,18	1,41	1,75
7	0,53	0,77	1,01	**1,25**	1,50	1,84

Table 6.71: Energy consumption per cycle for the 7kg archetype

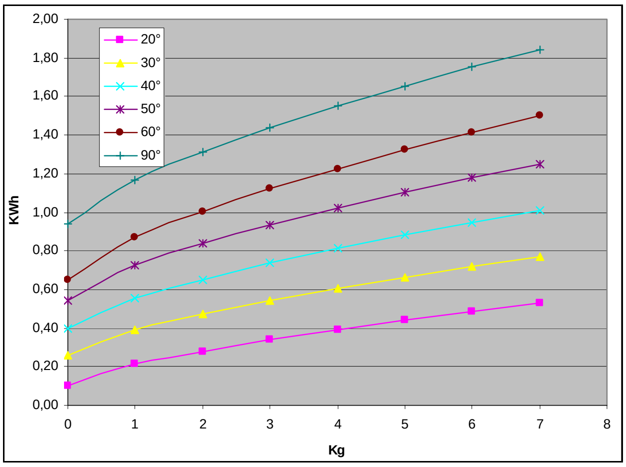


Figure 6.42: Energy consumption per cycle for the 7kg archetype

kg / T	Energy per cycle (kWh) 20°C	30°C	40°C	50°C	60°C	90°C
0	0,11	0,27	0,42	0,57	0,68	0,98
1	0,22	0,41	0,58	0,76	0,91	1,23
2	0,29	0,49	0,68	0,88	1,05	1,38
3	0,36	0,57	0,77	0,98	1,18	1,51
4	0,41	0,63	0,85	1,07	1,29	1,63
5	0,46	0,69	0,93	1,16	1,39	1,74
6	0,51	0,75	1,00	1,24	1,49	1,84
7	0,56	0,81	1,06	1,31	1,58	1,94
8	0,60	0,86	1,12	**1,39**	1,66	2,03

Table 6.72: Energy consumption per cycle for the 8kg archetype

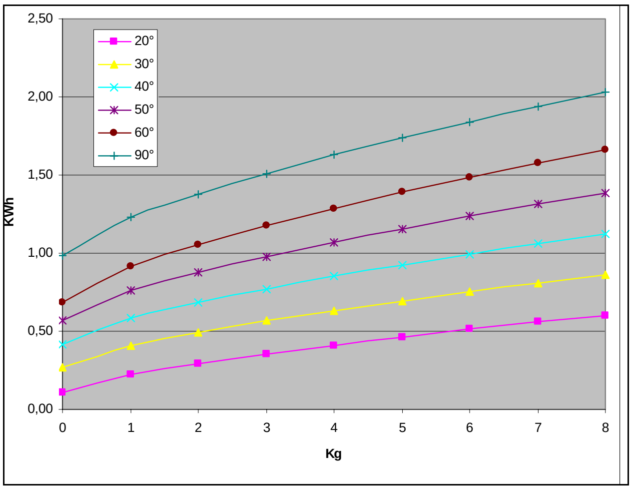


Figure 6.43: Energy consumption per cycle for the 8kg archetype

c) Present consumer habits and future scenarios

As stated in Task 3, differences between the "real life" behaviour in machine use and the standard test conditions could bring to significant differences in resources consumption. The two main factors affecting these differences are:

1. the actual amount of textile washed;
2. the water temperature (directly set by the user or indirectly selected with the chosen washing programme).

The real life frequency distributions for actual loads and washing temperatures, shown in Tables 6.73-6.74 and Figures 6.44-6-45 are derived from Task 3 results and are here considered "standard habits". From the frequency distribution of the washing loads per week is also possible to estimate the average number of washing cycles per week for each machine, which is approximately equal to 4.9 cycles/week, with an average load about 4,02 kg/cycle. These give an average load per week of about 19,71 kg/week for the average installed washing machine.

These figures are a very important point of reference, as they are related to the sizes of existing washing machines. The machine size is not the only issue that affects the consumer habits, the washing needs being another one and is related to both the availability at home of a stock of different clothes and laundry items and the inopportunity to store a large amount of dirty laundry for long periods.

Therefore, in spite of the possibility to wash larger loads, some inertia to change the own habits could be expected in the population. For this reason, some possible scenarios are investigated. The first scenario is based on the continuation of the "standard habits". This scenario is a reference scenario when applied to the 5kg archetype machine, which is very close to the standard base case" machine, defined in this Task 5.

Supposing two variables (load & temperature) to be statistically independent, a joint probability '$P_{l,t}$' to have a washing cycle with load 'l' at temperature 't', can be defined as the product of the corresponding probability of each variable, which is here inferred as the product of the two single

Load (kg)	Frequency (%)
2	1,2
3	12,6
4	69,0
5	17,2

Average load = 4,023 kg

Table 6.73: Washing cycles frequency distribution by load

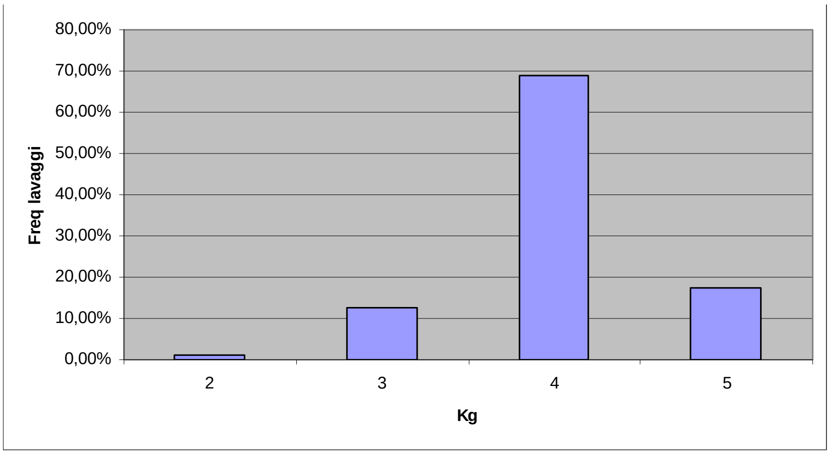


Figure 6.44: Washing cycles frequency distribution by load

Temperature (°C)	Frequency (%)
20°	6
30°	18
40°	37
50°	10
60°	22
90°	7

Table 6.74: Washing cycles frequency distribution by temperature

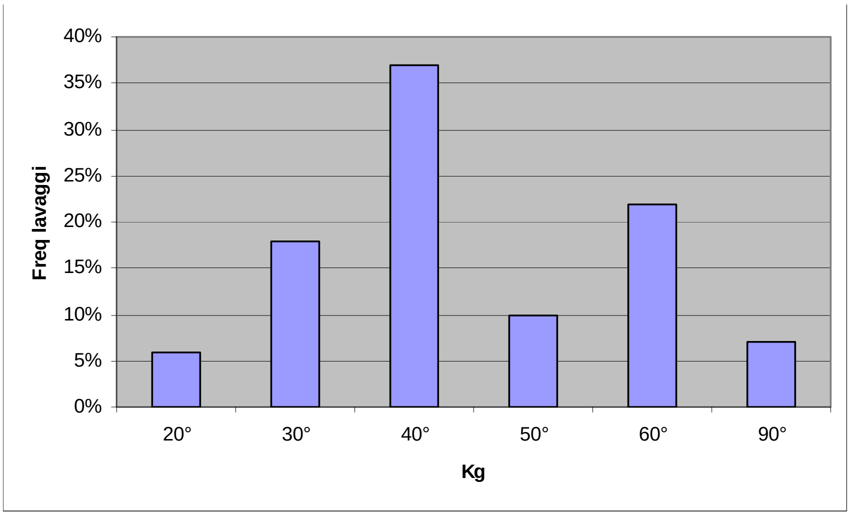


Figure 6.45: Washing cycles frequency distribution by temperature

frequencies, as shown in Table 6.75 and Figure 6.46. This is one of the major – and questionable - simplifications within this analysis. Nevertheless, if the actual joint distribution is available, it can easily used in Table 6.75 and the spreadsheet simulation can run as well.

The weekly washing cycles by loads and temperatures in standard habits, presented in Table 6.76 are obtained by the product of the joint frequencies and the average number of washing cycles per week.

Because of figures on standard habits – which show an average of about 4 kg and no loads (or almost no loads, according to available information from Task 3) over 5kg there is little chance for larger capacity machines to work at full load if consumer habits would not change. Therefore, there is no need to simulate the standard scenario for the other archetypes but the 5 kg one. By assuming that standard habits are used with other archetypes it is possible to analyse the impact of the different archetypes energy consumption characteristics. In fact, in case of invariant habit scenario the analysis results will just reflect the differences among the technical characteristics of archetypes.

Standard Scenario - Standard habits

kg T	20°C	30°C	40°C	50°C	60°C	90°C	Tot.
2	0,07%	0,21%	0,43%	0,11%	0,25%	0,08%	1,15%
3	0,76%	2,28%	4,68%	1,26%	2,78%	0,89%	12,64%
4	4,14%	12,41%	25,52%	6,90%	15,17%	4,83%	68,97%
5	1,03%	3,10%	6,38%	1,72%	3,79%	1,21%	17,24%
Tot.	6,00%	18,00%	37,00%	10,00%	22,00%	7,00%	**100,0 %**

Table 6.75: Joint frequency distribution of washing cycles by loads and temperatures in standard habits

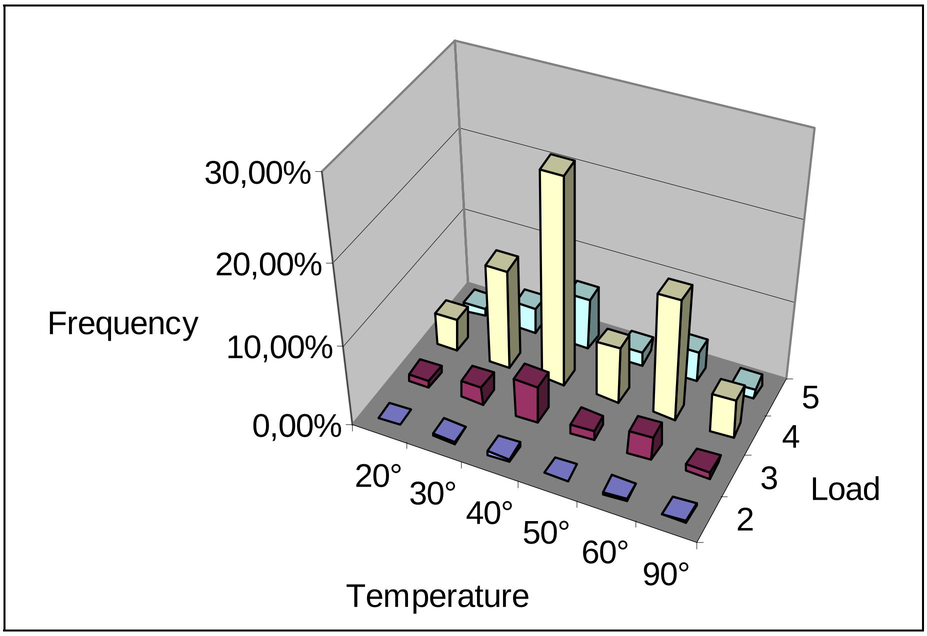


Figure 6.46: Joint frequency distribution of washing cycles by loads and temperatures in standard habits

Standard Scenario (standard habits)

kg T	20°C	30°C	40°C	50°C	60°C	90°C	Tot.
2	0,003	0,010	0,021	0,006	0,012	0,004	0,056
3	0,037	0,112	0,229	0,062	0,136	0,043	0,620
4	0,203	0,608	1,250	0,338	0,743	0,237	3,379
5	0,051	0,152	0,313	0,084	0,186	0,059	0,845
Tot.	0,29	0,88	1,81	0,49	1,08	0,34	4,90

Table 6.76: Number of weekly washing cycles by loads and temperatures in standard habits.

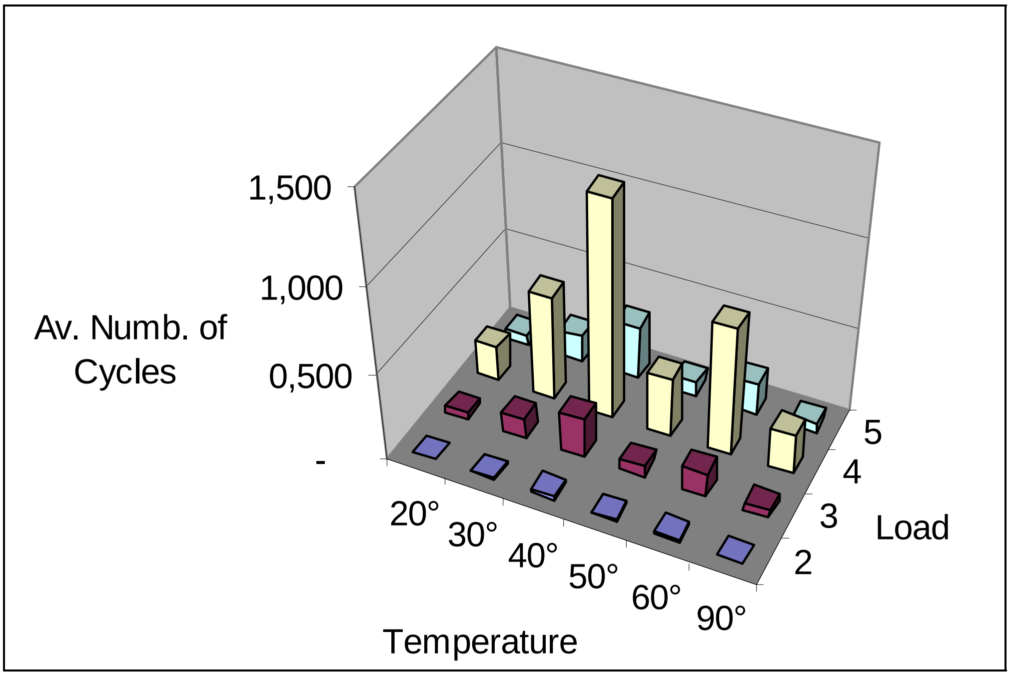


Figure 6.47: Washing cycles per week by load and temperature in Standard Scenario

In order to evaluate the variation in the load capacity category, two scenarios were defined for the 7kg archetype where no change is supposed on the distribution of washing temperatures:

- the first scenario, named "**Scenario I**", includes the changing of the frequency distribution of loads, without any variation of the average figures in the consumer habits (i.e. the average load remains 4,023 kg). Results are given in Tables 6.77-6.78. For sake of consistency in data distribution when an increase occurs in the frequency of higher loads also the frequency of smaller loads has be increased, so that a bimodal distribution of loads is implicit in this scenario. From a practical point of view, this scenario can be considered as a boundary situation: the consumer behaviour is pushed towards larger washing loads by the availability of larger capacity machines, but the "washing needs" are limiting any reduction in the number of washing cycles, and consequently any increase in the average washing load, since the total amount of laundry per week (19,71 kg/week) is assumed to be constant. An increase in smaller loads is therefore forecast for this scenario;

- in the second scenario – named "**Scenario II**" – the load distribution is quite similar to the standard scenario, but shifted to higher loads. The number of washing cycles per week is reduced accordingly in order to preserve the total amount of laundry to be washed per week (the average "washing need" estimated to be about 19,71 kg/week). Figures are given in Tables 6.79 and 6.80.

