Synergy Potential
of Smart Appliances

D2.3 of WP 2 from the Smart-A project

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BDE	Bund der Energieverbraucher
BRGC	Business Research Group Consult
BSRIA	Building Services Research and Information Association
CDD	Cooling degree days
CEE	Central and Eastern Europe
CENELEC	Comité Européen de Normalisation Electrotechnique (European Committee for Electrotechnical Standardization)
CHP	Combined Heat and Power
DDC	Dynamic Demand Control
EECCAC	Energy Efficiency and Certification of Central Air Conditioners
EEI	Energy Efficiency Index
EERAC	Energy Efficiency of Room Air Conditioners
EuP	Energy-using Products
GfK	Gesellschaft für Konsumforschung
JRAIA	Japan Refrigeration and Air Conditioning Industry Association
PRODCOM	Production Comunautaire
VHK	Van Holsteijn en Kemna BV

1 Introduction

The Smart-A project

The project „Smart Domestic Appliances in Sustainable Energy Systems (Smart-A)" aims at developing strategies how smart domestic appliances can contribute to load management in future energy systems. In order to do this, the project assesses the options for load-shifting by a variety of appliances across Europe and compares these with the requirements from energy systems both on the local and regional level. It is expected that these systems will have to integrate larger shares of renewable energy in the future, which are partly intermittent, and therefore will require a smarter management of generation, network capacities and demand.

The technical aspects of the assessment include an analysis of potential changes to appliances operation, of characteristics of local energy generation (from renewable energies and also cogeneration) and of load management requirements in the larger electricity networks. The project also features a detailed assessment of the acceptance of smart appliances operation by users, and an evaluation of the usability of available control technologies and communication standards. The overall potential of smart appliances is assessed based on a model which takes into account the variations of appliance use and the framework conditions in energy systems.

The project is conducted in cooperation with manufacturers of appliances and electric utilities. The findings from the analysis are being discussed with experts in regional case studies in selected European countries.

This report

The report of WP2 is based on publicly available data and reports on electricity consumption of private households with special regard to consumer behaviour and availability of household appliances. The operation probability and power demand of each appliance is analysed and described. Based on the obtained data load curves for single appliances, bundles of appliances and also for specified regions are created and preliminary hypotheses of consumer acceptance of smart operating appliances for the consumer survey within the Smart-A project are derived.

The theoretical model on which this survey is based upon is presented in chapter 2 of this report. The model describes the power demand per household appliance and the average power demand per day of a bundle of household appliances, both local and regional. It also identifies the relevant parameters for the possibilities of domestic appliances to adapt their operation to the requirements set by the energy supply.

In chapter 3 the technical possibilities for a more flexible operation of 10 appliances which are dishwasher, washing machine, tumble dryer, refrigerator, freezer, oven and stove, heating circulation pump, air conditioner, electric water heater and electric heating are investigated, including the impact on the quality of service delivered by the appliance caused by the adjustments suggested. Each of the 10 devices is analysed in its own subchapter, which is structured as follows: after a short overview of the technical functionality of the appliance the market penetration, energy and water consumption as well as the power demand are investigated separately. The main part of each subchapter concentrates on the synergy potential of each appliance when operated under smart energy conditions: what additional technical elements are needed to enable a smart operation and what is the amount of additional costs and energy required. Therefore different scenarios are developed which are divided into four levels. The complexity of technical adjustments increases from level 1 to level 4 steadily. Level 1, 2 and 3 deal with the operation probability of the appliance with different levels of connectivity to smart energy systems. In level 4 the possibilities of the device for a more intense use of renewable energy and CHP in connection to other technologies and storage capacities are investigated. Specific opportunities and restrictions are pointed out for each appliance.

In chapter 4 the main results of the investigation are summed up with special regard to restrictions and opportunities of the project „Smart Domestic Appliances in Sustainable Energy Systems (Smart-A)".

2 Theory of modelling appliance power demand

Data from electricity utilities about domestic electricity consumption is normally aggregated consumption of multiple households without knowledge about the events in individual households. Detailed knowledge at household level is necessary for optimising electricity production and consumption and can be created with simulation models [PAT 05].

The fluctuation of the power demand concerning an individual household mainly depends on regional circumstances like climate, the technical equipment used by a household and the consumer behaviour. Therefore the theoretical background of the analysis in this report mainly focuses on three variables: the load curve per appliance and operation *(p)* describing the typical power taken by an average appliance of this type per day or per operation, the probability of operation *(α)* and the number of the appliances of each type (β) in a specified country or region. To eliminate the absolute size of the region, this report considers only the specific penetration rates β_k of each appliance type in this region, thus leading to the typical load curve for one average household $P_k(t)$.

Altogether they define the average power demand for those appliances considered in this analysis, called the load curve $P(t)$.

The calculation starts in constructing power demand curves $p_{ij}(t)$ for each appliance type *i* assuming this appliance is started at any time *j* during the 24 hours of a day in quarter hour time intervals. These hypothetical demand curves are then multiplied by the probability of operation of this appliance at this point in time $\alpha_i(t)$. This information is retrieved from consumer studies about the time of typical operation of appliances or is estimated where no appropriate studies were available. Summing up these data for each time leads to the average power demand during the day $p_i(t)$.

$$p_i(t) = \sum_{j=1}^{96} \alpha_i(t)\, p_{ij}(t) \tag{1.1}$$

The average power demand per average household of a certain country or region over the time of the day $P_k(t)$ is then calculated by summing up the average power demand curves during the day of each appliance multiplied by the penetration rate of this appliance in a certain region or country. As the appliances investigated in this study only make up part of the total electricity load of a household, the base load $p_0(t)$ is defined as all other electricity consumption in the household. As this factor is not known a priori, it is set to zero for the purpose of this study.

$$P_k(t) = \sum_{i=1}^{n} \beta_{ik}\, p_i(t) + p_0(t) \tag{1.2}$$

The load curve of households for those appliances considered in a certain region or country is then defined as

$$P(t) = k\,P_k(t) \tag{1.3}$$

where *k* denotes the number of households in the country or region investigated.

From the perspective of energy management on the grid level this can easily be adopted by changing the probability of appliance operations: $\alpha_i\ (t) \rightarrow \alpha_j(t)$. But as a constraint, the sum over all α 's per day must be constant, assuming no change in the usage of appliances but only a shifting in time.

3 Domestic appliances

3.1 Washing machine

3.1.1 Technical description with regard to the use of water and energy

European type washing machines consist of a tub and a drum rotating around a horizontal axis. Water is filled into the tub up to a certain low level which his maintained throughout the main cleaning process. The laundry, normally loaded through a glass door, is only partially immersed into the water but mainly soaks up the water needed for the cleaning process. This cleaning is done at various temperatures (mainly 30, 40, 60 or 90°C), depending on the garments to be washed. The water is heated up to the desired temperature by a resistant heating system of between 1800 and 2500 W rated power. Heating may be interrupted for equalizing the temperatures in the water and in the load. When the desired temperature is reached, the cleaning process may be continued for some time, followed by several rinsing processes. Throughout the wash and rinse cycles the drum is rotated by a motor (universal or inverter motor) via a belt system at a defined speed in a reversing way. This rotation provides the necessary mechanical impact on the load and ensures a continuous exchange of water and suds between the load and the surrounding water. At the end of the whole washing process (and to some extend between the rinse cycles) the drum is rotated at a high speed to extract the water (and suds) from the load and to reach a - as much as possible - dry load at the end of the programme.

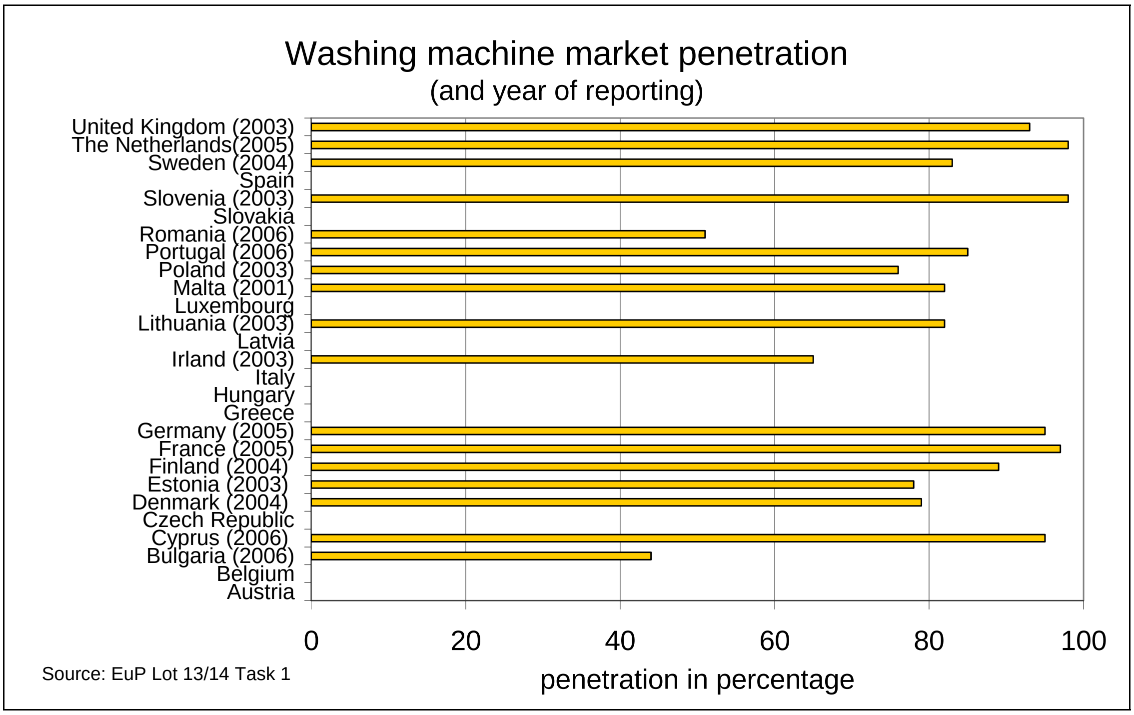
The whole process is controlled by a step timer or/and an electronic control device and lasts between about 15 minutes and up to 3 hours, depending on the programme and temperature chosen. Time delay functions are incorporated in some machines and allow either to shift the starting time by a defined number of hours or to end the process at a predefined time.

Electrical energy is used mainly for heating up the water to the desired temperature, for driving the drum motor and for the other electronic devices, including the user interface. But also after the end of the programme electricity is used by many machines (to a very small extend) to keep some safety functions alive, like water protection sensor systems or remote control systems. Regarding the total water consumption only about 1/4 to 1/3 of the water is being heated up, while the rest is used as cold water for rinsing.

3.1.2 Penetration in Europe

Washing machine penetration in the EU-15 is normally reported to be quite high (about 95%), although detailed figures are not publicly available for all countries. Most recent sources of information on washing machines include also the new Central and Eastern Europe (CEE) countries which show penetration levels between about 50 and also 95% [EUP14 07b] (Figure 3.1-1). As this penetration is increasing [EUP14 07b], a penetration of 95% of washing machines is assumed for this study.

Figure 3.1-1 Penetration of washing machines in EU-27 (where no data are shown, no data were available in [EUP14 07b])



Source: [EUP14 07b]

3.1.3 Consumption of energy and water in Europe

Only limited data are available regarding the amounts of energy and water used for laundry washing in Europe.

The European commission has published in its Green Book on Energy Efficiency [GRE 05] a total electricity consumption for washing machines of 26 TWh for the EU-15 in 2003. As the EU-15 consisted of about 160 million households this leads to an annual energy consumption per household owning a washing machine of about 170 kWh (95% penetration of washing machines assumed).

A recent metering study in Germany [BP 07] has measured the total energy consumption for laundry washing in 100 households for one month to be at 1045,5 kWh and the average consumption per cycle at 0,89 kWh (average load: 5 kg). Extrapolated to one year this leads to an annual electricity consumption of 125 kWh and 141 wash cycles per household.

