Institut für Landtechnik
Professur für Haushalts- und Verfahrenstechnik
Prof. Dr. rer. nat. Rainer Stamminger

Determination and verification of possible resource savings in manual dishwashing

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Natalie Anna Fuss

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Referent: Prof. Dr. rer. nat. Rainer Stamminger

Koreferent: Prof. Dr. rer. pol. Michael-Burkhard Piorkowsky

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Abstract

Many tests and consumer surveys have shown that manual dishwashing at home is done in very different ways, taking also different amounts of resources. Because almost every household, whether owning an automatic dishwasher or not still keeps on washing up a few items by hand, it seems necessary to investigate manual dishwashing regarding optimisation. Therefore, a project was run at the University of Bonn to find out an optimal way to clean the dishes by hand. Optimisation in this case means to reach a reasonably good cleaning performance with the minimum amount of resources, as water and energy for example. First, manual dishwashing was investigated experimentally: A repeatable method was developed for the sink washing process and with this method, several factorial studies were performed to find the factors in the process that influence the cleaning performance most. On the basis of the results of the experimental investigation and the knowledge – from previous studies on manual dishwashing – on how consumers wash up, Best Practice Tips were defined as an applicable guide for the consumer to save resources. In order to find out if it is possible to save resources when consumers apply the Best Practice Tips, several verification studies were run: three comparative laboratory studies, in which the test persons had to wash up different amounts of dishes, once with their usual behaviour and once by applying the Best Practice Tips. The results showed that especially with higher amounts of dishes, relevant resources of energy and water can be saved. However – possibly due to a different method existing for washing up of only a few items – no significant reduction was found when consumers were applying the Best Practice Tips with small amounts of dishes. As a next step, the possibility to save resources with the Best Practice Tips was verified in an in-home study in two countries (Germany and Spain). The findings of the previous studies could be confirmed in general. The savings of water and energy were especially high when persons usually washing up under running tap water changed their behaviour and washed up the dishes in a sink filled with water. However, the individual savings differed very much. This work delivers fundamental knowledge how resources can be saved in manual dishwashing. It is up to future studies to intensify the experimental investigation of manual dishwashing and the training with the Best Practice Tips.

Deutsche Kurzfassung

Viele Tests und Verbraucherstudien zeigen, dass Handgeschirrspülen im Haushalt sehr unterschiedlich ausgeführt wird und dabei auch sehr unterschiedliche Mengen an Ressourcen verbraucht werden. Da in fast allen Haushalten, sprich auch in denen mit Geschirrspülmaschine, zumindest einige Teile weiterhin von Hand abgespült werden, erscheint es nötig das Handgeschirrspülen hinsichtlich einer Optimierung zu untersuchen. Deshalb wurde an der Universität Bonn ein Projekt durchgeführt, um eine optimale Weise zu finden von Hand abzuspülen. Optimierung bedeutet in diesem Fall, ein zufriedenstellendes Reinigungsergebnis mit einem minimalen Input an Ressourcen, wie z.B. Wasser und Energie, zu erreichen. Zuerst wurde das Handgeschirrspülen in experimentellen Versuchen untersucht: Eine reproduzierbare Methode wurde für das Abspülen im Becken entwickelt und mit dieser Methode wurden mehrere Faktorenstudien durchgeführt um die Faktoren herauszufinden, die das Reinigungsergebnis am stärksten beeinflussen. Auf Basis der Ergebnisse der experimentellen Untersuchung und der aus den vorhergehenden Studien gewonnenen Erkenntnisse, wie der Verbraucher zu Hause abspült, wurden Best Practice Tips als praktikable Anleitung entwickelt, um Ressourcen einzusparen. Um herauszufinden, ob bei der Anwendung der Tipps eine Ressourceneinsparung möglich ist, wurden mehrere Studien durchgeführt. Zunächst fanden drei Vergleichsstudien im Labor statt, bei denen die Testpersonen verschiedene Geschirrmengen abspülen sollten – einmal so wie sie es auch zu Hause machen würden, und einmal unter Anwendung der Best Practice Tips. Die Ergebnisse zeigen, dass besonders bei größeren Geschirrmengen die Ressourceneinsparung groß ist, jedoch bei kleineren Mengen an Geschirr keine signifikante Reduzierung ausgemacht werden konnte. Dies liegt wahrscheinlich daran, dass es eine andere bessere Methode gibt kleine Geschirrmengen abzuspülen. Der nächste Schritt bestand darin, die Einsparungsmöglichkeiten im Haushalt mittels Haushaltsstudien in zwei Ländern, Deutschland und Spanien, zu überprüfen. Die Ergebnisse der vorhergehenden Studien konnten generell bestätigt werden: Die Einsparungen waren besonders hoch, wenn eine Person, die vorher unter fließendem Wasser abspülte, ihr Verhalten änderte und das Geschirr dann in einem mit Wasser gefüllten Becken abwusch. Die individuellen Einsparungen waren jedoch sehr

unterschiedlich. Diese Arbeit bietet grundlegende Erkenntnisse, wie beim Handgeschirrspülen Ressourcen eingespart werden können. In zukünftigen Studien sollte die experimentelle Untersuchung des manuellen Geschirrspülen intensiviert werden, genauso wie die das Training mit den Best Practice Tips.

Contents

1 Introduction

Dishwashing is a mundane task in almost every household. It is either carried out by hand or by machine. With the growing dissemination of dishwashing machines in households, it could be assumed that manual dishwashing becomes redundant. But this is not the case, because even in a household owning a dishwasher, at least a few items are still cleaned by hand (RICHTER, 2010a). Besides, RICHTER found out that the consumer behaviour with the dishwasher as well as with hand dishwashing leaves room for more efficiency and reveals therewith the need to introduce a more sustainable behaviour with dishwashing and "to create campaigns that are effective in changing consumer behaviour" (RICHTER, 2010b, p. 108).

It is important to clarify what sustainability means in this context, because there are various definitions and consequently confusion about what exactly the term means (KUROWSKA, 2003). A lot of these definitions are not referring specifically to the household. However, as the behaviour and the consumption patterns of households are profoundly affecting the stocks of natural resources and the environmental quality (OECD, 2011), a household near definition of this term seems to be necessary.

Goldsmith defines the term 'sustainability' as follows:

„Sustainability is about conscious design and the consideration of the impacts consumption choices make on the environment given finite resources. It involves ethics, ecology, and estimations of system life expectancies. The ultimate goal is sustainable development – a form of growth wherein societal needs, present and future, are met. Sustainable development requires the input and cooperation of all segments of society, producers as well as consumers. Towards this end, more careful decisions at every level are being made about the products and services brought into and used in the home." (GOLDSMITH, 2010, p. 330)

In this definition it is considered that the household's resource consumption amounts up to an important part of the total resource consumption and hence a sustainable everyday behaviour can contribute to the conservation and the protection of the environment (UNEP, 2004). Yet, the initial base of the resource consumption in households is different. The following chapter gives an idea of the water and energy consumption in the residential sector.

1.1 Household’s resource consumption

In a household’s day to day activities, especially the water and the energy consumption have an influence on the environment, besides food consumption, waste generation and transport choices (OECD, 2011).

According to the OECD, the share of the households of the total water consumption amounts to 10 to 30% of the total consumption. Average water consumption among OECD countries is at about 100,000 L per capita and year, which corresponds to a per-day water consumption of 274 L. The exact level is influenced by household characteristics, such as the number of persons per household and the residence size. It was found that the water consumption per person is the higher the less persons live in a household and the higher the income of the household is (OECD, 2011).

In Europe, the daily water consumption per person varies between 100 L and 320 L with an average of 155 L per person and day. Ukraine and Spain are with 320 L resp. 265 L the countries with the highest water consumption per person and day, whereas Lithuania and Estonia are with 97 L resp. 100 L at the bottom level (Figure 1-1) (EEA, 2005).

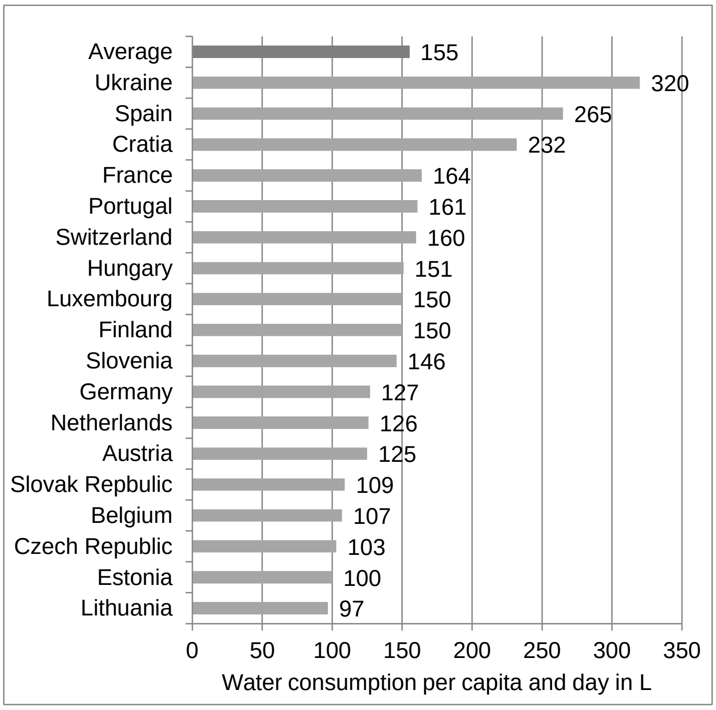

Figure 1-1: Water consumption per capita and day of some European countries
Source: own illustration based on EEA (2005)

Approximately one third of the daily water consumption is used for personal hygiene, another third for washing clothes and dishwashing, 20 to 30% for toilet flushing and 5% for drinking and cooking (EEA, 2001). The Bundesamt für Umwelt of Switzerland (BAFU) has also published data on how water is used in the household (Figure 1-2): Of 162 L of consumed water per person and day in Switzerland, the largest part is used for toilet flushing (48 L) and for bathing/ showering (32 L), whereas only 3 L are consumed for dishwashing (BAFU, 2003). It is not mentioned if this comprises manual and automatic dishwashing or if only dishwashing machines are considered. Figure 1-3 shows a similar categorisation with data for Germany published by the Bundesverband der Energie- und Wasserwirtschaft (BDEW, 2011). The highest percentage of the daily water consumption is used for bathing, showering and body care (36%) followed by toilet flushing with 20%. The share for dishwashing is with 6% (7 L/person and day) slightly higher than in the Suisse data. But as already in the Suisse data, no hint is given if this comprises only automatic dishwashing or also hand dishwashing.

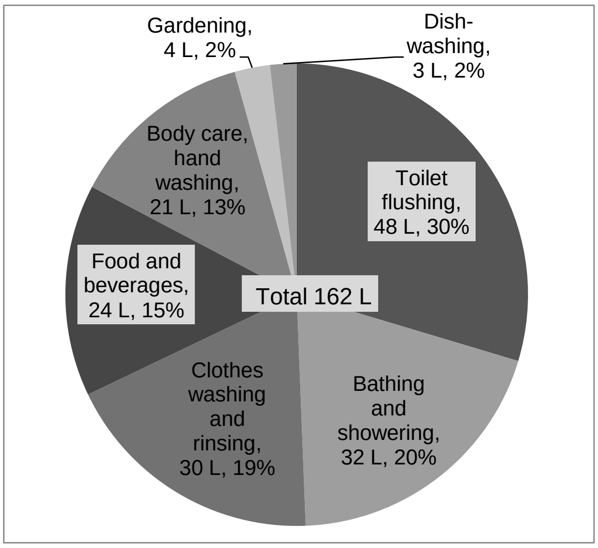

Figure 1-2: Allocation of the daily water consumption – average data from Switzerland
Source: own illustration based on BAFU (2003)

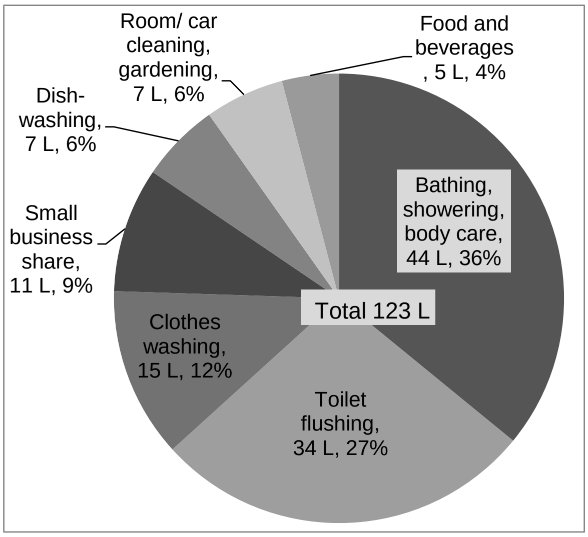

Figure 1-3: Allocation of the daily water consumption – average data from Germany
Source: own illustration based on BDEW (2011)

The household share for the energy consumption is comparable to the share of the water consumption. According to data of the OECD, the commercial and residential energy use lies between 15% and 30% of the final energy consumption. Additionally, it is the second fastest growing area of demand after transport (OECD, 2002). Among OECD countries, the household's energy use is expected to increase by some 1.4% per year. This number is even higher in non-OECD countries (OECD, 2008).

In 2005, an average U.S. household consumed per year 94.9 million Btu (equivalent to 27811 kWh) (EIA, 2005). This is equivalent to 76.2 kWh per day and household. This data does not include energy used for transport. The data from a German survey states that the residential German energy consumption (without energy for transport) in 2005 is at 2609 Petajoule (FORSA and RWI, 2005). Assuming a number of around 40 million households in Germany (DESTATIS, 2009), the energy consumption per household and year would be at 18118 kWh, which is equivalent to 49.6 kWh per household and day.

The largest part of the energy in U.S. households is used for space heating (31%). 5% of the energy used in households is consumed for dishwashers, washing machines and dryers. The hot water used for manual dishwashing is assumed to fall into the category "Water heating" which amounts up to a share of 12% (Figure 1-4) (DOE, 2007).

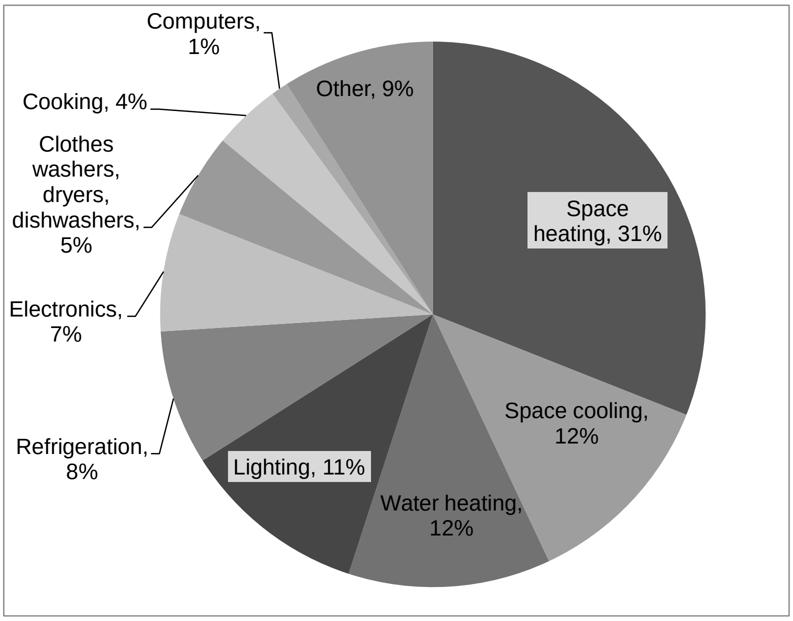

Figure 1-4: Energy use in U.S. households
Source: own illustration based on DOE (2007)

The data gives an overview on the household's water and energy consumption in general. However, the question occurs how exactly the consumption behaviour can be explained and influenced towards more sustainability.

1.2 Understanding and influencing the household's resource consumption

Despite the household's impact to the total resource consumption and the awareness that a more sustainable behaviour is necessary (OECD, 2011), DAWES found that consumers are facing a so-called "social dilemma" (DAWES, 1980). Collectively, everyone is better off if they change behaviour and engage in saving resources, but rational self-interest often leads to the contrary, i.e. environmental exploitation (KARP, 1996). Therefore, there are a lot of studies that attempt to predict conservation, as well as understand, shape and improve the household's resource consumption.

Three different classifications were found on how to influence pro-environmental behaviour. COOK and BERRENBERG describe in a conceptual framework seven commonly used approaches to encourage conservation behaviour: persuasive communication, evoke of attitude-consistent behaviour (when a general pro-conservation attitude already exists), material incentives and disincentives, social incentives (such as social recognition), famous role models, minimizing inhibitors, such as lack of knowledge on how to save resources and informing by feedback or self-monitoring (COOK and BERRENBERG, 1981). GOLDSMITH categorizes four general approaches on how consumer behaviour can be influenced towards a more sustainable way: the punishment-oriented approach, the rewarding approach (giving incentives), the persuasion-oriented approach and the approach to reach behaviour change with the influence of other (GOLDSMITH and GOLDSMITH, 2011).

Another classification is presented by ABRAHAMSE *et al.* who evaluate the effectiveness of interventions aiming to encourage households to reduce energy consumption. They distinguish studies according to whether they focus on antecedent strategies (commitment, goal setting, information, modelling) or consequence strategies (feedback, rewards). Antecedent strategies influence determinants prior to the performance of behaviour. Consequence interventions assume that positive or negative consequences motivate to change behaviour (ABRAHAMSE *et al.*, 2005).

Commitment as antecedent strategy is a promise to save resources and often linked with a specific goal, e.g. to save 10% of energy. Goal setting means that a specific goal to save resources is either given to the household or is set by the households itself. The instrument of giving information can either contain information on the general problem why resources should be saved or contain information on how resources can be saved. Furthermore, the modelling strategy is classified among the antecedent strategies (ABRAHAMSE *et al.*, 2005). Modelling means after Bandura's learning theory that examples are provided with recommended behaviour (BANDURA, 1977).

Among the consequence strategies, the rewards strategy is situated. Rewards are often monetary rewards given for realised conservation. The feedback instrument is also classified in the category of consequence strategies. It can be further distinguished between how often feedback is given on the actual resource consumption (continuously, daily, weekly, monthly). Another subset of the feedback strategy is the comparative feedback: Here, information on the actual resource consumption is presented in comparison to the consumption of others (ABRAHAMSE *et al.*, 2005).

In the reviewed literature, especially the feedback instrument was found to be studied. This instrument was already investigated in the seventies: A study of SELIGMAN AND DARLEY revealed that immediate feedback on the energy consumption can significantly reduce it (SELIGMAN and DARLEY, 1976). However, this is contradicting to some extent to what BECKER found, namely that only feedback had no influence on the energy consumption whereas feedback combined with setting a difficult goal shows effect on energy saving (BECKER, 1978). The feedback instrument was not only investigated for the energy consumption but also for the water consumption. GELLER *et al.* investigated three possible factors of influencing the water consumption: Education how and where to save water, daily feedback on the water consumption and low cost conservation devices such as a tap aerator. They revealed that significant water savings only occurred with the water conservation devices, but not with the instrument of feedback (GELLER *et al.*, 1983).

Giving feedback by technology to support sustainable behaviour in private households was studied by GRØNHØJ and THØGERSEN. They evaluated the effects of giving households feedback about their electricity consumption on a small screen. The participating households could save 8.1% of energy and especially families with teenage children were receptive to this type of feedback (GRØNHØJ and THØGERSEN, 2011). The results of a study by WALLENBORN, who investigated the influence of an installed electricity metre, were similar. The immediate feedback provided by such a device helped to save energy, but only in the households that were already involved in energy savings (WALLENBORN *et al.*, 2011).

Yet, not only the consequence strategies are examined, but also antecedent strategy investigations can be found: Instead of giving feedback STALL-MEADOWS AND HEBERT examined in which way consumer education has an impact on a more sustainable behaviour with different lighting alternatives. They revealed that, with an increased understanding of the energy efficiency of the three lighting types, consumers tend to choose the higher priced but more efficient alternative (STALL-MEADOWS and HEBERT, 2011).

Other studies are focusing more on social influence and investigate various aspects how this can influence the household towards a more sustainable handling of resources. A three-variable regression model with an explanation of the variation in the residential water consumption was developed by AITKEN *et al.*. They showed that the number of residents, the washing machine loads and the property value accounted for 60% of the variance. However, they concluded that attitudes, habits and values were poor predictors of the water consumption (AITKEN *et al.*, 1994). This is to some extent contradictory to what CORRAL-VERDUGO and FRIAS-ARMENTA found: They proved that personal normative beliefs have a positive effect on the water conservation and that anti-social behaviour inhibited that behaviour (CORRAL-VERDUGO and FRÍAS-ARMENTA, 2006). A similar subject was investigated eight years later by PINTO *et al.*: They found that water consumption increased with more socially oriented values. Wasteful habits could be predicted by environmental awareness and personal values (PINTO *et al.*, 2011).

The OECD investigated in a large project about to what extent different factors (market, demographic and policy related factors) affect the resource consumption in the household. It was a survey with 10000 households distributed over all OECD countries. One important result was that it is important to give the right economic incentive to induce a behaviour change in the household towards more sustainability. Especially, price-based incentives encourage water and energy savings. It was also revealed that there is a lack of knowledge about the own water and energy consumption. Therefore it was concluded that, beside the price as instrument for savings, the so-called “softer instruments” (OECD, 2011, p. 16) like information and education play a key role as supplement. The environmental awareness and the household’s concern for the environment were found to be other factors influencing the household’s resource consumption. On this basis, it was suggested that is an important task for governments to promote information campaigns which aim at reinforcing the environmental awareness and encourage behaviour changes. It was concluded from the study that a combination of instruments is necessary to promote effective behaviour changes. Because of a significant variation in the environmental behaviour, this mixture of instruments would have to be individually adaptable for specific target groups (OECD, 2011).

To conclude, varying degrees of effect can be determined when looking at interventions to conserve resources like water and energy. There are studies investigating the same instrument that prove success and others that show failure. Yet, all those studies have in common that they are focusing either on water or energy consumption in general and not on a specific household task, whereas up to now no studies were found that investigate the possibility to save resources in a specific household task.

1.3 Dishwashing as a specific task where resources are needed in the household

Dishwashing as a specific household task consuming resources can be either carried out by hand or by machine. While the efficiency of the automatic dishwasher is optimised in manifold ways, both ways of doing the dishes depend on the consumer's behaviour (RICHTER, 2010a).

1.3.1 The progress of automatic dishwashing

Since 1999, dishwashers on the European market have to be labelled with the European Energy Label. Four years later, in 2003, the European Committee of Domestic Equipment Manufacturers (CECED) published a voluntary agreement on improving the dishwasher efficiency, which some of the dishwasher manufacturers signed in order to diminish the energy consumption of domestic dishwashers by reducing the fleet consumption and by a stepwise phasing out of less efficient dishwashers (CECED, 2003). But already before this date, the efficiency of the automatic dishwasher was improved steadily. From 1975 on, it was possible to reduce the energy consumption of a standard household dishwasher with a capacity of 12 place settings from a bit more than 2.64 kWh per cycle down to some more than 1.14 kWh per cycle in 2005, which equals a reduction of 57% in less than 35 years

(STAMMINGER, 2006). The development of the water consumption is parallel to the energy consumption: In 1975, an average dishwasher needed more than 59.5 L of water and in 2005 only 13.3 L, equivalent to a reduction of 78%. And the tendency of the consumption is further decreasing: According to manufacturer's data, newest technologies lead to a water consumption of 6.5 L and an energy consumption of 0.93 kWh for washing up 13 place settings (SIEMENS-ELECTROGERÄTE GMBH, 2010).