Scenario I: standard cycles per week with a different distribution of loads

kg T	20°C	30°C	40°C	50°C	60°C	90°C	Tot.
2	1,94%	5,81%	11,94%	3,23%	7,10%	2,26%	1,15%
3	1,26%	3,77%	7,75%	2,09%	4,61%	1,47%	12,64%
4	0,60%	1,80%	3,70%	1,00%	2,20%	0,70%	68,97%
5	0,68%	2,04%	4,18%	1,13%	2,49%	0,79%	17,24%
6	0,00%	0,00%	0,00%	0,00%	0,00%	0,00%	
7	1,53%	4,59%	9,43%	2,55%	5,61%	1,78%	
Tot.	6,00%	18,00%	37,00%	10,00%	22,00%	7,00%	100,0 %

Table 6.77: Joint frequency distribution (%) of washing cycles by loads and temperatures in Scenario I

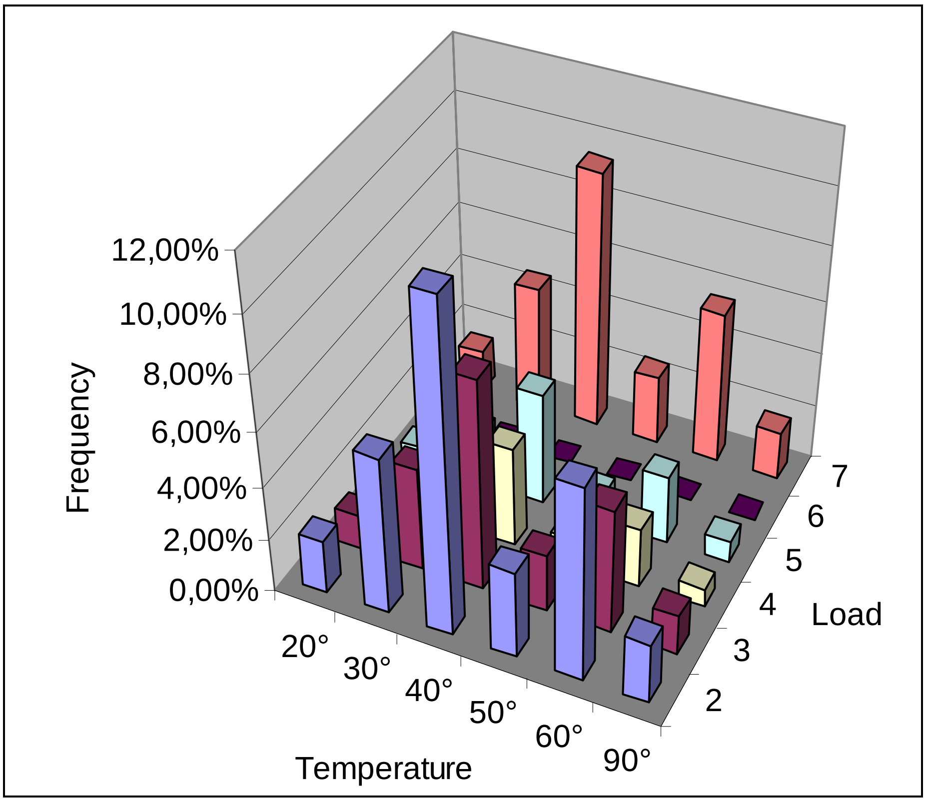


Figure 6.48: Washing cycles joint frequency (%) by load and temperature in Scenario I

Scenario I: Standard cycles per week with a different distribution of loads

kg T	20°C	30°C	40°C	50°C	60°C	90°C	Tot.
2	0,095	0,285	0,585	0,158	0,348	0,111	0,056
3	0,062	0,185	0,380	0,103	0,226	0,072	0,620
4	0,029	0,088	0,181	0,049	0,108	0,034	3,379
5	0,033	0,100	0,205	0,055	0,122	0,039	0,845
6	-	-	-	-	-	-	
7	0,075	0,225	0,462	0,125	0,275	0,087	
Tot.	0,29	0,88	1,81	0,49	1,08	0,34	4,90

Table 6.78: Number of weekly washing cycles by loads and temperatures in Scenario I

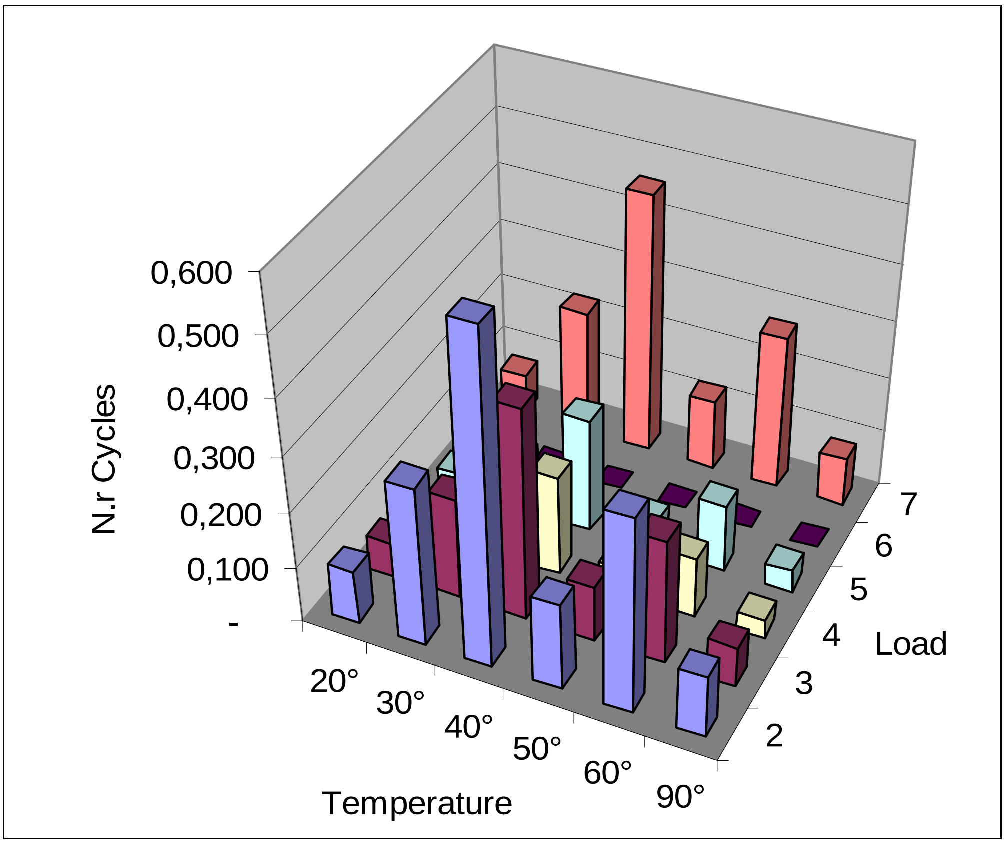


Figure 6.49: Number of washing cycles per week by load and temperature in Scenario I

Scenario II – Reduced cycles per week

kg T	20°C	30°C	40°C	50°C	60°C	90°C	Tot.
2	0,00%	0,00%	0,00%	0,00%	0,00%	0,00%	0,00%
3	0,07%	0,21%	0,43%	0,11%	0,25%	0,08%	1,15%
4	0,64%	1,92%	3,94%	1,06%	2,34%	0,75%	10,64%
5	3,90%	11,69%	24,04%	6,50%	14,29%	4,55%	64,97%
6	0,91%	2,74%	5,64%	1,52%	3,35%	1,07%	15,24%
7	0,48%	1,44%	2,96%	0,80%	1,76%	0,56%	8,00%
Tot.	6,00%	18,00%	37,00%	10,00%	22,00%	7,00%	**100,0 %**

Table 6.79: Joint frequency distribution (%) of washing cycles by loads and temperatures in Scenario II

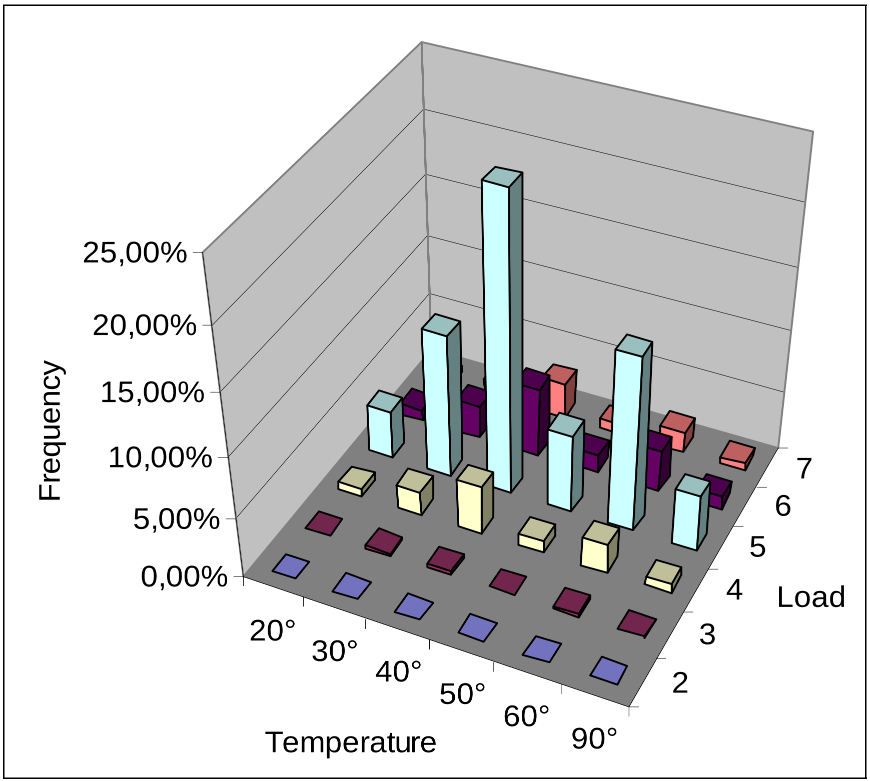


Figure 6.50: Washing cycles joint frequency (%) by load and temperature in Scenario II

Scenario II – Reduced cycles per week

kg T	20°C	30°C	40°C	50°C	60°C	90°C	Tot.
2	-	-	-	-	-	-	0,000
3	0,003	0,008	0,016	0,004	0,010	0,003	0,044
4	0,024	0,073	0,150	0,040	0,089	0,028	0,405
5	0,148	0,445	0,914	0,247	0,544	0,173	2,471
6	0,035	0,104	0,214	0,058	0,128	0,041	0,580
7	0,018	0,055	0,113	0,030	0,067	0,021	0,304
Tot.	0,23	0,68	1,41	0,38	0,84	0,27	**3,80**

Table 6.80: Number of weekly washing cycles by loads and temperatures in Scenario II

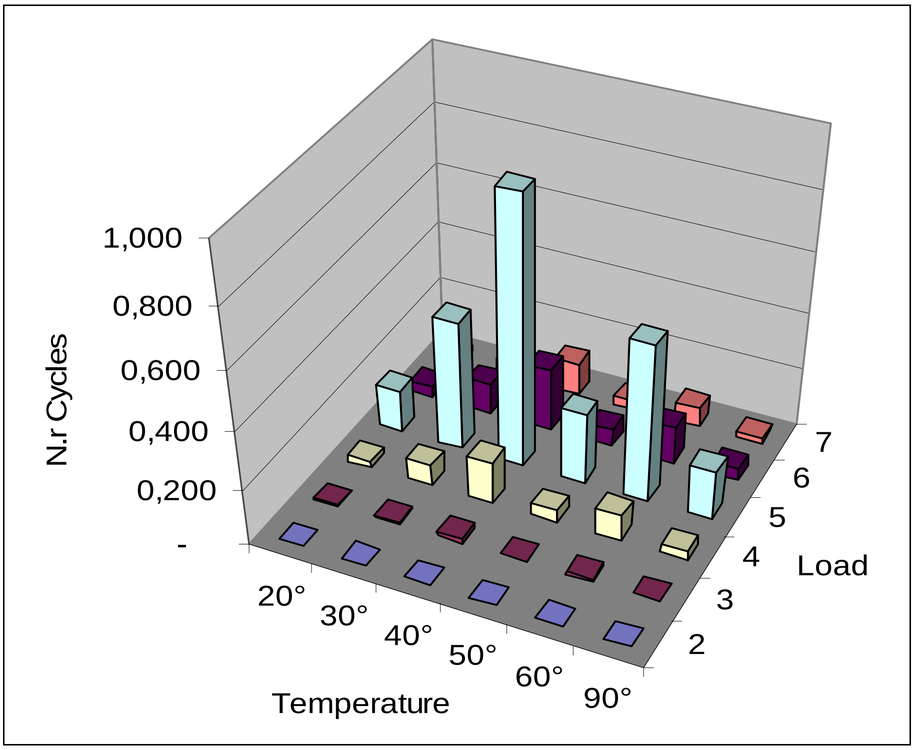


Figure 6.51: Number of washing cycles per week by load and temperature in Scenario II

d) Analysis results

Given the distribution of the "weekly washing cycles" and the resource consumption of each archetype, the weekly amount of resources required for washing according to each Scenario can be obtained by the sum of products between the corresponding elements of the two data matrix, namely the resource consumption curves and the weekly cycles by load and temperature joint frequencies, as follows:

$$W_{tot} = \sum_{L,T} \left(W_{l,t} \times P_{l,t} \right)$$

where:

L, T are the discrete sets of loads and temperatures, respectively.