The Preparatory Studies for Eco-design Requirements of Energy-using Products (EuP) [EUP14 07b] have investigated in an online consumer questionnaire in 10 European countries the consumer behaviour with washing machines and other household appliances. As a result the study shows that the average number of wash cycles declared is at 4,9 per week. Per year (50 weeks) this would lead to 245 wash cycles.

Regarding water consumption there are even less data available.

Berkholz [BP 07] has calculated an average consumption of the 100 households observed of 77,1 m³ per month. This leads to an amount of 9,25 m³ per household per year and dividing this by the observed 141 wash cycles to an average consumption of 66 L per cycle.

For the whole EU an annual energy consumption of 150 kWh per household owning a washing machine may be assumed. Taking the measured average energy consumption per cycle of 0,89 kWh (average load: 5 kg) into account this leads to an average number of about 170 wash cycles per year. At 66 L per cycle this will correspond to a total water consumption of 11,22 m³ per household per year.

3.1.4 Effects on energy and water consumption due to consumer usage

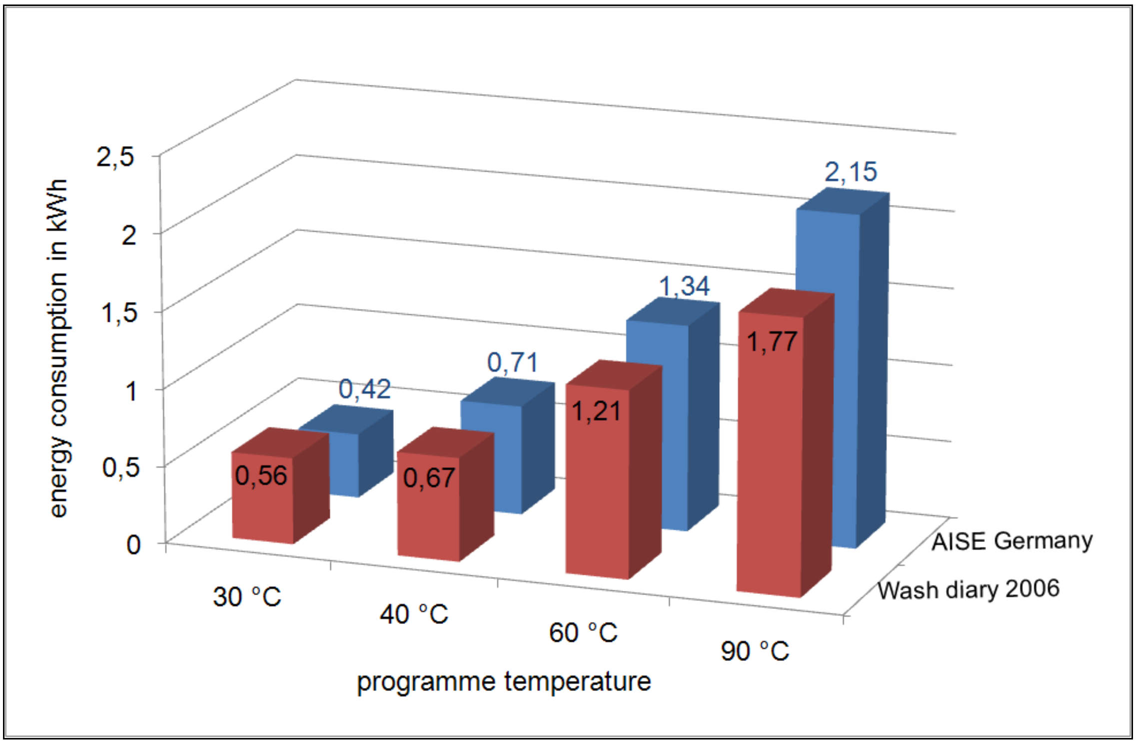
Washing machines are appliances which are operated on consumer demand only. Therefore the consumption of water and energy during the operation is determined by the following, mainly consumer driven, factors:

- Ambient conditions (e.g. temperature…)
- Frequency of operation
- Selected programme and temperature in combination with amount (and type) of detergent
- Additional rinse option chosen
- Machine efficiency under real use conditions
- Load size used
- Time span in low power mode (start delay + standby)

The frequency of operation mainly depends on the household size, as this defines the amount of load to be treated. For washing machines a consumer research [BP 07] of the real washing practice in 100 households in Germany for one month in 2006 has shown a more or less linear increase of wash cycles with the number of persons living in the household. The same study has measured the weight of the laundry washed and concluded, that per person per week an almost constant load of 4,0 kg of laundry was washed.

Average measured energy consumption per washing temperature found in this study in Germany may be compared to values which had been calculated in 2001 using a stock model [AISE 01] for the EU-15 (Figure 3.1-2). The comparison shows some significantly lower values for the boil wash programme and somewhat higher values for low temperature programmes at 30°C in [BP 07]. This increase at low temperatures between 2001 and 2006 may be explained by an increased washing performance at lower temperatures, as these programmes are more and more used as real washing programmes, while in former times these programmes where more seen as pure refreshing programmes.

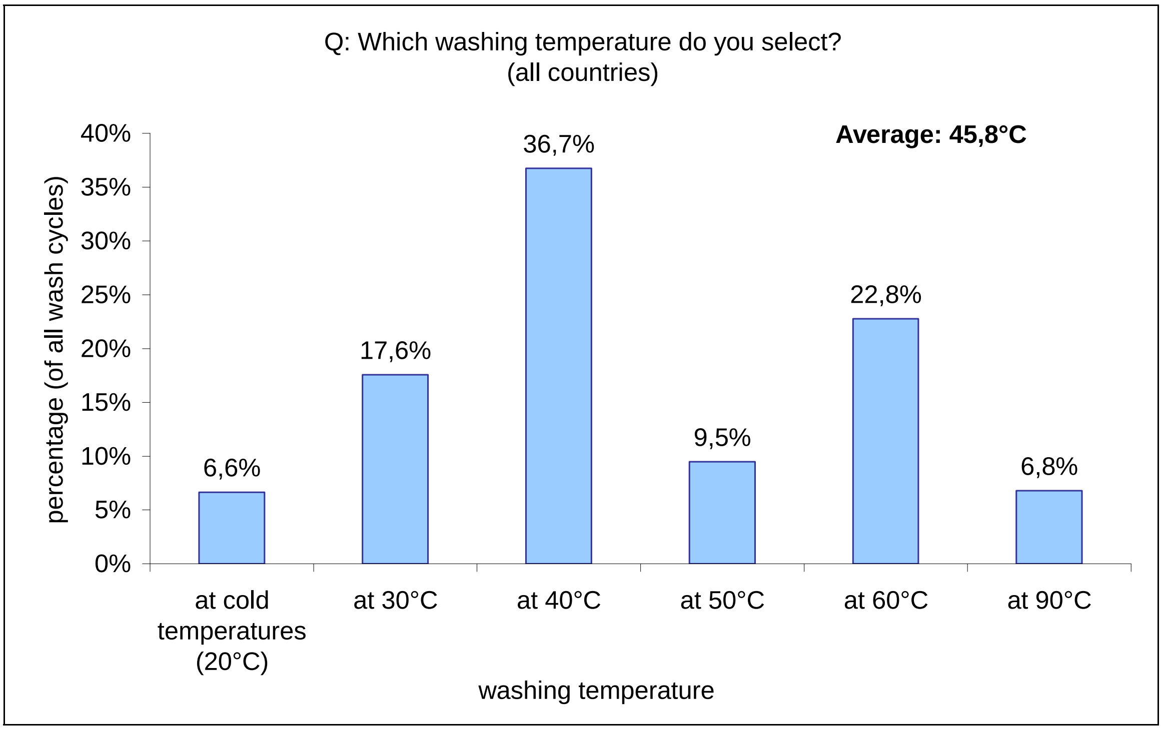
Figure 3.1-2 Average energy consumption at different wash temperatures in comparison to a stock model prediction



Source: University of Bonn

Investigating almost 2.500 consumers from 10 countries about their washing behaviour the result of the EuP-Studies [EUP14 07b] shows a clear preference for the 40°C programmes (Figure 3.1-3) with 37% of all programmes. The second most used temperature is 60°C with 23%. But also the 90°C is named to be used by almost 7%. The average of all these nominal wash temperatures is calculated to be 45,8°C.

Figure 3.1-3 *Relative occurrence of wash temperatures in Europe (average of 10 countries)*



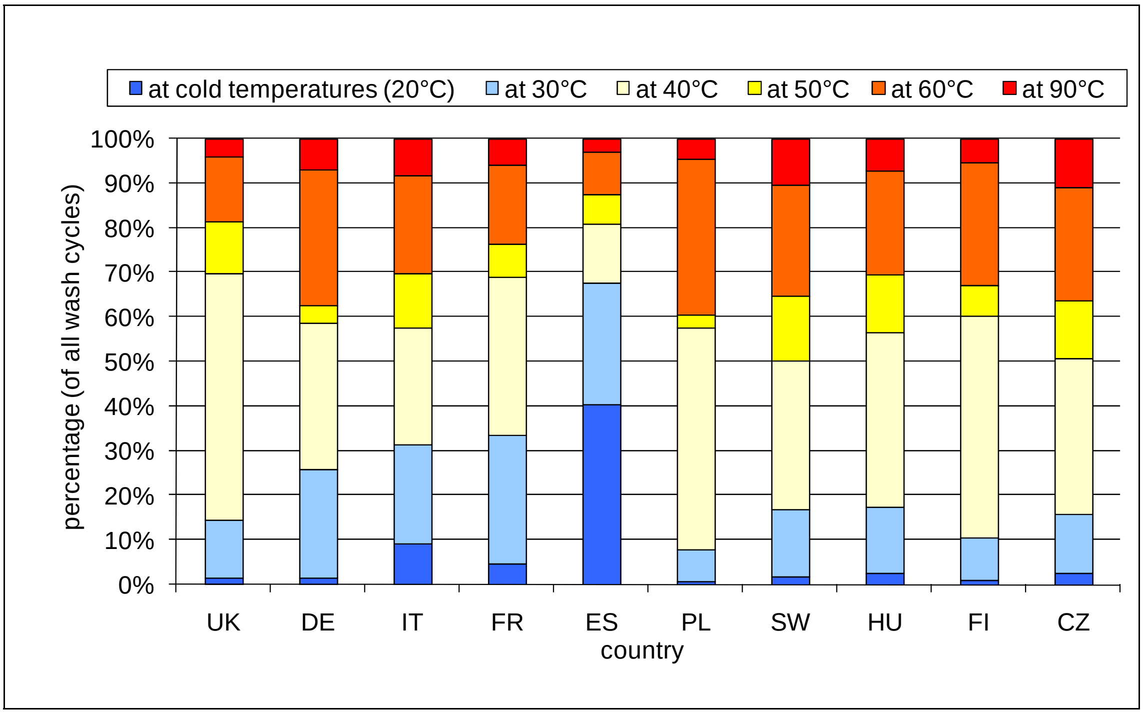
Source: *University of Bonn*

A closer view (Figure 3.1-4) on the distribution of temperature in the 10 countries shows that:

- in one country (Spain) more than 40% of the washing is done at cold temperatures, which means the water is used straight form the tap and almost no (3%) boil wash programmes are used,
- in other countries (especially Sweden and Czech Republic) more than 50% of the wash temperatures chosen are at or above 50°C and the boiling wash is used more often than 10%.