With the efficiency of automatic dishwashers, the penetration rate of automatic dishwashers is rising: In Germany in 2010, 67% of the households own a dishwashing machine, 47% more than in 1980 (ZVEI, 2011). In Canada, the penetration rate for automatic dishwashers has risen from 54% in 1993 up to 70% in 2007 (OEE, 2007). Nevertheless, a very efficient machine is useless if used in an inefficient way. RICHTER found that there is room for improvement with the consumers' behaviour with a dishwashing machine: Choosing the correct programme, using the maximum capacity of dishwasher and pre-treating the dishes in a correct way would help to save more resources with automatic dishwashing (RICHTER, 2010a). However, this does not mean that manual dishwashing has become redundant. It was found that even in households owning a dishwasher, some items are still cleaned by hand and others items are pre-cleaned by hand before they are placed in the dishwasher (RICHTER, 2010a; RICHTER, 2011).

1.3.2 Consumer behaviour with dishwashing

Manual dishwashing was already investigated in 1971 when four housewives had to compete with a dishwashing machine (LUECKE, 1971). In 1993, GUDD *et al.* compared the dishwashing behaviour of ten persons washing up a larger amount of dishes and an automatic dishwasher (GUDD *et al.*, 1993). GUTZSCHEBAUCH *et al.* compared systematically dishwashing by hand and in the machine regarding the detergent, life cycle assessment, economical efficiency, consumer habits, hygiene and surfactant residues (GUTZSCHEBAUCH *et al.*, 1996).

A cross-cultural analysis between Japan and Norway revealed that there are significant differences in dishwashing habits between those two countries. All the participants from Norway washed the dishes in a basin with water and detergent whereas the majority of Japanese households washed up under running tap water. The Japanese dishwashing behaviour is explained by too small kitchen sinks so that washing up under running tap water is more convenient. Furthermore, it was found that the Norway participants all used hot water for washing up whereas the majority of Japanese persons varied the temperature with the season: hot water in the winter and cold water in the summer (WILHITE *et al.*, 1996).

In a study conducted at the University of Bonn the consumer behaviour and resource consumption with manual dishwashing was investigated with 113 test participants from 10 European countries (Germany, Poland/ Czech Republic, Italy, Spain/ Portugal, Turkey, France, Great Britain/ Ireland). For washing up 12 place settings, the test participants needed on average 103 L of water, 2.5 kWh of energy, 35 g of detergent and a time of 79 min. The average did not reveal the main finding of the study, that habits and practices vary between individuals. The water consumption varied between under 20 L and above 440 L. Some of the test persons consumed less than 0.25 kWh of energy and others needed more than 8 kWh for washing up this amount of dishes. The cleaning result of the dishes varied much the same as the resource consumption. Some test persons reached a good cleaning result already with small amounts of resources and others did not achieve an acceptable cleaning performance with large amounts of water and energy. Despite the differences between individuals, country specific tendencies could be made out. (STAMMINGER *et al.*, 2007a).

In an extension of the study from STAMMINGER *et al.* (STAMMINGER *et al.*, 2007a), the dishwashing behaviour of 100 test persons from other countries (Hungary, Russia, Germany, South Africa and China) was studied. The same conclusion was drawn, namely, that the water, energy and detergent consumption as well as the time for washing up 12 place settings varied dramatically from person to person and from country to country (BERKHOLZ and STAMMINGER, 2009).

Another investigation studied the manual dishwashing behaviour of 150 U.K. consumers and compared it to the performance of an automatic dishwasher. On average, the test persons needed for washing up 12 place settings 49 L of water and 1.7 kWh of energy in comparison to 13 L of water and 1.3 kWh of energy for the dishwasher. As already found by STAMMINGER *et al.* for consumers of different Europeans countries (STAMMINGER *et al.*, 2007a) and BERKHOLZ and STAMMINGER for other countries (BERKHOLZ and STAMMINGER, 2009), the results of the U.K. consumers revealed a wide range of washing up techniques what finds expression in the large distribution of the consumption values. An additional questionnaire revealed that around two thirds of the test persons who owned an automatic dishwasher maintained washing up by hand once a day or even more often (BERKHOLZ *et al.*, 2010).

All the studies named above were conducted on the basis of 12 place settings, but the manual dishwashing behaviour with smaller amounts of dishes and pots and pans was also examined. In a study 46 with consumers washing up two place settings and pots and pans, it was found that cleaning smaller amounts of dishes did not reduce the per item consumption and that especially with hard soiled items such as pots and pans the resource consumption rises. The comparison of the consumer behaviour to an automatic dishwasher showed an advantage for the machine in terms of a better cleaning performance as well as a lower water consumption (STAMMINGER *et al.*, 2007b).

A survey of the German dishwashing behaviour revealed results on the self-assessment of the consumers. Especially interesting is the question regarding the categorisation of the behaviour: Regardless of the possession of an automatic dishwasher, the majority of the Germans wash up either completely in a sink or in a sink combined with washing up under running tap water. Only few of them state that they clean their dishes under running tap water (STAMMINGER and STREICHARDT, 2009).

Dishwashing habits by hand and in the machine were also investigated in an online survey with 1209 consumers from four European countries. The survey showed on the one hand the importance of low water and energy consumption when a dishwasher is to be purchased. On the other hand, the saving potential of an efficient dishwasher is partly counterbalanced by a less efficient consumer behaviour, e.g. pre-washing the dishes by hand before cleaning them in the dishwasher. It was also shown that differences in manual dishwashing habits exist between households with and without dishwasher as well as between countries: In households with a dishwasher, manually cleaned dishes are more frequently washed up under running tap water whereas in households without a dishwashing machine the practice of filling a sink with water is more common. In Italian and Swedish households without a dishwasher, the habit of cleaning dishes under running tap water is performed more often than in the U.K. and in Germany. In these two countries, the sink washing practice is predominant, especially in households without a dishwasher (RICHTER, 2010a).

Studies were not only conducted in the laboratory or with a questionnaire: RICHTER ran an in-house study in which he investigated the consumer behaviour with both manual and automatic dishwashing. In four European countries (Germany, Italy, Sweden and the U.K.), 200 households had to record their dishwashing behaviour in a diary. Additionally, measuring instruments were installed at the kitchen tap in some of these households. It was proved that households owning a dishwashing machine used on average 50% less water and 28% less energy per cleaned items in comparison to households without a dishwasher (RICHTER, 2011). Households without a dishwasher spent more time on cleaning the dishes by hand. However, a share between 24% (Germany) and 42% (Italy, U.K) of the items still were cleaned by hand even in households with a dishwashing machine. Different practices of cleaning the dishes by hand were also compared: It was found that less water is consumed per item if the dishes are cleaned in a sink filled with water, compared to the water consumption of cleaning the dishes under running tap water. It was concluded that even with the rise of the penetration of automatic dishwashers, manual dishwashing does not become redundant and that especially with manual dishwashing the majority of dishwashing cycles is carried out rather inefficiently under continuously running tap water (RICHTER, 2010b).

The total of the reviewed studies show the great variety of the consumer's behaviour and the resource consumption when washing up the dishes by hand. As EMMEL already claimed for automatic dishwashing, BERKHOLZ and STAMMINGER asked for manual dishwashing and RICHTER demanded for both ways of cleaning the dishes, there is a necessity to find information campaigns that are effective in changing the consumer's behaviour (BERKHOLZ *et al.*, 2010; EMMEL *et al.*, 2003; RICHTER, 2010b).

1.4 How to clean the dishes by hand? A review of dishwashing tips

A general categorisation of washing dishes by hand is presented by SHI *et al.* (SHI *et al.*, 2005). They differentiate between three different methods to wash up and present country specific differences on how often each method is used in different countries (Table 1-1). According to this data, the so-called "full sink method", meaning the consumer washes up in a sink filled with water is mainly carried out in Germany, the United Kingdom and in the United States. By contrary, the so-called "direct application method" is applied the most often in Japan. "Direct application" refers to the way of dosing the detergent, which – in this method – is directly poured on the washing up implement or the dishes. Then, the dishes are cleaned under running tap water. It is also reported about a third modification the so-called "concentrated minisolution". With this method, the person cleaning the dishes dilutes some detergent in a small bowl. The implement is dunked in this "concentrated minisolution" and applied the on the dishes. Afterwards the dishes are rinsed under running tap water. This method is mainly applied in Mexico whereas it seems to be almost unknown in Germany (Table 1-1). Though it is mentioned how often a certain method is carried out in some countries, it is not specified if and in which way the methods may differ in efficiency and resource consumption.

Table 1-1: Typical consumer hand dishwashing methods in selected countries

	Full sink	Direct application	Concentrated minisolution
Description	Washing up in a sink filled with water, detergent dosed in the sink	Washing up under running tap water, detergent dosed on the implement	Washing up under running tap water, detergent diluted in a small bowl
Country	**Data in % of dishwashing loads by consumers**		
United States	72	27	1
United Kingdom	82	14	4
Germany	93	7	0
France	51	38	11
Spain	35	50	15
Japan	3	90	7
Mexico	1	15	83

Source: own illustration based on unpublished data from WESTFIELD AND RUIZ-PARDO (2004) cited as per SHI *et al.* (2005, p. 111)

Little more is said in scientific resources about how to clean the dishes by hand. However, the World Wide Web provides a variety of Blogs, Forums and Websites of organisations with tips for manual dishwashing. Table 1-2 presents an overview on the tips and the corresponding sources from German, English, French and Spanish speaking websites. These tips are described more in-depth and discussed in the following.

Table 1-2: Gathering of dishwashing tips in the World Wide Web

Category	Recommendation	References	
Time to wash up	Wash up immediately after meal.	AID INFODIENST (n.d.) ARMENDARIZ (2011) BAYAN (n.d.) FOOD-MONITOR (2010)	FORUM WASCHEN (n.d.) N.N. (2007) N.N. (2010b) N.N. (n.d.-c)
	Accumulate dishes	REICHMANN (2008)	
Before washing up	Dispose of food leftovers into the bin.	ACSD (n.d.) AID INFODIENST (n.d.) BAYAN (n.d.) COMMENT FAIT-ON (n.d.) COTTAGE LIFE (2009)	EKOPEDIA (2011) FORUM WASCHEN (n.d.) N.N. (2007) N.N. (2008) N.N. (n.d.-b)
	Pre-rinse if necessary.	ACSD (n.d.) FIT GMBH (n.d.) FORUM WASCHEN (n.d.)	N.N. (2007) N.N. (2010c)
	Do not pre-rinse.	COTTAGE LIFE (2009)	

Category	Recommendation	References
	Soak hard burnt soils with hot water.	ACI (n.d.) ACSD (n.d.) AID Infodienst (n.d.) Cottage Life (2009) Ekopedia (2011) Euroresidentes (n.d.) Fit GmbH (n.d.) Forum Waschen (n.d.) Lifespy (2011) N.N. (2007) N.N. (2008) N.N. (2009c) N.N. (2010a) N.N. (n.d.-c) Reichmann (2008) Rozio (2008)
	Use detergent to soak.	Euroresidentes (n.d.) Forum Waschen (n.d.) N.N. (2010a) Tinoco (2008)
	Do not soak because of germs.	Armendariz (2011)
Washing up order	Washing up order: least soiled items (e.g. glasses) first.	AID Infodienst (n.d.) Fit GmbH (n.d.) N.N. (2007) N.N. (2008) N.N. (2009c) N.N. (2010c) N.N. (n.d.-b) Vivat (n.d.)
General ways of washing up	Do not wash up under running tap water.	Cave (n.d.) Comment Fait-On (n.d.) Cottage Life (2009) Coruzery (2008) Ecologic Barna (n.d.) Ekopedia (2011) Euroresidentes (n.d.) Forum Waschen (n.d.) N.N. (2008) N.N. (2009a) N.N. (2010c) Rozio (2008) Tinoco (2008) Vivat (n.d.)
	Wash up in a sink filled with water (not mentioned how many sinks).	Cave (n.d.) Ecologic Barna (n.d.) Ennovationz (2010) Euroresidentes (n.d.) Forum Waschen (n.d.) N.N. (2009a) N.N. (2010c) Rozio (2008) Henkel AG & Co. (n.d.): sink washing presumed
	Only wet the sponge for cleaning the plates (followed by rinsing).	Armendariz (2011)
	Wash up in two sinks filled with water.	AID Infodienst (n.d.) BC Hydro (2009) Cottage Life (2009) Coruzery (2008) Ekopedia (2011) N.N. (2007) N.N. (2008) N.N. (2009b) N.N. (2010a) Reichmann (2008) Vivat (n.d.)
	Wash up in three compartments.	Bayan (n.d.) NFSMI (2009)
	Wash up in basins or a pot placed in the sinks (less water, and possibility to dispose of fluids into the drain).	ACSD (n.d.) N.N. (2007)
	Only fill your sink half with water.	BC Hydro (2009) Ekopedia (2011) Ennovationz (2010) N.N. (2007) Peterson (2008) Priebe (n.d.)
	Use as hot water as possible.	ACSD (n.d.) AID Infodienst (n.d.) Comment Fait-On (n.d.) Ekopedia (2011) N.N. (2007) N.N. (2009c) N.N. (2010c)
	Use cold water for cleaning (in combination with hot rinsing water).	N.N. (2009b)
	Wash up under hot running tap water.	N.N. (n.d.-b)

Category	Recommendation	References	
	The second sink can be replaced by a basin.	Ekopedia (2011) Reichmann (2008)	Vivat (n.d.)
Water changes (if sink washing is recommended)	Change water if it is too dirty.	ACSD (n.d.) N.N. (2007)	N.N. (2008) N.N. (2010c)
	Change the water when there is no foam left.	N.N. (n.d.-a)	
Ways of dosing the detergent	Dose the detergent on the sponge.	Armendariz (2011)	
	Produce a concentrated minisolution.	Shi *et al.* (2005)	
	Dose the detergent in the sink.	Ecologic Barna (n.d.) N.N. (2008) N.N. (2009a)	N.N. (2010c) Rozio (2008)
	Try to produce little foam.	AID Infodienst (n.d.) Fit GmbH (n.d.)	Henkel AG & Co. (n.d.)
	Use vinegar for persistent soils.	N.N. (2009a)	
	Use detergent carefully/ as recommend by the manufacturer.	Fit GmbH (n.d.)	N.N. (n.d.-a)
Ways of rinsing	Rinse with hot water.	ACSD (n.d.) AID Infodienst (n.d.) Bayan (n.d.) Comment Fait-On (n.d.) Euroresidentes (n.d.)	N.N. (2007) N.N. (2009b) NFSMI (2009) Procter & Gamble (n.d.)
	Rinse with cold water.	Coruzery (2008)	Ekopedia (2011)
	Rinse in a sink/basin.	ACSD (n.d.) AID Infodienst (n.d.) BC Hydro (2009) Euroresidentes (n.d.)	Lifespy (2011) N.N. (2009b) N.N. (2009c)
	Rinse under running tap water.	Armendariz (2011)	N.N. (2007): only for glasses
	Rinse all your dishes at once with a sprayer.	BC Hydro (2009) N.N. (2009a)	Peterson (2008)
	Use vinegar in the rinsing water.	Lifespy (2011)	N.N. (2007)
After-treatment	Sanitize the dishes after cleaning.	Manitoba (2011) N.N. (2010b)	NFSMI (2009)
Drying method	Use a dish rack, let the dishes air dry.	ACSD (n.d.) AID Infodienst (n.d.) Armendariz (2011) Bayan (n.d.) Comment Fait-On (n.d.) Ekopedia (2011) Euroresidentes (n.d.) Fit GmbH (n.d.)	N.N. (2007) N.N. (2008) N.N. (2009c) N.N. (2010b) N.N. (2010c) N.N. (n.d.-a) N.N. (n.d.-b) Priebe (n.d.)
	Towel drying to avoid germs.	Food-Monitor (2010)	
	Towel drying for glasses.	AID Infodienst (n.d.)	
	Change tea towel daily.	Forum Waschen (n.d.)	

Category	Recommendation	References	
Additional tips	Use gloves.	ACSD (n.d.) AID INFODIENST (n.d.) COMMENT FAIT-ON (n.d.) EURORESIDENTES (n.d.) FORUM WASCHEN (n.d.) LIFESPY (2011) MANITOBA (2011)	N.N. (2007) N.N. (2008) N.N. (2009a) N.N. (2009c) N.N. (2010b)

The background of presenting such recommendations is different: Some sources have the aim to provide a guide on how to save money when washing dishes (e.g. BAYAN, n.d.) whereas others want to advise on how to get the best cleaning result (CROUZERY, 2008). Maximising the efficiency when washing dishes by hand (REICHMANN, 2008) is also found with the objectives as the limitation of germ formation (FOOD-MONITOR, 2010). Last but not least there are sources with the objective of a sustainable behaviour, such as saving water (e.g. CAVE, n.d.), saving energy (e.g. ENNOVATIONZ, 2010) or a general “green dishwashing behaviour” (e.g. COTTAGE LIFE, 2009).

It becomes obvious that the tips differ also in regard to the time when to do the washing up: Some recommend to wash up immediately after a meal (e.g. ARMENDARIZ, 2011) and others suggest to accumulate the dishes (e.g. REICHMANN, 2008). The reason for washing up directly after the dishes were used is that the soil does not have time to dry up, whereas the accumulation of dirty dishes should help to make sink washing more efficient.

As washing up steps besides the main cleaning step, a lot of sources include the tip to dispose of food leftovers (e.g. EKOPEDIA, 2011). Some recommend to pre-rinse the dishes if necessary (e.g. FORUM WASCHEN, n.d.) whereas others advise that no pre-rinsing is necessary (e.g. COTTAGE LIFE, 2009). A lot of sources recommend the step to soak persistent soils in hot water (EURORESIDENTES, n.d.) which is contradicting to ARMENDARIZ, who advises against soaking because of germ formation (ARMENDARIZ, 2011). Among the sources that recommend soaking, some advise to add detergent to the hot soaking water so that soils can be removed more easily (e.g. TINOCO, 2008).

Having removed the soil, a lot of the recommendation sources contain the tip to sort the dishes that have to be cleaned in order to use the same water for a larger number of items. Logically, this tip is only important when washing up in a sink is recommended because when washing up under running tap water, the same amount of water is only used for one item. There is a consensus amongst those who suggest a washing up order (e.g. AID INFODIENST, n.d.): Wash up less soiled items first, e.g. glasses, and clean more soiled items last, e.g. pots and pans.

Regarding the general way of washing up, the tips from the different sources vary: Most say that washing up in a sink filled with water is the most economical way to clean the dishes by hand (e.g. ROZIO, 2008). However, some advisors recommend to wash up under hot running tap water (N.N., n.d.-b), but do not give a reason. Especially in Spanish speaking websites, it is explicitly mentioned not to wash up under running tap water (CAVE, n.d.; ECOLOGIC BARNA, n.d.; N.N., 2009a; N.N., 2010c; ROZIO, 2008; TINOCO, 2008), probably because in Spain it is very common to wash up under running tap water (compare Table 1-1). According to the data presented in Table 1-1, the Germans mainly wash up in a sink filled with water. This might be the reason why on a website of a German detergent manufacturer, the use of the sink washing method is taken as granted (HENKEL AG & CO., n.d.) and they only mention to “let the water in” without referring to fill a sink with water in order to wash up. Francophone websites in particular recommend to wash up in two sinks filled with water, one for cleaning and one for rinsing (ACSD, n.d.; N.N., 2008; N.N., 2009b). Sources in German and English provide the same recommendation as well (e.g. AID INFODIENST, n.d.; N.N., 2007), yet, not one of the listed Spanish speaking sources does so. Instead of filling sinks with water, some recommend to fill basins or pots with water because this uses less water than filling a sink (e.g. ACSD, n.d.). A basin can be used instead of a second sink, when there is only one available (e.g. VIVAT, n.d.). In order to save water when filling sinks, the tip occurs to fill the sink not up to the brim but only up to the half (e.g. PRIEBE, n.d.). The National Food Service Management Institute of America advises to wash up in three compartments, because an additional sanitizing step is recommended after cleaning and rinsing (NFSMI, 2009).

Not only the way of washing up is varying, but also the recommended temperatures: On the one hand, the tip can be found to wash up with water as hot as possible (e.g.

COMMON FAIT-ON, n.d.), and on the other hand there is the tip to clean the items with cold water in order to save energy (N.N., 2009b). However, this last tip is advised in combination with a rinse under hot water (N.N., 2009b). A very common additional tip is to put on gloves to protect hands when using very hot water (e.g. MANITOBA, 2011).

When the sink washing method is recommended, the question occurs if and when the water should be changed. In some of the sources, the hint is given to change the water if one feels that it is too dirty (e.g. N.N., 2010c), others tell to change the water when there is no foam left (N.N., n.d.-a).

The way of dosing the detergent mainly depends on the advised way to clean the dishes: The detergent can be dosed on the utensil used to clean the dishes (ARMENDARIZ, 2011) or a so-called “minisolution” is mentioned (SHI *et al.*, 2005) when the dishes are cleaned under running tap water and not in a sink filled with water. This means that in a small bowl detergent is mixed with little water and the sponge is dunked in this solution before cleaning the item. When sink washing is recommended, one can mainly find the tip to dose the detergent into the water (e.g. ECOLOGIC BARNA, n.d.). Some sources mention to try to produce little foam (AID INFODIENST, n.d.). One reason given is that with little foam the dishes dry more easily (FIT GMBH, n.d.). For persistent soils, vinegar can be used instead of a detergent (N.N., 2009a). Another advice concerning the dosing of the detergent is to dose the detergent carefully and as it is recommended by the manufacturer (FIT GMBH, n.d.).

The majority of sources mention that rinsing is necessary in order to get rid of detergent leftovers or detached soil (N.N., 2007). However, there is a variation of tips how to rinse: with hot water (e.g. BAYAN, n.d.), so that the dishes can dry more easily, or with cold water (CROUZERY, 2008) in order to save energy. According to the tips of AID INFODIENST, the rinsing can be performed in a sink (AID INFODIENST, n.d.). ARMENDARIZ advises to rinse the dishes under hot running tap water (ARMENDARIZ, 2011) and another website recommends to rinse especially glasses under running tap water (N.N., 2007). A variation of the running tap rinsing method is the rinsing of the dishes all at once with a sprayer (e.g. BC HYDRO, 2009).

To dry the dishes, the majority of sources suggest to let the dishes air dry in a dish rack (e.g. EURORESIDENTES, n.d.) in order to avoid germ formation in the towel. However, AID INFODIENST recommends towel drying for glasses (AID INFODIENST, n.d.) and the tips of FOOD-MONITOR contain towel drying for all dishes because otherwise there would be germ formation on the dishes (FOOD-MONITOR, 2010).