With reference to the archetypes and scenarios, the energy consumed by the system per week, as well as its variation with respect to the reference case, are summarized in Table 6.81.

Table 6.81: Machine energy weekly used by each archetype, in front of different scenarios

Archetype (load)	Scenario	Energy consumption (kWh/week)	Variation (%)
5 kg	Standard	4,06	--
6 kg	Standard	4,26	+ 5,0%
7 kg	Standard	4,48	+ 10,3 %
7 kg	Scenario I	4,43	+ 9,0 %
7 kg	Scenario II	3,24	- 20,2 %
8 kg	Scenario II	3,65	- 10,1 %

As expected, the larger load capacity category archetypes result in an increase in the weekly energy consumption, if no change in the consumer behaviour takes place. From a theoretical point of view, it is worth noting that the Scenario I differs from the standard one only for the shape in the two frequency distributions, but the first order moments in the respective data sets are equivalent. Scenario II results in a significant savings in energy per week with the 7kg archetype, but this savings are reduced considerably (up to50%) with the 8 kg archetype.

The main conclusions is that with the larger capacity machines, represented by the 7kg archetype, a very large variation in energy savings, from -10% (negative savings) if consumers do not change their behaviour, and up to +20% savings if they do, along the lines of Scenario II. This is a 30% variation in energy consumption due to consumers behaviour, which is strongly related to the promotion of the proper information to them.

As any theoretical investigation, although based on actual information collected in Task 3, also this analysis has some limits, which are essentially the realism of the Scenarios due the possible necessity of small capacity washes for special fabrics or special needs.

Given the distribution of the washing loads from consumer habits, with an average load of about 4,02 kg/week, the load capacity of the average washing machine (the so called standard Base Case) is not fully used. This could be a symptom of the robustness of actual constraints (i.e. the user the washing needs) in spite of the possibility to wash larger loads.

The hypothesised Scenarios cannot be taken as absolute models. Different analytical models can be assumed for the archetype, within the same framework methodology. Similarly, users' habits have been inferred over the whole European population, but different behaviours do co-exist in different countries or geographical areas. The three hypothesised Scenarios are therefore to be considered as boundary situations a the extremes of the washing machine use. Any other behaviour scenario lies among such extreme cases.

Nevertheless, the achieved results are in quite good agreement with a previous analysis developed in 2004 by the German Öko-Institut[32], concluding than when comparison a standard 5kg washing machines with a larger 7kg washing machine, the latter is slightly better on the basis of the same

[32] Source: I. Rüdenauer, C. Gensch, D.Quack, Eco-Efficiency Analysis of Washing machines – Life Cycle Assessment and determination of optimal life span, Öko-Institut e.V. Geschäftsstelle FreiburgFreiburg, November 2nd, 2004, downloadable from http://www.oeko.de .

amount of wash laundry. But depending on the consumer behaviour the acquisition and use of a large washing machine can become much worse than the acquisition and use of a standard washing machine when the two are compared on the basis of the same amount of washing cycles.

Finally the investigated Scenarios are occurring against the backdrop of decreasing family size in Europe, and this element has not been considered in the simulation.

6.5.3.3 The impact of the energy used in detergent production

a) The methodological approach

In this paragraph the theoretical framework presented in the previous paragraph is extended to the evaluation of the detergent impact on energy resources consumption. The methodology is the same, but the energy consumption is given by the sum of two components: the energy consumed for the washing cycle by the washing machine plus the energy needed to manufacture the used detergent.

The potential impact of larger load capacity machines under different consumer habits is analysed through a mix of actual and theoretical hypothesis. The same four archetypes and three scenarios are instantiated herewith, which are consistent with the results of Task 3. The same weekly average laundry load is assumed in each scenario. In this analysis however, the total “energy consumption” is based on two system components that are separately analysed versus different loads and temperatures: the machine energy consumption and the specific energy needed to produce the detergent. The former has been evaluated in the previous paragraph, the latter is based on the amount of detergent dissolved in washing liquor at the selected loads and temperatures. It is known that the “washing performance” of this liquor depends on several factors: the type of detergent, the water amount and temperature, the water hardness, the type of fabric, the stains, etc.. To simplify the analysis, the amount of detergent defined in 4th Edition of IEC 60456 for the standard “cotton wash programme at 60°C” and used for the LCC analysis of the standard base case machine, is assumed, which is calculated according to the formula:

Detergent Amount = $d_0 + d_1$ * (“load”)

where: $d_0 = 54$ g
$d_1 = 16$ g/kg

Notice that an “optimal” use of the detergent is here assumed, neglecting the overdosing generally occurring in practice. In fact, although the appliance and detergents instructions describe the amount of detergent to be used according to the selected programme and load conditions, usually consumers tend to overdose it. In addition, when different loads and temperatures are considered the amount of detergent should be adapted to preserve the same final wash performance. This analysis assumes that the “ideal” detergent dosage is used for the different washing cycles, according to the actual load and temperature. Therefore, the above formula is modified to estimate the correct amount of detergent for each washing cycle:

(1) the constant term (detergent amount at null load) in the formula itself is incremented versus different archetypes;
(2) the standard dose obtained for the 60° programme is normalized by means of a suitable coefficient, in order to account for washing programmes at different temperatures.

The first variation is justified by the increased amount of water that a larger archetype loads independently from the laundry load. A 10% increase in the constant term of the formula is hypothesised between two “adjacent” machine categories (archetypes). In practice, values reported in Table 6.82 are assumed for the archetypes.

The second variation is introduced to account for the detergent performance at different temperatures. According to Task 3 results, it is assumed that the cotton 60°C programme performance level can be achieved by using just 50% of the nominal detergent dose in a cotton 90°C programme, or by 150% of the nominal dose in a cotton 40°C programme. The amount of detergent for the standard cotton 60° programme is multiplied by a corrective coefficient, according to the figures reported in Table 6.83 (ratio to standard case), to get the amount of detergent giving the same performance at the selected programme temperature.

Table 6.82: Used detergent amount for the standard “cotton 60°C programme”, for different archetypes

Machine capacity (kg)	Constant term d_0 (g)	coefficient d_1 (g/kg)
5	54,0	16,0
6	59,4	16,0
7	65,3	16,0
8	71,9	16,0

Table 6.83: Relative amount of detergent for washing cycles at different temperatures (ratio to standard case). Values at T=20, 30, and 50 °C are extra/interpolated according to the experimental results in Task 3

Temperature (°C)	**20**	**30**	**40**	**50**	**60**	**90**
Ratio	2	1,72	1,5	1,3	1	0,5

Finally, the calculated amount of detergent for each washing cycle is converted into “energy resources” to account for the manufacturing impact on the energy consumption and added to the energy used by the archetype machine to get the total amount of energy resources consumed by the overall washing system. To this purpose, **a conversion factor of 41,16 MJ per kg of detergent** is adopted.

b) Total energy consumption per washing cycle in different machine archetypes

The values of the overall energy consumption per washing cycle are reported in Tables 6.84-6.91 for the 5kg, 6kg, 7kg and 8kg archetypes. Trend curves are shown in Figures 6.52-6.55.

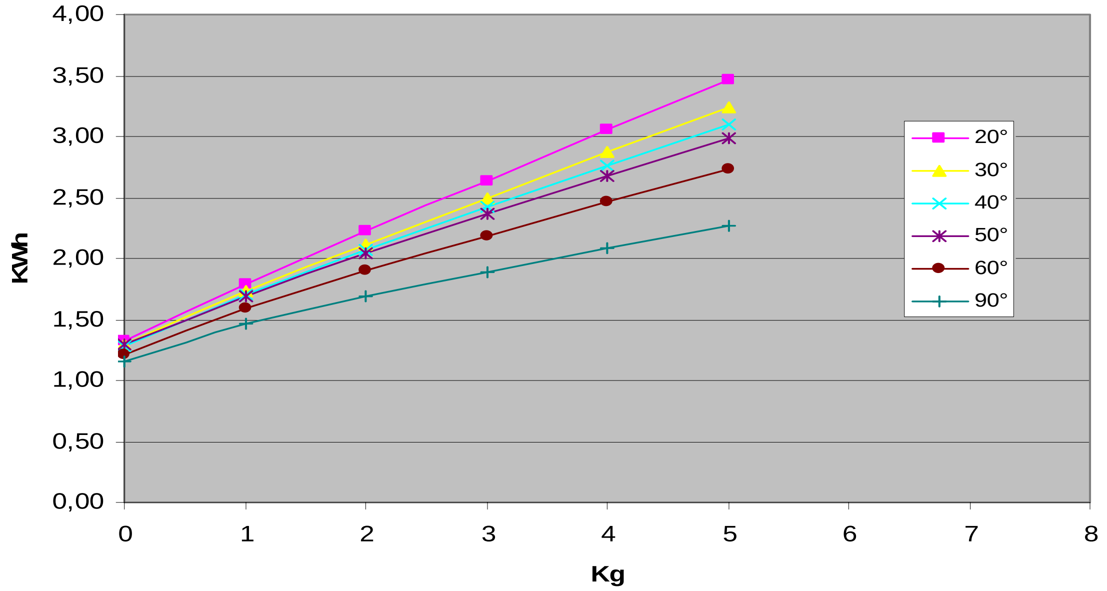
kg	**Equiv. energy for detergent** (kWh/cycle)					
T	20°C	30°C	40°C	50°C	60°C	90°C
0	1,23	1,06	0,93	0,80	0,62	0,31
1	1,60	1,38	1,20	1,04	0,80	0,40
2	1,97	1,69	1,48	1,28	0,98	0,49
3	2,33	2,01	1,75	1,52	1,17	0,58
4	2,70	2,32	2,02	1,75	1,35	0,67
5	3,06	2,64	2,30	1,99	1,53	0,77

Table 6.84: Equivalent energy consumption per washing cycle required to manufacture the detergent in the 5kg archetype machine

kg	**Total energy consumption** (kWh/cycle)					
T	20°C	30°C	40°C	50°C	60°C	90°C
0	1,33	1,30	1,29	1,29	1,21	1,16
1	1,79	1,73	1,70	1,70	1,59	1,46
2	2,22	2,12	2,07	2,04	1,89	1,68
3	2,64	2,50	2,42	2,36	2,18	1,89
4	3,05	2,87	2,76	2,68	2,46	2,08
5	3,46	3,24	3,10	2,99	2,73	2,27

Table 6.85: Total energy consumption per cycle with the 5kg archetype machine

Figure 6.52: Total energy consumption per cycle with the 5kg archetype machine



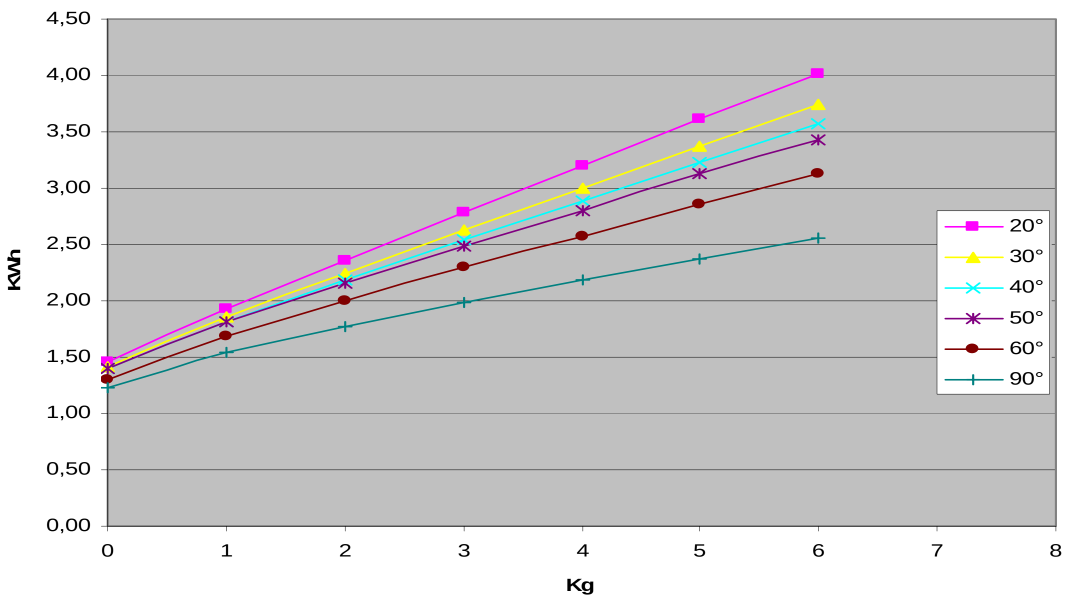
kg T	Equiv. energy for detergent (kWh/cycle)					
	20°C	30°C	40°C	50°C	60°C	90°C
0	1,36	1,17	1,02	0,88	0,68	0,34
1	1,72	1,48	1,29	1,12	0,86	0,43
2	2,09	1,80	1,57	1,36	1,05	0,52
3	2,46	2,11	1,84	1,60	1,23	0,61
4	2,82	2,43	2,12	1,83	1,41	0,71
5	3,19	2,74	2,39	2,07	1,59	0,80
6	3,55	3,06	2,67	2,31	1,78	0,89