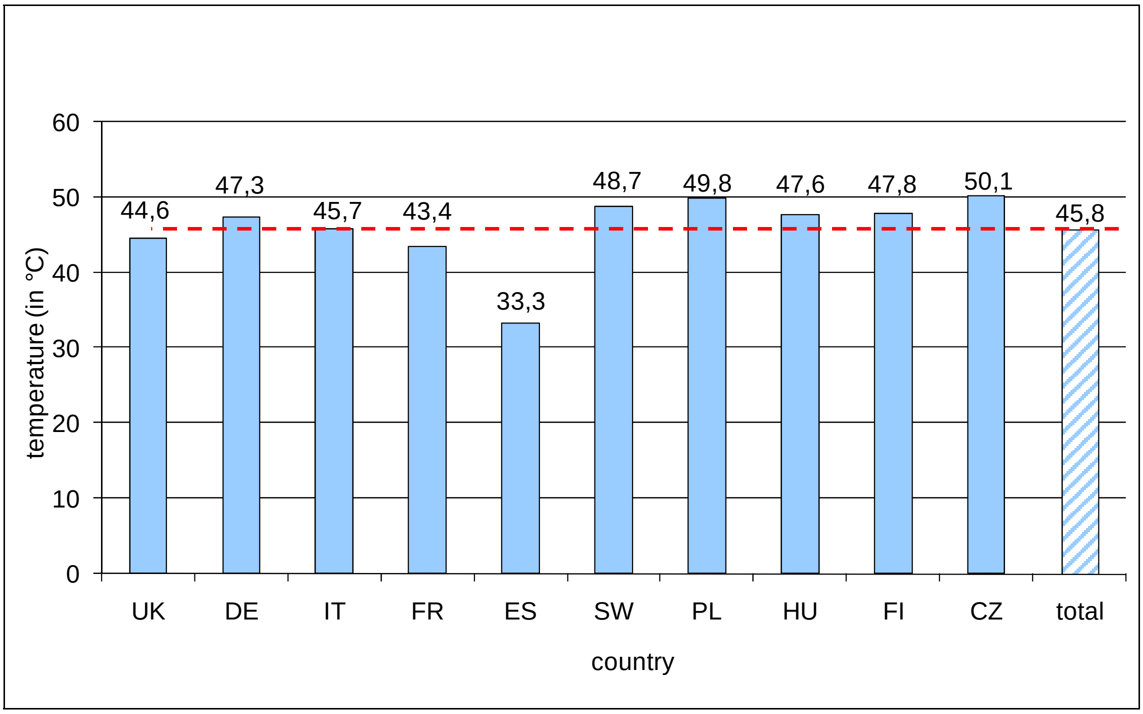
These differences are also visible when looking at the average washing temperature for all of the investigated countries (Figure 3.1-5), which range from 33,3°C to 50,1°C.

Figure 3.1-4 Temperature distribution of washing programmes for various countries



Source: University of Bonn

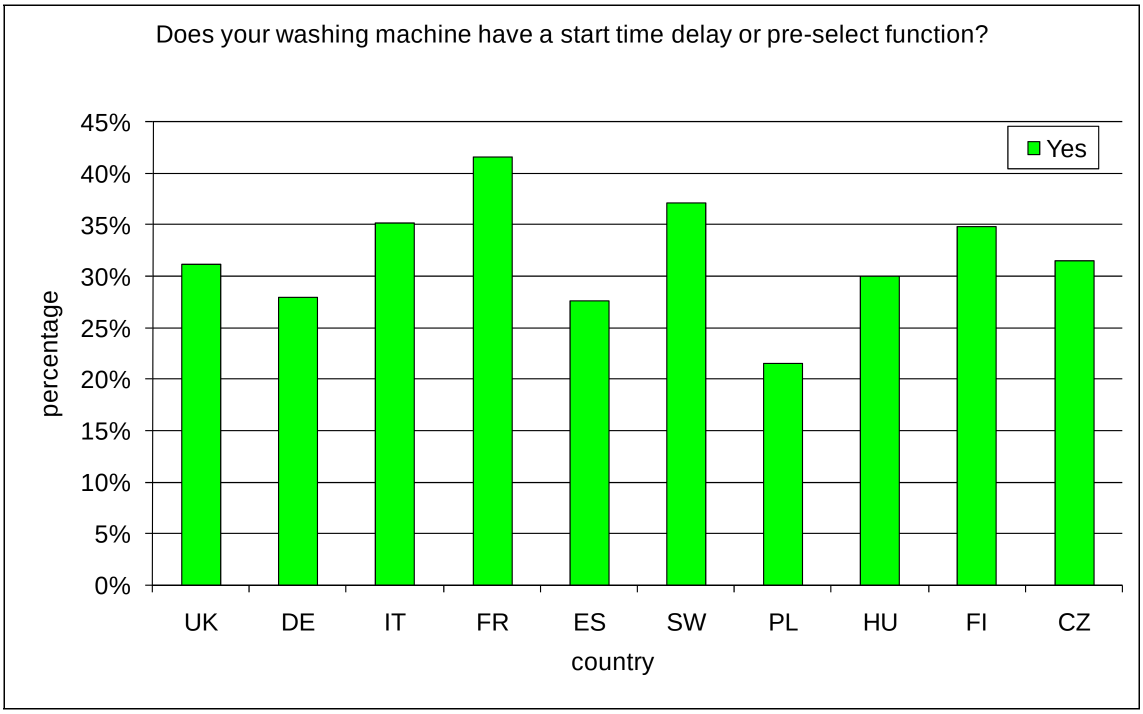
Figure 3.1-5 Average nominal washing temperature



Source: University of Bonn

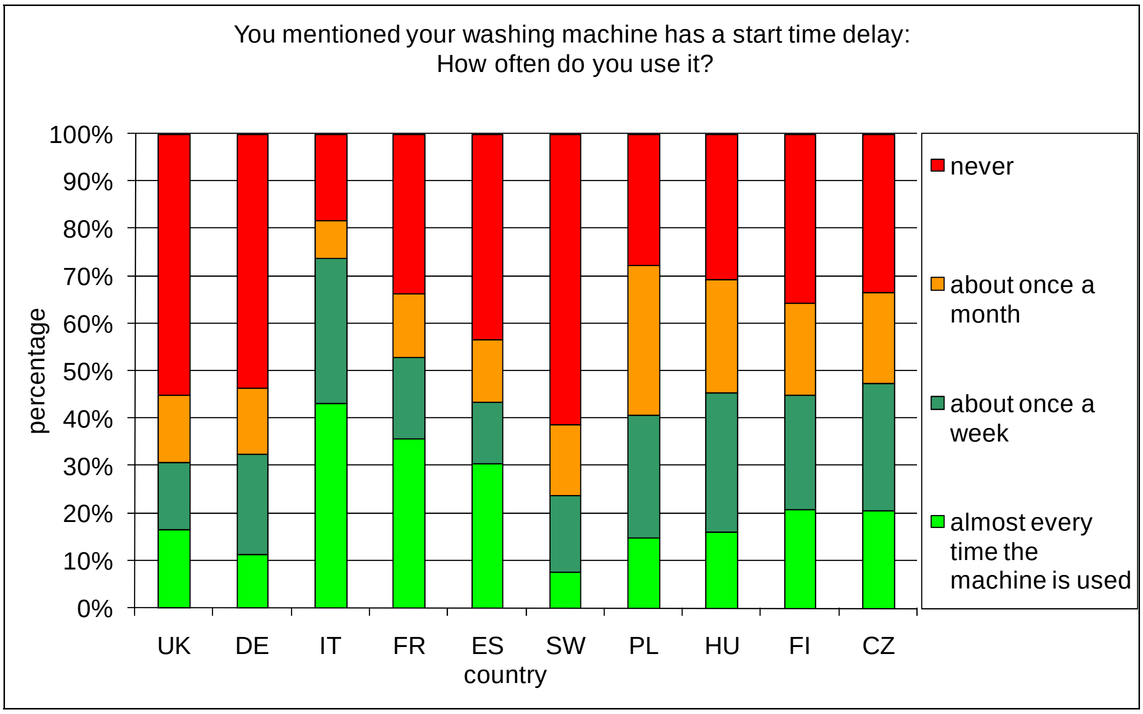
Another main issue of the same study [EUP14 07b] focused on the question whether or not a machine has a start time delay or pre-select function and how it is been used. This function allows to shift the starting time to any hour of the day or night when probably cheaper tariffs are offered. Overall 32% of the washing machines are equipped with such an option. The exact share differs between the regarded countries (Figure 3.1-6).

Figure 3.1-6 Availability of start-time delay or pre-select function



Source: University of Bonn

Figure 3.1-7 Usage frequency of the start time delay function

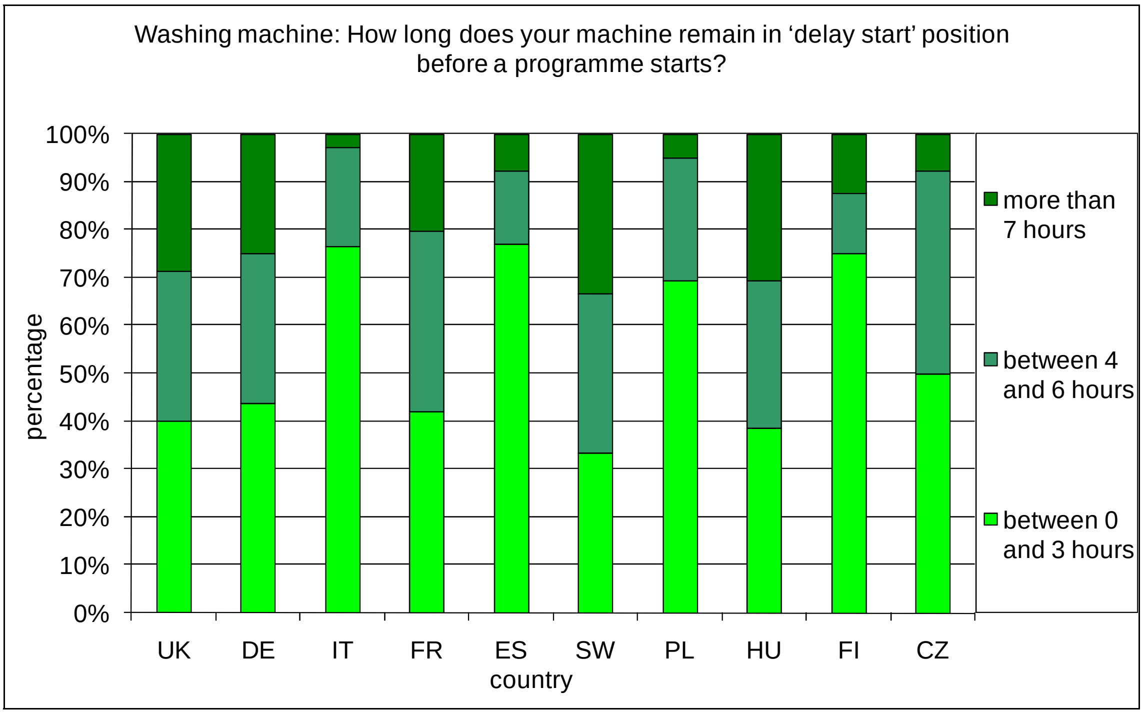


Source: University of Bonn

When asked about the frequency of usage of this start time delay option, most consumers confess (Figure 3.1-7) to ‘never’ use them (in average 40%). Only 22% say they almost always use this function and another 22% use it about once in a week.

This function also has a possible negative impact on the energy consumption, as the machine will consume a small amount of energy when waiting for the start time. Asking those consumers who have a start time delay function in their washing machine and who make use of it about the selected start time delay, in average 56% choose a time between 0 and 3 hours (Figure 3.1-8) while 28% use it to delay the start time between 4 and 6 hours and 16% to delay it for more than 7 hours.