To sum up, the dishwashing tips differ as much as the dishwashing habits shown in the previous sub-chapter. Nevertheless, tendencies can be made out, which the majority recommend:

- Disposing of food leftovers before washing up
- Soaking of persistent soils
- Washing up in sinks filled with water instead of washing up under running tap water
- Rinsing the dishes after cleaning them
- Air drying of the dishes instead of towel drying

The question occurs with the variety of sometimes contradicting dishwashing tips, if there is one combination of tips that proves to be optimal, uses a minimum amount of water and energy, is efficient concerning the time and leads at the same time to a reasonably good cleaning result.

2 General objectives and structure of the thesis

It was shown that on the one hand almost every household – whether owning a dishwasher or not – still keeps on washing up at least a few items by hand (e.g. RICHTER, 2010b). On the other hand, studies on consumer behaviour when doing the dishes showed that they use quite different ways with different amounts of resources (e.g. STAMMINGER *et al.*, 2007a). Both aspects taken together show the necessity to investigate manual dishwashing.

It was the overall aim of this project to answer the question if there is a possibility to save resources like water and energy when cleaning the dishes by hand. In order to reach this objective, the manual dishwashing process shall be investigated and optimised experimentally. Optimisation here means to reach a reasonably good cleaning performance while using a minimum amount of resources. Especially the sink washing process shall be investigated because the same amount of water can be used for more than one item whereas the cleaning under running tap water needs a certain amount of water for only one item. A repeatable method shall be developed for the sink washing process in order to study the impact factors on the cleaning performance. As an experimental optimum does not yet contribute to help the consumer saving resources like water and energy, Best Practice Tips shall be defined and then verified with different amounts of dishes and under different circumstances: in the laboratory and in real life. The consumption of water, energy, detergent, time and the cleaning results shall be compared before and after a training on the Best Practice Tips. Furthermore, the consumer’s attitudes towards such a guideline shall be found out.

As the project comprised different studies that were consecutive and different in their setup, this thesis is structured in four parts each consisting of the sections “objectives”, “material and methods”, “results” and “conclusion”.

3 Experimental optimisation of manual dishwashing[1]

The first study of the project was dedicated to the experimental investigation of manual dishwashing. It is described how the experiments were set up and run. Furthermore, it is presented how the results of the experiments can be interpreted and a model is shown, which lays out how the investigated impact factors influence the cleaning performance.

3.1 Objective

The objective of this study is the development of a repeatable method for the sink washing process. On this basis, a factorial study shall be run in order to find out the main impact factors of the sink washing process influencing the cleaning performance. A regression model shall be developed that contains the main impact factors as input variables and the cleaning performance as output variable. Furthermore, the optimum that leads to a reasonably good cleaning performance with a minimum amount of resources shall be defined.

3.2 Material and methods

Thirty pizza plates (flat plates made of porcelain, diameter: 32 cm) were each soiled with five soil types (minced meat, spinach, egg yolk, porridge and margarine). The soil types and the preparation were chosen according to the European standard for testing automatic dishwashers EN 50242:2008 (CENELEC, 2008). The minced meat consisted in equal shares of beef and pork meat and was mixed with whipped eggs. The porridge was prepared with oat flakes, milk and water. Each soil type was applied onto one fifth of each plate (Figure 3-1). The food for preparing the soil was from the same batch (regarding one experimental series). The plate sections were marked so

[1] published in a similar way in FUSS, N. & STAMMINGER, R. (2010): Manual dishwashing: how can it be

that the evaluator could tell how well each type of soil was removed by the washing up.

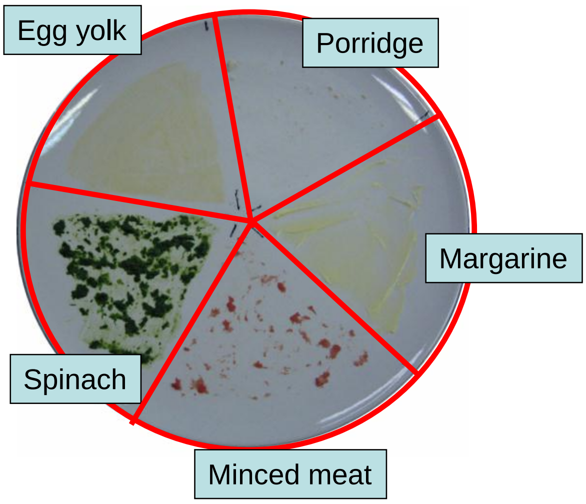

Figure 3-1: Pizza plate with five soil types
Source: own illustration

The soils were dried for two hours under controlled ambient conditions (temperature: 23 °C ±2 °C, relative air humidity: 55% ±5%) in order to simulate the consumer habit of not washing up immediately after the meal. After the drying period, the person running the experiments cleaned the plates. The work station used for washing up consisted of a double-bowl sink with a single-lever tap. The hot water was supplied by an on-demand water heater. In order to guarantee a repeatable washing up process, which allowed to clean each item under the same conditions, the work station had to be adapted as follows (Figure 3-2): Below one sink, an additional basin was installed. It was filled with water which was pumped through a thermostat connected to the basin with two pipes. This application allowed keeping the temperature of the water in the sink above constant during the cleaning process. For washing up, the plates were placed on a metal grid installed diagonally in the sink. On the one hand, this construction guaranteed a constant angle in which the plates were held, and on the other hand, it simulated the consumer habit of dunking the plates partly into the water while cleaning. The mechanical force with which a plate is cleaned was kept constant by a mechanical device shown in (Figure 3-2) on the right. Its main part consisted of a rotatable bar, so that the bar could be turned in circles in order to carry out the cleaning process. The rotatable bar consisted of two nested sticks, so that its length could be varied. At the end, the washing up implement was fixed. In this case a sponge was used, but only the soft side of the sponge came into contact with the plates. To vary the mechanical force on the sponge, variable weights had been hung at the rotatable bar. A ball joint connected the upper end of the rotatable bar to a stationary holder. This holder was made of two bars in a square angle placed on a wooden pedestal (Figure 3-2).

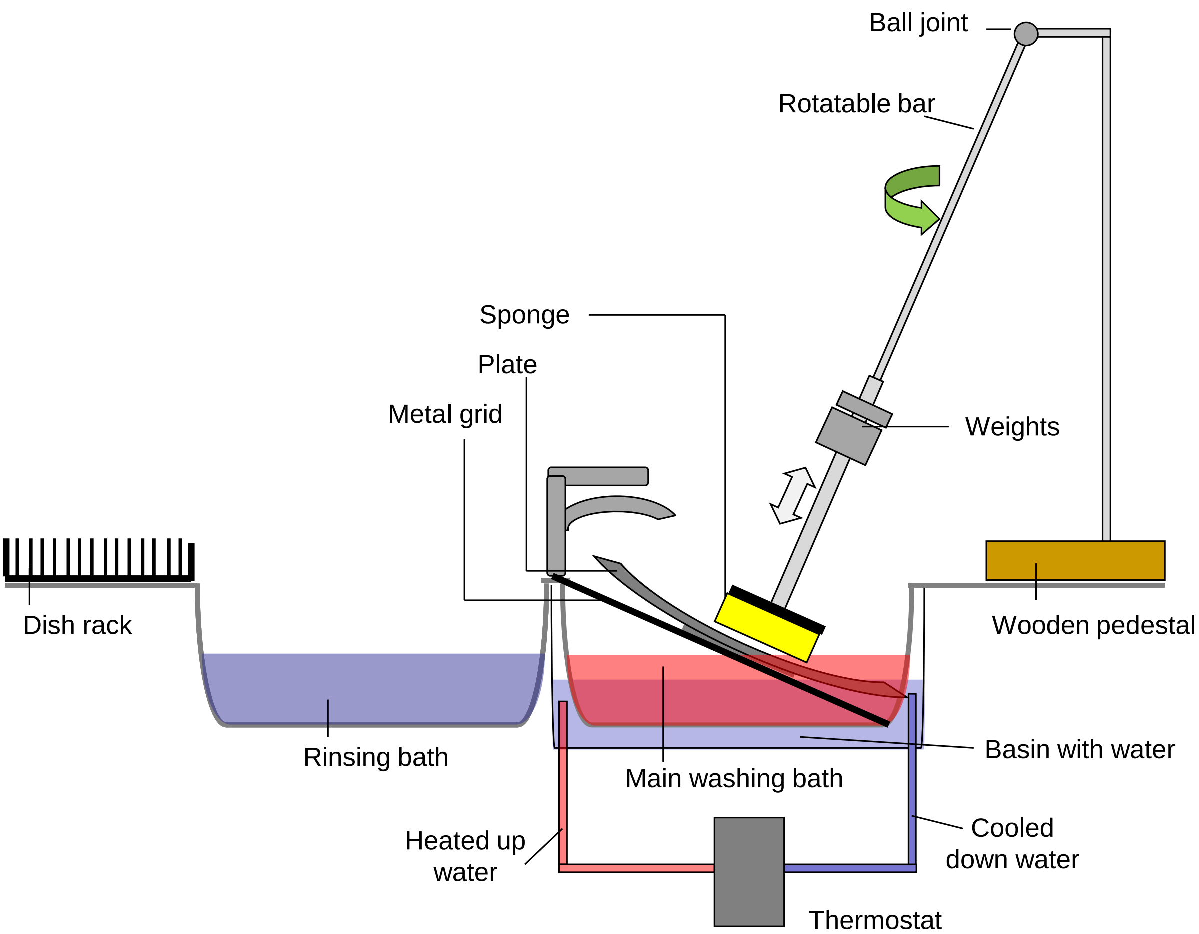

Figure 3-2: Work station for washing up experiments
Source: own illustration

The washing up procedure was carried out as follows: One sink was used to perform the soaking and main washing process and the other one was used as a rinsing bath. The detergent – a product from the market of the United Kingdom declared as containing 15 to 30% anionic surfactants and 5 to 15% non-ionic surfactants – was added to the main washing bath after the water let-in (6 litres of water per bath). Foam was produced by means of a hand mixer operated for a fixed time (10 s). To assure a constant foam level, the foam was mixed up again after every fifth cleaned plate.

Every dish was soaked for 30 seconds in the main washing bath (below the metal grid) before it was placed on the metal grid. Meanwhile, a new sponge for every plate was wetted in the main washing bath and attached to the mechanical wash arm. In order to simulate the cleaning process, the person running the experiments performed four circles (two outer and two inner circles) using the mechanical wash arm without putting additional force on the plate before the plate was rotated by one fifth (about 72 degree). This process was repeated four times, for a total of five times. This assured that each part of the plate was in contact with the water for the same amount of time. As a last step of the process, the plates were dunked shortly into the second bath for rinsing.

To assess the cleaning performance, a visual evaluation was performed according to the standard EN 50242:2008 (CENELEC, 2008) under a bright lamp on a scale from 0 to 5, with 5 as best grade for completely clean plates: the bigger the total surface of soil spots and the higher the number of soil spots, the lower the grade. Every fifth of the plate with one soil type was evaluated separately.

This method of simulating manual dishwashing was tested for repeatability. The same experiment was carried out nine times with the same factor combinations (Table 3-1). The tests were performed in one week and always evaluated by the same person. The arithmetic average of the cleaning performance was calculated for every experiment (average is used when speaking of a sample and not of the total population). To check for significant difference (with 95% probability), the Kruskal-Wallis-H test was carried out.

Table 3-1: Factors and factor levels for repeatability experiments

Dishes	**Amount**	10 pizza plates
Soaking	**Handling water**	Soaking in main washing bath
	Time	30 s
Main washing	**Handling water**	Washing up in a bath
	Time	30 s (20 circles with mechanical construction)
	Water amount	6 l per bath
	Water temperature	45 °C ±2 °C
	Number of water changes (WCMWB)	2 (every 10 plates)
	Detergent concentration	0.08%
	Implement	Sponge
	Mechanical weight	1.5 kg
Rinsing	**Handling water**	Rinsing bath
	Time	5 s
	Water amount	6 L
	Water temperature	18 °C ±2°C
	Number of water changes (WCRB)	0
Drying	**Method**	Air drying in a dish rack

Based on a sufficient level of repeatability, this three step washing up process with soaking, main washing and rinsing in two sinks was chosen for follow-up factor studies. Several experimental series were carried out to find out relevant factors impacting on the cleaning performance and the general behaviour of these factors. In the final series, three selected impact factors – namely the number of water changes in main washing bath (WCMWB) and the water changes in rinsing bath (WCRB) and the concentration of the detergent (C) in the main washing bath – were investigated in a so-called "response surface design" with five replicates of the experiment to look for their exact influences and their interactions. The experimental design was set up using JMP® software (SAS INSTITUTE INC., 2009). Table 3-2 gives an overview of the factors and the factor levels. In case only one value is given, the corresponding variable is a possible factor but was kept constant in this series of tests.

Table 3-2: Factors and factor levels for investigation of impact factors

Dishes	**Amount**	30 pizza plates		
Soaking	**Handling water**	Soaking in main washing bath		
	Time	30 s		
Main washing	**Handling water**	Washing up in a bath		
	Time	30 s (20 circles with mechanical construction)		
	Water amount	6 L per bath		
	Water temperature	45 °C ±2 °C		
	Number of water changes (WCMWB)	2 (every 10 plates)	1 (every 15 plates)	0
	Detergent concentration (C)	0.04 %	0.12 %*	0.20 %
	Implement	Sponge		
	Foam producing time	10 s		
	Mechanical weight	1.5 kg		
Rinsing	**Handling water**	Rinsing bath		
	Time	5 s		
	Water amount	6 L		
	Water temperature	18 °C ±2 °C		
	Number of water changes (WCRB)	0	1	
Drying	**Method**	Air drying in a dish rack		

* set by the software as a result of the chosen design (response surface design, D-optimal, 2 categorical factors, 1 continuous factors, 1 centre point)

For every experiment, the arithmetic average and standard deviation of the cleaning performance grades for the 30 plates was calculated. These grades consist of the averages of the values for each of the five soil types on one plate. The data were statistically analysed using appropriate tests of the JMP® software (SAS INSTITUTE INC., 2009): “Analysis of Variance” was used in order to determine if collectively the regression coefficients are statistically significant ($F \leq 0.05$). T-tests were performed in order to determine whether the individual coefficient had a statistically significant effect ($p \leq 0.05$) on the response – the cleaning performance. The results hereof will be presented in the following parts.

3.3 Results

Test on repeatability

The average cleaning performances of the experiments and standard deviations of the repeatability test are displayed in Figure 3-3. The explanation and interpretation will follow in sub-chapter 3.4.

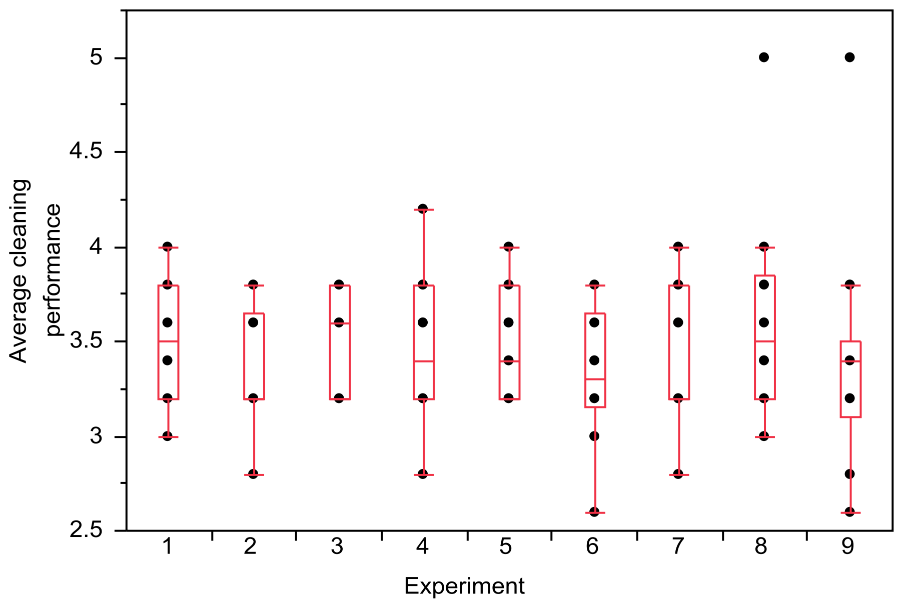

Figure 3-3: Average cleaning performances of experiments testing repeatability

No significant differences were found between the average cleaning performances tested with the Kruskal-Wallis-H test (Table 3-3).

Table 3-3: Results of the Kruskal-Wallis-H test

Null hypothesis	Distribution of Average Cleaning Performance is identical in the categories of experiment number
Test	Kruskal-Wallis-Test with independent samples
Significance	0.892
Decision	Keeping null hypothesis

Investigation of the main impact factors

Table 3-4 reveals the average cleaning performances for each factor combination.

Table 3-4: Average cleaning performances of experiments investigating impact factors

Factor combination			Resource consumption due to factor combination		Results	
Detergent concentration in %	Water changes main bath	Water changes rinsing bath	Total detergent consumption in mL	Total water consumption in L	Average cleaning performance	Standard deviation
0.04	0	0	4.8	12	2.04	0.59
0.04	0	1	4.8	18	1.43	0.50
0.04	1	0	7.2	18	2.89	0.68
0.04	1	1	7.2	24	2.97	0.33
0.04	2	0	9.6	24	3.86	0.51
0.04	2	1	9.6	30	3.32	0.21
0.12	0	0	7.2	12	2.53	0.60
0.2	0	0	12.0	12	2.83	0.33
0.2	0	1	12.0	18	2.89	0.31
0.2	1	0	24.0	18	2.21	0.31
0.2	1	1	24.0	24	3.73	0.17
0.2	2	0	36.0	24	2.41	0.52
0.2	2	1	36.0	30	3.42	0.68

The lowest cleaning performances (between 1.50 and 2.00) are reached with a C of 0.04% and 0 WCMWB. In contrast, the highest cleaning performances (>3.00) are depicted with factor combinations where the main washing bath is changed twice. However, sometimes this is not the case, for example with the factor combination 0.2% C, two WCMWB and 0 WCRB the average cleaning performance is below three. This shows that the interaction does not follow such simple rules.

3.4 Discussion

Test on repeatability

As the Kruskal-Wallis-H test does not reveal a significant difference between the average cleaning performances of the experiments, the method can be considered to be repeatable.

Investigation of main impact factors

Regression analysis was performed to derive a regression model from the average cleaning performances.

Table 3-5: Data of the regression model

Summary of fit	
R^2	0.573
R^2 adjusted	0.528
Root mean square error	0.506
Mean of response	2.863
Observations (or sum weights)	65

Analysis of variance				
Source	Degrees of Freedom	Sum of squares	Mean square	F ratio
Model	6	19.918	3.320	12.947
Error	58	14.872	0.256	Probability > F
Total	64	34.790		<.0001

Lack of fit				
Source	Degrees of freedom	Sum of squares	Mean square	F ratio
Lack of fit	6	5.513	0.919	5.106
Pure error	52	9.359	0.180	Probability > F
Total error	58	14.872		0.0003

Parameter estimates				
Term	Estimate	Standard error	t ratio	Probability >|t|
Intercept	3.486	0.253	13.770	<.0001
Concentration (0.04, 0.2)	0.104	0.065	1.590	0.117
Water changes main washing bath [difference from level 0 to 1]	-0.651	0.092	-7.050	<.0001
Water changes main washing bath [difference from level 1 to 2]	0.333	0.092	3.600	0.001
Water changes rinsing bath [0]	-0.246	0.065	-3.770	0.000
Concentration*Concentration	-0.600	0.261	-2.290	0.026
Water changes rinsing bath [difference from level 0 to 1] * Concentration	-0.204	0.065	-3.120	0.003

$$CP = 3.49 + 0.10 \cdot \left(\frac{C - 0.12\%}{0.08\%} \right) + \underbrace{Match(WCMWB)}_{\substack{0 \rightarrow -0.65 \\ 1 \rightarrow 0.33 \\ 2 \rightarrow 0.31}} + \underbrace{Match(WCRB)}_{\substack{0 \rightarrow -0.20 \\ 1 \rightarrow 0.20}}$$

$$- 0.60 \cdot \left(\frac{C - 0.12\%}{0.08\%} \right)^2 + \left(\frac{C - 0.12\%}{0.08\%} \right) \cdot \underbrace{Match(WCRB)}_{\substack{0 \rightarrow -0.24 \\ 1 \rightarrow 0.24}} \qquad (3\text{-}1)$$

where

CP	*Cleaning performance*
C	*Concentration in %*
WCMWB	*Water changes main washing bath*
WCRB	*Water changes rinsing bath*

In Table 3-5 the results of the modelling are presented and equation 3-1 describes the model with the best fit. The F-test reveals that the presented model itself is significant. The coefficient of determination R^2 is 0.57, meaning that 57% of the variation in the response can be attributed to factors included in the model rather than to factors outside the model. The factors WCMWB and WCRB turn out to have a significant impact on the cleaning performance. Likewise, C has a quadratic effect and the interaction between C and WCRB shows significance.

The formula in equation 3-1 identifies the impact of the significant factors with the cleaning performance. The value of the intercept is 3.49. As the WCMWB and WCRB represent ordinal factors, only the impact figures for the number of water changes in the respective bath are given. For example, if the water in the main washing bath is not changed, a negative value (-0.65) is to be inserted into the formula. However, if the main washing bath is refreshed once, a positive value (0.33) has to be inserted into the formula. C, as a single factor has an impact weight of 0.10. This single factor did not show significance but has to be kept due to the significance of the quadratic and the interaction effect. The term $\frac{C-0.12}{0.08}$ is appearing because of having used coded variables, that means “-1”, “0”, “1” rather than 0.04%, 0.12%, 0.20%. The quadratic term of the factor C has an impact on the cleaning performance with -0.60. The last term of the formula represents the interaction of the C and WCRB.