Table 6.86: Equivalent energy consumption per washing cycle required to manufacture the detergent in the 6kg archetype machine

kg T	Total energy consumption (kWh/cycle)					
	20°C	30°C	40°C	50°C	60°C	90°C
0	1,46	1,42	1,40	1,40	1,30	1,23
1	1,93	1,85	1,82	1,81	1,69	1,54
2	2,36	2,25	2,19	2,16	2,00	1,77
3	2,78	2,63	2,54	2,49	2,30	1,98
4	3,20	3,00	2,89	2,81	2,58	2,18
5	3,61	3,37	3,23	3,12	2,85	2,37
6	4,02	3,74	3,57	3,43	3,12	2,56

Table 6.87: Total energy consumption per cycle with the 6kg archetype machine

Figure 6.53: Total energy consumption per cycle with the 6kg archetype machine



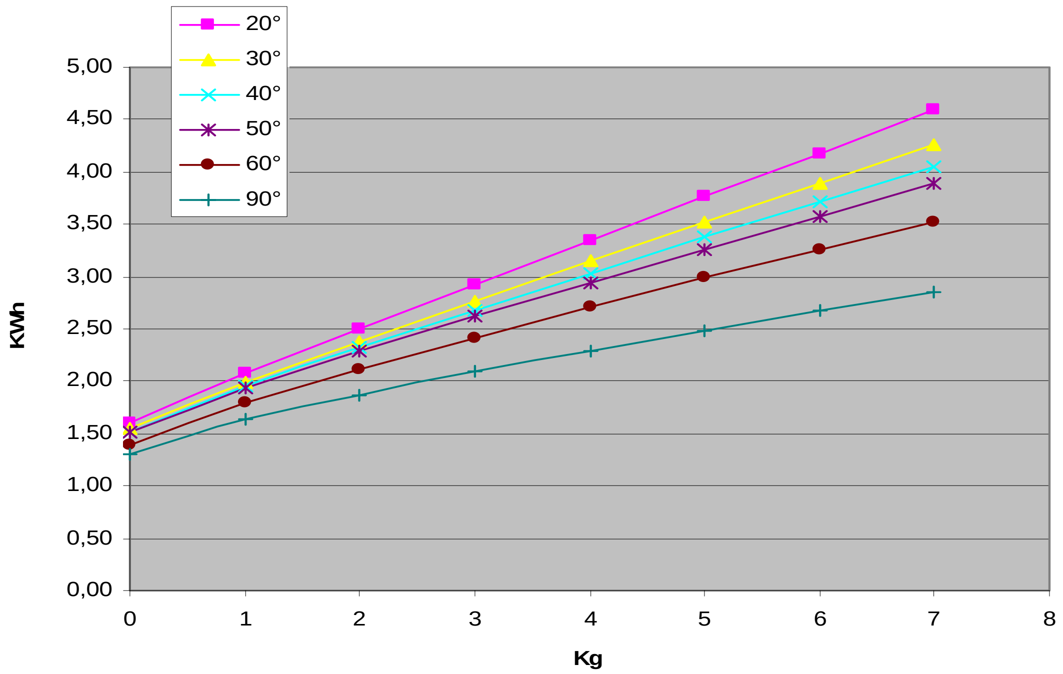
kg / T	Equiv. energy of detergent (kWh/cycle) 20°C	30°C	40°C	50°C	60°C	90°C
0	1,49	1,29	1,12	0,97	0,75	0,37
1	1,86	1,60	1,40	1,21	0,93	0,47
2	2,23	1,91	1,67	1,45	1,11	0,56
3	2,59	2,23	1,94	1,68	1,30	0,65
4	2,96	2,54	2,22	1,92	1,48	0,74
5	3,32	2,86	2,49	2,16	1,66	0,83
6	3,69	3,17	2,77	2,40	1,84	0,92
7	4,06	3,49	3,04	2,64	2,03	1,01

Table 6.88: Equivalent energy resources per washing cycle required to manufacture the needed detergent in the 7kg load category archetype

kg / T	Total energy consumption (kWh/cycle) 20°C	30°C	40°C	50°C	60°C	90°C
0	1,60	1,54	1,52	1,51	1,40	1,31
1	2,07	1,99	1,95	1,93	1,80	1,63
2	2,51	2,39	2,32	2,28	2,12	1,87
3	2,93	2,77	2,68	2,62	2,42	2,09
4	3,35	3,15	3,03	2,94	2,70	2,29
5	3,76	3,52	3,37	3,26	2,98	2,48
6	4,18	3,89	3,72	3,58	3,26	2,67
7	4,59	4,26	4,05	3,89	3,53	2,86

Table 6.89: Total energy consumption per cycle with the 7kg archetype machine

Figure 6.54: Total energy per cycle consumption curves by washing with the 7kg load category archetype



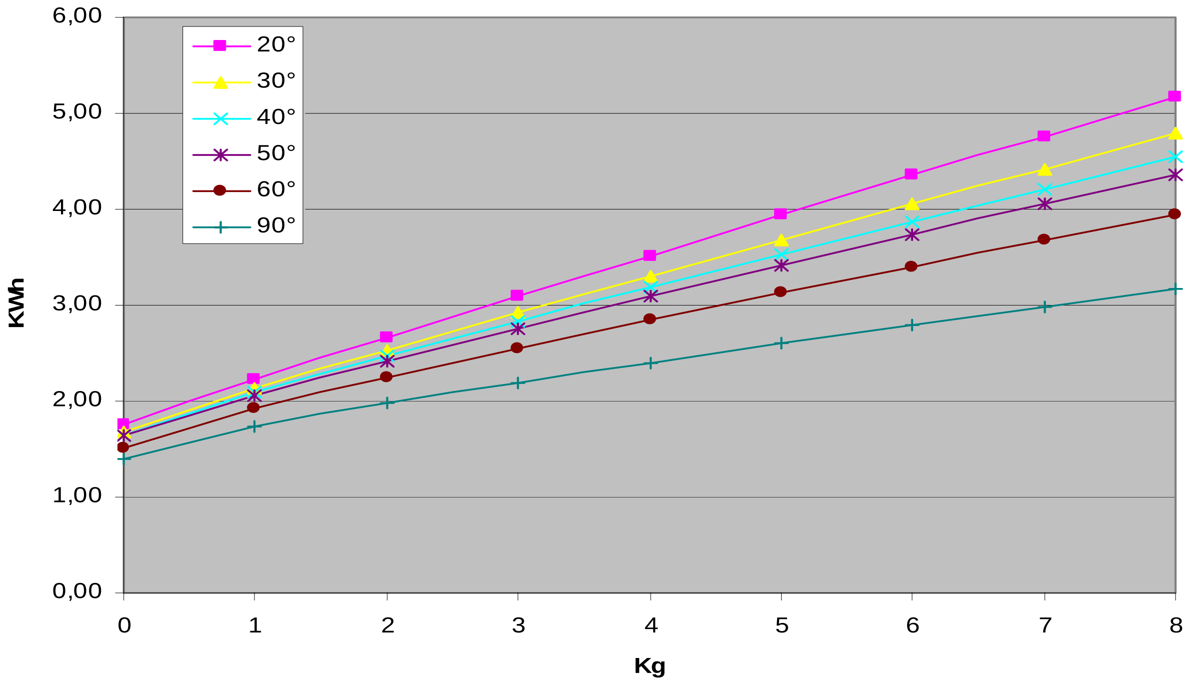
kg / T	Equiv. energy for detergent (kWh/cycle) 20°C	30°C	40°C	50°C	60°C	90°C
0	1,64	1,41	1,23	1,07	0,82	0,41
1	2,01	1,73	1,51	1,31	1,00	0,50
2	2,38	2,04	1,78	1,54	1,19	0,59
3	2,74	2,36	2,06	1,78	1,37	0,69
4	3,11	2,67	2,33	2,02	1,55	0,78
5	3,47	2,99	2,60	2,26	1,74	0,87
6	3,84	3,30	2,88	2,50	1,92	0,96
7	4,21	3,62	3,15	2,73	2,10	1,05
8	4,57	3,93	3,43	2,97	2,29	1,14

Table 6.90: Total energy consumption per cycle with the 7kg archetype machine

kg / T	Total energy consumption (kWh/cycle) 20°C	30°C	40°C	50°C	60°C	90°C
0	1,75	1,69	1,65	1,64	1,50	1,39
1	2,23	2,14	2,09	2,06	1,92	1,73
2	2,67	2,54	2,47	2,42	2,24	1,97
3	3,10	2,93	2,83	2,76	2,55	2,20
4	3,52	3,31	3,18	3,09	2,84	2,40
5	3,94	3,68	3,53	3,42	3,13	2,60
6	4,35	4,05	3,87	3,73	3,40	2,80
7	4,76	4,42	4,22	4,05	3,68	2,99
8	5,17	4,79	4,55	4,36	3,95	3,17

Table 6.91: Equivalent energy resources per washing cycle required to manufacture the needed detergent in the 8kg load category archetype machine

Figure 6.55: Total energy per cycle consumption curves by washing with the 8kg load category archetype



c) Analysis results

To compare the analysis results with the results of the previous analysis dealing only with the machine energy consumption, the same three Scenarios have been hypothesised.

Given the distribution of the "weekly washing cycles" and the "total energy per cycle" consumption of each archetype, the weekly overall amount of energy required to wash according to each Scenario can be obtained by the sum of products between the corresponding elements of the two data matrix, namely the resource consumption curves and the weekly cycles by load and temperature joint frequencies, as follows:

$$W_{tot} = \sum_{L,T} \left(W_{l,t} \times P_{l,t} \right)$$

where L, T are the discrete sets of loads and temperatures, respectively.

With reference to the archetypes and Scenarios, the overall energy consumed by the system per week, as well as its variation with respect to the reference case, are summarized in Table 6.92.

Table 6.92: Total energy (machine and detergent) weekly archetype, in front of different scenarios

Archetype (kg)	Scenario	Energy/Week (kWh)	Variation (%)
5 kg	Standard	13,14	--
6 kg	Standard	13,76	+ 4,7
7 kg	Standard	14,43	+ 9,8
7 kg	Scenario I	14,38	+ 9,4
7 kg	Scenario II	10,71	- 18,5
8 kg	Scenario II	12,27	- 6,6

As expected, the larger load capacity archetypes show an increase in the total energy consumption per week, if no change in the consumer behaviour takes place.

From a theoretical point of view, it is worthy noting that Scenario I differs from the standard one only for the shape in the two frequency distributions, but the first order moments in the respective data sets are equivalent. Scenario II presents significant savings in the total energy consumption for the 7kg archetype, but this savings is considerably reduced (to 1/3 of the initial value) with the 8kg archetype.

Besides the concerns discussed for the analysis developed in the previous paragraph, it is worth noting that the energy required to produce the detergent has a significant impact over the overall washing system energy consumption.

6.5.3.4 The trade-off between washing machine spin speed and the use of a (tumble) dryer (methodological analysis and preliminary results)

a) Basic information and analysis boundaries

To dry wet clothes energy is needed in any case. If a 5 kg laundry load is 60% wet, no matter which method is used including drying around the house on radiators, it must cost at least 2,4 kWh to dry it; if this load is dried in a tumble dryer, additional energy is taken up in turning the drum and heating the load and tumble dryer itself[33].

The more water is removed by mechanical treatment (usually through spinning in the washing machine) the less thermal energy is required for subsequently drying. This causes on one side an additional energy demand through higher spin speeds at the washing machine level and a contemporary reduction in thermal energy demand in the drying action, again whatever drying system and energy source is considered.

According to the German Energy Agency Dena[34], a high-speed spinning, above 1 200 rpm, requires between 5% (at 60°C) and 10% (at 40°C) more energy than lower spin speeds. The increase in energy consumption for an increase in spinning speed from 1 200rpm to 1 600 rpm has been evaluated in 50 Wh/cycle (Table 6.8) with an increase of the purchase price of 30 € for the consumer. Considering that the same 400 rpm increase occurs from 800 rpm to 1200 rpm, a similar increase in energy consumption can be assumed.

When the laundry is dried:

- on a clothes line outside besides direct sun or wind energy
- in a non heated room or in a direct solar heated greenhouse
- in a heated room where wasted heat is provided (for example an open boiler room, where heat is provided by the thermal loss of the boiler and will be in any case wasted),

no other energy source is needed. In all other cases additional energy is used that is usually supplied by the residential heating system or, in case a (tumble) drier is used, by electricity or natural gas.

[33] Source: BNW19: Domestic clothes dryers –current and future technologies, market status and priority action plan, version 1.1, 08 october 2006, downlodable from http://www.mtprog.com .
[34] source: Revision of the Energy Labelling System, Final Report, 2006, Deutsche Energie-Agentur GmbH (Dena)

To calculate the influence of different spin speeds on the energy demand for the drying process the specific energy demand of a conventional condenser (energy efficiency class C) drier is taken. The energy demand against percentage of water remaining after spin (Residual Moisture Content, RMC) is assumed to be according to the data of a 2004 German Öko-Institut study presented in Table 6.93[35].