Figure 3.1-8 Frequency of start time delay hours

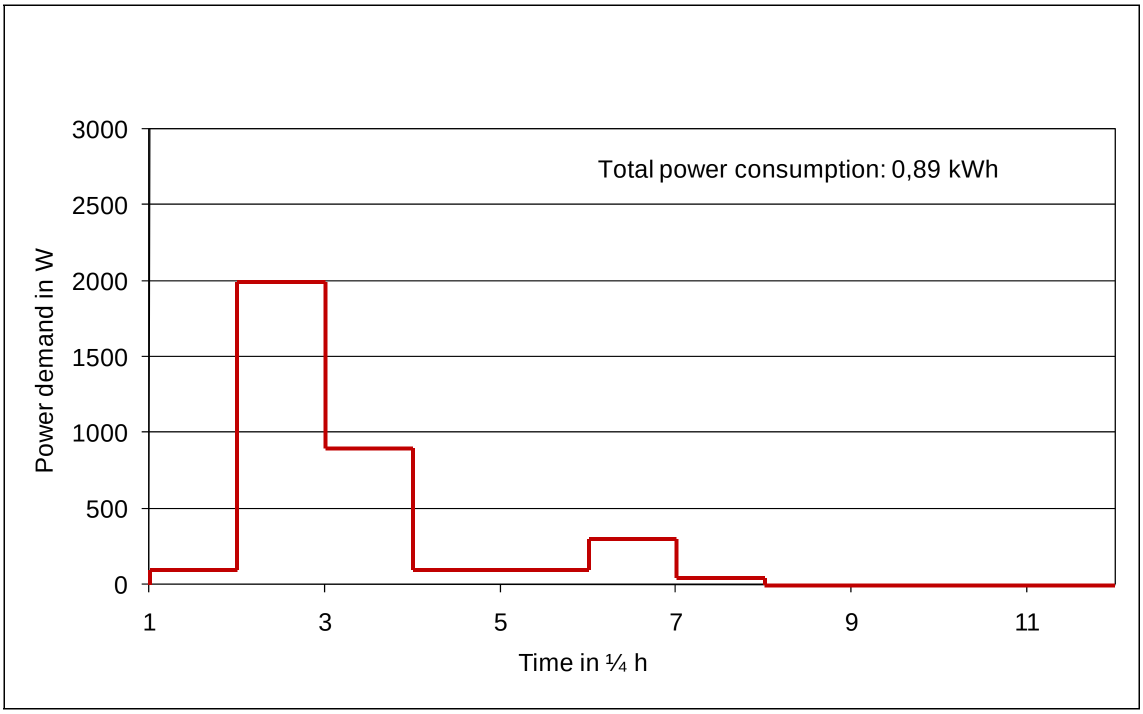


Source: University of Bonn

3.1.5 Power demand and load curves

The power demand curve of an average washing process needs to fit the average total energy consumption value of 0,89 kWh per cycle (average load: 5 kg). Having a normal cotton programme as a guidance and splitting the power demand into ¼ hour steps this leads to an estimated power demand curve (Figure 3.1-9).

Figure 3.1-9 General pattern of a power demand curve of a washing machine in ¼ hour steps

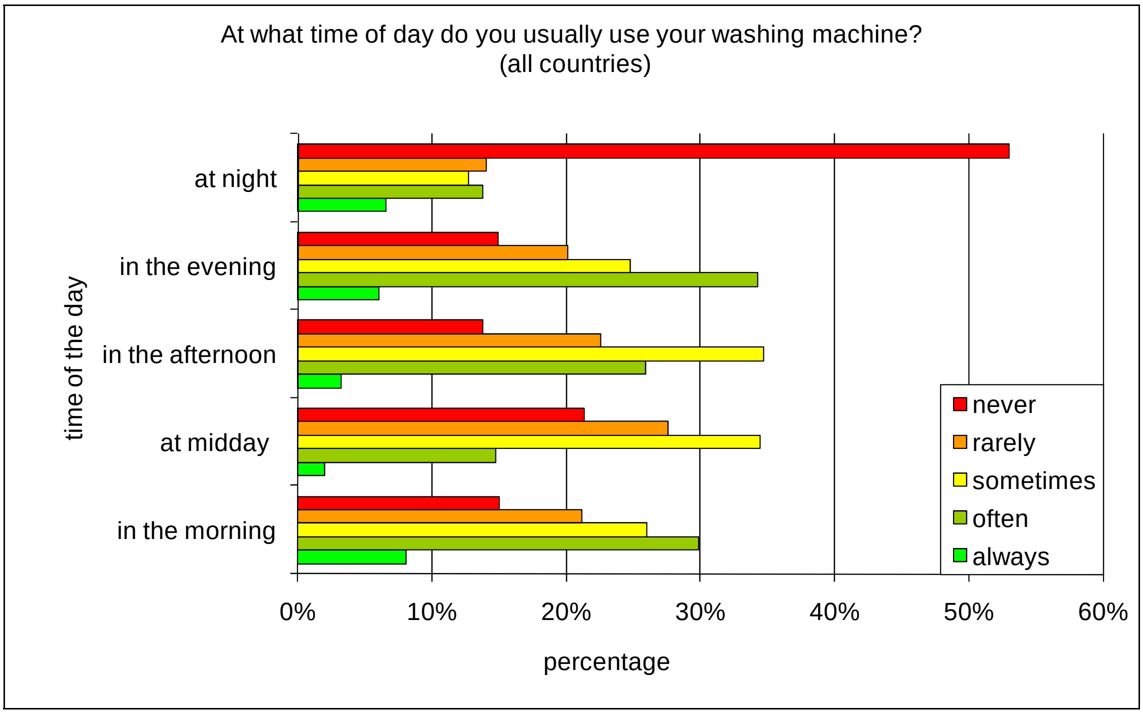


Source: University of Bonn

This power demand may vary from programme to programme and between machines. But when the machine is started by the consumer this kind of power demand will be drawn by the machine from the power line automatically. Only if the consumer has activated a start time delay function this power demand is shifted by a defined number of hours.

Having asked how often and at what time consumers usually run their washing machines the survey of almost 2500 consumers from 10 European countries [EUP14 07b] reveals a very fragmented behaviour (Figure 3.1-10).

Figure 3.1-10 Frequency of operation of the washing machine during the day



Source: [EUP14 07b]

To transfer this behaviour into information about the hour of the day when the operation is started the data of the consumer survey were prepared as follows:

- Transforming the time of the day into hours of the day

Time of the day	Hours
Morning	6:00 - 9:59 h
Midday	10:00 - 13:59 h
Afternoon	14:00 - 17:59 h
Evening	18:00 - 21:59 h
Night	22:00 - 5:59 h

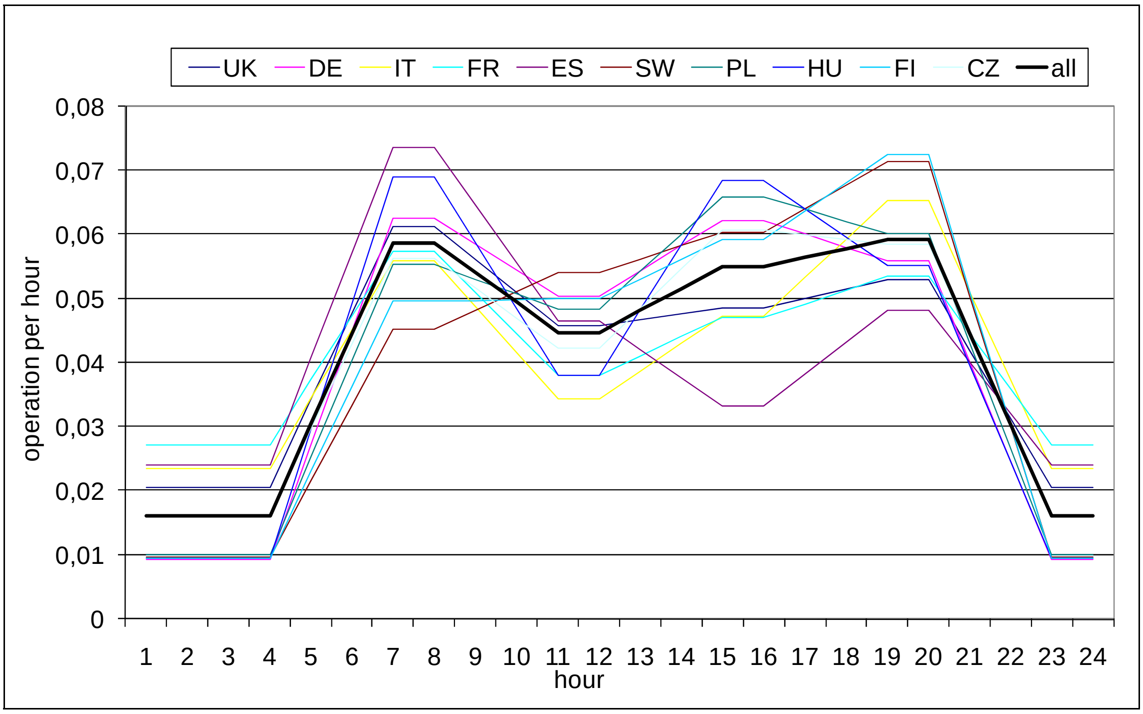
- Transforming the indication about the frequency into percentage information

Frequency	Percentage
Always	100%
Often	75%
Sometimes	20%
Rarely	25%
Never	0%

- Normalizing the sum of percentages per household to be at 100%
- Smoothing the curve by calculating the moving average over three hours.

This leads to a detailed estimation about the start time of the washing machine operation for all 10 countries investigated (Figure 3.1-11).

Figure 3.1-11 Estimated probability of start time of washing machine operation for 10 European countries

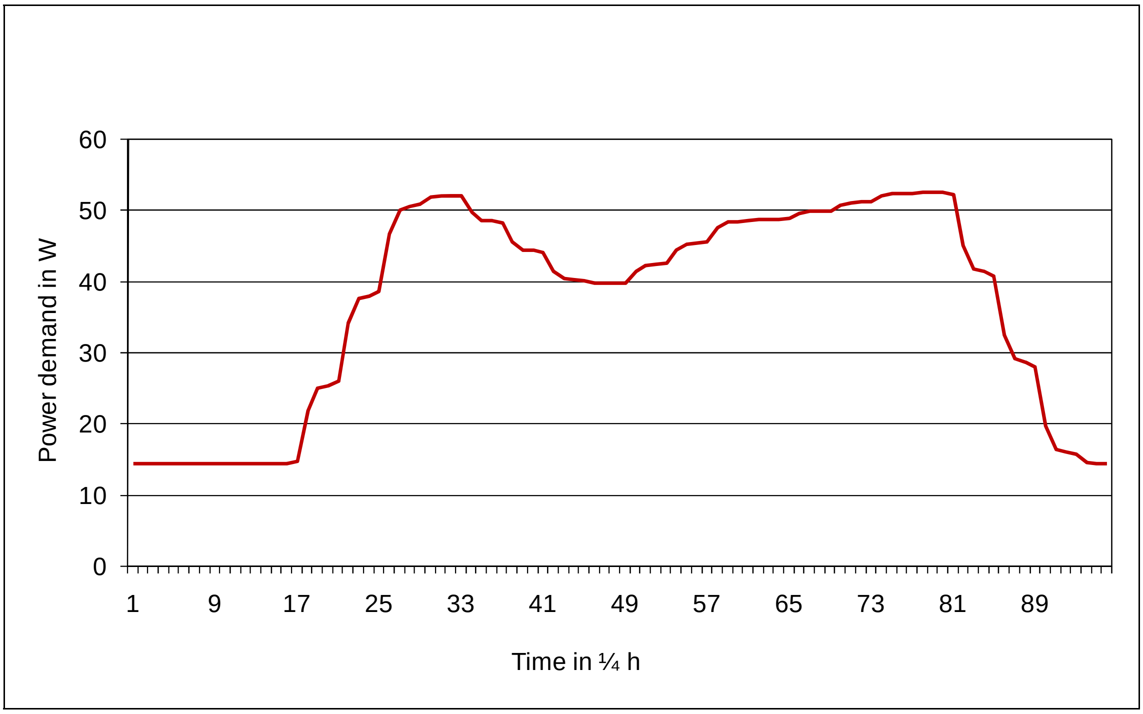


Source: University of Bonn

This analysis shows some significant behaviour as there are two dominating periods where washing machines are being used: either in the morning or in the late afternoon/evening. But there are exceptions, as in Sweden and Finland where are significant more machines operated in the evening than in the morning and vice versa in Spain where more machines are run in the morning.

Using the average behaviour to start a washing machine cycle of the consumers in these 10 countries and combining this with the average power demand a washing machine cycle will take when started (Figure 3.1-9), results in the average power demand which is needed for operating a washing machine (Figure 3.1-12) per day per household. While during the night this power demand is low at about 14 W, during day time two peak periods are seen: one in the morning and one in the afternoon and evening.