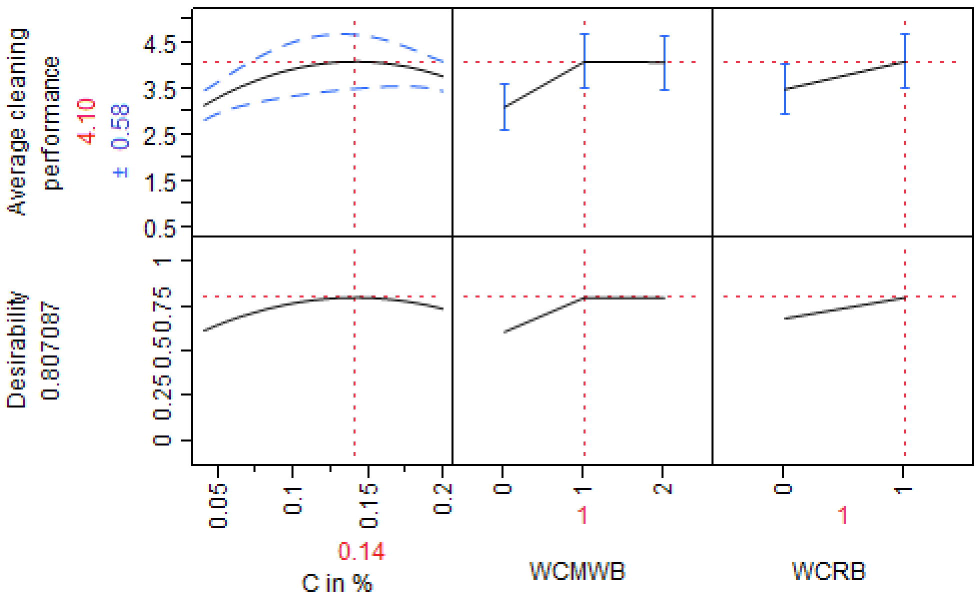

Figure 3-4: Plot of single effects with maximised desirability

Figure 3-4 reveals three graphs of the cleaning performance plotted against the single factors. The cleaning performance is rising with C up to 0.14% (this is equivalent to 8.4 mL of detergent in 6 L of water), afterwards the average cleaning performance is descending again. The first change of the main washing bath causes a rise of the cleaning performance of about 0.9, whereas the second water change does not induce any increase of the cleaning performance. One refreshment of the water in the rinsing bath generates an increase of the cleaning performance of about 0.4.

The dotted lines in Figure 3-4 indicate the optimum combination with the highest cleaning performance of 4.10 (with a confidence interval of ± 0.58), which can be achieved with a C of 0.14% and with one WCMWB and one WCRB. This implies a total water consumption of 24 L of water, namely two times a filled sink for the washing bath and for the rinsing bath, each with 6 L of water.

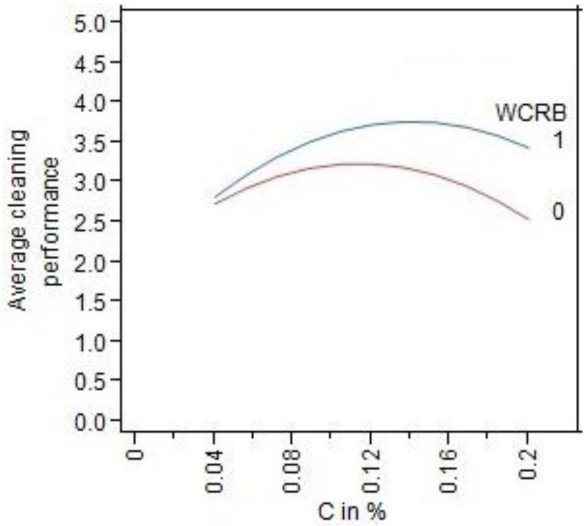

Figure 3-5: Cleaning performance in dependence of C and WCRB

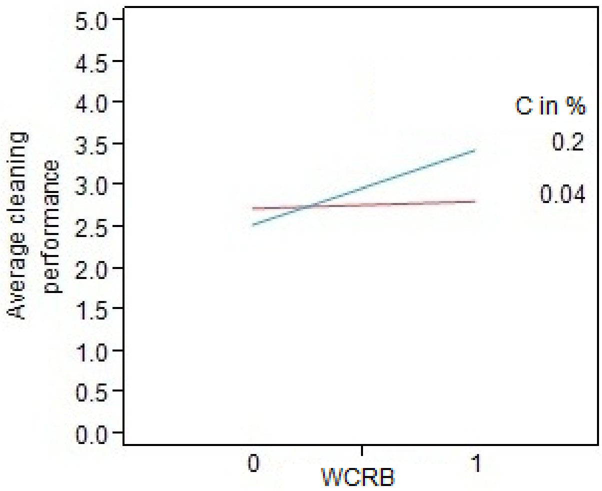

Figure 3-6: Cleaning performance in dependence of WCRB and C

Figure 3-5 and Figure 3-6 show the interaction profile of the significant interaction effect C with WCRB. Figure 3-6 indicates that a low C generates almost no difference in the cleaning performance if the water in the rinsing bath is not changed or refreshed once. In contrast, a higher C reveals a greater difference. Similarly, it becomes evident (Figure 3-6) that zero WCRB do not generate a variation in cleaning performance at a low cleaning performance level, but that one change causes a difference in the cleaning performance of about 1.

3.5 Conclusion

The investigation has shown that cleaning performance in manual dishwashing can be reproduced in a laboratory measurement set-up and that three variables (WCMWB, WCRB, C) define more than 50% of the variability of the cleaning performance in a sink washing process.

Further findings are:

- An equation has been developed to express the cleaning performance of a hand dishwashing detergent as a function of the water changes and the product concentration (amount of product used).
- Using this equation, it is possible to find conditions that maximize the cleaning performance of the dishes, while minimizing the amount of resources during the washing up process.
- Regarding the detergent concentration (amount of product used), this amount is not correlated linearly with the cleaning performance, but there is a negative quadratic effect. This means that a certain C is necessary to achieve reasonably good cleaning results, but when exceeding a maximum concentration the cleaning performance is decreasing again. This may be explained by the observation that a high C causes a lot of foam which is not completely rinsed off. Consequently, soil particles are transferred by the foam residuals.
- An affirmation of this visual determination consists in the significant interaction of C with WCRB: The higher C, the more foam emerges and the more foam residuals stay on the plates, having to be washed off by the rinsing bath. Therefore, the rinsing bath has to be changed more often when C is higher in order to guarantee that foam residuals are completely rinsed off.
- In the experimental optimum, the minimum amount of resources consist in 24 L of water and 8.4 mL of detergent to achieve an average cleaning result above 4 (on a scale from 0 to 5) when thirty pizza plates (containing 3 grams of soil each) are to be washed up.
- Comparing the results of the experiments to the findings of STAMMINGER *et al.* (STAMMINGER *et al.*, 2007a), there might be a potential that those test persons with extremely high resource consumptions and washing up under running tap water will save an enormous amount of water and energy when changing their behaviour to a double sink washing up method. However,

those test persons using low amounts of water and achieving low cleaning performances might need on the one hand a slightly higher amount of resources but would reach on the other hand a better cleaning performance.

To make a more precise statement, further studies would have to be run. However, the tendencies presented above can indicate an approach on how to optimise dishwashing regarding the resource of water consumption. Taking this experimental test as a starting point, one of the next steps will be to derive a consumer recommendation on how to wash up dishes by hand in an economic way. In the following, the development of Best Practice Tips for manual dishwashing is presented and with a first check if consumers are able to save resources by applying the Best Practice Tips.

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4 Application of Best Practice Tips in a laboratory study (1)[2]

In this study, Best Practice Tips are presented, derived from the results of the experimental investigation of manual dishwashing (compare chapter 3) and from the knowledge of what the consumer is practising. Additionally, a test is described in which the Best Practice Tips are tested on their application and on how far resource savings are possible.

4.1 Objective

On the basis of the experimental investigation in combination with the knowledge about the consumer's behaviour in real life, Best Practice Tips shall be defined. To gain a first insight into impact of the Best Practice Tips, two comparative consumer studies shall be run. One shall be carried out with 30 pizza plates – as in the experimental study (compare chapter 3) – and one with two place settings to see the effect of the tips on small amounts of dishes. It shall be the aim of these studies to check firstly if Best Practice Tips based on the experimental optimum are applicable (consumer understands what he has to do) and acceptable (consumer is willing to apply recommendation). Secondly, it shall be found out if the consumers are able to save resources by applying the Best Practice Tips in comparison to their former washing up behaviour.

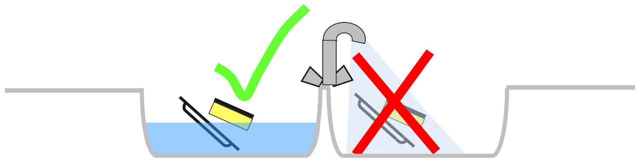
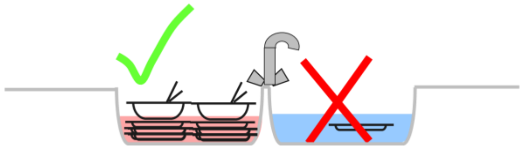
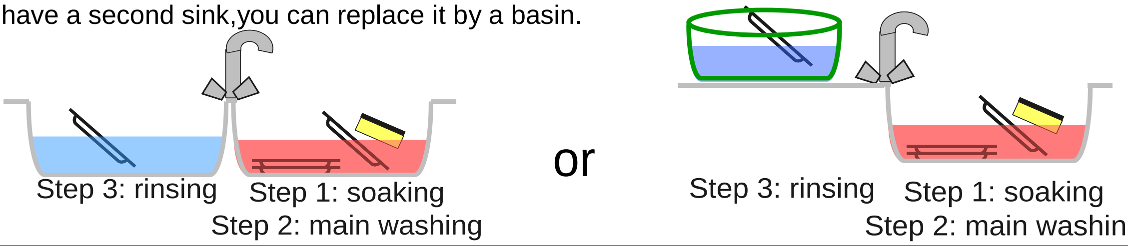
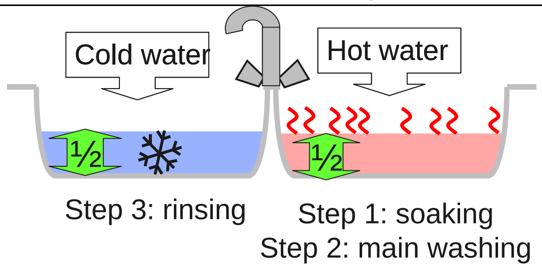
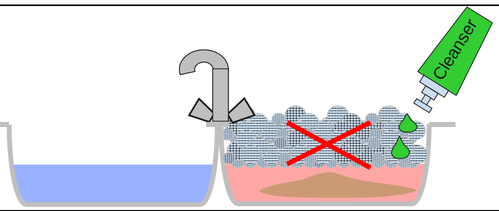
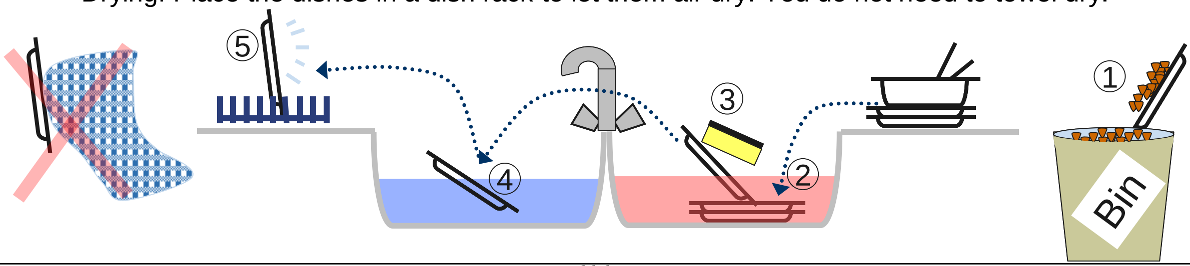
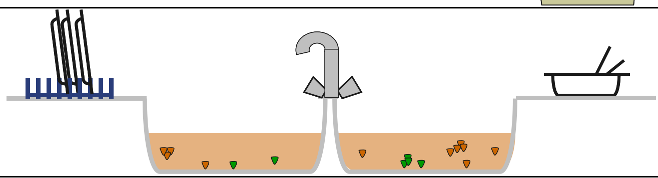
4.2 Material and methods

The Best Practice Tips

The Best Practice Tips were deduced from the knowledge gained in the experimental manual dishwashing tests (compare chapter 3) and dishwashing tips already published (Table 1-2). These tips are shown in Table 4-1.

[2] to be published in a similar way in FUSS & STAMMINGER (2011b): Resource savings by training – how much can be saved in manual dishwashing? *Tenside, Surfactants, Detergents.*

Table 4-1: Best Practice Tips

Tip 1 Wash up in sinks filled with water. Avoid washing up under running tap water.	
Tip 2 Collect some items to make sink washing efficient, do not wash up single items.	
Tip 3 Wash up in three steps: Soaking and main washing in one bath, rinsing in a second bath. If you do not have a second sink,you can replace it by a basin.	
Tip 4 Fill two sinks half with water: The sink for soaking and main washing with hot water, the sink for rinsing with cold water.	
Tip 5 Detergent: Add the detergent AFTER water let in. Dilute detergent, but avoid foam production because the foam restrains soil residuals and a fat film.	
Tip 6: Washing up process 1 Dispose of food leftovers into the bin. 2 Soaking: In the sink with hot water; the harder the soil, the longer the soaking time. 3 Main wash: While some of the hard soiled items are soaking, start cleaning lighter soiled ones. 4 Rinsing: Short dunking in second sink with cold water. 5 Drying: Place the dishes in a dish rack to let them air dry. You do not need to towel dry.	
Tip 7 Change the water if you feel it is too dirty. For example, if the foam emerging while washing up is collapsing again.	

Source: own illustration

In order to check the applicability of the Best Practice Tips and how far a consumer is able to save resources by applying the tips, two studies each with two parts were conducted.

Overview of the studies

Table 4-2 gives an overview of the studies and the parts of each study. One study was run with 30 pizza plates, in the following referred to as the PP study (Pizza plate study), and another one with two standard place settings, in the following referred to as the PS study (Place setting study). Each of the studies consisted of two parts: one in which the subject had to wash up as he/ she would do at home in everyday life (EDB part), and another part in which he/ she was trained to follow the Best Practice Tips (BPT part).

Table 4-2: Overview of the studies and parts of the studies

	PP study (Pizza plate study)	PS study (Place setting study)
Part 1:	Recording participants' everyday behaviour (EDB part)	
Part 2:	Application of the Best Practice Tips (BPT part)	

Equipment for the test participants

All studies took place in a laboratory at a double-bowl sink with a single lever tap. The hot water was supplied by a flow-through heater which supplied a maximum water temperature of 60 °C. Different washing up utensils and dish racks were provided for the test participants. The test participants all used Fairy dark green washing up detergent.

Samples of test participants

The sample in the PP study consisted of 38 German test participants. The EDB part and the BPT part consisted of a different sample as the tests took place on different dates and not all participants were available twice. The sample of test participants in the PS study (EDB part and BPT part) was the same as in the second part of the PP study.

Dishes to wash up

The PP study was performed as closely as possible to the experimental tests (compare chapter 3) regarding the number and type of plates, soiling on the plates and soiling drying time. Thirty pizza plates (Rösler, diameter 32 cm) were soiled with five types of soiling (minced meat, spinach, egg yolk, porridge and margarine) (Figure 3-1). The soiling was dried for two hours at defined ambient conditions of a temperature of 23 °C ±2 and 55% ±5 of relative humidity.

The dish load in the PS study consisted of two standard place settings (each composed of a dinner plate, a soup plate, a dessert plate, a bread plate, a saucer, a cup, a glass, a knife, a fork, a soupspoon, a dessertspoon, and a teaspoon). These items were soiled as prescribed in the standard EN 50242:2008 (CENELEC, 2008), with seven types of soiling (minced meat, spinach, egg yolk, porridge, margarine, milk and tea). Similarly to the PP study, the soiling was dried for two hours at defined ambient conditions.

Recorded data

In both studies, the dishes washed up by the test participants were evaluated according to the automatic dishwashing standard EN 50242:2008 (CENELEC, 2008), on a scale from 0 to 5 with 5 as the best grade. Totally clean dishes were rated at 5.

A data logging system, which was calibrated beforehand, recorded the hot and cold water consumption with a turbine flow meter, and the temperature in both sinks, as well as the temperature at the tap with thermo elements. The energy consumption was a calculated variable resulting from the hot water consumption. It was corrected by terms considering the efficiency of the flow-through heater and the differing cold water temperature. The data was recorded every second. The water consumption was also recorded.

Test procedure

In the EDB part of both the PP and the PS study, the test participants were asked to wash up the load of soiled dishes as they would do in everyday life. They were free to choose the washing up utensil (sponge, sponge cloth, cloth, or scrubber) and they were free to dry the dishes with a tea towel or let them air dry in a dish rack.

For the BPT part of both the PP and the PS study, the test participants were informed about the Best Practice Tips by means of an oral briefing and a fact sheet. They were then expected to wash up the load of soiled dishes following the Best Practice Tips. As one of the Best Practice Tips was to let the dishes air dry in a dish rack, no tea towel was provided. A dosage device was provided to enable to dose the detergent more accurately. After the washing up had been completed, each test person had to fill out an evaluation questionnaire where they were asked about the applicability and acceptability of the given washing up recommendations. As the BPT part of the PP study and the PS study took place at the same time, the evaluation questionnaire was filled out only once.

Data analysis

Although the consumption data proved not to be normally distributed, the arithmetic averages and the standard deviations of the parameters (water, energy and detergent consumption, time taken, and cleaning performance) are presented because these averages are of prior use for economic purposes. The Kruskal-Wallis-H test was carried out to find statistically significant differences (with 95% probability).

4.3 Results

The graphs in Figure 4-1 to Figure 4-5 show a comparison of the average results of the two studies before and after training on the Best Practice Tips. The error bars show the standard deviation of each measured parameter. All percentage values mentioned in the context of the consumption data have the value of the EDB part as 100% basis.

Results of the PP study

The average water consumption in the EDB part of the PP study was 38.9 L, whereas in the BPT part it was 24.1 L, which is 38% less. On average, the test participants needed 1.3 kWh energy in the EDB part, and 0.8 kWh in the BPT part. This also means a reduction of 38%. The average detergent consumption amounted to 15.2 g of detergent in the EDB part, and 26% less in the BPT part, namely 11.3 g. The average time the test participants needed for washing up in the BPT part was 32 min, 4 min more than in the EDB part (28 min). On average, the test participants reached a cleaning performance of 2.0 in the EDB part and 3.2 in the BPT part – an improvement of 60%.

Results of the PS study

The average water consumption in the EDB part of the PS study was 15.9 L, whereas in the BPT part, test participants needed 15.2 L on average, a difference of 0.7 L or 4%. The reduction of the energy consumption from the EDP part (0.4 kWh) to the BPT part (0.3 kWh) is 25%. The test participants needed 5.0 g of detergent in the EDB part, and 4.1 g in the BPT part, which equals to a reduction of 18%. The average time in the BPT part amounted to 15.1 min, and to 13.2 min in the BPT part (a difference of 13%). The cleaning performance, however, was improved by 0.3 (9%), from 3.6 in the EDB part to 3.9 in the BPT part.

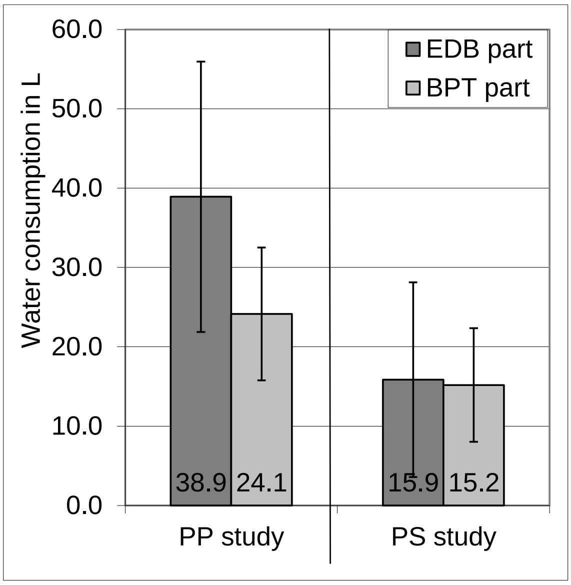


Figure 4-1: Arithmetic averages and standard deviation of the water consumption

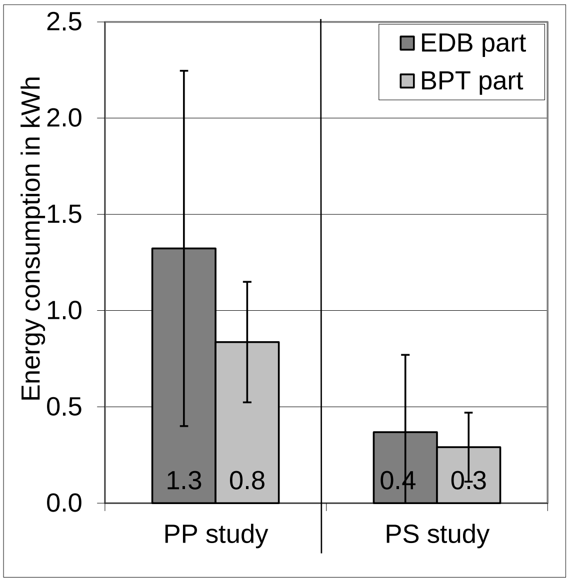


Figure 4-2: Arithmetic averages and standard deviation of the energy consumption

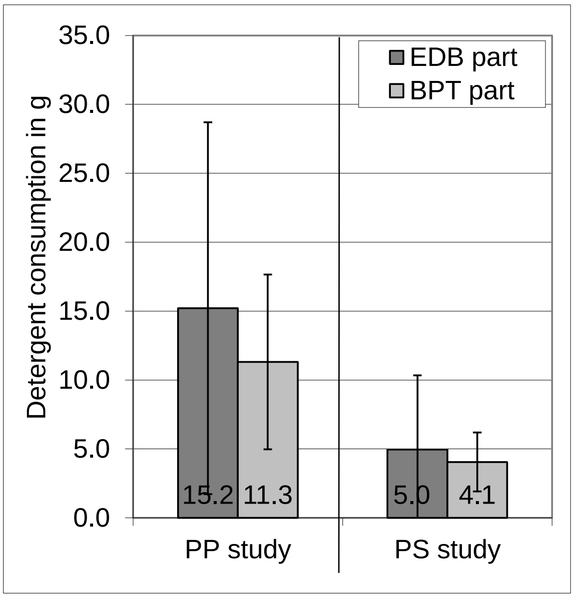


Figure 4-3: Arithmetic averages and standard deviation of the detergent consumption

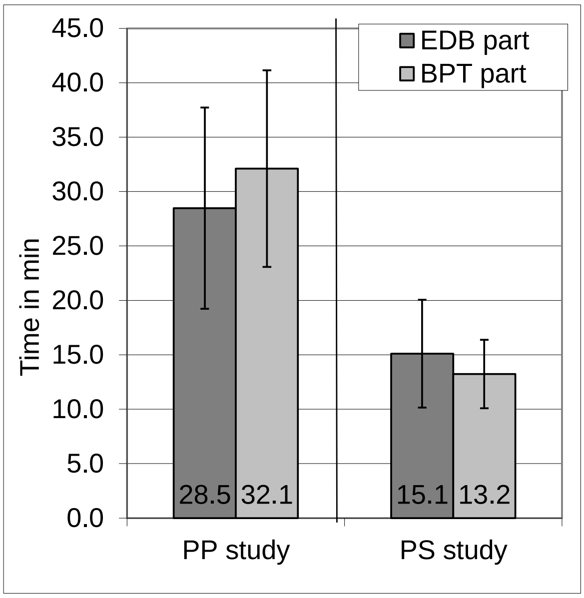


Figure 4-4: Arithmetic averages and standard deviation of the time taken

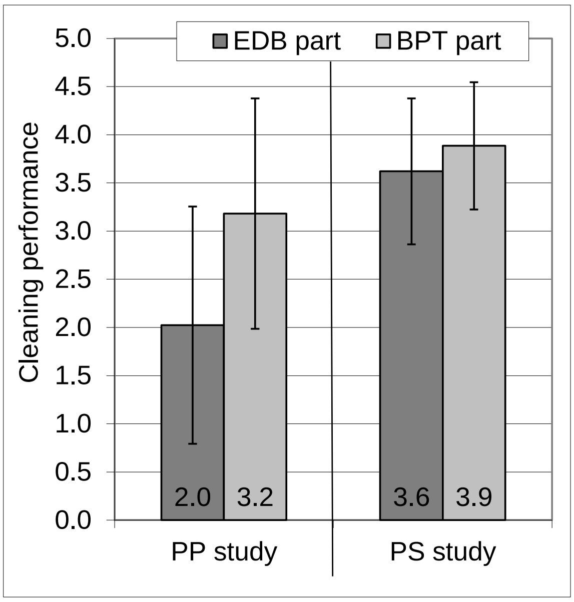


Figure 4-5: Arithmetic averages and standard deviation of the cleaning performance

Statistical analysis of the PP study

It has been proved by the Kruskal-Wallis-H test as statistically significant that test participants in the PP study used less water, less energy and less detergent when following the recommended process of washing up and at the same time, they achieved a better cleaning performance. Whereas, the time they spent on the washing up process increased slightly, but showed no significance.