Table 6.93: Spin speed and energy demand with respect to remaining water after spin

Water remaining after spin (cotton)	Unit	62 %	56 %	52 %	49 %
Corresponding approximately spin speed	rpm	1 000	1 200	1 400	1 600
Relative energy demand ('cotton dry' programme)	%	100	90	86	82
Specific energy demand ('cotton dry' programme)	kWh/kg	0,70	0,64	0,60	0,57

A linear correlation is assumed between the water remaining after spin and the specific energy demand (in kWh/kg of dried load), according to the following formula:

Specific energy demand = 0,0100 x RMC + 0,0800

which allows to estimate the energy demand also at higher residual moisture contents (or lower spin drying efficiency classes) as shown in Table 6.94

.

Table 6.94: Washing machine spin speed and dryer energy demand with respect to remaining water after spin

Spin drying efficiency classes (WM)		A	B	C	D	E	F	G
Residual moisture content	(%)	45	54	63	72	81	90	94
Energy consumption condenser dryer, C class[36], 5kg	(kWh/kg)	0,530	0,620	0,710	0,800	0,890	0,980	1,020
Washing machine spin speed	(rpm)	1600	1300	1000	800	600	480	400

Analysing in detail the 2005 CECED technical database, and associating a residual moisture content to each model (assuming that for each spin drying class the residual moisture content is the highest compatible with the declared class, for G class a value of 94% has been used) the resulting models disaggregation is presented in Table 6.95.

It is worth noting that the models in the database, which are assumed to reflect the market share of the relevant sales, are almost perfectly divided intro two groups: machines with spinning speed in the range 400-1100 rpm and machines with spinning speed in the range 1150-2000 rpm. Very few models (34 in total), highlighted in blue in the Table, deviate from this disggregation. Excluding the

[35] Source: I. Rüdenauer, C. Gensch, D.Quack, Eco-Efficiency Analysis of Washing machines – Life Cycle Assessment and determination of optimal life span, Öko-Institut e.V. Geschäftsstelle FreiburgFreiburg, November 2nd, 2004, downloadable from http://www.oeko.de .

[36] According to Commission Directive 95/13/CE of 23 May 1995, implementing Council Directive 92/75/EEC with regard to energy labelling of household electric tumble driers OJ. L. 136, 21.6.1995, the energy efficiency classes of condenser dryers depend from the energy consumption (in kWh/kg) of the iron-dry cotton: class A, C ≤0,55; class B: 0,55 < C ≤ 64; class C: 0,64 < C ≤ 73; class D: 0,73 < C ≤ 82; class E: 0,82 < C ≤ 91; class F: 0,91 < C ≤ 1,00; class G > 1,00.

'deviating models' from the analysis (leaving a database of 5 158 models), the weighted average spin speed and residual moisture content can be calculated, as shown in Table 6.96.

Table 6.95: Number of models per spin speed and (estimated) residual moisture content in 2005 CECED technical database

Spin drying class	A	B	C	D	E	F	G	Models number	
RMC (%) / Spin speed	**45**	**54**	**63**	**72**	**81**	**90**	**94**		
400						54	33	87	
450						4	2	6	
500					65	50		115	
550					1			1	
600				20	245			265	
650				28	5			33	
700			1	32	17			50	
750			2	10	1			13	2 425
800			74	383	1			458	
850			22	50				72	
900			59	77				136	
950			4					4	
1000		**4**	978	4				986	
1050			8					8	
1100		**14**	177					191	
1150		4						4	
1200		1 016	**9**	**4**				1 029	
1250		6	**2**					8	
1300		230	**1**					231	
1350		4						4	
1400	67	740						807	
1450		6						6	2 767
1500	33	63						96	
1550		6						6	
1600	497	23						520	
1700	3							3	
1800	47							47	
2000	6							6	
Models number	2 769		2.423						5 162
	653	2 116	1337	608	335	108	35	5 192	Tot.

Table 6.96: Average spinning speed and RMC for the two groups of washing machines in 2005 CECED technical database

Machine types	Models number	rpm (number)			RMC (%)		
		min	max	weighted aver.	min	max	weighted aver.
lower spin speed	2.407	400	1 100	**856**	63	94	**69,4**
higher spin speed	2.751	1 150	2 000	**1 367**	45	54	**52,2**

A quite good agreement can be seen with the outcome of Task 3. Looking at the final spin speed (Figure 6.56) the distribution showed large differences among countries: while in Italy, Spain, Poland, Hungary and Czech about 70% of the spin cycles are at or below 900 rpm, in UK, Germany and Sweden 70% are above 900 rpm. Taking the average of the individual range of spin speeds given from ≤400rpm up to ≥1 300rpm, the average spin speed per country can be calculated which confirms the same differentiation between the low-spin and high-spin countries. The average of all investigated country is 914 rpm (Figure 6.57).

Figure 6.56: Distribution of spin speeds

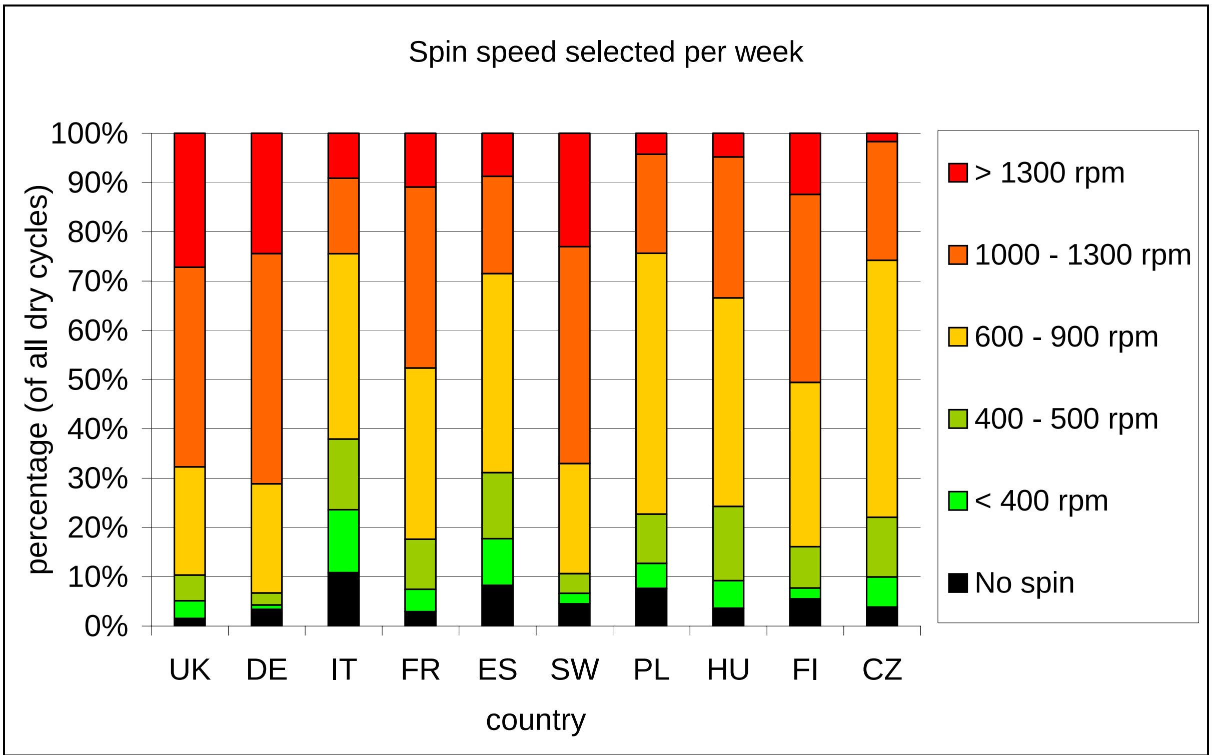
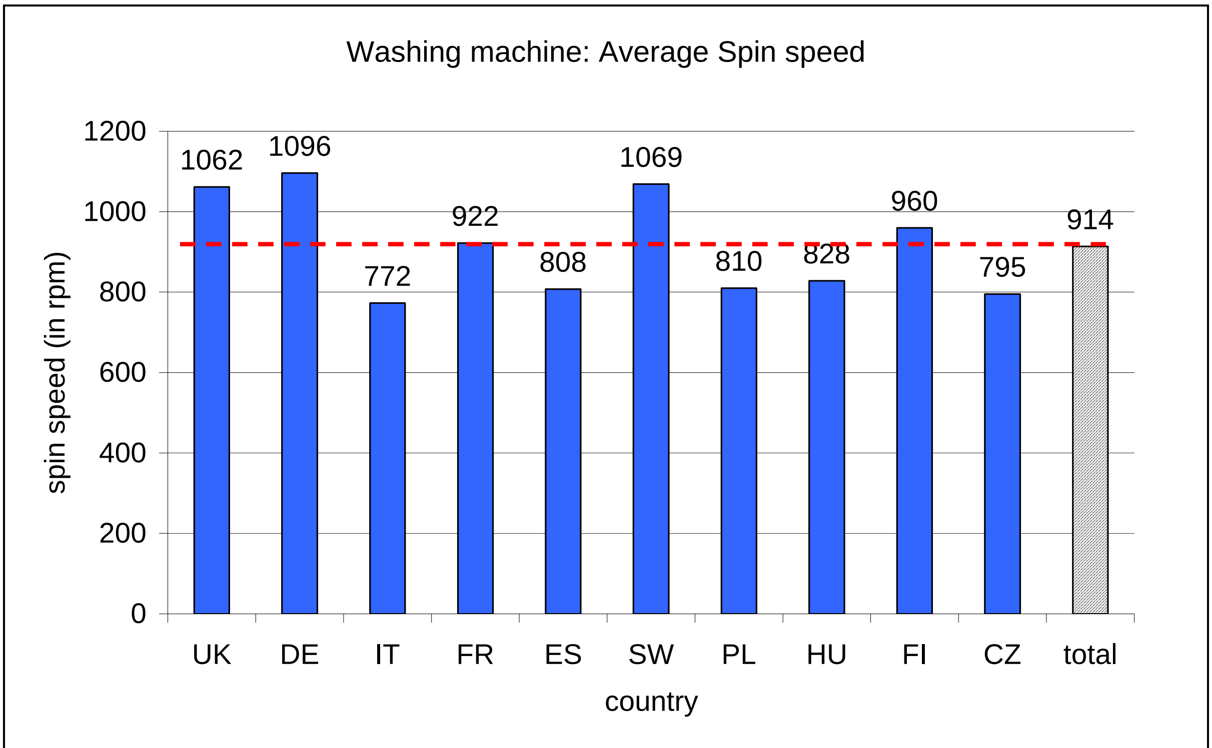


Figure 6.57: Calculated average spin speed per country and in total



Regarding drying of the clothes, large differences can be found between summer and winter time: while in summer time (Figure 6.58), about 40% of the consumer always dry the clothes outside on a cloth line and another 28% do it often (total 68%) these figures reduce in winter time (Figure 6.59) to just 7% and 10 %, respectively. The preferred way of drying clothes in winter is to dry them in the house in a heated room: this is always done by 28% and often by 33% of the consumers (total 61%). However, no better disaggregation of the dryer use is reported as being outside of the study scope.