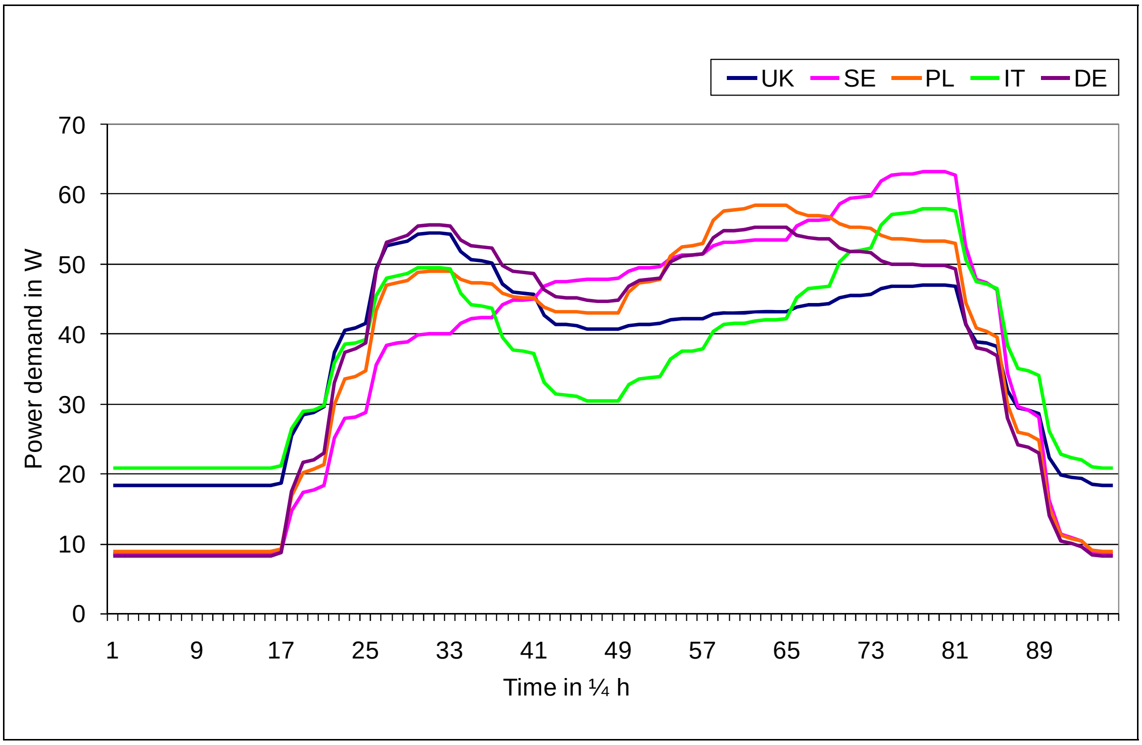
Figure 3.1-12 General pattern of a daily load curve for washing machines using average EU start time function



Source: University of Bonn

The shape of the curve varies due to the different behaviour of the consumers from country to country. The different curves for the countries representing the regions selected in this study are shown in Figure 3.1-13.

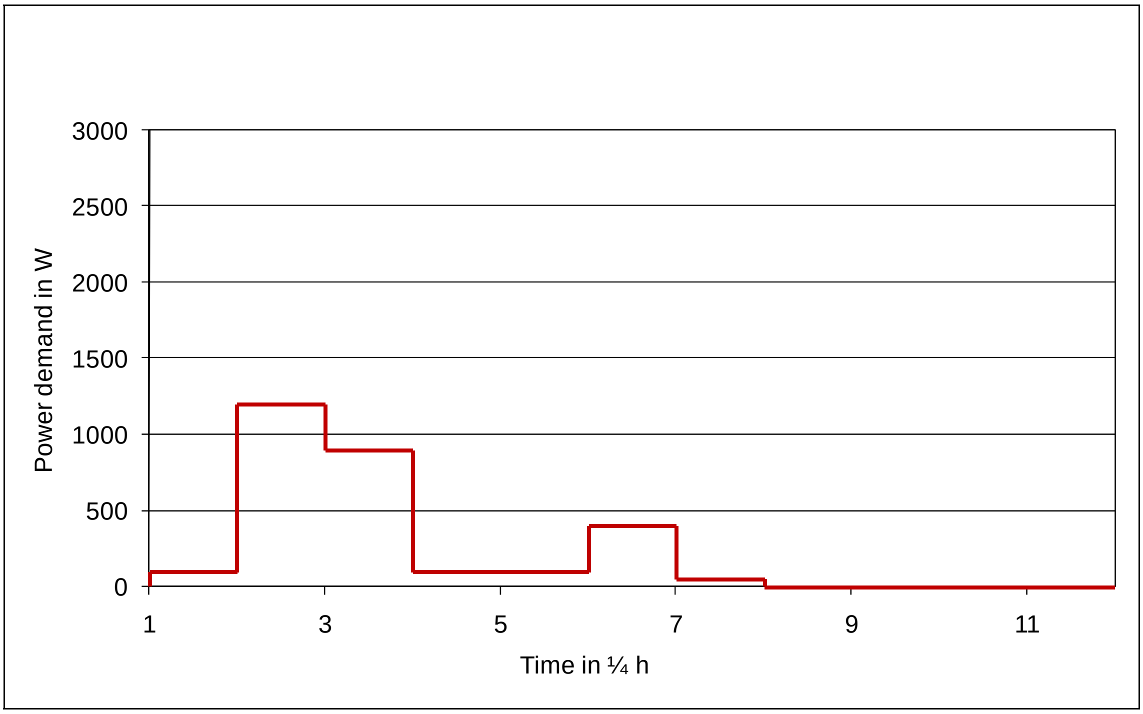
Figure 3.1-13 General pattern of daily load curves for washing machines in the countries representing the regions selected in this study



Source: University of Bonn

Forecasting the development of washing machine power demand and energy consumption for year 2025 is mainly based on an expected increasing pressure for further reductions coming from overall CO2-saving requirements, backed in Europe by policies like Energy Labelling or other EuP measures. This leads to a possible reduction of the energy consumption per cycle of about 20% (0,71 kWh per cycle with an average load of 5 kg), but the number of washes per year are expected to raise by 10% to 165 cycles. The energy saving will be realised by using lower washing temperatures, but spinning requirements will be maintained or even increase. This will cause a significant shift in the power demand curve (Figure 3.1-14).

Figure 3.1-14 Estimated power demand curve of an average washing machine in year 2025



Source: University of Bonn

No other dramatic changes are expected to happen in a 'business as usual' scenario affecting the power demand of washing machines in 2025.

3.1.6 Synergistic potentials

Within this chapter it is tried to explore possible synergies when washing machines are somehow linked to sustainable energy sources, like solar or wind energy or heat from CHP processes. For each of these synergistic potentials it is described where the synergy comes from, what are possible constraints and what needs to be fulfilled to gain the potential. It is also estimated how many appliances might be affected and how these synergies might affect the power demand curve or the probability of operation of washing machines, including a possible recovery phase. As most of these synergies are not yet realised, they are somewhat hypothetical, but based on best engineering practise. If costs are given, they describe the expected additional prize the consumer has to pay for this feature. If ranges are given, the higher value normally corresponds to an implementation of this feature in a first introduction phase, while the lower value estimates how costs may develop at a large scale use. Results of the consumer survey will be added in a supplementary document to this report.

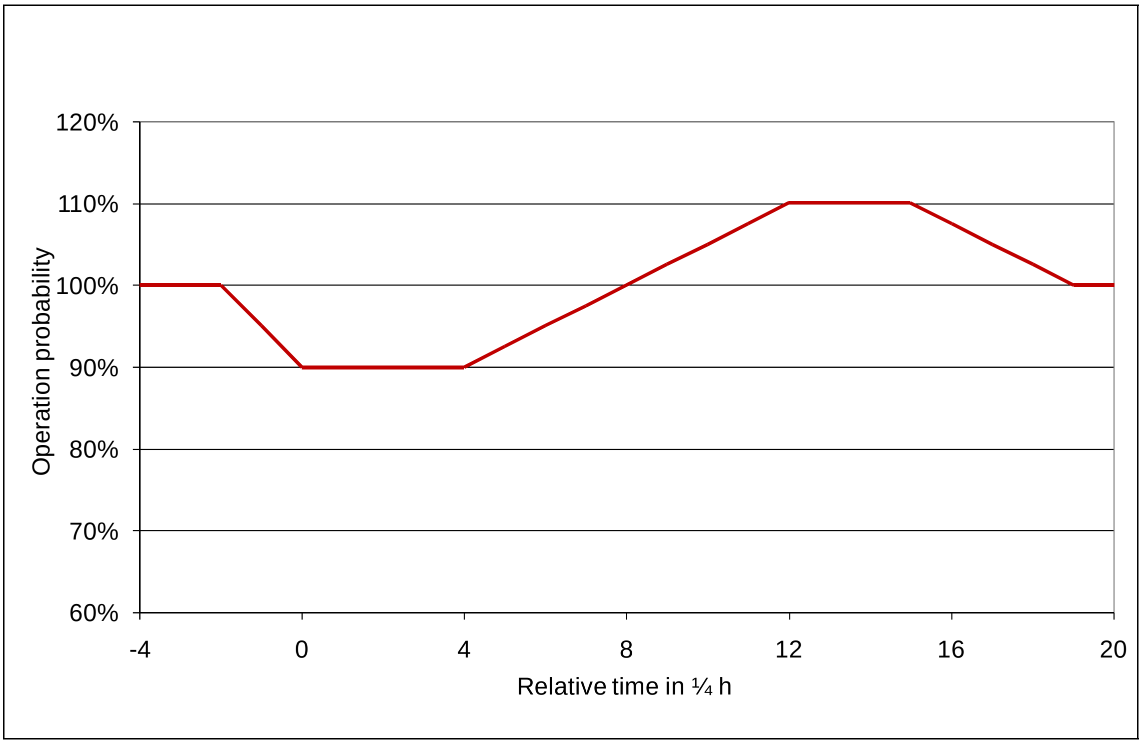
In the following synergy scenarios the complexity of technical adjustments on the device considered increases from level 1 (3.1.6.1) to level 4 (3.1.6.4) steadily. Whereas in level 1 the consumer still has the full control whether to use the described option or not, in level 2 some of that control was handed over to the machine which then reacts to incoming signals. In level 3 the full control is in the hands of an external manager (e.g. electric utility) who decides about when and how often the machine is being switched on or off after it was set in a ready mode by the consumer. Therefore signals are being transmitted in a bidirectional way. In level 4 additional options for storing energy or using other technologies are taken into account.

3.1.6.1 Shifting operation in time

Id and title: 1-1 Consumer shifts operation in time
Description: The consumer receives a signal about the availability of renewable energy or energy from CHP plants. Depending on the signal, he shifts the operation of a washing machine cycle to run at a time, where in relation to the expected load too much electricity is generated. The information about the availability may be communicated via radio (e.g. weather forecast), internet or remote control signals coming from the electricity provider. The consumer has to make his own decision whether to use this information or not. Available “start time delay” options may be used.
Strategy for appliance control: This synergy option requires the active engagement of the consumer by transferring the information of shortage or surplus of renewable energy into the operation of the appliance. The broadcasting of the information may be randomized or varied in time locally to avoid that too many consumers are acting on the same signal at the same time.
Change in power demand curve of single appliance: No change.
Change in day curve (of power demand of all appliances): As at present about 8% of the washing machines are operated by using the start time delay function [EUP14 07b] it is estimated that at maximum perhaps for 10% of the operations the described mode is used. The option allows shifting the power demand at any time in any direction. A delay of the operation by up to 3 hours is estimated as the most likely scenario (at maximum a shift of up to 9h is assumed), which will result in a reduction of the operation probability, followed by a recovery period (Figure 3.1-15).
Consumer benefits and drawbacks: Consumers may engage themselves in the enhanced use of renewable energy and CHP.
Demand management benefits and drawbacks: Consumer behaviour is unpredictable. Experience may allow forecasting consumer behaviour. Consumer acceptance may depend on the time of the day and season (e.g. the use of sunshine for drying).
Impact on appliance design and service provided: (additional costs, limitations, additional energy consumption): Delay start timer may be helpful. Already today available in about 30% of appliances in the stock. Additional costs for consumer between 5 € - 25 € for start-time delay option. Additional energy consumption: 0 W - 4 W (depends on the use of a start time delay function)

Consumer acceptance questions:
Willingness to accept this solution if additional costs are balanced by savings via energy bill. Calculation (additional costs: 15 €): 150 kWh/a at 0,20 €/kWh = 30 €/a energy costs Amortisation in 5 years: 3 €/a saving Reduction of energy costs by 10% needed.
Strategies for success:
Increase environmental awareness and practise.

