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Larger Washing Machines and Smaller Household Size – How Can They Fit Together? Simulation of a Sustainable Use of Washing Machines

In order to simulate the usage of washing machines by the consumer, a concept of a "virtual washing household" is developed that, to some extent, behaves as a real life household. As essential part of this virtual household is the virtual washing machine in which washing cycles are conducted in dependence of the washing parameters, household size and behavioral parameters. The concept stipulates that a washing cycle is conducted only when the household has enough laundry collected, so that the loading capacity of the washing machine is used, otherwise the houshold waits. Houshold, however, washes the laundry despite the loading capacity restrictions when a certain, waiting time (defined by the houshold) is elapsed. The consequences of all washing cycles during one year are calculated in terms of CO_2 equivalent emissions caused by the energy, water and detergent consumed for reaching a well-defined level of washing performance. This model offers a high range of possibilities to simulate some of the consumer's behavioral patterns and so helps to identify an optimal washing behavior for different sizes of washing machines.

Key words: Washing machine, household, sustainability, simulation, consumer behavior

Größere Waschmaschinen und kleinere Haushaltsgrößen – Wie können sie zueinander passen? Simulation eines nachhaltigen Gebrauchs von Waschmaschinen. Um dem Gebrauch von Waschmaschinen durch die Verbraucher zu simulieren, wurde das Konzept des virtuellen Waschhaushalts entwickelt, das zu einem gewissen Grad das Waschen im realen Haushalt widergibt. Ein wesentlicher Bestandteil des virtuellen Waschhaushaltes ist die virtuelle Waschmaschine, mit der Waschzyklen in Abhängigkeit von den Waschparametern, der Haushaltgröße und den Verhaltensparametern durchgeführt werden. Das Konzept schreibt vor, dass ein Waschzyklus nur dann durchgeführt wird, wenn im Haushalt so viel Wäsche angesammelt wurde, so dass die Beladungskapazität der Waschmaschine ausgenutzt werden kann, ansonsten wird gewartet. Allerdings führt der Haushalt einen Waschgang ungeachtet der Beladungskapazität durch, wenn eine bestimmte, vom ihm definierte Wartezeit verstrichen ist. Die Auswirkungen aller Waschzyklen eines Jahres werden berechnet als CO_2-equivalente Emissionen, die von dem Energie-, Wasser- und Waschmittelverbrauch, der notwendig ist, um einen definiertes Waschergebnis zu erzielen, herrührt. Das Modell liefert einen weiten Bereich an Möglichkeiten, einige Verhaltensmuster von Verbrauchern zu simulieren und hilft so, ein optimales Waschverhalten für verschiedene Waschmachinengrößen zu ermitteln.

Stichwörter: Waschmaschine, Haushalt, Nachhaltigkeit, Simulation, Verbraucherverhalten

1 Introduction

On the European market, the average washing machine load capacity has increased from 4.8 kg in 1997 to 5.4 kg in 2005 (CECED, 2005 cited after [1]). In 2009 washing machines with a rated capacity of 6 kg were the most important market segment [2]. In 2010 washing machines with a rated capacity between 5.5 kg and 7 kg were the most important market segment in 10 EU countries (AT, BE, DE, ES, FR, GB, IT, NL, PT, SE) [3]. In 2012 the top selling appliances were those with a 7 kg rated capacity [4]. This shows that within about two decade the rated capacity of washing machines has increased by about 2 kg!

On the other side, the household size is decreasing. According to a study published by OECD by 2025–2030 the single households will make up around 40% or more of all households in following European countries: Austria, France, Germany, Netherlands, Norway Switzerland and England [5]. According to projections of the German Federal Statistical Office, the number of single and 2-person households will increase from 74% in 2009 to 82% in 2030 [6].

Furthermore, many studies show that consumers do not fully use the rated capacity of their washing machine. So for example in Germany the average load of a washing machine is 3.2 kg per washing cycle [7]. Another study shows that for an average washing machine capacity of 5 kg, consumers consider an average load of 3.7 kg as a full load [8]. At present there is no reliable data on the loading behavior of washing machines with average rated capacity larger than 5 kg.

When taking into the account the cradle to the grave life cycle of a washing machine, i.e. including the production, use and disposal phase it becomes obvious that the use phase is the most resource consuming and waste producing [9]. Washing machines are operated on the consumer demand and its consumption of water, energy and detergents for a washing cycle is determined by mainly consumer driven factors such as the frequency of washing, loading behavior, selection of the washing temperature/program, dosing of detergents [10–12].