Figure 6.58: Ways of drying in summer time

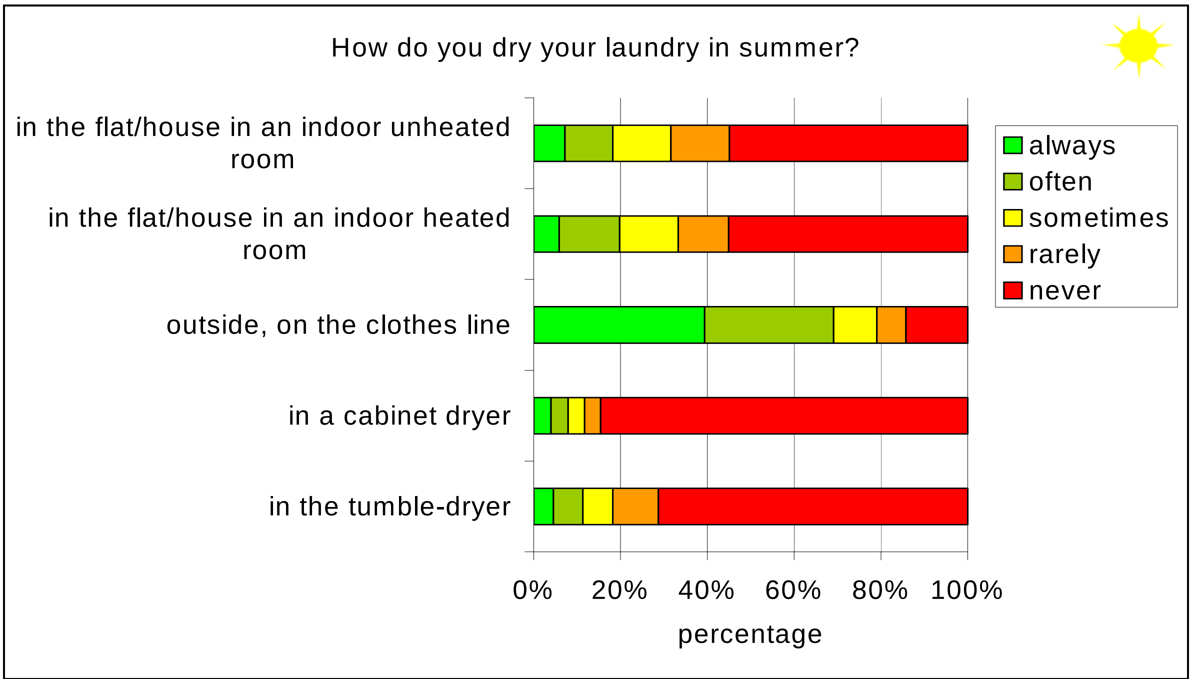
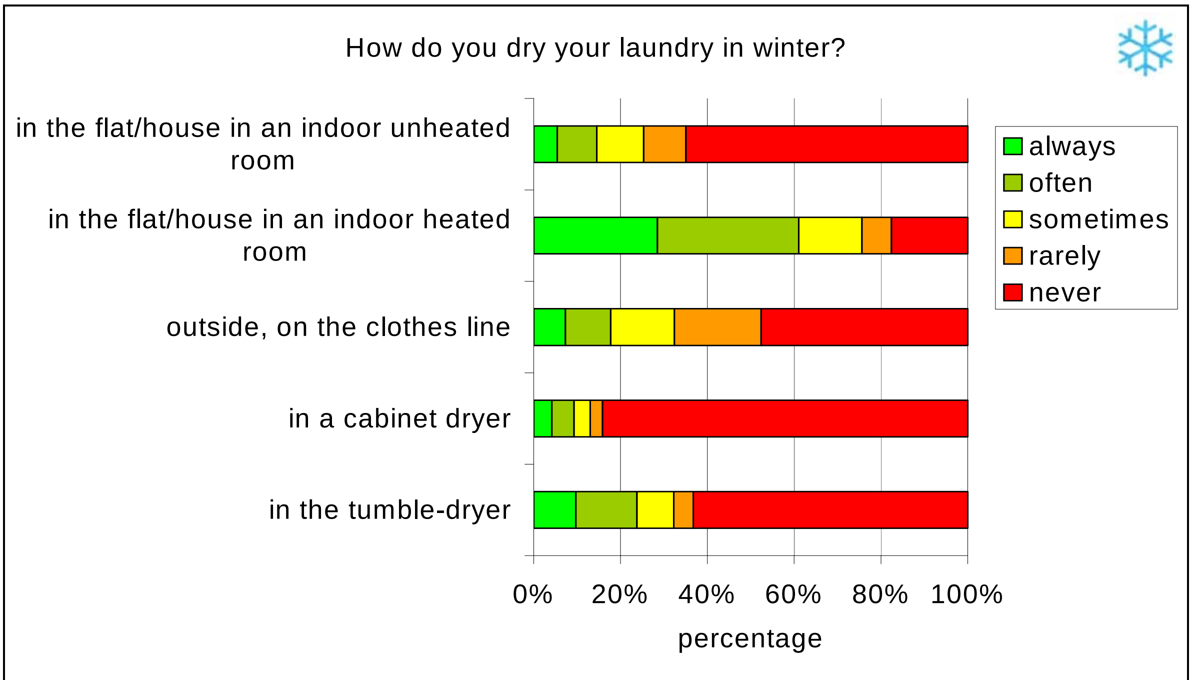


Figure 6.59: Ways of drying in winter time



According to another study of the German Öko-Institut[37], the different climatic conditions in Europe can roughly be summed up in three climatic zones. The '*cold climatic zone*' (comprising Finland, Norway and Sweden), the '*moderate climatic zone*' (comprising countries as Belgium, Denmark, Germany, France, UK, Ireland, Luxembourg, The Netherlands, Austria and Switzerland) and the '*warm climatic zone*' (comprising Greece, Italy, Portugal, Spain and Turkey). With a multi-criteria approach the countries Norway, Germany, France and Spain were chosen as representative of their respective climatic zone.

Unfortunately there is no statistical data about the dryer annual use pattern available. To cover different situations both the use of the drier during the whole year and the use of the drier only during the heating season have to be regarded. The length of the heating period varies between the different countries. Of course it is not possible to draw a sharp line between 'heating season/use of the drier' and 'non-heating season/no use of the drier' (as also confirmed by the previously presented data from Task 3) as not only temperature but also other weather conditions make people use their drier in the summer (e.g. when it is raining). But this is assumed to be compensated by the contrary effect during the heating season, when the laundry is hanged on a clothesline on a sunny and dry day.

Considering the average mean temperatures per month in the different countries the heating/non heating months could roughly be estimated as "heating season = months when the drier is used" by the owners of this appliance. The dark grey highlighted months in Table 6.96 are considered as months where the drier is used the whole month, the lighter grey highlighted months are considered as months where the drier is used only half of the month and the not highlighted months are considered as months where the drier is not used at all.

Table 6.97: Heating and non-heating periods according to the climatic zones (dryer use- and non-use months)

Months	J	F	M	A	M	J	J	A	S	O	N	D
Cold climatic zone												
Moderate climatic zone												
Warm climatic zone												

The capacity of the regarded driers is 5 kg, whereas average loading is generally assumed to be 3,2 kg. Due to reduced loading the specific energy demand of driers (electricity demand per kilogramme fabric) is higher than with full load conditions. The total and the specific energy demand against loading is shown in Table 6.97. Under standard conditions the loading for 'cotton dry' programme is set 5 kg (for driers with a capacity of 5 kg).

Table 6.98: Total and specific energy demand (%) with respect to loading of the dryer (m=measured; i=interpolated)

Loading	5,0 kg	4,5 kg	4,0 kg	3,5 kg	3,2 kg	3,0 kg
Total energy demand (per cycle)	100	93	85	78	73	70
Specific energy demand (per kg)	100	103	106	111	114	117
data quality	m	m	m	m	i	m

Taking into consideration that not all laundry washed is suitable to be dried in a tumble-dryer, an

[37] Source: I. Rüdenauer, C. Gensch, Energy demand of tumble dryers with respect to differences in technology and ambient conditions, Öko-Institut e.V. Geschäftsstelle FreiburgFreiburg, 13 January 2004, downloadable from http://www.oeko.de .

estimate was done of 80% of the total washed amount that can be dried in a tumble drier in the 'dry cotton' programme. Since the real life base case washing machine (Task 5) has a capacity of 5,36kg, and a load on 3,4kg, the calculated 80% is 3,2 kg, which is surprisingly in line with previous seen average loading from the Öko-Institut study.

Therefore the actual energy consumption of dryer with a 3,2 kg load is 73% of the consumption at full load standard (5kg) conditions.

b) Energy consumption evaluation for countries in the Warm Climatic Zone

The trade-off is evaluated in terms of the minimum dryer ownership that saves enough energy when using a lower RMC laundry from a washing machine with increased spinning speed (of 400 rpm, from 800rpm to 1200 rpm) needed to compensate the increase in the washing machine energy consumption due to the higher spin speed.

Basic assumption:
- washing machine ownership: 100%
- washing machine average load: 3,4 kg
- number of washing cycles per year: 200 equally divided during the year
- increase in washing machine energy consumption for a 400rpm increase in spin speed, from 800 rpm to 1200 rpm): 50 Wh/cycle
- RMC = 72% (Class D) at 800rpm; RMR = 54% (Class B) at 1200 rpm
- increase in washing machine purchase price: 30€
- dryer type: condenser, 5kg
- dryer average load 3,2 kg with a 73% of the full load energy consumption
- dryer energy consumption 0,800 kWh/kg (energy efficiency class C) at RMC = 72%
- dryer use profile: according to the climatic zone.

Since the washing machine cycles are equally divided during the year, an average of 16,7 wash cycles/month are considered. The same maximum number of drying cycles is also considered.

When the spinning speed of the standard base case washing machine (5,36 kg) is increased from 800 rpm to 1200 rpm (with an increase of 400 rpm) the same 50Wh increase in the energy consumption is assumed as for the improvement from 1200 rpm to 1600 rpm. But since the washing machine load is only 3,4 kg, the 50Wh are reduced to 31,7 Wh/cycle (or 50/5,35*3,4). For 200 washing cycles per year, this amounts to 6,34 kWh/year or 95,1 kWh over the 15 year washing machine lifetime.

The number of months for the 'heating season' and the 'use of the drier' for the warm climatic zone is 1 month where the drier is used the whole month and 3 months where the drier is used only half of the month, or in other terms, the dryer is fully used (16,7 cycles/month) for 2,5 months or 41,7 drying cycle/year.

To dry 3,2kg of 72% RMC laundry, a 5kg dryers uses 73% (or 2,92 kWh/cycle) of the full load energy consumption (or 0,800 kWh/kg x 5 kg = 4kWh). To dry 3,2kg of 54% RMC laundry the same dryers consumes 73% (or 2,26 kWh/cycle) of the full load energy consumption (or 0,620kWh/kg x 5 kg = 3,1 kWh). The savings is therefore 657 Wh/cycle, or 27,4 kWk/year, giving a total saving of 410,6 kWh/15y when 41,7 cycles per year are considered.

On a machine basis, the use of the dryer with a lower RMC (from 72% to 54%) allows to save 315 kWh over 15 years or about 3 times the amount of extra energy consumed by the washing machine with the improved spinning speed.

But the dryer is not owned in 100% of the families (while the washing machine is, or better is assumed to be). This means that when 100 washing machines are considered, the extra energy consumption reaches 9.515 kWh/15y. Only when 23,2 dryers are run for the same 15 years the saved energy reaches 9.527 kWh and starts to overcome the energy waste.

The difference in price for the consumer of the higher spin speed machine is 30 €, unused for the moment because the difference in energy cost has been considered the trade-off until now. Instead, from an economic point of view the trade-off is when the discounted savings minus the difference in price becomes positive (or positive NPV, like in all the previous analysis).

The NPV could be easily calculated with the existing data. For a tumble dryer machine, assuming 100% recovery that is 100% ownership of the dryers it is:

NPV = [(27,4 kWh/year × 0,17 €/kWh) × 10,4 × do] - 30 € = 18,4 €

where:

- 10,4 is the PWF at 5% discount rate for 15 years
- do = dryer ownership (1 = 100%)
- 0,17 € is the average price of the electric energy per kWh.

Thus if ownership of dryers (the 'do' factor) drops below 62% the higher spin speed and higher price washing machines are not convenient in the warmer climatic zone, as a whole.

This means that if the dryer ownership is lower than 20-25% the energy wasted through the increase of the washing machine spinning speed is not recovered via the energy savings of the drying process. But with the 30€ subtracted and the annual energy savings discounted, the breakeven point is even higher in terms of dryers ownership and reaches 62%. For a specific individual user in the warm climatic zone, if she/he will use the dryer more than 62% of the time, it is convenient; otherwise no.

c) Energy consumption evaluation for countries in the Moderate Climatic Zone

The same analysis is repeated for the countries belonging to the *moderate climatic zone*. The number of months for the 'heating season' and the 'use of the drier' for this climatic zone is 5 months where the drier is used the whole month and 2 months where the drier is used only half of the month, or in other terms, the dryer is fully used (16,7 cycles/month) for 6 months or 100 drying cycle/year.

To dry 3,2kg of 72% RMC laundry, a 5kg dryers uses 73% (or 2,92 kWh/cycle) of the full load energy consumption (or 0,800 kWh/kg x 5 kg = 4kWh). To dry 3,2kg of 54% RMC laundry the same dryers consumes 73% (or 2,26 kWh/cycle) of the full load energy consumption (or 0,620kWh/kg x 5 kg = 3,1 kWh). The savings is therefore 657 Wh/cycle, or 65,7 kWk/year, giving a total saving of 985,5 kWh/15y when 100 cycles per year are considered.

On a machine basis, the use of the dryer with a lower RMC (from 72% to 54%) allows to save 894,4 kWh over 15 years or about 9 times the amount of extra energy consumed by the washing machine with the improved spinning speed.

But again the dryer is not owned in 100% of the families (while the washing machine is, or better is assumed to be). This means that when 100 washing machines are considered, the extra energy consumption reaches 9.515 kWh/15y. Only when 9,7 dryers are run for the same 15 years the saved energy reaches 9.559 kWh and starts to overcome the energy waste.

For a tumble dryer machine, assuming 100% recovery that is 100% ownership of the dryers the NPV is:

NPV = [(65,7 kWh/year × 0,17 €/kWh) × 10,4 × do] - 30 € = 116,2 €

Thus if ownership of dryers drops below 26% the higher spin speed and higher price washing machines are not convenient in the moderate climatic zone, as a whole.

This means that if the dryer ownership is lower than 9-10% the energy wasted through the increase of the washing machine spinning speed is not recovered via the energy savings of the drying process. But with the 30€ subtracted and the annual energy savings discounted, the breakeven point is even higher in terms of dryers ownership and reaches 26%. For a specific individual user in the moderate climatic zone, if she/he will use the dryer more than 26% of the time, it is convenient; otherwise no.

d) Energy consumption evaluation for countries in the Cold Climatic Zone

The same analysis is finally repeated for the countries belonging to the *cold climatic zone*. The number of months for the 'heating season' and the 'use of the drier' for this climatic zone is 9 months where the drier is used the whole month and 1 month where the drier is used only half of the month, or in other terms, the dryer is fully used (16,7 cycles/month) for 9,5 months or 158,3 drying cycle/year.

To dry 3,2kg of 72% RMC laundry, a 5kg dryers uses 73% (or 2,92 kWh/cycle) of the full load energy consumption (or 0,800 kWh/kg x 5 kg = 4kWh). To dry 3,2kg of 54% RMC laundry the same dryers consumes 73% (or 2,26 kWh/cycle) of the full load energy consumption (or 0,620kWh/kg x 5 kg = 3,1 kWh). The savings is therefore 657 Wh/cycle, or 104 kWk/year, giving a total saving of 1 560,4 kWh/15y when 158,3 cycles per year are considered.

On a machine basis, the use of the dryer with a lower RMC (from 72% to 54%) allows to save 1.465,2 kWh over 15 years or about 15 times the amount of extra energy consumed by the washing machine with the improved spinning speed.

But again the dryer is not owned in 100% of the families (while the washing machine is, or better is assumed to be). This means that when 100 washing machines are considered, the extra energy consumption reaches 9.515 kWh/15y. Only when 6,1 dryers are run for the same 15 years the saved energy reaches 9.518 kWh and starts to overcome the energy waste.