Figure 3.1-15 Example of a change in operation probability for synergy scenario 1-1



Source: University of Bonn

3.1.6.2 Applying flexibility on appliance power demand

Id and title:
2-1 Power line triggered operation
Description:
Signals via e.g. power line may be used to communicate about the availability of surplus power on the grid. This can be detected by the washing machine and transferred into action. Action may be an immediate start as far as the machine is in a start time delay or in a special "ready for operation" mode. Alternatively other means like frequency sensing might be used as the frequency is changing with total load on the grid and high availability of energy will increase the load and thus the frequency.
Strategy for appliance control:
Washing machine start is anticipated when machine is in start time delay or "ready for operation" mode. To avoid overload by too many machines starting the same time, the algorithm used to define the start time shall have a random factor including shifting the decision up to two hours.

Change in power demand curve of single appliance:

No change.

Change in day curve (of power demand of all appliances):

May allow to shift perhaps 10% of the operations at any time in any direction. As it is assumed that the machine is in start time delay operation mode, an anticipation of the operation will allow an increase of the operation probability (Figure 3.1-16) short term, followed by a drop of the probability. A shift of the operation by 3 hours is estimated as the most likely scenario (at maximum a shift of up to 9 hours would be possible).

Consumer benefits and drawbacks:

Enhanced use of renewable energy and CHP. Possible irritation of consumers when machine starts at any time (e.g. also during night).

Demand management benefits and drawbacks:

Usage depends on the acceptance of a start time delay operation by the consumer.

Impact on appliance design and service provided: (additional costs, limitations, additional energy consumption):

Start delay timer needs including frequency sensing (or other) means. After programme end some reversing function is needed to avoid sticking together and going mouldy of the load.
Additional costs for consumer (start time delay or the like): 10 € - 50 €.
Additional power consumption:

- in start time delay mode: > 0 W - 4 W
- after programme end: 0 W - 4 W.

Consumer acceptance questions:

Willingness to accept this solution if additional costs are sponsored by energy utility.

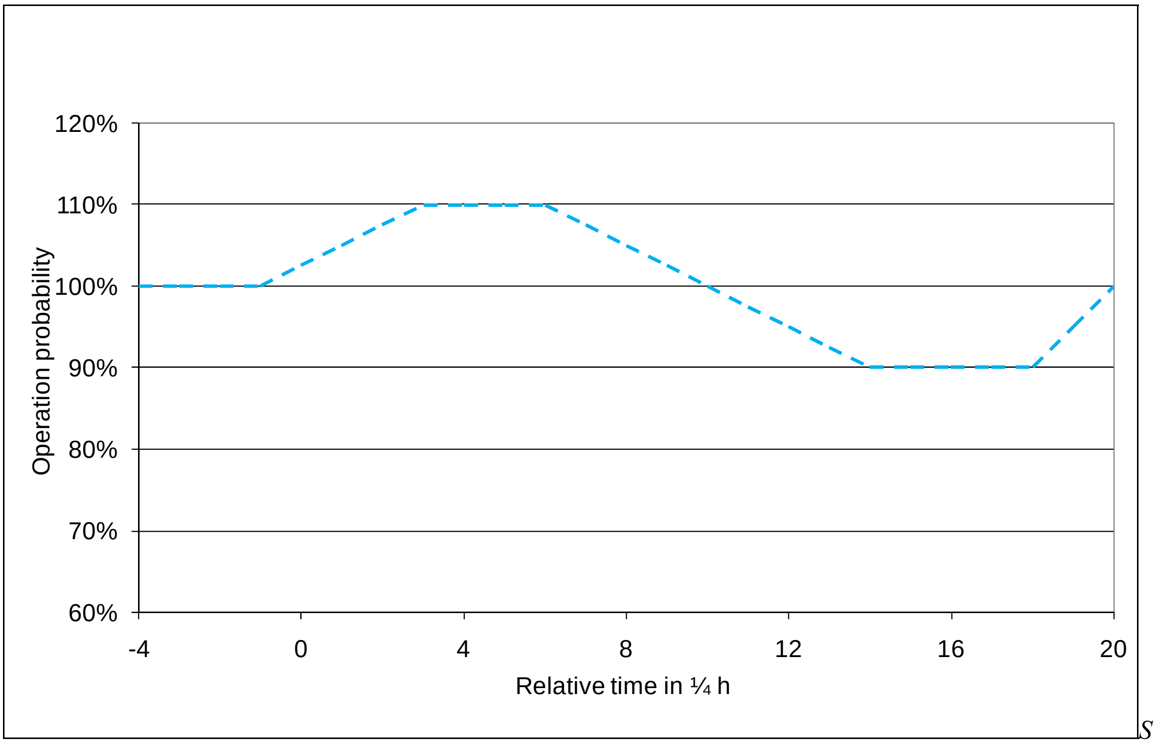
If differentiated tariffs are offered, there is a willingness to use start delay function to save money.

Calculation (additional costs: 30 €):
150 kWh/a at 0,20 €/kWh = 30 €/a energy costs
Amortisation in 5 years: 6 €/a saving
Reduction of energy costs by ~20% needed.

Strategies for success:

Define business model where energy utilities sponsor the implementation of these “Power line triggered” modules.

Figure 3.1-16 *Example of a change in operation probability for synergy scenario 2-1*



Source: *University of Bonn*

Id and title:

2-2 Internal energy manager agent

Description:

Triggered by an external signal about shortage of energy the washing machine may change its operation:

- delay the start of the heating phase
- interrupt the heating phase up to a certain time
- reduce the power demand by choosing a lower temperature for the programme and prolonging the washing time
- prolong the final rinsing phase to shift the final spinning operation.

Strategy for appliance control:

The external signal should include information on the shortage of energy and how long it may last. Washing machines being in an appropriate state will then react by their own intelligence to find the appropriate answer.

Change in power demand curve of single appliance:

Various. May shift heating time or heating power by seconds and minutes.

Change in day curve (of power demand of all appliances):

As today 8% of the washing machines are operated in the start time delay mode it is estimated that at maximum 10% of the operations may be used in the described mode and allows to shift the operation by seconds and minutes. Assuming an immediate stop of all smart controlled appliances for a ¼ hour (plus a recovery of the operation after this time) the operation probability will be changed as shown in Figure 3.1-17.

Consumer benefits and drawbacks:

Enhanced use of renewable energy and CHP. Possible irritation of consumers when machine stops. But short term breaks may not be recognized at all. Impact on washing results must be limited. Too long breaks during heat-up period will cause a loss of energy.

Demand management benefits and drawbacks:

Influence on power demand by short term action. Effect will depend on the time of the day, the season and the penetration of energy management agents in washing machines. As short term interruptions of the washing process may cause damages (e.g. colour fading) some reservations at consumer side may hamper a large-scale usage.

Impact on appliance design and service provided: (additional costs, limitations, additional energy consumption):

Internal energy manager agent needs to be included in electronic unit of machine.
A harmonised signal of power shortage is needed.
Additional costs for consumer (signal recognition plus energy agent): 10 € - 100 €.
Additional power consumption: during operation > 0 W - 4 W.

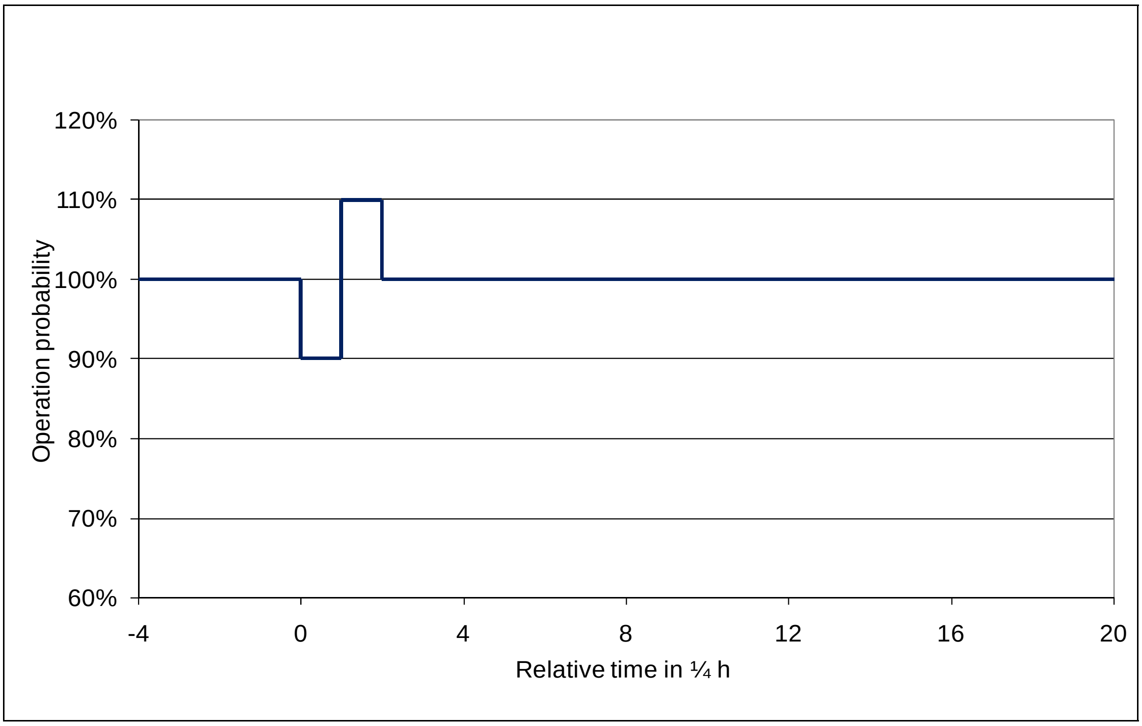
Consumer acceptance questions:

Willingness to accept this solution if additional costs are balanced by savings via energy bill.
Calculation (additional costs: 55 €):
150 kWh/a at 0,20 €/kWh = 30 €/a energy costs
Amortisation in 5 years: 11 €/a saving
Reduction of energy costs by ~37% needed.

Strategies for success:

Define harmonised signal for shortage of power (CENELEC).
Define business model where energy utilities sponsor the implementation of these “Internal energy management agent” modules.