Taking into account the opposing trends of increasing the average washing machine rated capacity and the change of the demographic structure of the European households (hence decrease of amount of laundry that has to be washed per household) and bearing in mind that consumers generally do not fully use the rated capacity of their washing machines and consider a partial load level as a full load the question poses: "What kind of washing behavior is needed, so that the usage of washing machines with a higher rated capacity has a low impact on the environment?"

In order to answer that question, firstly a virtual household that incorporates various washing behavioral parameters shall be developed. Secondly, simulations of the usage of the virtual washing machine [13] by the virtual household shall be conducted.

By varying washing machine-, household- and behavioral parameters an optimal parameter combination with low environmental impact shall be determined and so optimal consumer behavior conclusions shall be drawn.

2 Material and Methods

The "virtual household" is constructed as presented in the 30 °C washing temperature/program flow chart (Fig. 1). Analogously, the simulation structure is applied to a 40 °C and 60 °C washing program.

The routine is programed by using Matlab software (Matlab version 7.10.0.449 R2010a). In the simulation program the "virtual washing machine"[13] is also included.

The basis for the virtual washing machine is data received from testing (in accordance with EN 60456:2011) of nine different washing machines with loading capacity of 5 kg, 6 kg 7 kg, 8 kg and 11 kg [14].

All washing machines were tested by varying the load (tests with 0%, 25%, 50%, 75% and 100% of the rated washing machine load capacity) the washing program/temperature (30 °C, and 40 °C and 60 °C using the normal cotton program) and detergent dosage (50%, 100% and 150% of the nominal dosage as defined by EN 60456:2011). Energy and water consumption, duration of the main wash cycle and total washing cycle duration as well as the washing performance were measured for all conditions and machines.

The simulation routine is programed in such a manner that following parameters can be varied: (1) washing machine rated capacity (2) number of person in household (3) amount of laundry per person, (4) type of laundry per person, (5) maximal laundry waiting time (MLWT), (6) loading behavior for certain type of laundry, (7) duration of the simulation.

The concept includes three different consumer behavioral elements, which are based on the consumer washing behavior research. So, the research has shown, that the amount of laundry washed per week per household depends on the number of persons living in the household and that the number of washing cycles per week also strongly depends on the household size [19, 20]. Additionally, it was shown that the real life load size of the different wash programs depends on the program type [7, 8]. Therefore it is assumed that, firstly, every week a certain amount of laundry per person is produced and has to be washed. Secondly, it is assumed that the household conducts a washing cycle only when enough laundry is accumulated for certain wash temperature so that the washing machines capacity can be used. Thirdly, it is also assumed that when there is not enough laundry to conduct a washing cycle the household waits until enough laundry is accumulated so that the washing machines capacity can be used. The model also assumes that the consumer does not wait endlessly. When the maximal laundry waiting time (MLWT) is reached a washing cycle (so-called "emergency washing cycle") is conducted despite the fact the amount of the accumulated laundry is not sufficient to fully use the washing machine's loading capacity.

The simulations are conducted by assuming that the duration of the simulation is 52 weeks, and that every week 4 kg per person are accumulated [8]. Furthermore it is assumed that 23% of total load is to be washed at 30 °C, 46% of the total load has to be washed at 40 °C and 31% of the total load has to be washed at 60 °C [8].

It is also assumed that the washing machine's rated capacity is not fully used as already pointed out by [1, 7, 8]. In dependence of the type of laundry, the washing machine's rated capacity and the washing temperature/program different amount of load are loaded into the washing machine. The factor that sets in proportion the amount of load and the washing machines rated capacity is called load factor and various associations (e. g. "Forum Waschen" [18]) promote differentiated load factors along with its washing recommendations. Based on research of [1, 7, 8] and the promoted washing recomendations [18] following loading factors are assumed: in the case of the 30 °C washing cycle the load factor is 50% of the rated capacity, in the case of 40 °C washing cycle the loading factor is 70% of the rated capacity and in the case of the 60 °C washing cycle the loading factor is 90% of the rated capacity.