Statistical analysis of the PS study

The Kruskal-Wallis-H test revealed that the results of the PS study show a slight but not significant decrease in water, energy, detergent, and time consumption, while the cleaning performance increased slightly but not significantly.

Selected results of the evaluation questionnaire

In addition to the data measured, the evaluation questionnaire contributed to the understanding of the behaviour of the test participants. In Figure 4-6, the results are shown of how the participants evaluated each of the Best Practice Tips. All tips were rated by 60% and more by the test participants to be “good” or “very good”. Some were appreciated by up to 97%.

Question:
Please rate the single tips of the Best Practice on a scale from “1: very good” to “5: not good at all”.

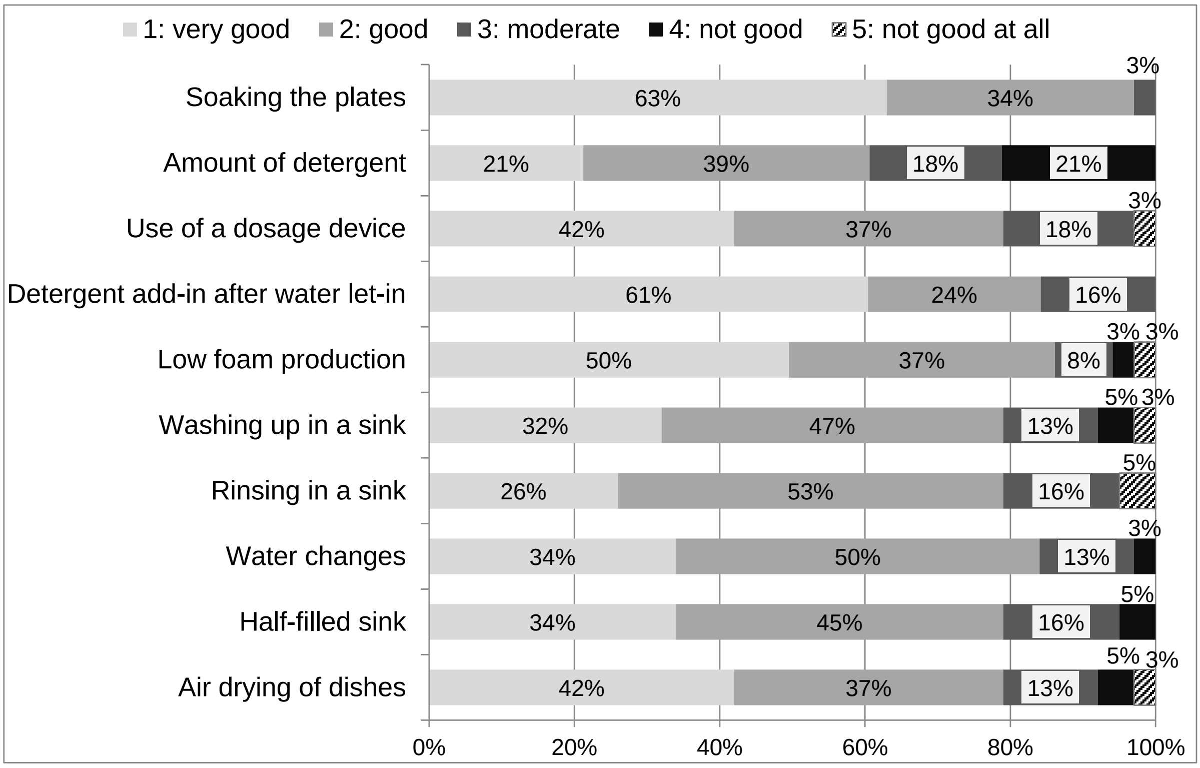


Figure 4-6: Rating of the Best Practice Tips[3]

In Figure 4-7, the answers are shown to the question which of the tips will probably be applied in everyday life. The answers accord with the rating of the dishwashing tips when considering the tips “soaking”, “amount of detergent”, “detergent add-in after water let-in”, and “low foam production”. According to Figure 4-7, these tips will probably be applied by a percentage up to 90%, whereas the tip “rinsing in a sink” will less likely to be applied by the test participants.

[3] Because of rounded values, it occurs that the summation per statement does not amount up to 100%.

Question:
Which of the tips will you probably apply in your everyday life? Please rate on a scale from "1: by all means" to "5: under no circumstances"

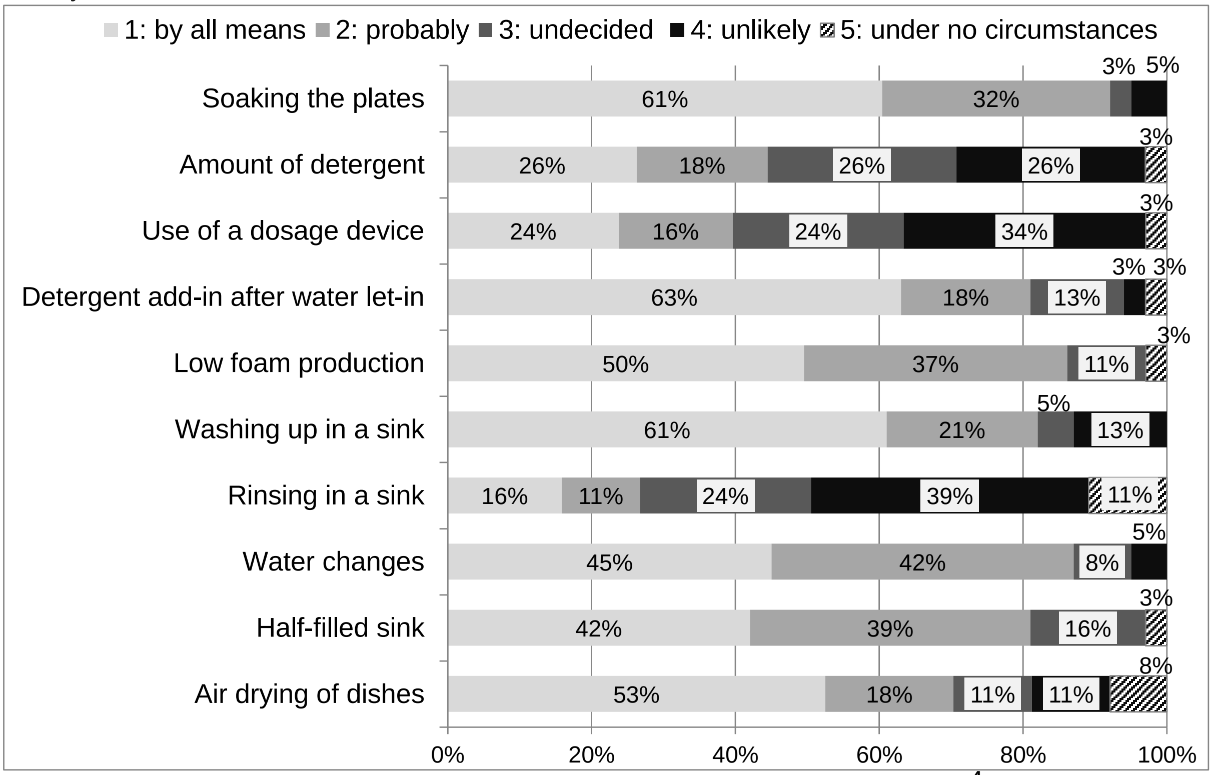


Figure 4-7: Probable application of the Best Practice Tips in the everyday life[4]

4.4 Discussion

Water consumption

While the PP study showed a decrease in water consumption of about 40% when applying the recommended process of washing up, the water consumption in the PS study only showed a small decrease. A possible reason for this phenomenon can be found in the washing up in a sink. While for the PP study, several changes of the water in the sinks were necessary, the place settings in the PS study could be easily washed up just by using one (the first) filling of the sinks. It may be concluded that filling two sinks with water is not economical when washing up only a few items. Therefore, either a different procedure may need to be developed or the consumer is asked not to wash up a small number of items but to collect them until a larger amount of dishes has to be washed.

[4] Because of rounded values, it occurs that the summation per statement does not amount up to 100%.

Energy consumption

The data on the energy consumption is more or less in parallel with the results of the water consumption. However, while the water reduction is nearly zero in the PS study, the energy consumption is about 25% less after the training on the Best Practice Tips. This is probably due to participants using more cold water for rinsing than before.

Detergent consumption

The savings of detergent is 25% in the PP study and 18% in the PS study. It is remarkable that although the recommended amount of detergent is one of the least “good” rated of the Best Practice Tips and people have the impression that the amount of detergent is too much, they are using less detergent when they are applying the recommended washing up procedure.

Time taken

The time participants used has slightly increased in the PP study and slightly decreased in the PS study. Perhaps, this is because the participants needed some time to adapt to the tips and the new behaviour.

Cleaning performance

Test participants could reach significantly higher cleaning performances in the PP study when applying the dishwashing tips. In the PS study, the cleaning performances did not differ significantly before and after training. Comparing both studies, the average cleaning performances of the PS study are better than those of PP study. A probable reason is that participants found the pizza plates heavy and extremely difficult to handle. Additionally, the number of the pizza plates (30) was higher than the number of accumulated items in two place settings (22). Test participants were probably tiring while washing up the pizza plates, so that they did not pay attention to the cleaning performance of the pizza plates as much as they did to the cleaning performance of the place settings.

Evaluation questionnaire

People like rinsing in a sink more than they are willing to apply it (compare Figure 4-6 and Figure 4-7). This can be extrapolated by their comments that a second sink is not available and they have not enough space for an additional basin.

The dosage device was quite highly accepted but will probably not be applied as much in everyday life. The reason most given was that they could not buy a detergent bottle with a dispenser in Germany.

4.5 Conclusion

It has been shown that important resources such as energy and water can be saved when a large amount of dishes have to be washed by training consumers how to wash up. However, it seems that with a smaller amount of dishes, the full sink washing up method does not seem to be an optimal way of washing up. Therefore, more experimental studies will have to be run to develop an optimal way of washing up small amounts of dishes. As the sample was quite small in this test, more studies will have to be run to confirm the water and energy savings with large amounts of dishes. The realisation is shown in the next chapter.

5 Application of Best Practice Tips in a laboratory study (2)[5]

This part presents a follow up study of the one presented in chapter 4. It is used to confirm that, with large amounts of dishes, important resource saving such as water and energy are possible when the consumer applies the Best Practice Tips (compare Table 4-1).

5.1 Objective

On the basis of the study reported about in chapter 4, the assumption was made that especially with large amounts of dishes resource savings might be possible when consumers apply the Best Practice tips. Thirty pizza plates are obviously a large amount of dishes yet are not comparable to dishes commonly used in the household. This shall be the aim of the current part of the project: The application of the Best Practice Tips shall be checked with large amounts of dishes which are commonly used in the household, such as 12 place settings. The resource consumption of consumers applying the Best Practice Tips shall be compared to the consumption data of previous studies in which consumers applied their everyday behaviour when washing up the same amount of dishes. Another aim shall be to find out what test participants think of the Best Practice Tips, how well they can be used on real life conditions and if they would continue to apply the Best Practice Tips.

5.2 Material and methods

In general, a data comparison was conducted between data about the resource consumption of consumers' everyday behaviour when washing up dishes by hand, and data of test participants applying the Best Practice Tips.

[5] published in a similar way in FUSS, N., BORNKESSEL, S., MATTERN, T. & STAMMINGER, R. (2011a): Are resource savings in manual dishwashing possible? Consumers applying Best Practice Tips. *International Journal of Consumer Studies*, 35**,** 2, 194-200.

The data about the everyday behaviour was taken from previously run studies (in the following referred to as the Everyday Behaviour Studies (EDB studies)) which includes data from the so-called EU study (STAMMINGER *et al.*, 2007a) and the so-called Global study (BERKHOLZ and STAMMINGER, 2009). The sample of the EU study comprised 113 participants from seven European countries and regions (Germany, Great Britain and Ireland, France, Spain and Portugal, Italy, Turkey, Poland and Czech Republic). The complete sample of the Global study comprised 100 participants from all over the world. Because only Europeans participated in the EU study, only the data of European citizens of the Global study (60 participants from Germany, Hungary and Russia) were considered in the data comparison reported here. Both studies have shown that individual differences of the washing up behaviour are large and more relevant than country of origin differences. The data on the application of the Best Practice Tips was newly gained in the current study (in the following called the Best Practice Tips study (BPT study) by trying to have a good mixture of European washing up practisers.

Test participants in the BPT study

Table 5-1 shows an overview on the number of test participants in the BPT study in comparison to the EDB studies.

Table 5-1: Overview on the number of test persons in the different studies

		Total number of test persons	Test persons from European countries
EDB studies	EU study	113	113
	Global study	100	60
BPT studies	Current study	53	53

Source: own illustration partly based on STAMMINGER *et al.* (2007a) and BERKHOLZ and STAMMINGER (2009)

There were 53 test participants from European countries (Germany, Poland, Czech Republic, Hungary, Slovenia and Romania) in the BPT study. The recruitment took place in Germany and to assure that they had not yet adapted to the German washing up behaviour only non-German European citizens were chosen who had lived in Germany for no longer than two years. The same requirement was applied to the test participants in the EDB studies. To make the data comparable to the two EDB studies, we tried to recruit the same participants again. However, only seven of the test participants taking part in the Global study were available and willing to take part again. Therefore, the sample of the BPT study consisted of 46 newly recruited test participants. This fact is to be taken into account when drawing conclusions.

Process of the BPT study

The test participants coming to the laboratory at the University of Bonn were instructed by an oral briefing and a fact sheet on how to apply the Best Practice Tips. Afterwards, they washed up 12 soiled place settings (the same sort of dishes as in the EDB studies) by applying the Best Practice Tips. Finally, they had to fill in an evaluation questionnaire on their opinions about the Best Practice Tips.

Work station

The work station provided for the consumers was the same used in the two EDB studies. It consisted of a double-bowl sink with a two-handled tap. Hot water was provided by a flow-through water heater which worked up to a maximum temperature of 60 °C.

The test participants were free to choose between a choice of concentrated detergent products and between a range of washing up utensils (sponge, sponge cloth, dishcloth, and scrubber). No exact amount of detergent was prescribed, however the test participants were given a small glass with a marker as a guideline of how much detergent to use for a half-filled sink. This recommended amount of detergent was based on the results of the experimental dishwashing study (FUSS and STAMMINGER, 2010). The test participants were additionally equipped with several dish racks in order to let the dishes air dry.

Collected data

While the test participants were washing up, a data logger was recording the water consumption with a turbine flow meter. The temperature of the water was measured by temperature sensors (thermocouples) at the outflow of the tap. With the temperature recorded, the energy consumption was calculated on the basis of an assumed average cold water temperature of 15 °C.

Furthermore, the time that the test participants needed for washing up was recorded and the detergent consumption was measured. After finishing the dish cleaning, the cleanliness of the dishes was evaluated according to EN 50242:2008 (CENELEC, 2008) on a scale from 0 to 5, with 5 as the best grade.

Dishes to wash up

The dishes that the test participants had to wash were the same and soiled in the same way as in the EDB studies: 12 place settings soiled with seven soil types (milk, tea, minced meat, spinach, egg yolk, porridge and margarine). The type of dishes and the soiling process was carried out as specified in EN 50242:2008 (CENELEC, 2008), the European standard for automatic dishwashing. The only deviation from the standard, but in line with the two previous studies, was the drying period of the soiled dishes for two hours at controlled ambient conditions (temperature: 23 °C ±2 °C, relative air humidity: 55% ±5%) instead of two hours in a thermal cabinet at 80 °C.

Although the conditions of the two EDB studies were reproduced as far as possible, there were some restrictions. In the EDB studies, test participants were asked to dry their dishes with a tea towel. However, as it was one of the Best Practice Tips, the test participants in the current study were asked to let their dishes air dry in a dish rack. This might have an influence both on the time and on the cleaning performance. It should also be kept in mind that, despite the fact that the cleaning performance was measured with a standard grading scale, the different studies were run with different trained graders.

5.3 Results

Figure 5-1 shows the average water consumption of the three studies to be compared. The averages of the EDB studies are at more than 100 L of water, whereas the average of the BPT study is at only slightly more than 40 L of water. This is equal to a reduction of around 60% from the EDB studies to the BPT study (the percentage values of the consumption data is calculated with the values from the EDB studies as 100% basis). The standard deviation of the current study is much smaller compared to the standard deviation of the Global study. Data on the standard deviation of the EU study was not published.

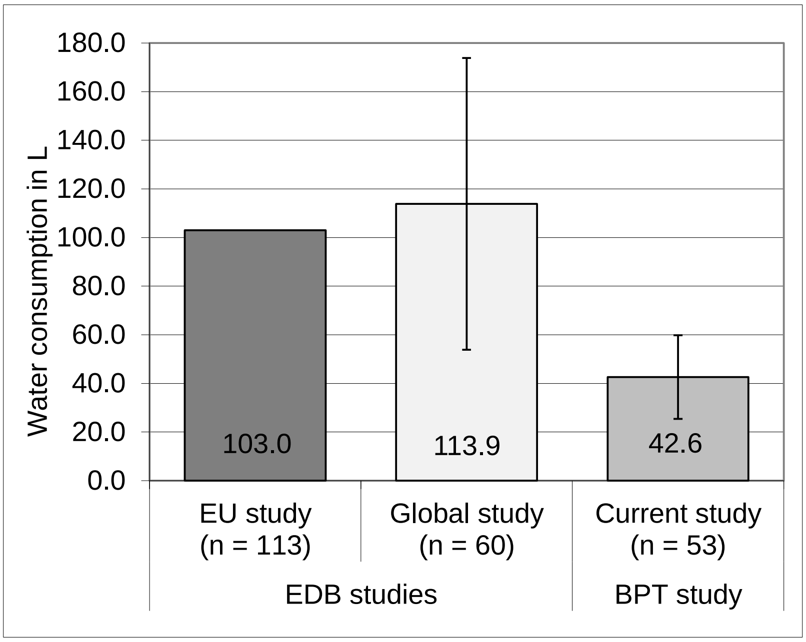


Figure 5-1: Water consumption, average and standard deviation as assessed in the EDB studies and the BPT study.

Regarding the energy consumption in Figure 5-2, the test participants in the BPT study consumed 0.8 kWh on average, whereas the energy consumption in the EDB studies was at more than 2.5 kWh. The percentage of the reduction from the EDB studies to the BPT study is about 70%. Furthermore, the variance of the consumer behaviour, expressed in the standard deviation of the measured values, is much smaller in the BPT study compared to the EDB study.

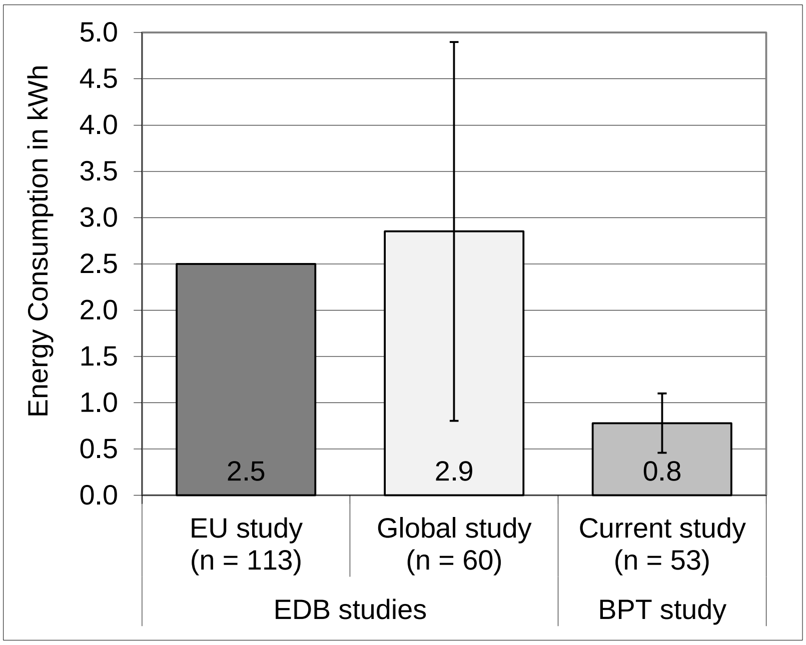


Figure 5-2: Energy consumption, average and standard deviation as assessed in the EDB studies and the BPT study.

Figure 5-3 shows the comparison of the detergent consumption. The average of the EDB studies amounts to a detergent consumption of nearly 36 g, which is about 12.2 g (around 34%) more than the average of the BPT study (23.7 g).

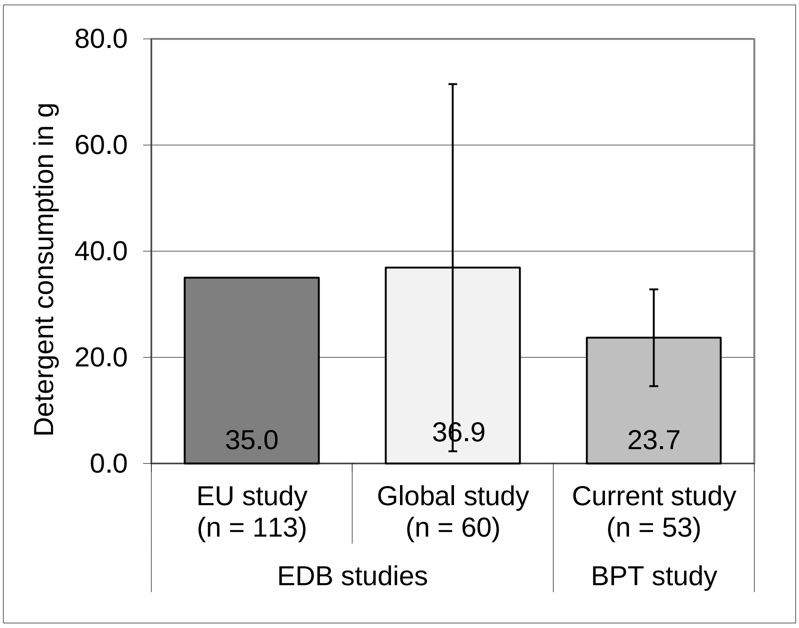


Figure 5-3: Detergent consumption, average and standard deviation as assessed in the EDB studies and the BPT study.