For a tumble dryer machine, assuming 100% recovery that is 100% ownership of the dryers the NPV is:

NPV = [(104 kWh/year × 0,17 €/kWh) × 10,4 × do] - 30 € = 183,9 €

Thus if ownership of dryers drops below 16% the higher spin speed and higher price washing machines are not convenient in the moderate climatic zone, as a whole.

This means that if the dryer ownership is lower than 6% the energy wasted through the increase of the washing machine spinning speed is not recovered via the energy savings of the drying process. But with the 30€ subtracted and the annual energy savings discounted, the breakeven point is even higher in terms of dryers ownership and reaches 16%. For a specific individual user in the cold climatic zone, if she/he will use the dryer more than 16% of the time, it is convenient; otherwise no.

e) Conclusions

A simple calculation of the additional energy consumption for a 400 rpm improvement of the washing machine spinning speed, with the spin drying efficiency going from class D to class B, and the energy savings of the drying phase in a condenser, class C, tumble dryer due to the lower laundry moisture content was developed. Depending from the climatic zone of a country, the dryer ownership and the dryer use there is an overall energy consumption increase or a savings.

Data about the dryer ownership in Member States have been collected during the study[38] from different sources and are reported in Table 6.99 together with the estimated economic ownership threshold.

Table 6.99: Dryer ownership and threshold level for some Member States in different climatic zones

Country	Dryer ownership (%)	Year	Threshold dryer ownership level (%)
	Warm climatic zone		
MT	12,2	2001	62
PO	13	2006	
SL	18	2003	
ES	n.a.	--	
IT	n.a.	--	
GR	n.a.	--	
	Moderate climatic zone		
FR	29	2005	26
DE	39	2005	
PL	41	2003	
DK	44	2004	
IR	46	2005	
UK	54	2003	
NL	68	2005	
	Cold climatic zone		
FIN	59	2004	16
SW	52	2004	

Although no complete and updated data are available about the ownership of the dryers in countries belonging to the different climatic zones and moreover about the pattern of use (with the exception of UK[39] where the dryer is estimated to be used for 60% of the washing machine use), it is clear that for counties in the warm climatic zone the use of the dryer is far below the economic threshold. In other words, is these countries a 400 rpm higher spin speed machine is not convenient from both the energy consumption and the economic points of view: the higher energy consumption for the

[38] Source: A Portrait of the Household Appliance Industry and Market in Europe, Task 1 common deliverable.
[39] Source: BNW06: Assumptions underlying the energy projections for domestic tumble dryers, version 2.0, 19 September 2006, downloadable from http://www.mtprog.org .

washing cycle will never be recovered through the use of a dryer. Even for UK, with a nominal ownership of 54% for the dryer, if the use of this appliance is only 60% of the washing cycles, then the actual use is 32,4%, which is higher than the economic ownership threshold but less higher that probably expected. Should the ownership level be confirmed, France is in a border line situation.

The same approach can be also used to estimate the transition between the average machine with 856 rpm and RMC=69,4% to a machine with 1 367 rpm and RMC=52,2%, as described in Table 6.96, although the difference is 511 rpm, higher than the previously hypothesised 400 rpm and therefore the increase in the energy consumption for the washing machine is expected to be higher.

To achieve robust results, the previous analysis was developed considering an additional energy consumption for the improved spin speed washing machine of 31,7 Wh/cycle only, instead of 50Wh, considering that a reduced 3,4kg load could lead to a lower spinning time and therefore overall energy consumption. However, if this reduction does not occur (i.e. the spinning consumption is independent from the machine load) and the initial 50Wh/cycle are considered the minimum dryer ownership percentage necessary to compensate the higher washing machine energy consumption increases:

- warm climatic zone: 36,6% on a pure energy consumption balance basis
- moderate climatic zone: 15,3%
- cold climatic zone 9,7.

The general impression deriving from the preliminary analysis results is that the existing market division of different spin speed machines (see Table 6.95) is rational and a one minimum high spin speed machine for all of Europe is a suboptimum

In this paragraph the environmental impact assessment of the LCC and BAT cases analysed in paragraph 1.4 is carried out and the results have been compared to those calculated for the base cases in task 5. The technological improvements analysed in paragraph 1.4 do not change in sensible way the bill of material - at least for what concerns the environments impact of the production and waste phases - so the environmental analysis has been focused to the use phase only. The analysis developed in this paragraph concerns in particular the 5 kg Washing Machines and the 12 settings Dishwasher and the tool used has been the EuP Ecoreport

6.6 Environmental Assessment of the Technological Improvements

In the following two paragraphs the environmental impact assessment of the LCC and BAT cases analysed in paragraphs 6.4.2 and 6.4.3 are carried out and the results have been compared to those calculated for the base case in task 5. The technological improvements analysed in these paragraphs do not change in sensible way the bill of material - at least for what concerns the environments impact of the production and waste phases - so the environmental analysis has been focused to the use phase only. The tool used for this analysis has been the EuP Ecoreport

6.6.1 Washing machine 5 kg

The following table shows the main base case, LCC and BAT data that have been taken into consideration in this analysis.

Table 6.100: WM 5 kg – Main data for comparison of BASE CASE, LLCC and BAT cases

WM 5 KG		BASE CASE	LLCC	BAT
Use	cycles/year	245	245	245
Energy consumption	kWh/cycle	0,998	0,9	0,855
Water consumption	litre/cycle	50,7	38,7	38,7
	m3/year	12,42	9,48	9,48

According to this inputs the main environmental outputs as energy consumption and air and water emissions has been calculated for all the WM life (all other parameters, as materials used, transport and end of life have been considered to be the same in the three cases).

Table 6.101:WM 5 kg – Output of LCA made by EuP-Ecoreport for BASE CASE, LLCC and BAT cases

CASE	Resources Use and Emissions	Unit	Production	Distribution	Use	END-OF-LIFE	TOTAL
01 - BASE CASE	Total Energy (GER)	MJ	3830	547	39855	-507	43725
02 - LLCC	Total Energy (GER)	MJ	3830	547	36073	-507	39943
03 - BAT	Total Energy (GER)	MJ	3830	547	34337	-507	38206
01 - BASE CASE	of which, electricity (in primary MJ)	MJ	923	1	39439	-47	40316
02 - LLCC	of which, electricity (in primary MJ)	MJ	923	1	35658	-47	36535
03 - BAT	of which, electricity (in primary MJ)	MJ	923	1	33921	-47	34798
01 - BASE CASE	Water (process)	ltr	1358	0	188942	-31	190269
02 - LLCC	Water (process)	ltr	1358	0	144590	-31	145917
03 - BAT	Water (process)	ltr	1358	0	144474	-31	145801
01 - BASE CASE	Water (cooling)	ltr	1105	0	105158	-260	106003
02 - LLCC	Water (cooling)	ltr	1105	0	95074	-260	95919
03 - BAT	Water (cooling)	ltr	1105	0	90443	-260	91288
01 - BASE CASE	Waste, non-haz./ landfill	g	69120	290	46410	-146	115674
02 - LLCC	Waste, non-haz./ landfill	g	69120	290	42025	-146	111289
03 - BAT	Waste, non-haz./ landfill	g	69120	290	40012	-146	109276
01 - BASE CASE	Waste, hazardous/ incinerated	g	176	6	910	362	1454
02 - LLCC	Waste, hazardous/ incinerated	g	176	6	823	362	1367
03 - BAT	Waste, hazardous/ incinerated	g	176	6	783	362	1327
01 - BASE CASE	Greenhouse Gases in GWP100	kg CO2 eq.	245	34	1753	-8	2024
02 - LLCC	Greenhouse Gases in GWP100	kg CO2 eq.	245	34	1588	-8	1859
03 - BAT	Greenhouse Gases in GWP100	kg CO2 eq.	245	34	1512	-8	1783
01 - BASE CASE	Ozone Depletion, emissions	mg R-11 eq.					
02 - LLCC	Ozone Depletion, emissions	mg R-11 eq.					
03 - BAT	Ozone Depletion, emissions	mg R-11 eq.					
01 - BASE CASE	Acidification, emissions	g SO2 eq.	1870	102	10202	-12	12162
02 - LLCC	Acidification, emissions	g SO2 eq.	1870	102	9228	-12	11188
03 - BAT	Acidification, emissions	g SO2 eq.	1870	102	8781	-12	10741
01 - BASE CASE	Volatile Organic Compounds (VOC)	g	7	8	21	1	37

CASE	Resources Use and Emissions	Unit	Production	Distribution	Use	END-OF-LIFE	TOTAL
02 - LLCC	Volatile Organic Compounds (VOC)	g	7	8	20	1	36
03 - BAT	Volatile Organic Compounds (VOC)	g	7	8	19	1	35
01 - BASE CASE	Persistent Organic Pollutants (POP)	ng i-Teq	427	2	263	0	691
02 - LLCC	Persistent Organic Pollutants (POP)	ng i-Teq	427	2	238	0	666
03 - BAT	Persistent Organic Pollutants (POP)	ng i-Teq	427	2	227	0	655
01 - BASE CASE	Heavy Metals	mg Ni eq.	2429	15	784	24	3251
02 - LLCC	Heavy Metals	mg Ni eq.	2429	15	719	24	3186
03 - BAT	Heavy Metals	mg Ni eq.	2429	15	689	24	3156
01 - BASE CASE	PAHs	mg Ni eq.	190	19	164	-2	371
02 - LLCC	PAHs	mg Ni eq.	190	19	157	-2	363
03 - BAT	PAHs	mg Ni eq.	190	19	153	-2	360
01 - BASE CASE	Particulate Matter (PM, dust)	g	388	1248	1632	375	3643
02 - LLCC	Particulate Matter (PM, dust)	g	388	1248	1611	375	3622
03 - BAT	Particulate Matter (PM, dust)	g	388	1248	1602	375	3612
01 - BASE CASE	Heavy Metals	mg Hg/20	1597	0	270	2	1870
02 - LLCC	Heavy Metals	mg Hg/20	1597	0	246	2	1845
03 - BAT	Heavy Metals	mg Hg/20	1597	0	235	2	1834
01 - BASE CASE	Eutrophication	g PO4	40,71	0,01	1,62	-0,94	41,39
02 - LLCC	Eutrophication	g PO4	40,71	0,01	1,50	-0,94	41,27
03 - BAT	Eutrophication	g PO4	40,71	0,01	1,45	-0,94	41,22
01 - BASE CASE	Persistent Organic Pollutants (POP)	ng i-Teq					
02 - LLCC	Persistent Organic Pollutants (POP)	ng i-Teq					
03 - BAT	Persistent Organic Pollutants (POP)	ng i-Teq					

Table 6.102 shows the decrease in percentage of the LLCC and BAT main environmental indicators with respect the base case.

For some environmental impact indicators (as ozone depletion and POP) no value have been reported because, according to EuP Ecoreport, these impacts are negligible.

Table 6.102: WM 5 kg – Percentage decrease of LCA's outputs from Base case vs LLCC and BAT cases

CASE	Resources Use and Emissions	UNIT	USE	TOTAL
01 - BASE CASE	Total Energy (GER)	MJ		
02 - LLCC	Total Energy (GER)	MJ	-9%	-9%
03 - BAT	Total Energy (GER)	MJ	-14%	-13%
01 - BASE CASE	of which, electricity (in primary MJ)	MJ		
02 - LLCC	of which, electricity (in primary MJ)	MJ	-10%	-9%
03 - BAT	of which, electricity (in primary MJ)	MJ	-14%	-14%
01 - BASE CASE	Water (process)	ltr		
02 - LLCC	Water (process)	ltr	-23%	-23%
03 - BAT	Water (process)	ltr	-24%	-23%
01 - BASE CASE	Water (cooling)	ltr		
02 - LLCC	Water (cooling)	ltr	-10%	-10%
03 - BAT	Water (cooling)	ltr	-14%	-14%

CASE	Resources Use and Emissions	UNIT	USE	TOTAL
01 - BASE CASE	Waste, non-haz./ landfill	g		
02 - LLCC	Waste, non-haz./ landfill	g	-9%	-4%
03 - BAT	Waste, non-haz./ landfill	g	-14%	-6%
01 - BASE CASE	Waste, hazardous/ incinerated	g		
02 - LLCC	Waste, hazardous/ incinerated	g	-10%	-6%
03 - BAT	Waste, hazardous/ incinerated	g	-14%	-9%
01 - BASE CASE	Greenhouse Gases in GWP100	kg CO2 eq.		
02 - LLCC	Greenhouse Gases in GWP100	kg CO2 eq.	-9%	-8%
03 - BAT	Greenhouse Gases in GWP100	kg CO2 eq.	-14%	-12%
01 - BASE CASE	Ozone Depletion, emissions	mg R-11 eq.		
02 - LLCC	Ozone Depletion, emissions	mg R-11 eq.		
03 - BAT	Ozone Depletion, emissions	mg R-11 eq.		
01 - BASE CASE	Acidification, emissions	g SO2 eq.		
02 - LLCC	Acidification, emissions	g SO2 eq.	-10%	-8%
03 - BAT	Acidification, emissions	g SO2 eq.	-14%	-12%
01 - BASE CASE	Volatile Organic Compounds (VOC)	g		
02 - LLCC	Volatile Organic Compounds (VOC)	g	-7%	-4%
03 - BAT	Volatile Organic Compounds (VOC)	g	-10%	-6%
01 - BASE CASE	Persistent Organic Pollutants (POP)	ng i-Teq		
02 - LLCC	Persistent Organic Pollutants (POP)	ng i-Teq	-9%	-4%
03 - BAT	Persistent Organic Pollutants (POP)	ng i-Teq	-14%	-5%
01 - BASE CASE	Heavy Metals	mg Ni eq.		
02 - LLCC	Heavy Metals	mg Ni eq.	-8%	-2%
03 - BAT	Heavy Metals	mg Ni eq.	-12%	-3%
01 - BASE CASE	PAHs	mg Ni eq.		
02 - LLCC	PAHs	mg Ni eq.	-5%	-2%
03 - BAT	PAHs	mg Ni eq.	-7%	-3%
01 - BASE CASE	Particulate Matter (PM, dust)	g		
02 - LLCC	Particulate Matter (PM, dust)	g	-1%	-1%
03 - BAT	Particulate Matter (PM, dust)	g	-2%	-1%
01 - BASE CASE	Heavy Metals	mg Hg/20		
02 - LLCC	Heavy Metals	mg Hg/20	-9%	-1%
03 - BAT	Heavy Metals	mg Hg/20	-13%	-2%
01 - BASE CASE	Eutrophication	g PO4		
02 - LLCC	Eutrophication	g PO4	-7,18%	-0,28%
03 - BAT	Eutrophication	g PO4	-10,48%	-0,41%
01 - BASE CASE	Persistent Organic Pollutants (POP)	ng i-Teq		
02 - LLCC	Persistent Organic Pollutants (POP)	ng i-Teq		
03 - BAT	Persistent Organic Pollutants (POP)	ng i-Teq		

6.6.2 Dish Washer 12 ps

In the following table main data for base case, LCC and BAT has been reported.