For explanation of the model a simplified example shows the development of the laundry stock versus time (Fig. 2). Each one of the lines shows the progress of the stock of one type of laundry that has to be washed at different washing temperature. For ease of understanding – only in this

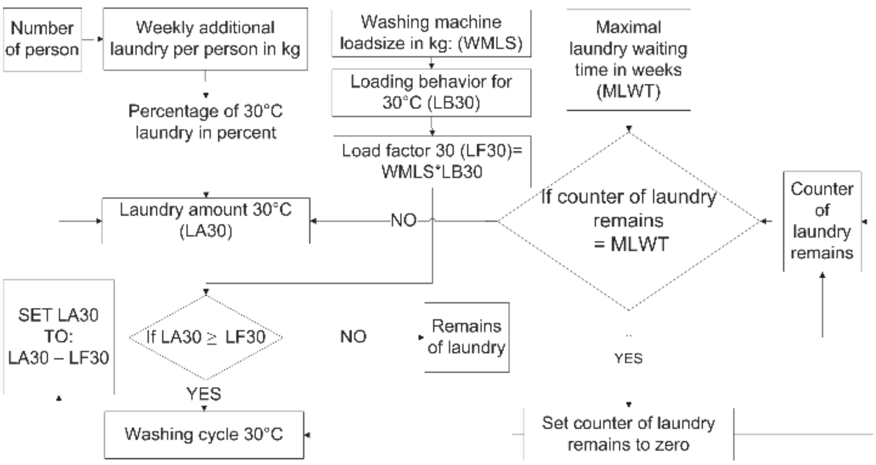

Figure 1 Flow chart of the virtual household

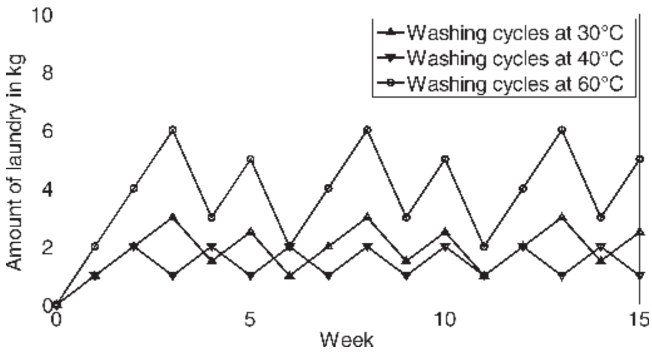

Figure 2 Example of simulation of a usage of a 5 kg washing machine for 15 weeks: comparison of three laundry stocks (30 °C, 40 °C and 60 °C laundry stock)

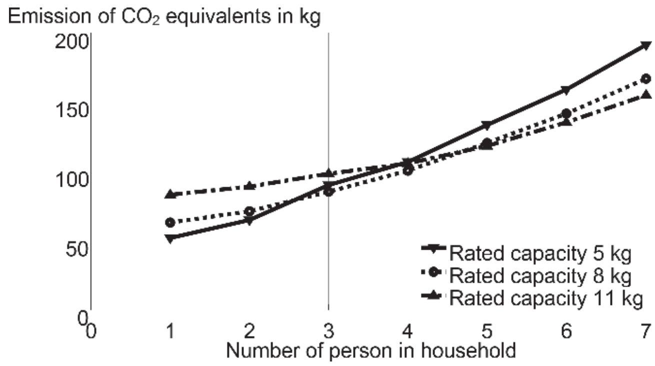

Figure 3 Yearly simulation of usage of three washing machines with a rated capacity of 5 kg, 8 kg and 11 kg. Comparison of the CO_2 equivalent emission in dependence of the household size, washing machines rated capacity and the household behavior regarding the maximal laundry waiting time. It is assumed that household does not wait and washes the laundry in the same week (MLWT = 0)

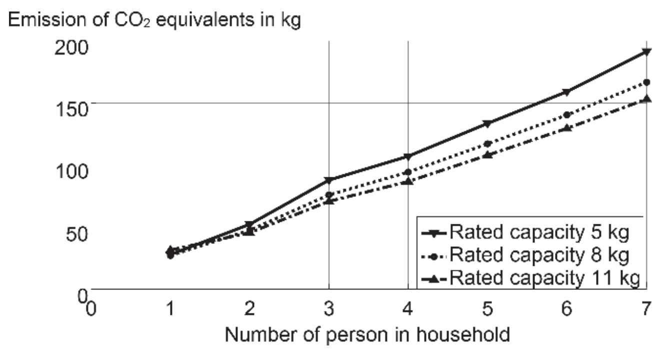

Figure 4 Yearly simulation of usage of three washing machines with a rated capacity of 5 kg, 8 kg and 11 kg. Comparison of the CO_2 equivalent emission in dependence of the household size, washing machines rated capacity and the household behavior regarding the maximal laundry waiting time. It is assumed that household waits for two weeks and washes the laundry in the third week (MLWT = 2)

case – it was assumed that every week 1 kg of 30 °C laundry, 1 kg of 40 °C and 2 kg of 60 °C laundry is added to the stock.