Figure 5-4 presents the average cleaning performances. The averages of the EDB studies were at 3.3 and 2.5, respectively. These are between around 10% and 50% lower than the average of the BPT study at 3.7.

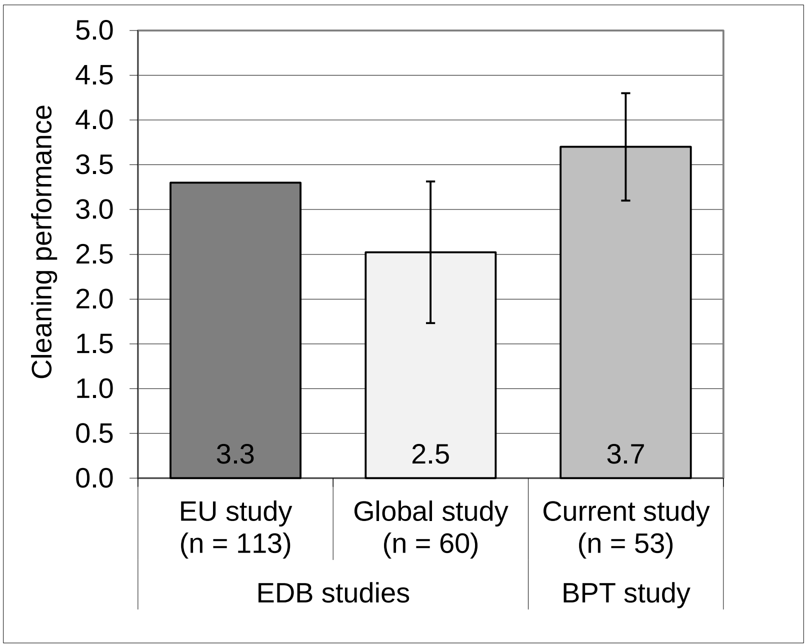


Figure 5-4: Cleaning performance, average and standard deviation as assessed in the EDB studies and the BPT study.

The test participants were asked in one part of the evaluation questionnaire to rate the Best Practice Tips in general on the basis of different contrasting adjectives. They should rate with "++" or "+" towards the positive or negative adjective or with "0" for a neutral statement. The result is presented in Figure 5-5. On average, the Best Practice Tips are rated with approximately 80% ("++" or "+") towards the positive adjectives. The adjective "clearly understandable" received a high positive rating with more than 90% answers "++" or "+". However, some of the test participants (up to 10% with "++" or "+" rating the negative adjective) found the Best Practice Tips "difficult to apply", "boring" or "old-fashioned".

Question:
Please rate the Best Practice Tips in total with different positive or negative adjectives. Rate with “++” or “+” towards the positive or the negative adjective or with “0” for a neutral

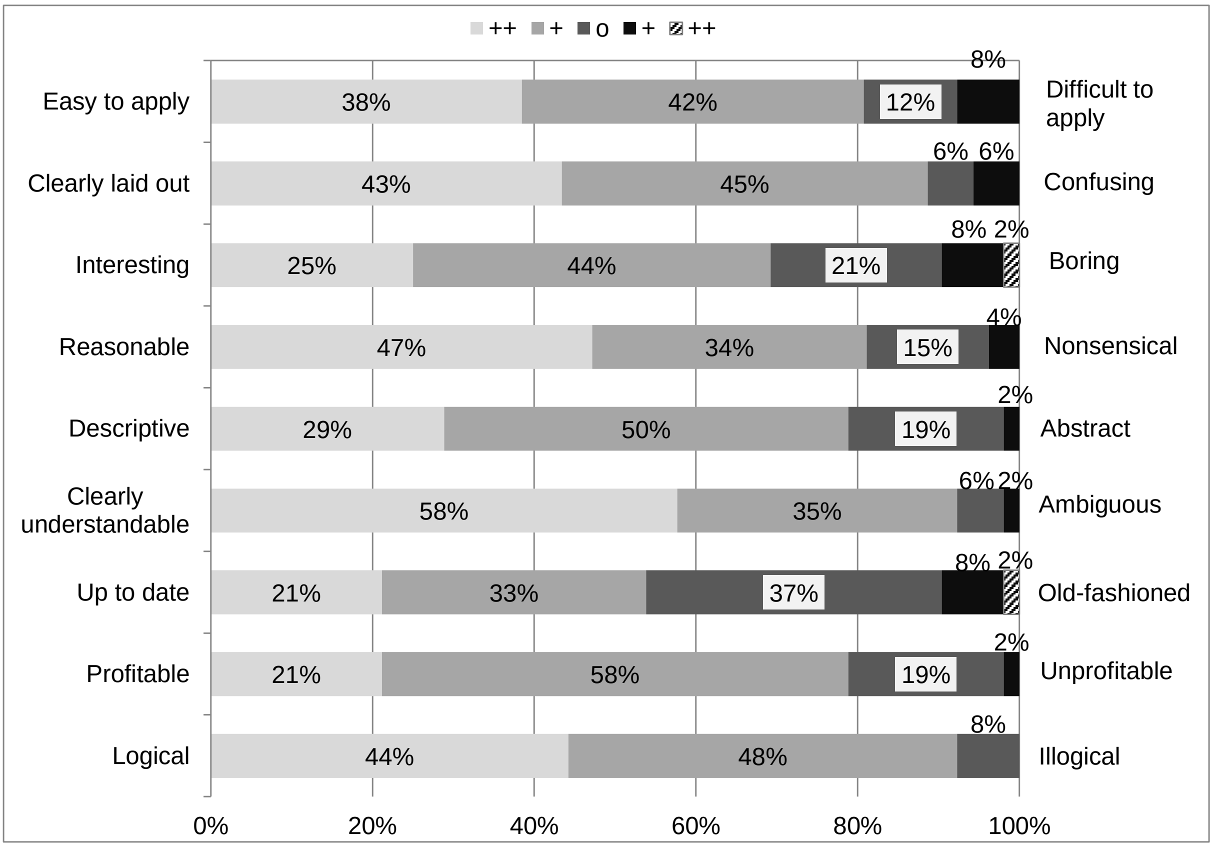


Figure 5-5: Evaluation questionnaire – general rating of the Best Practice Tips[6]

Another question on the evaluation questionnaire asked for an opinion of the individual Best Practice Tips. The test participants should rate every tip on a scale from “1: very good” to “5: not good at all”. The results are shown in Figure 5-6. The soaking and air drying of the dishes were among the most favourite tips, whereas the recommended amount of detergent was the least accepted. On average, the individual tips were rated at around 70% “very good” or “good”.

[6] Because of rounded values, it occurs that the summation per statement does not amount up to 100%.

Question:
Please rate the single tips of the Best Practice on a scale from “1: very good” to “5: not good at all”.

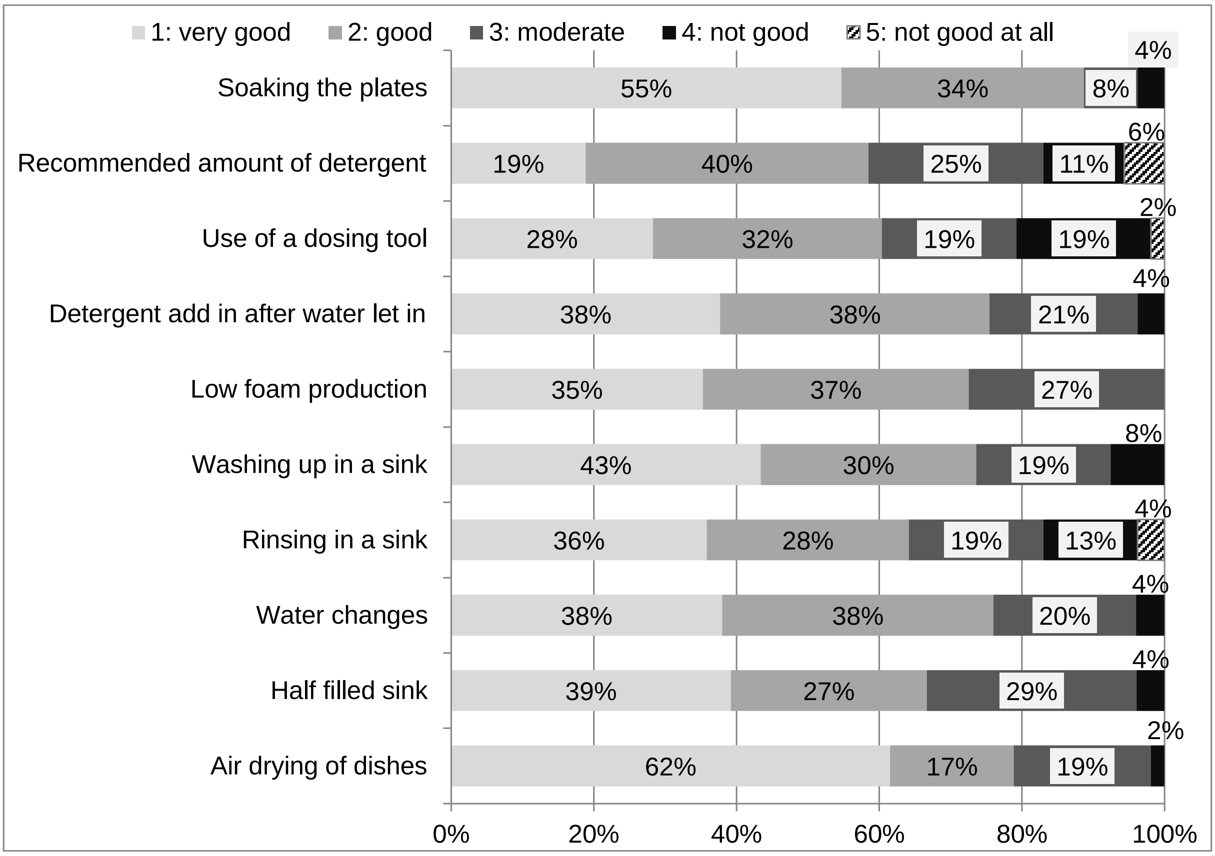


Figure 5-6: Evaluation questionnaire – rating of the individual tips of the Best Practice Tips[7]

5.4 Discussion and conclusion

All experiments in the EDB studies and in the BPT study are performed with 12 place settings. This is the load of dishes that is used in the measurement standard for automatic dishwashing EN 50242:2008 (CENELEC, 2008). It is argued by STAMMINGER *et al.* that a normal household may only use half of the capacity of a dishwasher for normal dishes, using the rest of the capacity for bulky items (STAMMINGER *et al.*, 2007b). Other studies report that consumers only put between 40 and 70 items into a dishwasher before starting the – in the consumers opinion – completely filled machine (RICHTER, 2010a). The difference to the 140 items of the 12 place settings fitting into a normal dishwasher can be explained by the variety of the shapes normal dishes have which does not allow the filling of a dishwasher as

[7] Because of rounded values, it occurs that the summation per statement does not amount up to 100%.

completely as under standardised conditions. The 12 place settings in the BPT study were chosen to make the results comparable to the two other studies (EU study and Global study), and also to the amount of resources an automatic dishwasher needs.

Although the samples of the three different studies washed up 12 place settings at the same work station, it can be argued whether the behaviour of three different populations is compared. BERKHOLZ *et al.* proved in their study that it is possible in the field of manual dishwashing to use only a small sample to get a good estimate of the everyday behaviour in manual dishwashing. In this study, a small sample of 27 randomly chosen U.K. consumers from the EU study was compared to a large sample of 150 U.K. consumers selected to be representative. The results of the two studies showed no significant differences in the results for water consumption, energy consumption, time needed, and detergent consumption. The only exception was the cleaning performance, and this was explained by the subjective visual evaluation of the cleanliness. It was thus concluded that the populations show the same distributions, and also that the small sample of the EU study gives a good estimation of the overall consumer behaviour (BERKHOLZ *et al.*, 2010). This evidence is used to assume that the everyday behaviour of the consumers in the BPT study is the same as in the EU study and in the Global study.

The comparison of the averages of the three studies shows that savings seem to be actually possible by applying the Best Practice Tips resource. The application of the Best Practice Tips especially promises high resource savings with water (60%) and energy consumption (70%). However, the savings of the detergent consumption at around 30% cannot be neglected either. Nevertheless, it should be kept in mind that it is a comparison of averages and that the Global study shows a large variation between individuals. This means that there are also consumers who use approximately the same amount of resources or even less by the application of their everyday behaviour as test participants who are applying the Best Practice Tips. Being aware that the figures are based on three different samples, it is not possible to draw sound conclusions from the comparison; however, it is possible to say that tendencies in a reduction of the resources are obvious.

The smaller standard deviation (smaller than the one in the Global study) of the test participants applying the Best Practice Tips regarding water, energy and detergent usage leads to the assumption that either the population variation is smaller or the test participants are actually able to apply the Best Practice Tips more or less in the same way.

Although there are restrictions in the evaluation of the cleaning performance (different people evaluating the dishes in the different studies), a tendency for improved cleaning performance can be recognised when test participants apply the Best Practice Tips.

Time as another consumer relevant issue was recorded in the BPT study. However, it could not be compared to the EDB studies because in those studies, the consumers were asked to towel dry their dishes. In the BPT study it was one of the Tips to let the dishes air dry.

Results on the feelings about and opinions on the Best Practice Tips were gathered in addition to comparing the technical figures, e.g. water and energy consumption. The results of the evaluation questionnaire in the BPT study show a generally high acceptance of the Best Practice Tips. Among the most favourite tips were the soaking of the dishes, because of a relief of soil removal, and the air drying of the dishes, because of time savings. Frequently mentioned concerns were that the Best Practice Tips would not be totally applicable at home. The reason given in most cases was that there is no second sink available and not enough space to replace it with a basin. It was also mentioned that a second basin for rinsing is inconvenient to some extent. In this case, an adaptation of the Best Practice Tips is proposed: The rinsing step can be carried out by briefly opening the tap and turning it off directly afterwards. These results confirm the assumptions of EMMEL *et al.* and RICHTER: With a behaviour change towards more sustainability, it is possible to save resources (EMMEL *et al.*, 2003; RICHTER, 2010a). Up to now, the Best Practice Tips and the training for the consumer do not consider the importance of social and psychological factors. This is one aspect in a wide range of possibilities and options for further research to improve the Best Practice Tips and study the application of the Best Practice Tips more deeply.

5.5 Outlook

The results presented in this part were recorded entirely in a laboratory. Up to now, it is unknown if it is possible to save resources in real life, and also over a longer period, when applying the Best Practice Tips. As DEYOUNG stated, it is necessary to lay focus on psychological aspects to reach a long-term change in dishwashing behaviour (DEYOUNG, 1993). His proposal of instruments to change environmental behaviour in the long term could be combined with the Best Practice Tips. This might be especially important in countries where the resources of water and energy are restricted. Differences between different ways of washing up have also to be considered. It would be interesting to find out if consumers washing up under running tap water were willing to change their behaviour to the recommended sink washing method.

6 Application of the Best Practice Tips in an in-house study[8]

In laboratory studies, it seemed to be possible to save resources by training people on Best Practice Tips in manual dishwashing. The transfer of the idea into the consumer's homes and the everyday behaviour, i.e. the verification of possible resource savings by application of the Best Practice Tips is subject of this part.

6.1 Objectives

This study aims at finding out if the consumer is willing to apply the Best Practice Tips for manual dishwashing in his everyday life. Besides, it shall be checked if resource savings can be realised when consumers apply the Best Practice Tips in their day-to-day behaviour in comparison to their usual way of cleaning the dishes by hand. Country specific differences shall be investigated between Germany as a country where the so-called sink washing process is mostly applied and Spain as a country where the majority washes up under running tap water (compare Table 1-1).

6.2 Material and methods

A four week in-house study was run in two countries and data was gathered on manual dishwashing behaviour before and after a training on the Best Practice Tips as presented in Table 4-1. The results of both periods were compared with each other and between the countries.

[8] to be published in a similar way in FUSS, N. & STAMMINGER, R. (2011a): Application of Best Practice Tips in manual dishwashing - a comparison between Germany and Spain. *International Journal of Consumer Studies.*

Overview on the test procedure in each household

The data gathering in every household comprised two periods of two weeks (Figure 6-1).

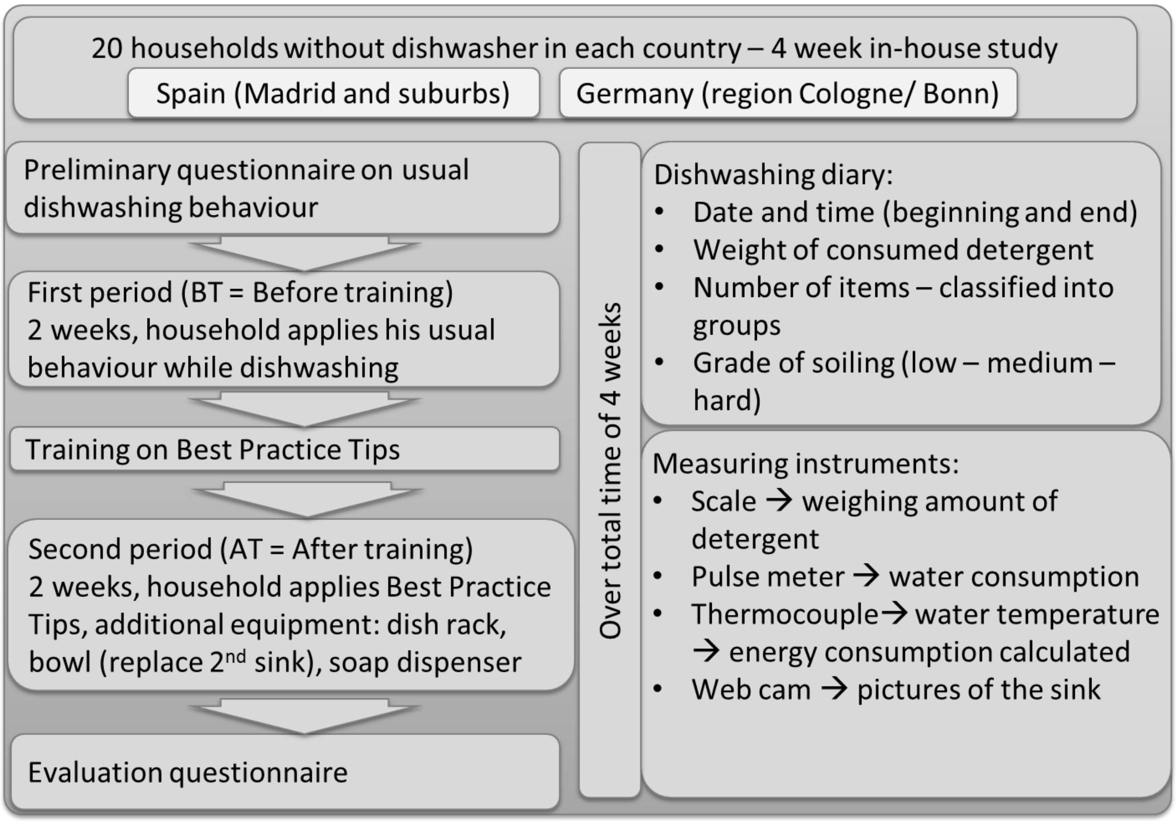


Figure 6-1: Overview on the test procedure
Source: own illustration

In the first period, called "Before Training (BT)", data was recorded while the households were performing their usual way of dishwashing. After this first period, the households were visited and trained on the Best Practice Tips (compare Table 4-1) in an oral briefing. Furthermore, every household got a printed copy of the Best Practice Tips. In the second period, called "After Training (AT)", the households should apply the Best Practice Tips. Therefore, every household was equipped with a dish rack, a bowl to compensate for a missing second sink and a soap dispenser in order to allow a better dosing of the detergent. Each household had to fill out questionnaires: a preliminary one on the household's usual dishwashing behaviour before the period BT and an evaluation questionnaire after the end of the period AT. In addition, the households were asked to tell in a short oral feedback what they had liked about the training or what problems they had encountered. Over the total duration time (both periods BT and AT), the households had to fill in a diary every time they were cleaning the dishes. They were asked to keep track of how many dishes were cleaned, what type of items (cooking items, plates and cups, glasses, cutlery or “other items”) were washed up, and to give an estimation of how hard the items were soiled. Several photographs of examples of soiled dishes were provided for support. The amount of used detergent was also recorded in the diary. The household was asked to weigh the bottle with detergent before and after the wash up on an electronic kitchen scale which was provided.

Samples

The samples from Germany and Spain comprised each 20 households not owning a dishwasher. The recruitment in Germany was performed in the region Bonn/ Cologne and in Spain in Madrid and its suburbs. Figure 6-2 presents general data on the test households. In the German sample, 16 of 20 households were fully evaluable and in the Spanish sample 18 of 20. The other four (German sample) resp. two (Spanish sample) test households could not be evaluated completely because of incomplete data caused by temporary failure of the measuring instruments and were therefore not included in the final results. The major part of the test households in both countries were one- and two-person households. In the preliminary questionnaire, the households were asked about their usual way of washing up. “Sink washing” means washing up the dishes in a plugged sink filled with water. “Running tap washing” stands for cleaning the dishes under running tap water while the sink is not plugged. A mixed washer combines both ways of washing up, for example he/ she cleans the dishes in a sink filled with water but rinses them under running tap water. While in the Spanish sample the greatest part of the test persons claims to be a running tap washer, the majority in the German sample states to be a mixed washer.