Figure 3.1-17 Example of a change in operation probability for synergy scenario 2-2

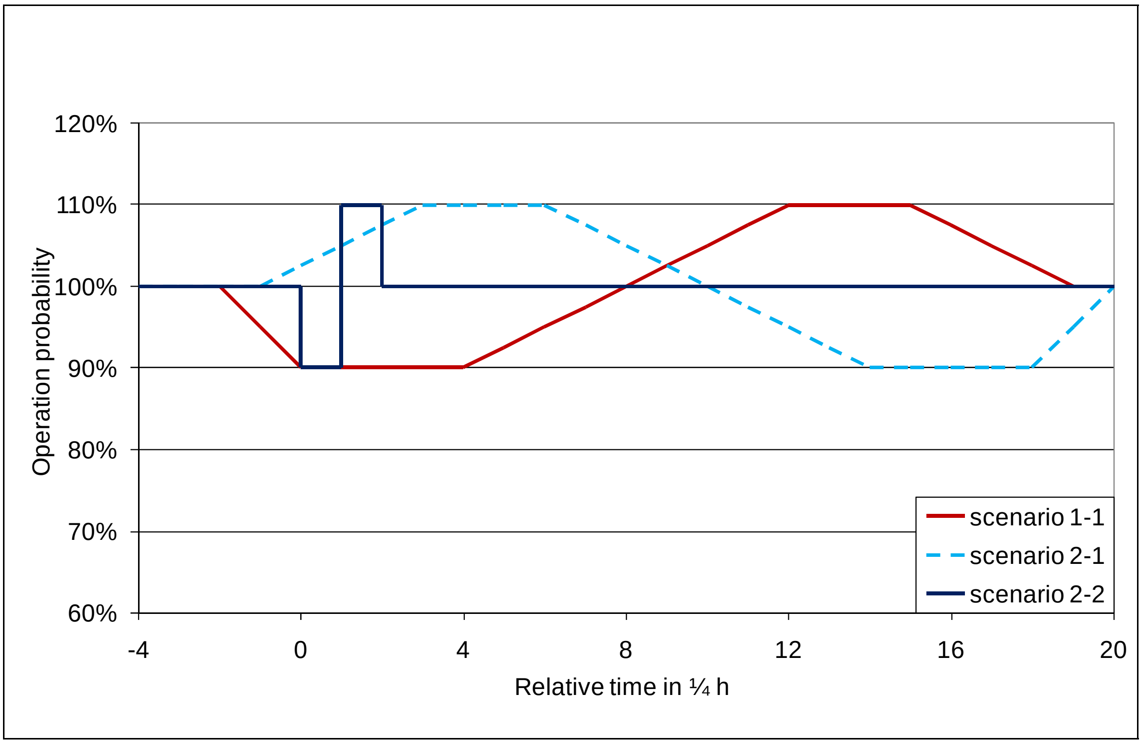


Source: University of Bonn

3.1.6.3 Managing the power on the grid

Id and title: 3-1 Energy demand manager
Description: The energy demand manager tries to harmonise the available power on the grid coming from conventional and renewable resources with the demand. Therefore the washing machine when started is set in a remote control mode which allows the energy demand manager to decide about the start of the machine within a predefined time interval. The energy demand manager is informed about the selected programme or at least the expected energy demand.
Strategy for appliance control: Knowing the demand for the next few hours the energy demand manager tries to use as much renewable energy and energy from CHP as possible and optimises the overall costs.
Change in power demand curve of single appliance: Unchanged.
Change in day curve (of power demand of all appliances): As today 8% of the washing machines are operated in the start time delay mode, it is assumed that at maximum 10% of the operations - at full implementation of the described feature - might be shifted according to any of the probability curves as shown for the synergy scenarios 1-1, 2-1 or 2-2 in Figure 3.1-18 (managed by the energy demand manager). As the consumer is not involved in the operation of the device any more, the probability curve of scenario 1-1 (delayed start) stands for a second option of scenario 2-2.
Consumer benefits and drawbacks: Enhanced use of renewable energy and CHP. Cost benefits must be transferred to the consumer. Consumer remains in the position to decide whether he wants to use this option or not.
Demand management benefits and drawbacks: Influence on power demand by medium term action. Influence only on those machines which are 'online'.
Impact on appliance design and service provided: (additional costs, limitations, additional energy consumption): Bidirectional communication needed. Additional switch needed to signal 'remote operation accepted'. A harmonised communication protocol is needed. Additional costs for consumer (communication module via power line): 30 € - 130 €. Additional power consumption: - during waiting for operation: > 0 W - 4 W
Consumer acceptance questions: Willingness to accept this solution if additional costs are balanced by savings via energy bill. Calculation (additional costs: 80 €): 150 kWh/a at 0,20 €/kWh = 30 €/a energy costs Amortisation in 5 years: 16 €/a saving Reduction of energy costs by ~53% needed.
Strategies for success: Define harmonised communication protocol (CENELEC). Define business model where savings balance the additional costs for the appliance.

Figure 3.1-18 Change in operation probability for synergy scenarios 3-1 (any of 1-1, 2-1 and 2-2)



Source: University of Bonn

3.1.6.4 Using energy storage capacity and other technologies

Id and title: 4-1 Energy storage capacity
Description: As washing is done in many cases consecutively heat may be transferred from one to the other process. Therefore a heat storage tank (either water, phase change material or other) is installed, which is loaded with the energy of the main wash water by a heat exchanger and this heat is transferred to the next (cold) main wash water intake. If washing is done from hot to cold processes the best effect will be achieved. Even if there is no consecutive washing process started, in the next washing process the main wash water will be heated close to ambient temperature and will therefore also save heating-up energy.
Strategy for appliance control: No.
Change in power demand curve of single appliance: Reduced heating power demand by about ⅓.
Change in day curve (of power demand of all appliances): No change.
Consumer benefits and drawbacks: Enhanced use of renewable energy and CHP when operation is additionally linked with availability of renewable energy or energy by CHP.
Demand management benefits and drawbacks: Reduced power demand from washing process in general

Impact on appliance design and service provided: (additional costs, limitations, additional energy consumption):

Heat storage unit needed + heat exchanger.
Cleaning and disinfection of heat storage and heat exchanger needed.
Additional costs for consumer: 150 € - 250 €.
Additional power consumption: 0 W

Consumer acceptance questions:

Willingness to accept this solution although no payback in short term (5 years) will be possible.

Strategies for success:

Define business model where savings balance the additional costs for the appliance.

Id and title:

4-2 Enhanced use of hot water

Description:

As washing is done most frequently at 40°C and higher temperatures, the water intake may be already hot. Hot and cold water intake machine are already available on the market, but without much success. Most of these machines take only hot water for the main wash phase and make therefore only a limited use of hot water. If hot water is available for almost free, it may make sense to use the hot water throughout the washing process to gain the benefits also for the final spinning, which is more effective when the load is warm. By this effect, the load gets out drier and uses therefore less energy in a consecutive drying process. Benefits will be maximised, if electrical drying is used throughout the year.

Strategy for appliance control:

Connect the washing machine to a hot water supply. To avoid negative effects on the washing results, the maximum temperature of the water intake should be at 40°C. If water supply is hotter, a mixing with cold water should be done. This can also be done in a separate unit outside the washing machine.

Change in power demand curve of single appliance:

Heating power reduced by about 50% - total power consumption: 550 Wh (= 62%) (Figure 3.1-19)

Change in day curve (of power demand of all appliances):

No change.

Consumer benefits and drawbacks:

Enhanced use of renewable energy and CHP. Cost benefits.

Demand management benefits and drawbacks:

Operation of the washing machine may be linked to availability of renewable hot water.

Impact on appliance design and service provided: (additional costs, limitations, additional energy consumption):

Either two water inlets (hot and cold) or outside mixing unit.
Programme must be adopted to ensure re-heating and appropriate washing times.
Additional costs for consumer (hot/cold inlet): 50 € - 150 €.
Additional power consumption: 0 W

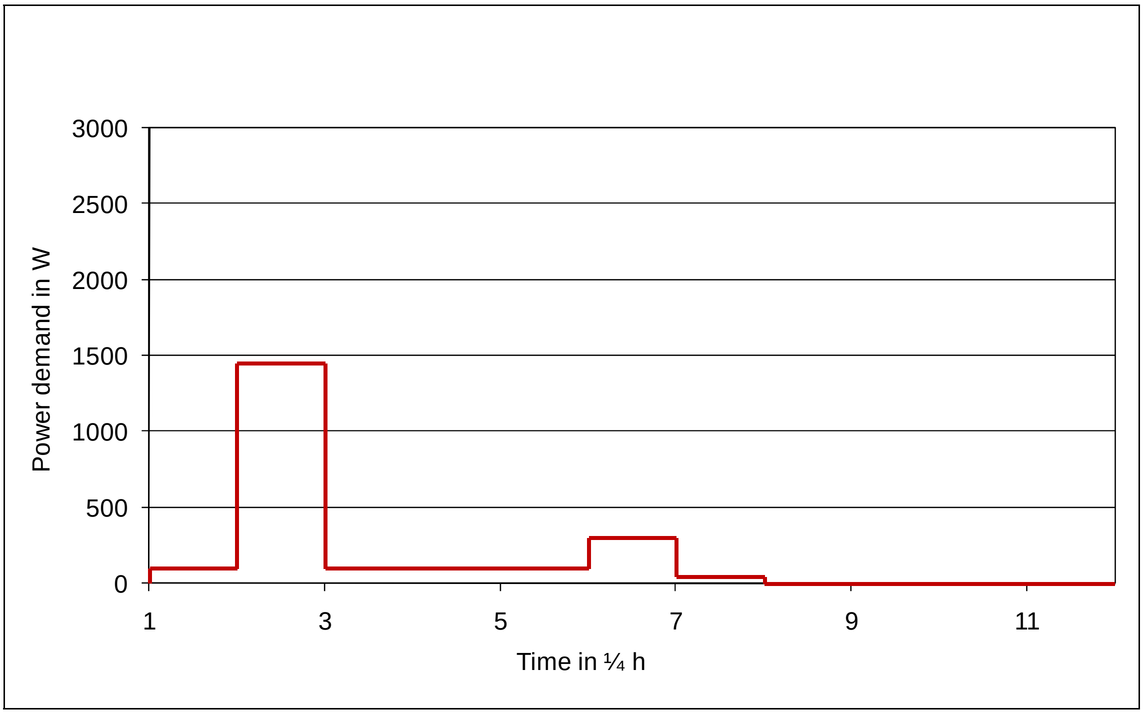
Consumer acceptance questions:

Willingness to accept this solution if additional costs are balanced by savings via energy/water bill.
Calculation (additional costs: 100 €):
150 kWh/a at 0,20 €/kWh = 30 €/a energy costs
Amortisation in 5 years: 20 €/a saving
Reduced electrical energy consumption (62% of 150 kWh) and no costs for hot water assumed:
93 kWh/a at 0,20 €/kWh = 19 €/a energy costs
Reduction of energy costs by 30% needed!

Strategies for success:

Promote use of washing machine with H/C-fill together with renewable (or by CHP) production of heat.
Promote development of external hot-cold mixing unit.
Promote development of washing programmes which can work with water of 40°C water inlet temperature (also of programmes designed for 30°C!).

Figure 3.1-19 General pattern of a power demand curve of a washing machine with H/C-fill



Source: University of Bonn

Id and title:

4-3 Heating by hot water

Description:

Using the warmth produced by a CHP, a solar plant or district heating for heating up the water in the washing machine. The heat is led into the heating rods within the machine which then heat up the water to the desired temperature. Therefore the total amount of electricity for this heating phase is replaced by the use of heat of other systems. Electricity is here only needed for the basic functions of the machine and the spinning cycle.

Strategy for appliance control:

Connect the washing machine to a CHP, solar plant or district heating. To avoid negative effects on the washing results, the water temperature should be controlled by a sensor which stops the heat supply when the desired temperature is reached.

Change in power demand curve of single appliance:

Heating power reduced by 100% - total power consumption: 200 Wh (= 22%)

Change in day curve (of power demand of all appliances):

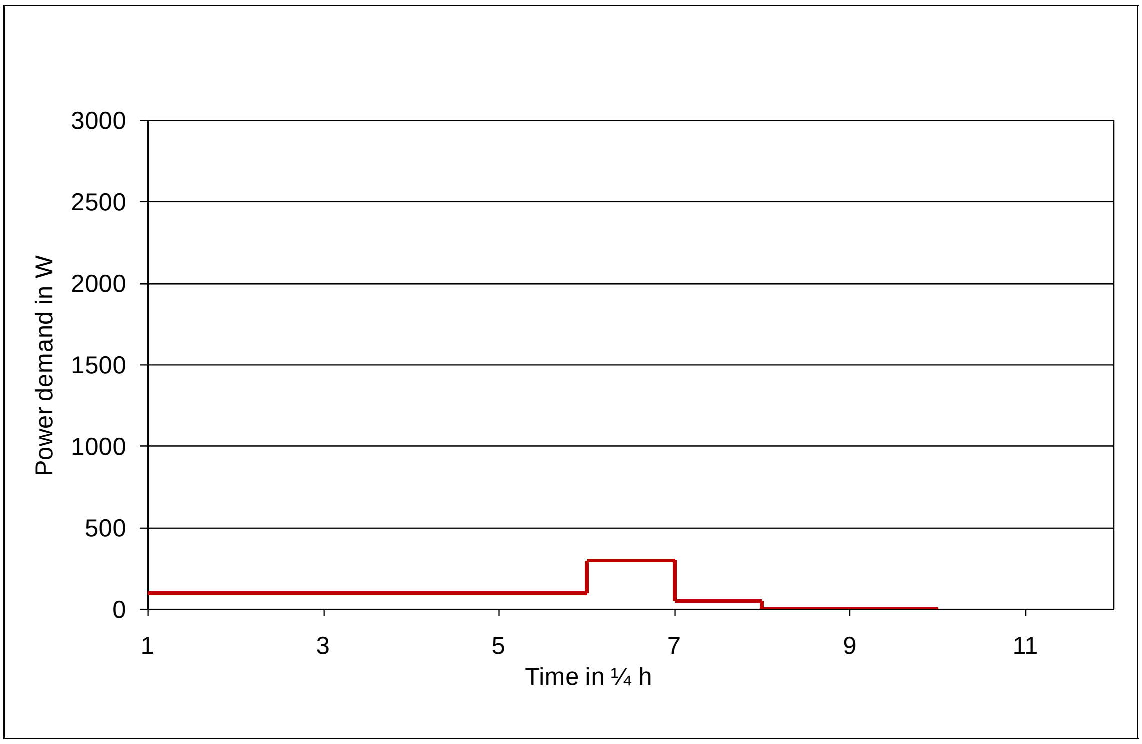
No change.