In the case of the laundry stock 40 °C it was assumed that the maximal laundry waiting time is 1 (i.e. the consumer waits maximally for 1 week). For this reason in the second week a washing cycle is conducted although a capacity of the washing machine is not fully used. In the case of laundry stock 30 °C and 60 °C no maximal laundry waiting time is defined. For this reason, because the load capacity of the washing machine is reached (2.5 kg in the case of the 30 °C laundry, and 5 kg in the case of 60 °C laundry) a washing cycle is conducted in the 3^{rd} week. In the case of the laundry stock 30 °C it was assumed that the washing machine's loading factor is 50 % of the washing machines rated capacity. For this reason in the 3rd week a washing cycle is conducted with a load of 2.5 kg of laundry. The reminding 0.5 kg is then together added to 1 kg laundry in the 4^{th} week.

3 Results and Discussion

The model was used to simulate usage of washing machines of different rated capacity (5 kg, 8 kg and 11 kg) by households with different number of household members, and so calculate the respective CO_2 equivalent emission (Fig. 3).

Comparison of the slopes show that when the household does not wait until enough laundry is accumulated and washes every week, washing machines with lower rated capacity have the lowest impact on the environment for households up to 3 persons. With an increase of the number of person in the household the amount of laundry increases and so a washing machine with a higher rated capacity is more adequate, as a lower amount of CO_2 equivalent emissions is produced.

If enough laundry is accumulated so that the loading capacity of the washing machine can be used (Fig. 4) the absolute amount of CO_2 equivalent emissions is considerably lower especially for small households. When the household waits for 2 weeks at a specific program and conducts a washing cycle in the third week the amount of laundry is sufficient, so that the loading capacity of the washing machine can be better used. In such a case even an 11 kg washing machine could be optimally used by a single or 2-person household.

The time consumed for washing purposes is also an important factor when evaluating the different washing behavior patterns. Although the time consumed for washing purposes includes the washing machine loading/unloading time as well as the actual washing time, in this research the time consumption is solely represented by the washing frequency.

As the data show for one and two person households (Fig. 5) when the MLWT = 0, there is no difference among washing machines with 5, 8, or 11 kg rated capacity regarding its usage frequency. In all cases not enough laundry is accumulated to fully use the load capacity of the washing machine. For this reason, the most of the washing cycles are emergency washing cycles. With an increase of the household size, more laundry is accumulated so that the number of emergency washing cycles decrease and the differences among washing machines of different rated capacity become more visible.

With the increase of the maximal laundry waiting time the amount of laundry that is accumulated in the household increases as well, so that the capacity of the washing machine can be used and the number of emergency washing cycles decrease (Fig. 6). However, as the data show, in the case of the single household the time consumption differences as represented by the number of washing cycles done are among the washing machines very low.

One of the promotion arguments for washing machine with a large load capacity is that it is time saving, since more load can be washed at the same time (e.g. [21]). However, this depends on the household size and the washing machine's rated capacity as well as on the consumer behavior when using the washing machine. As the data shows in the case of the single and 2-person households, there is no time saving advantage, except the household wait for more than two weeks or washes at even lower load factors. Another promotion argument is that washing machines with a higher rated capacity offer the possibility to wash large pieces [21, 22]. However, in the case of smaller households it is to question whether the advantage of occasional washing large pieces justifies the higher specific energy and water consumption that may occur, when a washing machine with a larger load capacity is used with small loads [14].

With an increase of the maximal laundry waiting time the average washing temperature of all cycles done in one year decreases as well (Fig. 7). When the maximal laundry waiting time is prolonged, the rated capacity of the washing machine is more often used (especially in the case of the 60 °C washing cycles where the loading factor is highest) and hence the average washing temperature decreases.

In order to lower energy consumption laundry washing at lower temperatures has been promoted in the past decades. For this reason since the early 1970-ies the average washing temperatures is in a decline [1, 15–17]. As the data suggests, promotion of an increase of the maximal laundry waiting time would result in an increase of the usage of the maximum load capacity of the washing machines and thus would also have impact on the decrease of the average washing temperature and hence would lead to a lower energy consumption.

4 Conclusion

The developed virtual washing household model offers possibility to simulate some of the consumer's behavioral patterns.

The model reflects, to some extent, the real life, especially considering the fact that in the model the amount of laundry that has to be washed is not static but it rather develops during the course of the simulation. Furthermore, it also offers the possibility to vary many household and washing machine parameters.