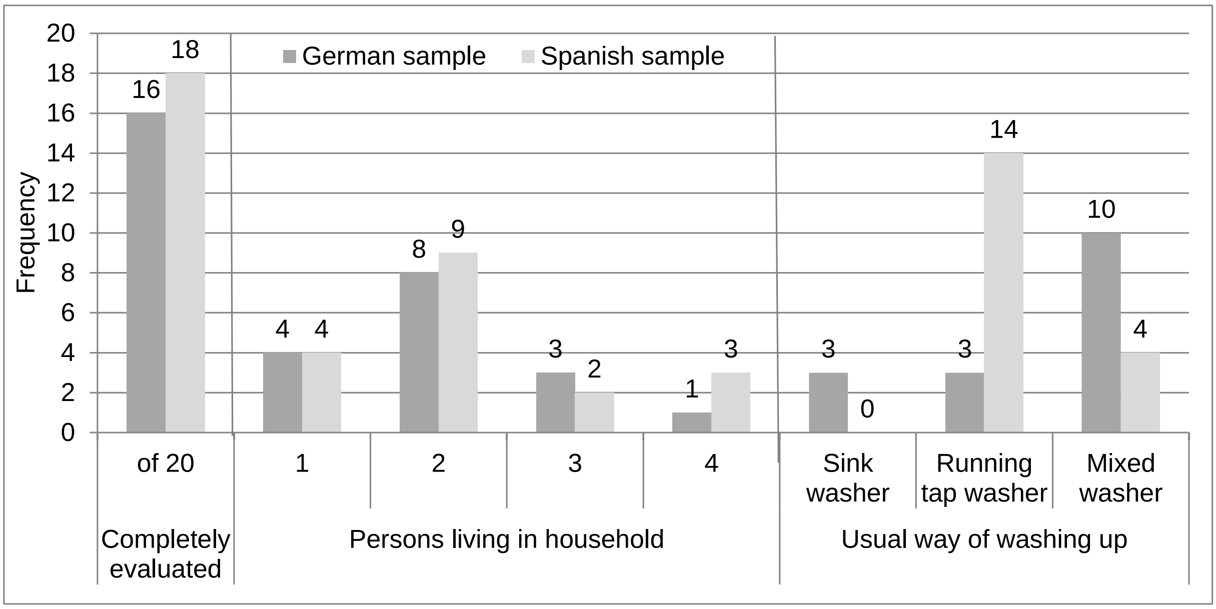


Figure 6-2: General data on the samples

Measuring instruments

In order to gather data on the household's resource consumption when cleaning dishes by hand, a meter box with an adapter and a pipe was installed at the kitchen tap (Figure 6-3). The meter box contained a turbine flow meter and a thermocouple to measure amount and temperature of the water. When the water had passed the meter box, it flew out through a standard tap aerator. Water consumption and water temperature were recorded on a common personal computer. A webcam was installed and combined with a motion detector software to record pictures of the sink as soon as there was a movement.

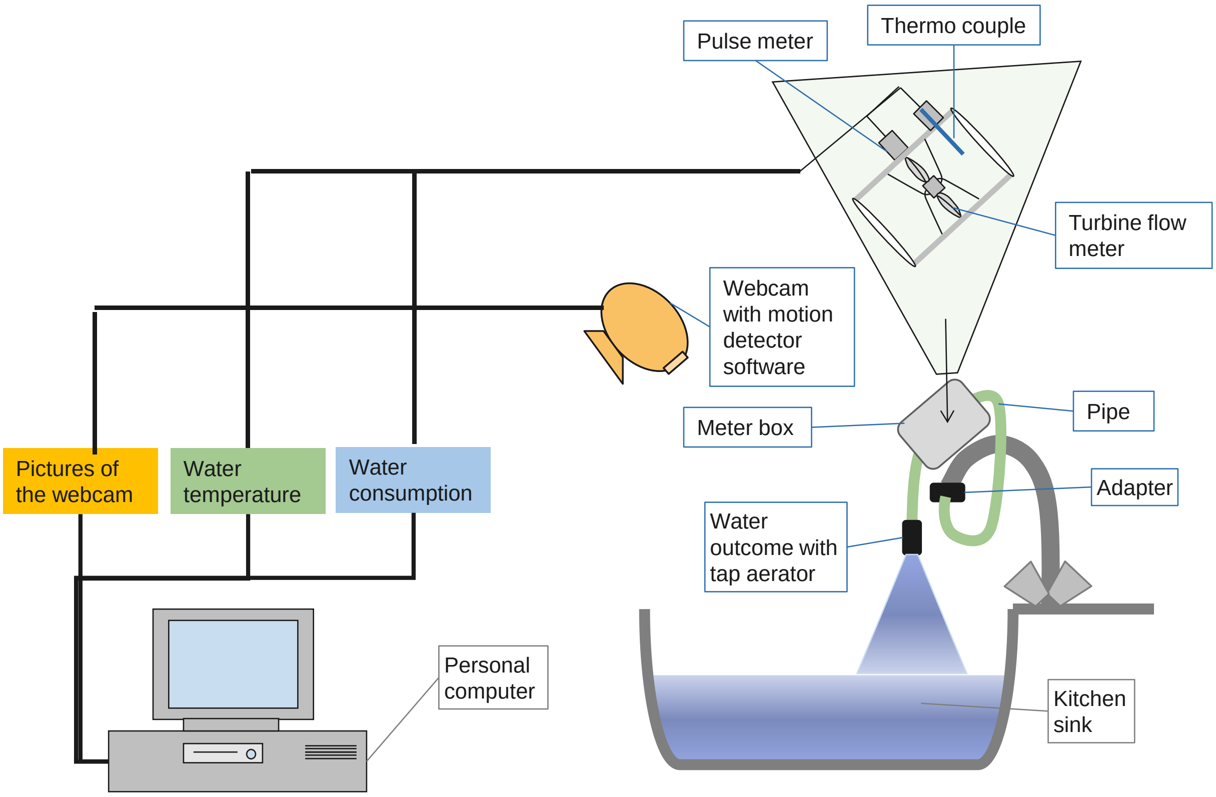


Figure 6-3: Scheme of the installed measuring instruments
Source: own illustration

The energy consumption was calculated as a variable resulting of the hot water consumption:

$$Q = m * c * \Delta T \qquad \textbf{(6-1)}$$

where

Q *Energy in kWh*
m *amount of water used in kg*
c *specific heat capacity of water: 4.19 kJ/(kg*K)*
ΔT *measured water temperature – cold water temperature (15 °C) in K*

To make the results comparable despite different cold water temperatures in different countries and seasons, an average cold water temperature of 15 °C was assumed.

Video evaluation

The video data was used to determine if additional items were washed up, which were not recorded in the diary. For those wash ups, the water and energy consumption as well as the time could be identified and were added accordingly. However, it was impossible to measure the used amount of detergent when the household had not weighed it.

Correction of the water consumption

The turbine flow meters were tested on accuracy. With different flow speeds, water was collected and weighed in a bowl for 30 s and the displayed value was compared to the weighed value. Figure 6-4 shows the error in % of the weighed value in dependency of the displayed value. The regression function with the best fit is a quadratic one with an R^2 of 0.8261. The water flow as displayed was corrected for several households with this formula. The results show that, on average per household, the displayed data is 5% higher than the weighed value with an uncertainty of ±5%. However, a correction of the data was not carried out because of the small dimension of the error and other errors possibly also affecting the water consumption (reviewed in detail in the sub-chapter 6.4).

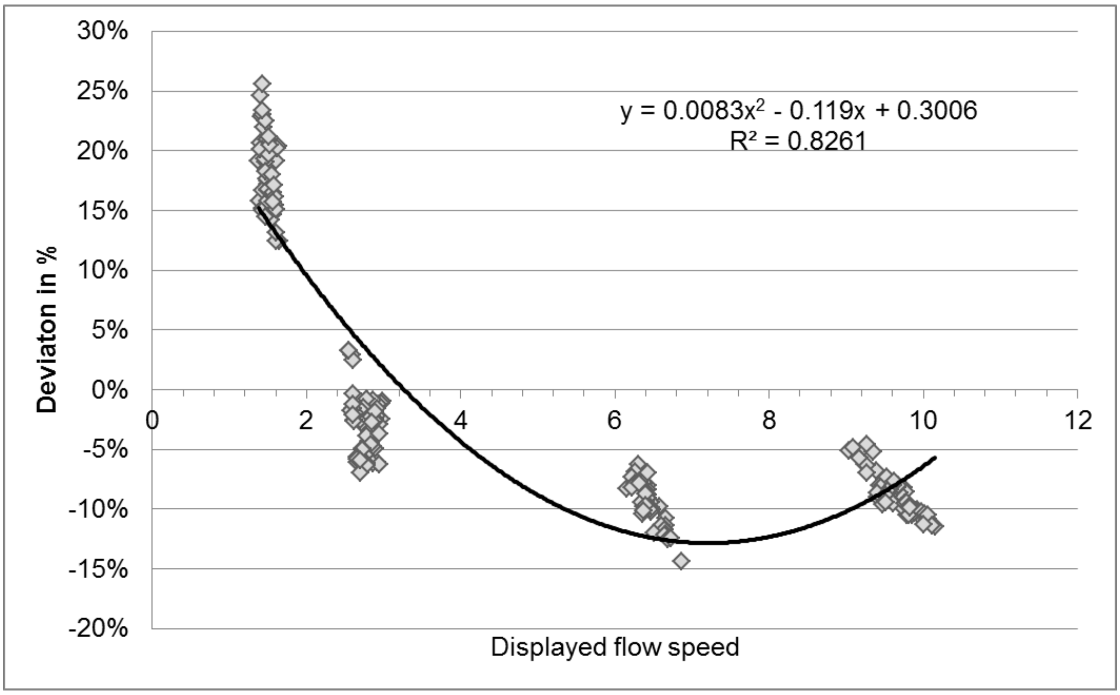


Figure 6-4: Deviation of the real flow in dependency of the measured flow speed

6.3 Results

The distribution of all data was checked and proved not to be normally distributed. Nevertheless, the arithmetic averages are presented here, because these values are of prior use for economic purposes. The standard deviation is indicated to give an impression of the scatter. The Figures 6-5 to 6-9 present the arithmetic averages with standard deviation of the measured data in the periods BT and AT (totals over 14 days). All percentage values stated in relation with the consumption data have the value of period BT as 100% basis.

The average water consumption for the German sample is in period BT 52 L higher than in period AT. This equals a reduction of 29% (from 182 L to 130 L). The reduction for the Spanish sample is around 50% from 405 L to 206 L. The average energy consumption shows a similar result. In the German sample, a reduction of 38% is observed, from 3.9 kWh in period BT to 2.4 kWh in period AT. In the Spanish sample, the average energy consumption in period BT comes to 8.8 kWh and is more than 5 kWh higher than in period AT. The decrease in energy usage among the Spanish test participants is at 61%. The numbers concerning the average detergent consumption are as follows: In the German sample, there is a decrease from 77 g to 45 g (-42%), whereas in the Spanish sample, the average detergent consumption decreased from 113 g to 55 g (-51%).

The average time taken for dishwashing in 14 days is in the German sample in period BT 17% higher than in period AT. In the Spanish sample, the same value is in period BT 30% higher than in period AT. The average number of items washed up in one period decreases slightly: In the German sample, there are on average 51 items less to be washed up and in the Spanish sample on average 35 items less to be cleaned.

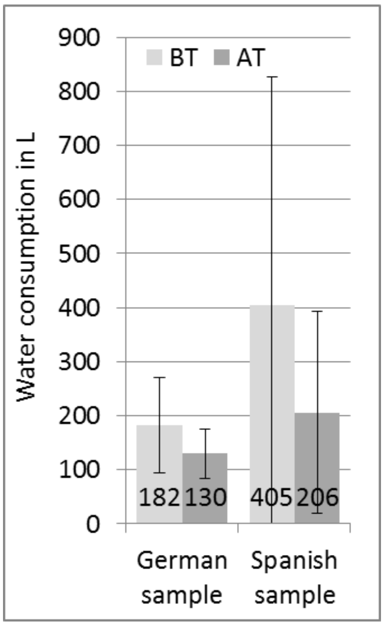


Figure 6-5: Arithmetic average and standard deviation of the water consumption in 14 days

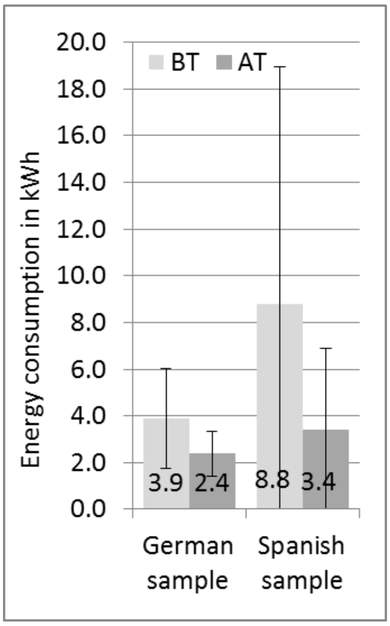


Figure 6-6: Arithmetic average and standard deviation of the energy consumption in 14 days

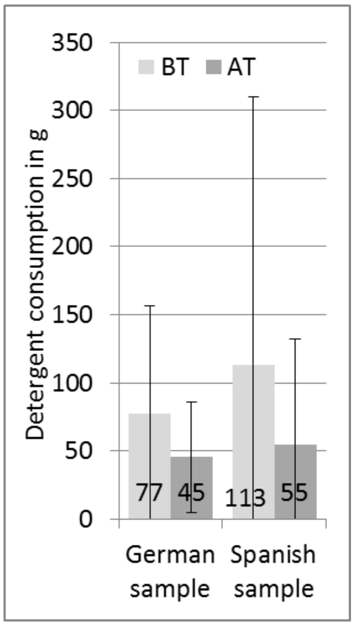


Figure 6-7: Arithmetic average and standard deviation of the detergent consumption in 14 days

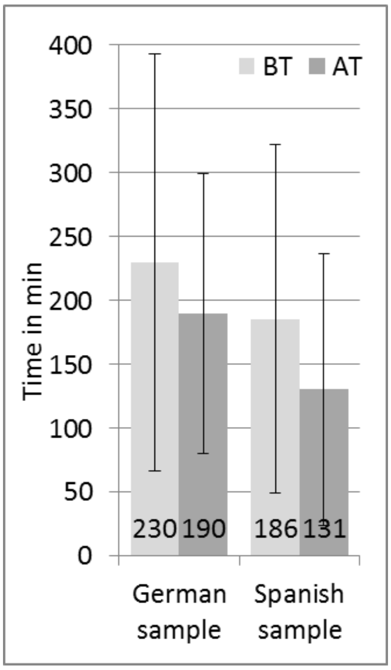


Figure 6-8: Arithmetic average and standard deviation of the time taken in 14 days

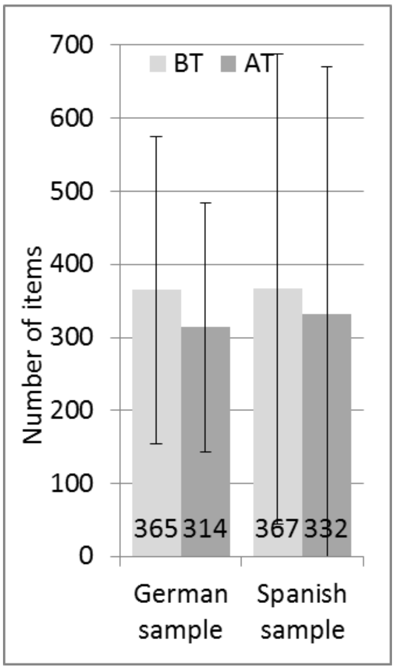


Figure 6-9: Arithmetic average and standard deviation of the number of items in 14 days

The average data per washed item is shown in the Figures 6-10 to 6-13. The average reduction for water consumption per washed item in the German sample comes to 19% and in the Spanish sample to 39%. Per item, the German test persons use on average 31% less energy and the Spanish test persons consume 41% less energy after the training (in period AT). The average detergent consumption in period AT is 38% lower than in period BT in the German sample and 39% lower in the Spanish sample. The time needed to wash up one item was approximately the same (3% less in period AT compared to period BT) in the German sample, and the value for the Spanish sample is 18% lower in period AT compared to period BT.

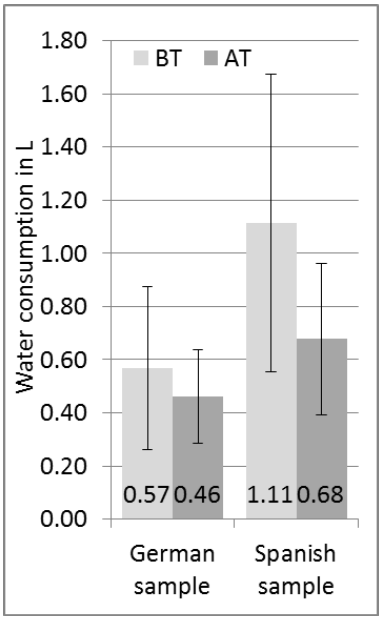


Figure 6-10: Arithmetic average and standard deviation of the water consumption per item

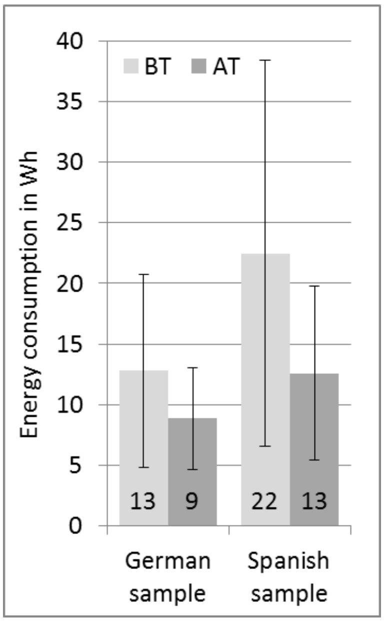


Figure 6-11: Arithmetic average and standard deviation of the energy consumption per item

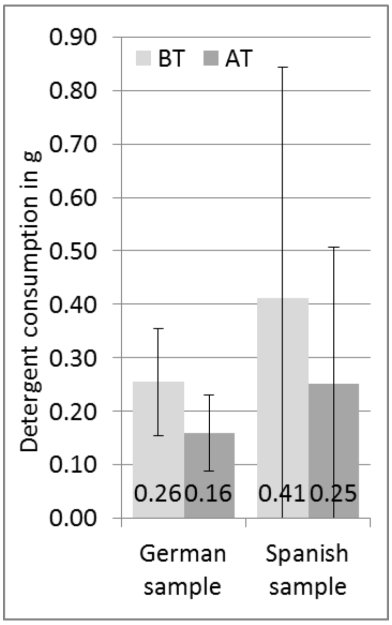


Figure 6-12: Arithmetic average and standard deviation of the detergent consumption per item[9]

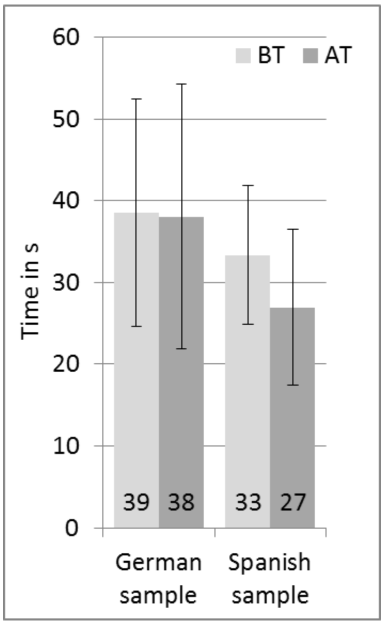


Figure 6-13: Arithmetic average and standard deviation of the time taken per item

[9] For the calculation of the detergent consumption per item, only the number of items recorded in the diary was taken in to account because in the video evaluation it was not possible to determine to amount of detergent used.

Figure 6-14 presents a comparison of the resource consumption of the single households. It is shown the percentage of test households that had a higher or a lower resource consumption per item when the result of period AT is compared to the one of period BT. It becomes obvious that over 60% of the households in the German and the Spanish sample had a lower per item consumption for the resources water, energy, detergent and time.

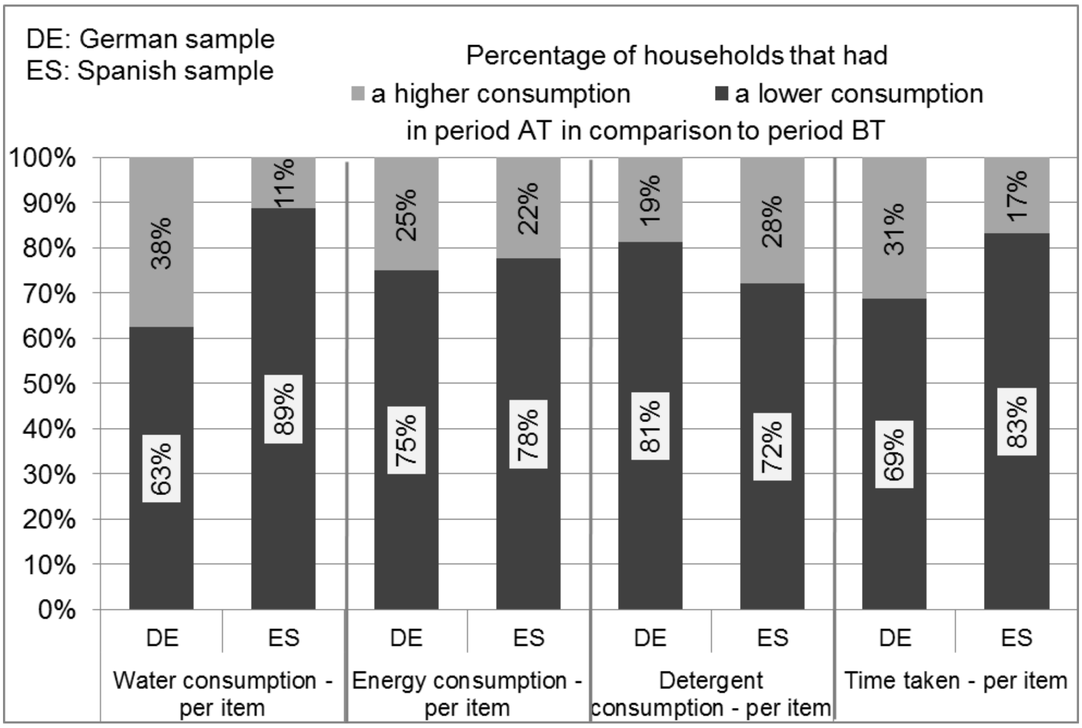


Figure 6-14: Comparison of the resource consumption per item of the single households[10]

Statistical analysis of the measured data

The Wilcoxon test is chosen to test statistically significant differences between the periods BT and AT, because the data is not normally distributed and this test is more robust than a parametrical test. The test proves (Table 6-1) a statistically significant difference with a probability of 95% that test persons in the German sample use less energy and less detergent in 14 days, whereas the difference in water consumption and in time show no significant difference. In the Spanish sample, the differences for water and energy consumption in 14 days show significance but the time reduction and the detergent consumption in 14 days are only marginally above the significance level of

[10] Because of rounded values, it occurs that the summation per sample does not amount up to 100%.

0.05. The difference in the number of items between the periods BT and AT is not significant, neither in the German nor in the Spanish sample.

The reduction per item is significant for the detergent consumption in the German sample, the water consumption and time taken in the Spanish sample. The detergent and energy consumption in the Spanish sample missed significance only marginally.

Table 6-1: Results of the statistical analysis

Wilcoxon-Test				
H_0: Medians BT and AT show no significant difference				
H_1: Medians BT and AT show significant difference				
$p < 0.05$ reject H_0 (significance level: 5%)				
	in 14 days		per item	
p values	German sample	Spanish sample	German sample	Spanish sample
Water consumption	0.1134	0.0462	0.5465	0.0104
Energy consumption	0.0348	0.0480	0.2119	0.0842
Detergent consumption	0.0104	0.0817	0.0067	0.0577
Time taken	0.6511	0.0713	0.7063	0.0024
Number of items	0.5465	0.2293		

Results of the evaluation questionnaire

In the evaluation questionnaire, the test persons were asked to rate the Best Practice Tips in regard to different positive or negative adjectives (Figure 6-15). They should rate with “++” or “+” towards the positive or the negative side or with “0” for a neutral statement. In both countries, the Best Practice Tips are rated very positive in general. Especially the Spanish test persons rate the Best Practice Tips “easy to apply” (83% rated with “++” or “+”), “easy to understand” (95% rated with “++” or “+”) and “profitable” (78% rated with “++” or “+”). However, some of the Spanish participants are undecided (39% rated with “0”) whether the Best Practice Tips are “up to date” or even “old-fashioned”. The German test persons find the Best Practice Tips “easy to understand” (94% rated with “++” or “+”) but only a smaller part judge them “easy to apply” (62% rated with “++” or “+”) and some of them are undecided if they can profit from the Best Practice Tips (38% rated with “0”). In contrast to the Spanish test persons, more German participants consider the Best Practice Tips “up to date” (75% rated with “++” or “+”).