Table 6.103: DW 12 ps – Main data for comparison of BASE CASE, LLCC and BAT cases

DW12ps		BASE CASE	LLCC	BAT
Use	cycles/year	280	280	280
Energy consumption	kWh/cycle	1,07	1,009	0,914
Water consumption	litre/cycle	15,2	11	10,6
	m3/year	4,256	3,08	2,968

According to this input the following output, as energy consumption and air and water emissions has been calculated for all the life of the DW (all other parameters, as materials used, transport and end of life have been considered to be the same in the three cases).

Table 6.104: DW 12 ps – Output of LCA made by EuP-Ecoreport for BASE CASE, LLCC and BAT cases

CASE	Resources Use and Emissions	UNIT	PRODUCTION	DISTRIBUTION	USE	END-OF-LIFE	TOTAL
01 - BASE CASE	Total Energy (GER)	MJ	3945	595	43250	-291	47499
02 - LLCC	Total Energy (GER)	MJ	3945	595	41008	-291	45257
03 - BAT	Total Energy (GER)	MJ	3945	595	37517	-291	41766
01 - BASE CASE	of which, electricity (in primary MJ)	MJ	1142	1	39535	-29	40649
02 - LLCC	of which, electricity (in primary MJ)	MJ	1142	1	37293	-29	38407
03 - BAT	of which, electricity (in primary MJ)	MJ	1142	1	33802	-29	34916
01 - BASE CASE	Water (process)	ltr	1955	0	55933	-19	57869
02 - LLCC	Water (process)	ltr	1955	0	41084	-19	43019
03 - BAT	Water (process)	ltr	1955	0	39451	-19	41386
01 - BASE CASE	Water (cooling)	ltr	1213	0	105407	-160	106461
02 - LLCC	Water (cooling)	ltr	1213	0	99429	-160	100483
03 - BAT	Water (cooling)	ltr	1213	0	90119	-160	91173
01 - BASE CASE	Waste, non-haz./ landfill	g	66470	313	50318	781	117884
02 - LLCC	Waste, non-haz./ landfill	g	66470	313	47719	781	115284
03 - BAT	Waste, non-haz./ landfill	g	66470	313	43671	781	111236
01 - BASE CASE	Waste, hazardous/ incinerated	g	409	6	991	1514	2920
02 - LLCC	Waste, hazardous/ incinerated	g	409	6	939	1514	2869
03 - BAT	Waste, hazardous/ incinerated	g	409	6	859	1514	2788
01 - BASE CASE	Greenhouse Gases in GWP100	kg CO2 eq.	270	37	1901	0	2208
02 - LLCC	Greenhouse Gases in GWP100	kg CO2 eq.	270	37	1804	0	2110
03 - BAT	Greenhouse Gases in GWP100	kg CO2 eq.	270	37	1651	0	1958
01 - BASE CASE	Ozone Depletion, emissions	mg R-11 eq.					
02 - LLCC	Ozone Depletion, emissions	mg R-11 eq.					
03 - BAT	Ozone Depletion, emissions	mg R-11 eq.					

CASE	Resources Use and Emissions	UNIT	PRODUCTION	DISTRIBUTION	USE	END-OF-LIFE	TOTAL
01 - BASE CASE	Acidification, emissions	g SO2 eq.	**2155**	**111**	**11084**	**7**	**13357**
02 - LLCC	Acidification, emissions	g SO2 eq.	**2155**	**111**	**10507**	**7**	**12780**
03 - BAT	Acidification, emissions	g SO2 eq.	**2155**	**111**	**9608**	**7**	**11881**
01 - BASE CASE	Volatile Organic Compounds (VOC)	g	**9**	**8**	**22**	**1**	**41**
02 - LLCC	Volatile Organic Compounds (VOC)	g	**9**	**8**	**22**	**1**	**40**
03 - BAT	Volatile Organic Compounds (VOC)	g	**9**	**8**	**20**	**1**	**39**
01 - BASE CASE	Persistent Organic Pollutants (POP)	ng i-Teq	**433**	**2**	**285**	**6**	**726**
02 - LLCC	Persistent Organic Pollutants (POP)	ng i-Teq	**433**	**2**	**270**	**6**	**711**
03 - BAT	Persistent Organic Pollutants (POP)	ng i-Teq	**433**	**2**	**247**	**6**	**688**
01 - BASE CASE	Heavy Metals	mg Ni eq.	**3249**	**16**	**850**	**53**	**4169**
02 - LLCC	Heavy Metals	mg Ni eq.	**3249**	**16**	**812**	**53**	**4130**
03 - BAT	Heavy Metals	mg Ni eq.	**3249**	**16**	**752**	**53**	**4070**
01 - BASE CASE	PAHs	mg Ni eq.	**152**	**20**	**169**	**-2**	**340**
02 - LLCC	PAHs	mg Ni eq.	**152**	**20**	**165**	**-2**	**335**
03 - BAT	PAHs	mg Ni eq.	**152**	**20**	**158**	**-2**	**328**
01 - BASE CASE	Particulate Matter (PM, dust)	g	**295**	**1370**	**1650**	**431**	**3746**
02 - LLCC	Particulate Matter (PM, dust)	g	**295**	**1370**	**1637**	**431**	**3733**
03 - BAT	Particulate Matter (PM, dust)	g	**295**	**1370**	**1618**	**431**	**3714**
01 - BASE CASE	Heavy Metals	mg Hg/20	**2150**	**0**	**279**	**13**	**2442**
02 - LLCC	Heavy Metals	mg Hg/20	**2150**	**0**	**264**	**13**	**2427**
03 - BAT	Heavy Metals	mg Hg/20	**2150**	**0**	**242**	**13**	**2405**
01 - BASE CASE	Eutrophication	g PO4	**57**	**0**	**4859**	**0**	**4917**
02 - LLCC	Eutrophication	g PO4	**57**	**0**	**4859**	**0**	**4917**
03 - BAT	Eutrophication	g PO4	**57**	**0**	**4859**	**0**	**4917**
01 - BASE CASE	Persistent Organic Pollutants (POP)	ng i-Teq					
02 - LLCC	Persistent Organic Pollutants (POP)	ng i-Teq					
03 - BAT	Persistent Organic Pollutants (POP)	ng i-Teq					

Table 6.105 shows the decrease in percentage of the LLCC and BAT main environmental indicators with respect the base case.

Also in this case, the ozone depletion and POP environmental impact indicators have not been reported because, according to EuP Ecoreport, these impacts are negligible.

Table 6.105: DW 12 ps – Percentage decrease of LCA's outputs from Base case vs LLCC and BAT cases

CASE	OUTPUT	Resources Use and Emissions	UNIT	USE	TOTAL
01 - BASE CASE	**Other Resources & Waste**	Total Energy (GER)	MJ		
02 - LLCC	**Other Resources & Waste**	Total Energy (GER)	MJ	-5,18%	-4,72%
03 - BAT	**Other Resources & Waste**	Total Energy (GER)	MJ	-13,26%	-12,07%
01 - BASE CASE	**Other Resources & Waste**	of which, electricity (in primary MJ)	MJ		
02 - LLCC	**Other Resources & Waste**	of which, electricity (in primary MJ)	MJ	-5,67%	-5,51%
03 - BAT	**Other Resources & Waste**	of which, electricity (in primary MJ)	MJ	-14,50%	-14,10%
01 - BASE CASE	**Other Resources & Waste**	Water (process)	ltr		

CASE	OUTPUT	Resources Use and Emissions	UNIT	USE	TOTAL
02 - LLCC	**Other Resources & Waste**	Water (process)	ltr	-26,55%	-25,66%
03 - BAT	**Other Resources & Waste**	Water (process)	ltr	-29,47%	-28,48%
01 - BASE CASE	**Other Resources & Waste**	Water (cooling)	ltr		
02 - LLCC	**Other Resources & Waste**	Water (cooling)	ltr	-5,67%	-5,62%
03 - BAT	**Other Resources & Waste**	Water (cooling)	ltr	-14,50%	-14,36%
01 - BASE CASE	**Other Resources & Waste**	Waste, non-haz./ landfill	g		
02 - LLCC	**Other Resources & Waste**	Waste, non-haz./ landfill	g	-5,17%	-2,20%
03 - BAT	**Other Resources & Waste**	Waste, non-haz./ landfill	g	-13,21%	-5,64%
01 - BASE CASE	**Other Resources & Waste**	Waste, hazardous/ incinerated	g		
02 - LLCC	**Other Resources & Waste**	Waste, hazardous/ incinerated	g	-5,21%	-1,77%
03 - BAT	**Other Resources & Waste**	Waste, hazardous/ incinerated	g	-13,33%	-4,52%
01 - BASE CASE	**Emissions (Air)**	Greenhouse Gases in GWP100	kg CO2 eq.		
02 - LLCC	**Emissions (Air)**	Greenhouse Gases in GWP100	kg CO2 eq.	-5,15%	-4,43%
03 - BAT	**Emissions (Air)**	Greenhouse Gases in GWP100	kg CO2 eq.	-13,16%	-11,33%
01 - BASE CASE	**Emissions (Air)**	Ozone Depletion, emissions	mg R-11 eq.		
02 - LLCC	**Emissions (Air)**	Ozone Depletion, emissions	mg R-11 eq.		
03 - BAT	**Emissions (Air)**	Ozone Depletion, emissions	mg R-11 eq.		
01 - BASE CASE	**Emissions (Air)**	Acidification, emissions	g SO2 eq.		
02 - LLCC	**Emissions (Air)**	Acidification, emissions	g SO2 eq.	-5,21%	-4,32%
03 - BAT	**Emissions (Air)**	Acidification, emissions	g SO2 eq.	-13,32%	-11,05%
01 - BASE CASE	**Emissions (Air)**	Volatile Organic Compounds (VOC)	g		
02 - LLCC	**Emissions (Air)**	Volatile Organic Compounds (VOC)	g	-3,76%	-2,07%
03 - BAT	**Emissions (Air)**	Volatile Organic Compounds (VOC)	g	-9,62%	-5,30%
01 - BASE CASE	**Emissions (Air)**	Persistent Organic Pollutants (POP)	ng i-Teq		
02 - LLCC	**Emissions (Air)**	Persistent Organic Pollutants (POP)	ng i-Teq	-5,16%	-2,02%
03 - BAT	**Emissions (Air)**	Persistent Organic Pollutants (POP)	ng i-Teq	-13,18%	-5,18%
01 - BASE CASE	**Emissions (Air)**	Heavy Metals	mg Ni eq.		
02 - LLCC	**Emissions (Air)**	Heavy Metals	mg Ni eq.	-4,52%	-0,92%
03 - BAT	**Emissions (Air)**	Heavy Metals	mg Ni eq.	-11,57%	-2,36%
01 - BASE CASE	**Emissions (Air)**	PAHs	mg Ni eq.		
02 - LLCC	**Emissions (Air)**	PAHs	mg Ni eq.	-2,61%	-1,30%
03 - BAT	**Emissions (Air)**	PAHs	mg Ni eq.	-6,68%	-3,33%
01 - BASE CASE	**Emissions (Air)**	Particulate Matter (PM, dust)	g		
02 - LLCC	**Emissions (Air)**	Particulate Matter (PM, dust)	g	-0,75%	-0,33%
03 - BAT	**Emissions (Air)**	Particulate Matter (PM, dust)	g	-1,91%	-0,84%
01 - BASE CASE	**Emissions (Water)**	Heavy Metals	mg Hg/20		
02 - LLCC	**Emissions (Water)**	Heavy Metals	mg Hg/20	-5,18%	-0,59%
03 - BAT	**Emissions (Water)**	Heavy Metals	mg Hg/20	-13,25%	-1,51%
01 - BASE CASE	**Emissions (Water)**	Eutrophication	g PO4		
02 - LLCC	**Emissions (Water)**	Eutrophication	g PO4	-0,0014%	-0,0014%
03 - BAT	**Emissions (Water)**	Eutrophication	g PO4	-0,0036%	-0,0036%
01 - BASE CASE	**Emissions (Water)**	Persistent Organic Pollutants (POP)	ng i-Teq		

CASE	OUTPUT	Resources Use and Emissions	UNIT	USE	TOTAL
02 - LLCC	**Emissions (Water)**	Persistent Organic Pollutants (POP)	ng i-Teq		
03 - BAT	**Emissions (Water)**	Persistent Organic Pollutants (POP)	ng i-Teq		