Although the model does not include all the aspects of the real life, it however offers the possibility to compare the pros and cons of some consumer behavior patterns when using washing machines of different capacities.

The variable maximal laundry waiting time is of great help to add the time dimension to the virtual consumer model and so explore the effects that might occur when consumer is ready to postpone an action (in this case the washing of laundry) to a later point of time.

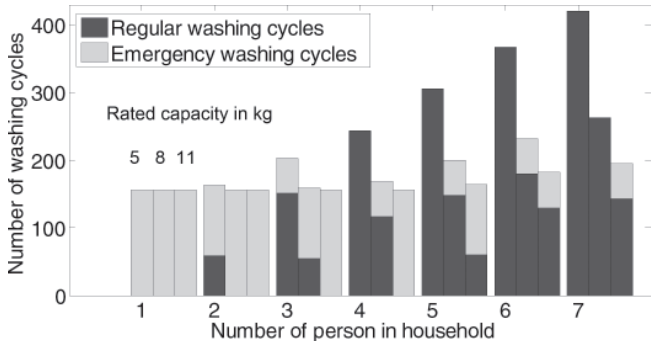

Figure 5 Yearly simulation of usage of three washing machines with a rated capacity of 5 kg, 8 kg and 11 kg. Comparison of the number of washing cycles done in dependence of the household size, washing machines rated capacity and the household behavior regarding the maximal laundry waiting time. It is assumed that household does not wait and washes the laundry in the same week (MLWT = 0)

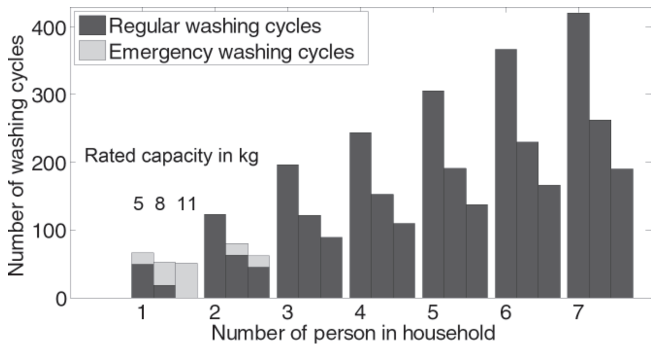

Figure 6 Yearly simulation of usage of three washing machines with a rated capacity of 5 kg, 8 kg and 11 kg. Comparison of the number of washing cycles in dependence of the household size, washing machines rated capacity and the household behavior regarding the maximal laundry waiting time. It is assumed that household waits for two weeks and washes the laundry in the third week (MLWT = 2)

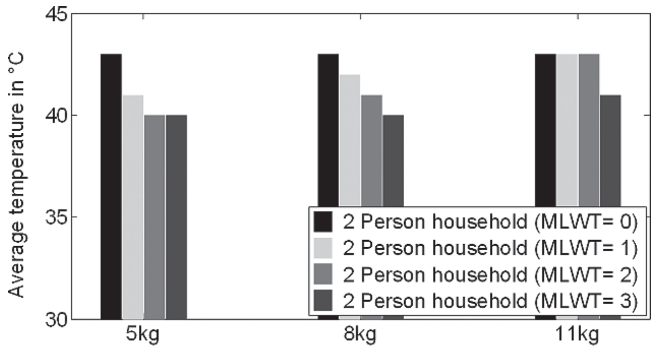

Figure 7 Comparison of average washing temperatures in dependence of the maximal laundry waiting time on an example of a 2-person household

Such a parameter is very valuable because of its ease of use and it should be included as an eventual standard variable in future models where the sustainability related consumer behavior is being explored. Up to the present research no evidence of usage of such a moderating factor has been presented in the literature.

It can be concluded that a sustainable use of washing machine with higher rated capacity is possible, when consumer behavior changes with a goal to use the loading capacity of the washing machine fully.

This can be achieved by increasing the maximal laundry waiting time and waiting until enough laundry is accumulated so that the rated capacity of the washing machine can be used.

Another possibility for a more sustainable usage might be in combining the different washing loads (e.g. combining 30 °C and 40 °C washing load) and by choosing the washing temperature in accordance with the recommendation of the most sensitive laundry piece. In combination with prolonging of the washing cycle the same washing performance at lower resource consumption may be achieved. Janczak et al. [10] already showed that lowering the temperature to the next possible level and prolonging the washing time lead to a remarkable decrease of the energy consumption while the washing performance remains the same.

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