Question:
Please rate the Best Practice Tips in total with different positive or negative adjectives.
Rate with “++” or “+” towards the positive or the negative adjective or with “0” for a neutral statement.
(DE: German sample, ES: Spanish sample)

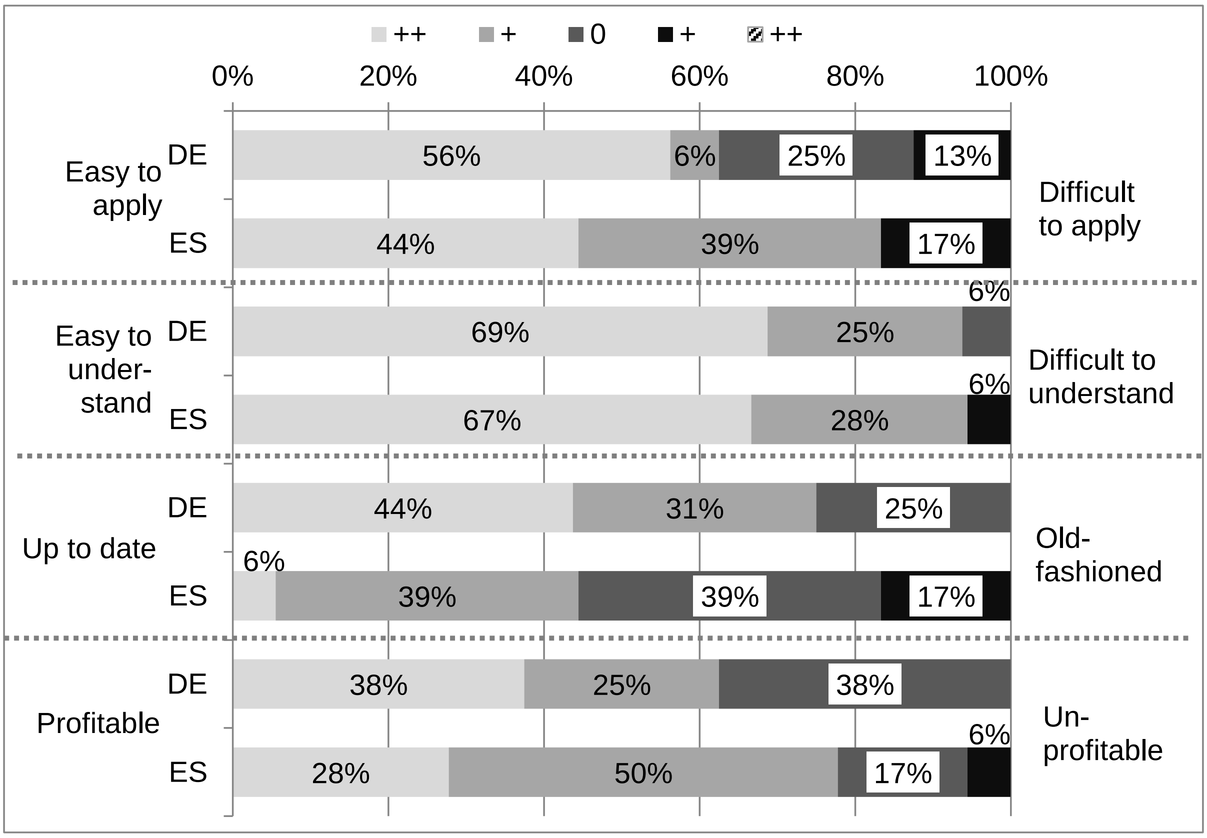


Figure 6-15: Rating of the Best Practice Tips in general[11]

The test persons were asked to rate each tip on a scale from “1: very good” to “5: not good at all”. On average (Figure 6-16), the Best Practice Tips are rated with over 80% “good” or “very good”. The tip “rinsing in a sink or a second bowl” is the least positive rated tip in both samples (69% of the German test persons resp. 56% of the Spanish test persons rate with “very good” or “good”). The reason given in most cases is that there is no space for an additional sink or bowl. The most positive rated tip is the air drying of the dishes (94% resp. 95% rated with “very good” and “good”). This tip is chosen as favourite mostly because of time savings.

[11] Because of rounded values, it occurs that the summation per statement does not amount up to 100%.

Question:
Please rate the single tips of the Best Practice on a scale from "1: very good" to "5: not good at all".
(DE: German sample, ES: Spanish sample)

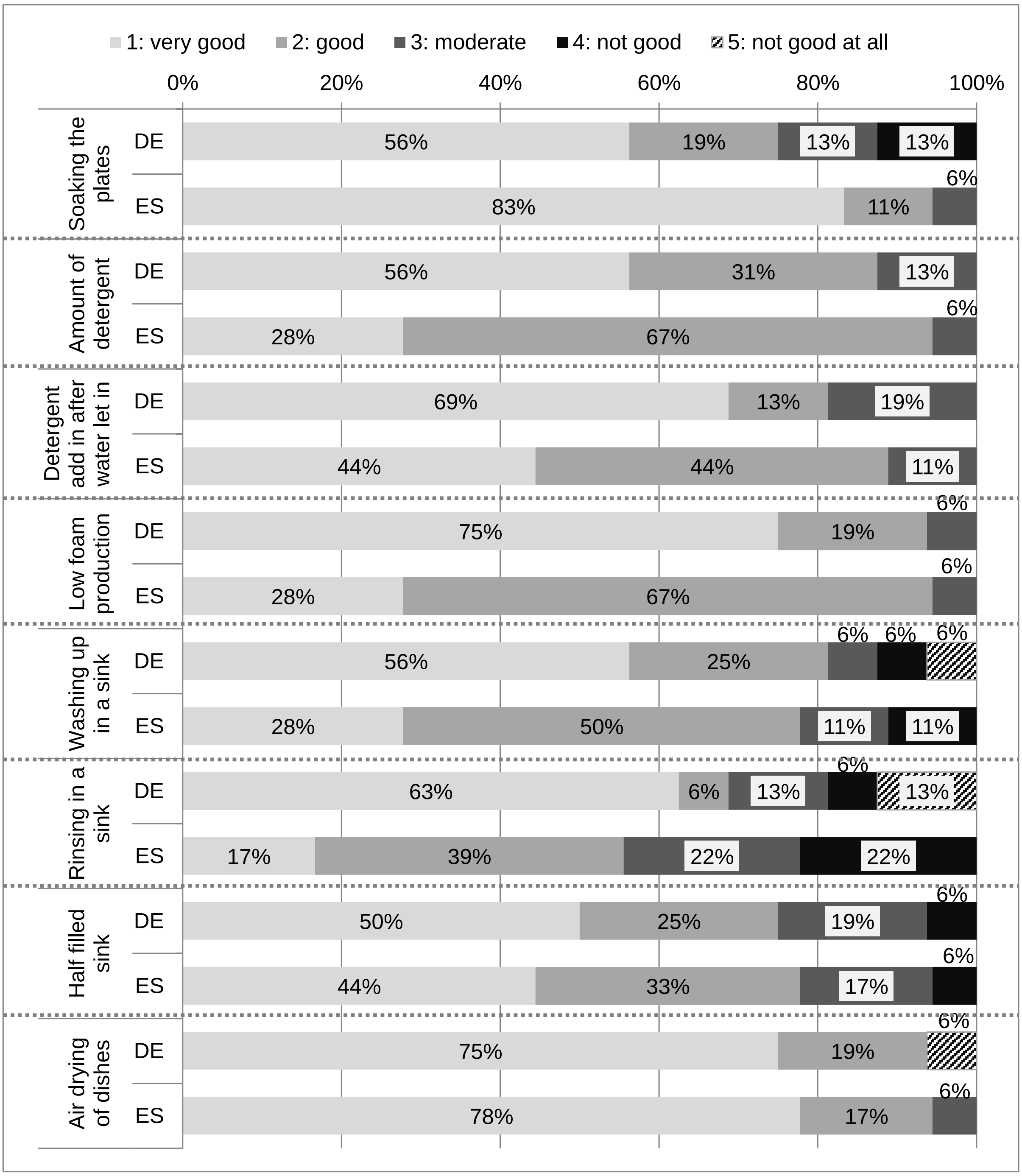


Figure 6-16: Rating of the single tips of the Best Practice[12]

[12] Because of rounded values, it occurs that the summation per statement does not amount up to 100%.

Case reports from the Spanish sample

Especially in the participating Spanish households, a great variety of consumption and resource savings were observed. To demonstrate these differences, two case reports are presented.

Case report 1: "enormous water consumer"

The data presented in Table 6-2 belongs to a three-person household of which two persons go working and one stays at home.

Table 6-2: Average consumption data of the "enormous water consumer"

Consumption in 14 days for dishwashing					
	Water in L	Energy in kWh	Detergent in g	Time in min	Number of items
Period BT	1758	40.4	224	561	839
Period AT	506	8.7	342	282	569
Reduction/ Increase (BT as 100% basis)	-71%	-78%	53%	-50%	-32%
Consumption per item					
	Water in L	Energy in Wh	Detergent in g[13]	Time in s	
Period BT	2.09	48	0.48	40	
Period AT	0.89	15	0.85	30	
Reduction/ Increase (BT as 100% basis)	-57%	-69%	77%	-25%	

In the day-to-day behaviour before the training, the person doing the wash up is cleaning the dishes under continuously running tap water. The webcam evaluation shows that, while the water is still running, he is doing other things. This explains the total water consumption of 1758 L in period BT and along with it an energy consumption of around 40 kWh in two weeks' time. During the interview, the person states that he tried to apply the Best Practice Tips in period AT, but that it took him effort to change customs. Due to very confined living conditions, he finds it awkward to rinse in a second bowl, because there is almost no space for it. Comparing the consumption per item of period BT to period AT, the person reaches a resource saving of 57% regarding water and 69% regarding energy. In 14 days, he consumes over 70%

less water and energy. However, the detergent consumption increases per item, as well as in total for over 50%. The test person spends 25% less time to wash up one item by applying the Best Practice Tips and in total 50% less time for dish cleaning. However, it has to be taken into account that in period AT, he washes up 32% less items. He states in the evaluation that the benefits of the Best Practice Tips are quite obvious and that he also feels that he consumes less resources by applying them. In the future – so his statement – he will continue to apply most of the tips, like washing up in a sink, but he will replace rinsing in a bowl by shortly opening the tap.

Case report 2: few item consumer

The data shown in Table 6-3 belongs to a one-person household. The woman is a professional who spends almost no time at home and prepares very few meals at home. Therefore, only the small number of 73 resp. 76 items were dirtied in 14 days.

Table 6-3: Average consumption data of the "few item consumer"

Consumption in 14 days for dishwashing					
	Water in L	Energy in kWh	Detergent in g	Time in min	Number of items
Period BT	70	0.5	37	38	73
Period AT	99	1.7	49	28	76
Reduction/ Increase (BT as 100% basis)	41%	240%	32%	-26%	4%
Consumption per item					
	Water in L	Energy in Wh	Detergent in g[13]	Time in s	
Period BT	0.95	6	0.60	31	
Period AT	1.31	22	0.71	22	
Reduction/ Increase (BT as 100% basis)	38%	267%	18%	-29%	

The person's usual dishwashing behaviour when dishwashing is to open the tap shortly at a very low flow speed, wash and rinse the item and then close the tap before the next item is cleaned. With this method, on average per item, she consumes 0.95 L of water, 6 Wh of energy and 0.60 g of detergent and needs on average 31 s to per cleaned item. When applying the Best Practice Tips, the person needs 38% more water

[13] For the calculation of the detergent consumption per item, only the number of items recorded in the diary was taken in to account because in the video evaluation it was not possible to determine to amount of detergent used.

(1.31 L per item), 267% more energy (22 Wh per item) and 18% more detergent (0.71 g per item) but 29% less time (22 s per item). In the evaluation, she states that the sink washing method of the Best Practice Tips is something completely new to her and that she does not necessarily see the benefit for herself. However, some of the tips please her, like the accumulation of the dishes, and she will continue to apply those.

6.4 Discussion

Looking at the average data of the studies in German and Spanish households, one can see that it was possible to confirm the potential of resource savings of the laboratory studies (FUSS *et al.*, 2011; FUSS and STAMMINGER, 2011b) by applying the Best Practice Tips. Although not all of the reductions show statistical significance at a 95% level , the majority of households has a lower resource consumption per item in period AT compared to period BT (Figure 6-14).

Even in the German households, which were already mostly applying the sink washing method already before the training, an average reduction of the resource consumption can be measured between the periods BT and AT. In Spanish households, the average savings are higher in general (except regarding the detergent), but nevertheless the total water and energy consumption in the Spanish sample after training is still higher than in the German sample before training. This is possibly due to the fact that the Spanish participants were mostly running tap washers. With the running tap method, the water can be used essentially for one item only, whereas with the sink washing method, the water can be used for more than one item. As the Spanish persons have to make the “bigger” change of their everyday behaviour when applying the Best Practice Tips, the reductions of the resource consumptions are higher than in Germany. Despite the fact that the reduction in the number of items from period BT to AT in both samples is not significant, this may contribute partly to the reduction of the resource consumption.

In the German study, as well as in the Spanish study, the individual savings are very different: There are test persons who save enormous amounts of water and energy and other test persons who consume even more resources by applying the Best Practice Tips. In general, this is possibly due to individual living conditions, such as the space of the apartment or the percentage of meals taken out of home. Other possible reasons are more or less speculations. Especially the number of dirty dishes in the household seems to affect the savings. This can be seen in the presented case “few item consumer”: She produces only a small number of dirty dishes and cleans them quite efficiently under running tap water by turning the tap off in between. Filling two sinks with water (one for main washing and soaking and one for rinsing) is less efficient, even if she is accumulating the dirty dishes over a few days. This example is a confirmation of the assumption of a study by FUSS and STAMMINGER, which state that there might be another optimal way of cleaning the dishes by hand when there are only a few items (FUSS and STAMMINGER, 2011b). When the two examples are compared, it becomes also obvious that there are more and less efficient running tap washers.

Data comparison to previous data on manual dishwashing

In the German sample of this study, the average water consumption per item in period BT lies at 0.57 L. In a German sample of RICHTER, the average per item water consumption comes to 1.0 L in households without a dishwasher (RICHTER, 2010b). Taking into consideration that the Italians, just like the Spanish, are mostly running tap washers, both values can be compared as well. In the current study, the Spanish per item water consumption is at 1.11 L and after RICHTER the Italian one is at 1.7 L of water for households without dishwasher. The values of the reported study are lower than the results of RICHTER’s study (Table 5), but they are still in the range of the variation. The differences might be explained with the small size of the samples and the large range of the values in both studies.

Table 6-4: Average water consumption per item in households with and without dishwasher

Country	with dishwasher (w DW) or without dishwasher (w/o DW)	Water use per item in L (arithmetic average)
Germany	w DW	0.6
	w/o DW	1.0
Italy	w DW	1.0
	w/o DW	1.7
Sweden	w DW	0.8
	w/o DW	1.7
UK	w DW	0.6
	w/o DW	1.6
Total	w DW	0.7
	w/o DW	1.5

Source: own illustration based on RICHTER (2010b)

Accuracy of the data

As described in the part "Material and methods", tests on the accuracy of the turbine flow meters showed that the displayed value of the water consumption is on average 5% higher than the real value and deviates around ±5%. However, this error fades into the background if one considers all other influences on the accuracy of the data, for example different consumer behaviour in different studies, the small samples with large deviation or potential mistakes in the video evaluation. In the first place, the aim of the study consists in comparing two periods, so the difference between the values is more important than the absolute values which can be taken as orientation values. Not only the water consumption, but also the calculation of the energy consumption is affected by errors. The energy consumption was calculated on the basis of a cold water temperature of 15 °C. However, it was not possible to take into account the line losses and the different ways of heating the water with different speeds and also varying efficiencies. The pictures recorded by the webcam were analysed in regard to the question whether the household was washing up items which were not recorded in the diaries. This evaluation was partly based on assumptions, because the exact number of items was not countable at times.

6.5 Conclusion

In spite of the restrictions mentioned above, this study showed that it seems to be possible to save, on average, resources like water and energy, not only in a laboratory study, but also in real life. However, it also became obvious that there are restrictions of such a training, like prejudices or difficulties in overcoming habits. Despite the prejudices that were common especially among running tap washers, some of them promised to continue applying the sink washing method in future time. The future application of the proposed Best Practice Tips can only be assumed on the basis of these statements. Therefore, it would be helpful to run a long term study that would investigate the number of tips still applied for example after one year. Besides, it seems necessary to gain deeper insight in how to convince and influence the consumers so that they apply the Best Practice Tips and act more sustainably. In order to reach a broader range of consumers, an improvement of the dissemination of the Best Practice Tips is required.

7 Summary, conclusion and outlook

Previous studies about manual dishwashing concentrated on assessing how dishes are cleaned in different countries and regions. It was shown in these studies that the consumer behaviour and the resource consumption with manual dishwashing leaves potential to optimise (e.g. BERKHOLZ *et al.*, 2010). In contrast to these studies, the target of this project was to concentrate on what can be done to change the manual dishwashing consumer behaviour to a more sustainable one. This target was developed by conducting four different subsequent studies:

- The first study investigated the sink washing process of manual dishwashing experimentally. It was found that the sink washing method carried out in three steps in two sinks (soaking and main washing in one sink and rinsing in another) led to reasonably good cleaning results. The main influencing factors were the number of the water changes in both sinks, as well as the correct amount of detergent. This experimental-based knowledge was combined with experience from everyday life and put down in writing as an applicable guide for the consumer, called Best Practice Tips in manual dishwashing.
- In the second study, the application of the Best Practice Tips was checked in a laboratory study. Consumers had to wash up different amounts of well-defined soiled dish items: once by applying their everyday behaviour and once by applying the Best Practice Tips. While for the larger amount of items it was possible to save important amounts of resources, smaller dish loads showed in average no significant reduction in the resource consumption.
- In the following third study, consumers had to wash up the amount of dishes that fit into a normal dishwasher by applying the Best Practice Tips. The gained consumption data was compared to data of other studies where consumers had to wash up the same load by applying their everyday behaviour. The result of the previous study – important amounts of resources can be saved with large amounts of dishes – could be confirmed.

- In contrast to the first three studies, the fourth study investigated the application of the Best Practice Tips in an in-house consumer study in Germany and Spain. The comparison of the behaviour and the resource consumption before and after a training on the Best Practice Tips showed that that saving considerable amounts of resources is possible for most households when they are trained how to apply Best Practice Tips in manual dishwashing.

Despite the fundamental results achieved about the best way of how dishes can be cleaned with the least possible resources maintaining a reasonably good cleaning result, the experimental investigation of manual dishwashing still has to be intensified: It is recommendable to study in-depth more factors for the sink washing process, for example, how different soils lead to different cleaning results. Apart from the sink washing process which was the only process investigated in this project, it seems necessary to study the running tap washing process, as it is a way of washing up only a few items by hand.

Beside the thorough experimental investigation of manual dishwashing, the work with the Best Practice Tips should be continued as well. It is suggested to optimise the manner in which the consumer is given an understanding of the Best Practice Tips. Different ways of trainings could be studied on its effect on the consumer behaviour, for example, a training on the Best Practice Tips by a video record in comparison to a personal demonstration or information on the Best Practice Tips only by a leaflet. Besides, the strategy of giving feedback on the resource consumption and on the possible resource savings should be studied. As mentioned in sub-chapter 1.2, this instrument can also influence behaviour changes. Then, of course, there is the question of how the Best Practice Tips can be disseminated so that a larger audience has knowledge of the Best Practice Tips and can apply them. It could be considered as a good way to disseminate them through organisations that are engaged in bringing more sustainability into the household, for example the International Federation for Home Economics (IFHE).

In the current project, the effects of the application of the Best Practice Tips have been studied only in a short time perspective. It would be interesting to gain deeper insight into the way in which the Best Practice Tips would affect the household's behaviour on the long run. Out of such a study, knowledge could be gained what is to be done that a sustainable behaviour in manual dishwashing is applied as everyday behaviour. To reach a longer duration of a applying the Best Practice Tips for manual dishwashing, it is recommended also to lay focus on psychological factors, as DEYOUNG already claimed for a general behaviour change towards pro-environmental behaviour (DEYOUNG, 1993).

The work with the consumers has revealed a great variety of individual manners. Therefore, it is suggested to enlarge the Best Practice Tips by a part about "What to do in case if…?" in order to take into account questions that might occur on the consumers' side.

RICHTER claims the necessity to combine both ways of cleaning dishes, manual dishwashing and automatic dishwashing (RICHTER, 2010b). Here, there might be some potential for future work: It is recommended to study the impact of Best Practice Tips that combine both manual and automatic dishwashing.

This work gives an insight into ways of contributing to a sustainable behaviour in manual dishwashing. The idea of defining Best Practice Tips for resource savings could not only be applied in dishwashing but also in other households' works, such as clothes washing or cooking.

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List of abbreviations

°C	degree Celsius
ACSD	Association Canadienne de la Savonnerie et de la Détergence
AID	Auswertungs- und Informationsdienst
BAFU	Bundesamt für Umwelt Schweiz
BDEW	Bundesverband der Energie- und Wasserwirtschaft in Deutschland
BPT	Best Practice Tips
Btu	British thermal unit
C	concentration of detergent
CECED	European Committee of Domestic Equipment Manufacturers
CENELEC	European Committee for Electrotechnical Standardisation
cm	centimetre
DOE	U.S. Department of Energy Use
DW	dishwasher
e.g.	exempli gratia (for example)
EDB	everyday behaviour
EEA	European Environment Agency
EIA	U.S. Energy Information Administration
EN	European Norm
et al.	et altera (and others)
EU	European
g	gram
i.e.	id est (that is to say)
IEA	International Energy Agency
IFHE	International Federation for Home Economics
K	Kelvin
kJ	kilojoule
kg	kilogram

kWh	kilowatt hour
L	litre
min	minute
mL	millilitre
n.d.	not dated
N.N.	nomen nescio (author unkown)
OECD	Organisation for Economic Co-operation and Development
OEE	Office of Energy Efficiency Canada
p.	page
PP	pizza plate
PS	place setting
resp.	respectively
RWI	Rheinisch-Westfälisches Wirtschaftsinstitut Essen
s	second
U.K.	United Kingdom
U.S.	United States
w/o	without
w	with
WCMWB	water changes in main washing bath
WCRB	water changes in rinsing bath
Wh	Watt hour
ZVEI	Zentralverband Elektrotechnik- und Elektronikindustrie e.V.

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