Consumer benefits and drawbacks:

Enhanced use of renewable energy and CHP. Cost benefits.

Demand management benefits and drawbacks: Operation of the washing machine is linked to the availability of heat by the described suppliers.
Impact on appliance design and service provided: (additional costs, limitations, additional energy consumption): Special heating rods are needed. Programme must be adopted to ensure re-heating and appropriate washing times. Additional costs for consumer: 60 € - 120 €. Additional power consumption: 0 W
Consumer acceptance questions: Willingness to accept this solution if additional costs are balanced by savings via energy/water bill. Calculation without costs for heat from other systems (additional costs: 90 €): 150 kWh/a at 0,20 €/kWh = 30 €/a energy costs Amortisation in 5 years: 18 €/a saving Reduced energy consumption (22% of 150 kWh): 33 kWh/a at 0,20 €/kWh = 7 €/a energy costs This option is economically beneficial for the consumer without any incentive.
Strategies for success: Promotion of washing machines with direct use of renewable (or by CHP) produced heat.

Figure 3.1-20 *General pattern of a power demand curve of a washing machine heated by hot water*



Source: *University of Bonn*

3.2 Tumble dryer

3.2.1 Technical description with regard to the use of water and energy

European type tumble dryers consist of a large drum rotating around a horizontal axis in a squared housing. The wet laundry (coming from a preceding washing process) is loaded through a door into the drum. Hot air is usually generated by an electrical heating system and blown over and through the wet laundry, thus taking up humidity from the laundry and drying it. The humid air is then either vented to the ambient (best via an air duct - vented dryer), or condensed by cooling it down in a heat exchanger via a second air stream (condensation dryer). In both types of dryers energy is mainly needed to evaporate the water from the laundry, thus given by the latent heat. Additional energy is needed to rotate the drum and drive the fans and other components of the gadget. Normal heating power for the heating devices are at 2000 – 2500 W.

As an alternative for heating the air with an electrical heater a gas fired heater is possible. Gadgets following this approach are available on the market, but have a very low acceptance among the consumers. Another alternative is to regain the energy contained in the humid air flow after the drum by the use of a heat pump. If this energy is extracted, it can immediately be used to heat up the air flow of the air going into the drum. In such machines e.g. no electrical heating element is necessary and a saving of about 40 to 50% of the total energy consumption is possible. Such kind of appliance is on the market from several producers, but has due to higher prices so far a minor significance in the market.

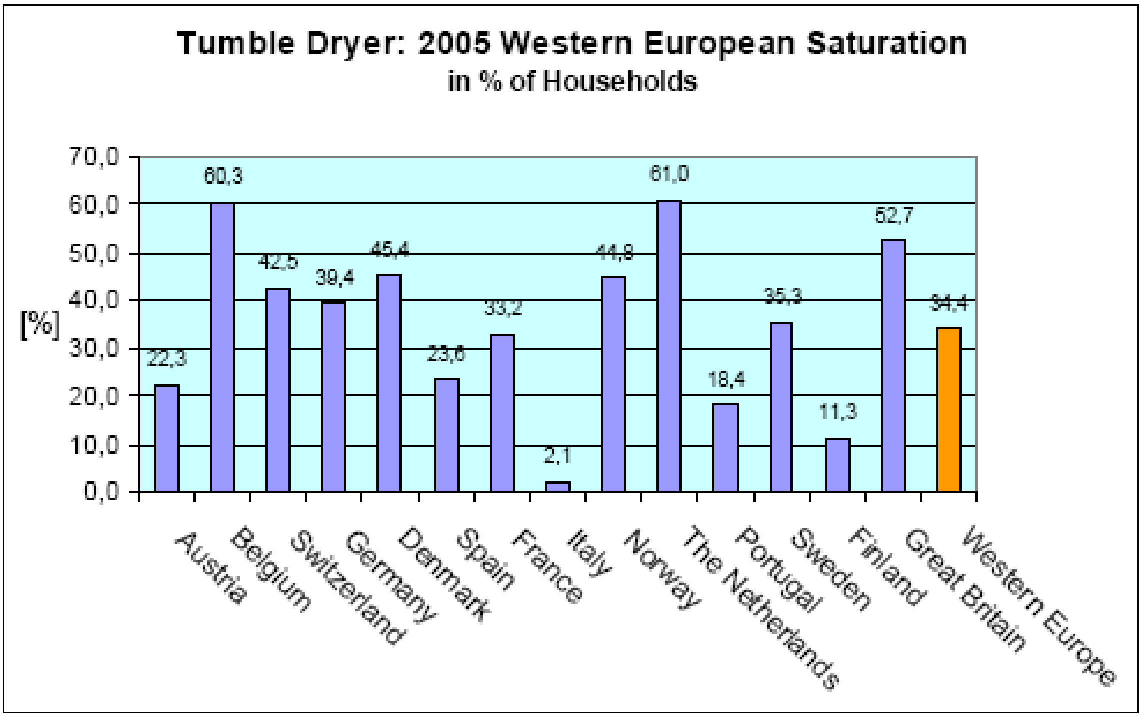
The whole drying process is controlled either by a timer-function where the consumer has to set a predefined drying time or by an electronic control device which detects the humidity of the load and can therefore be used to target a specific final humidity. Time delay functions are incorporated in some machines and allow either to shift the starting time by a defined number of hours or to end the process at a predefined time. To avoid damping of the wet laundry, some kind of drum rotation or pre-drying is recommended for the time waiting for the start of the process.

Regarding water consumption, only oldest dryers were designed to use water for air condensing purposes.

3.2.2 Penetration in Europe

The tumble dryer penetration in Western Europe is in average at 34,4% but showing wide variations from country to country (Figure 3.2-1) which lie between 2 and 61%. In Eastern European countries tumble dryers are not present in the market (the average is at 1%).

Figure 3.2-1 Penetration of tumble dryers in Western Europe



Source: [IEC 07]

3.2.3 Consumption of energy and water in Europe

Only limited data are available regarding the amounts of energy used for tumble drying in Europe.

The European commission has published in its Green Book on Energy Efficiency [GRE 05] a total electricity consumption for tumble dryers of 13,8 TWh for the EU-15 in 2003. As the EU-15 consisted of about 160 million households this leads to an annual energy consumption per household owning a tumble dryer of about 251 kWh (34,4% penetration of tumble dryers assumed).

As not the whole laundry washed is put into the tumble dryer (not all garments are suitable for tumble drying and also air drying is used when the weather conditions allow it) it is assumed that only 60% of the reported 170 wash cycles (see chapter on washing machines) are followed by a tumble drying process. This leads to an average of 102 drying cycles per household owning a tumble dryer and year with an average energy consumption of 2,46 kWh per cycle.

3.2.4 Effects on energy and water consumption due to consumer usage

Tumble dryers are appliances which are operated on consumer demand only. Therefore the consumption of energy during the operation is determined by the following, mainly consumer driven, factors:

- Ambient conditions (e.g. temperature…)
- Frequency of operation
- Selected programme
- Additional rinse option chosen
- Machine efficiency under real use conditions
- Load size used
- Time span in low power mode (start delay + standby)

The frequency of operation mainly depends on the household size, as this defines the amount of load to be treated. For washing machines a consumer research [BP 07] of the real washing practice in 100 households in Germany for one month has shown a more or less linear increase of wash cycles with the number of persons living in the household. The same study has measured the weight of the laundry washed and concluded, that per person per week an almost constant load of 4,0 kg of laundry was washed. All of this laundry needs to be dried, but only a part of it will be dried in an electrical tumble dryer.

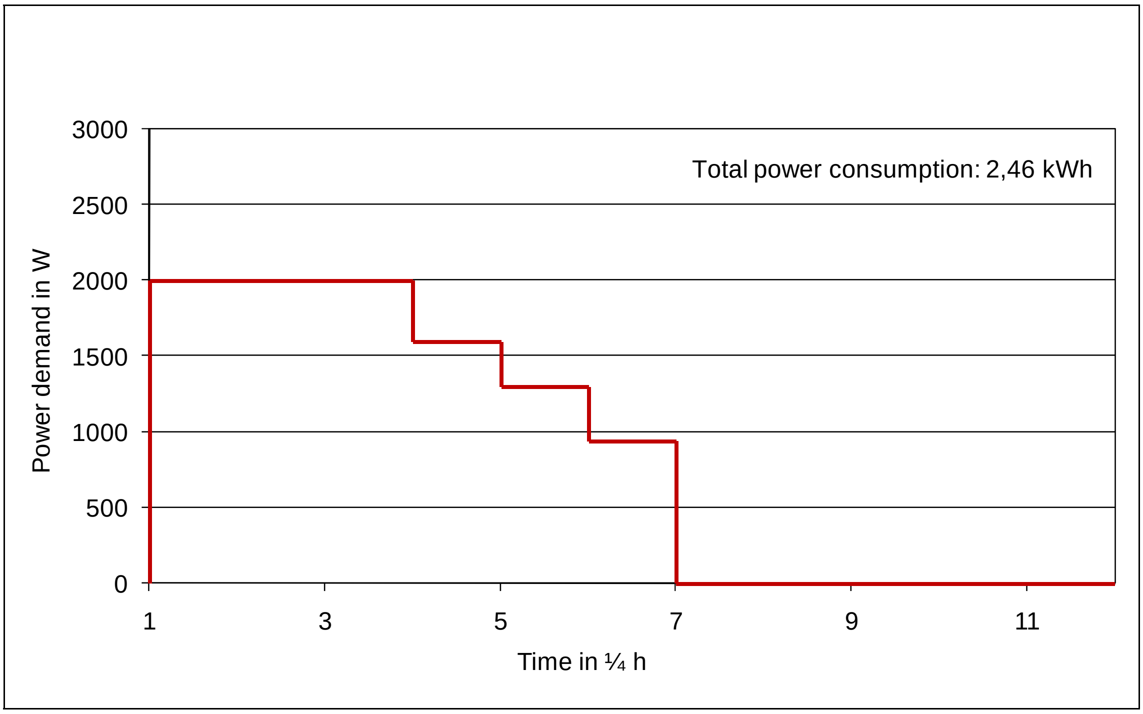
The EuP study has also shown that tumble drying is done more often in winter than in summer time [EUP14 07b]. While 23,8% of the consumers from 10 countries stated to use a tumble dryer always or often in winter, only 11,3% do so in summer.

A start time delay function may be available on tumble dryers as frequently as on washing machines (32% in average), but their use will be limited, as the consumer has first to unload the washing machine and second to put the laundry into the dryer. If a start time delay function was used for the washing process (e.g. to avoid noise in the night or to have the washing done on off-times during the day) the tumbling process may follow immediately. Thus the laundry drying process in most case will be directly linked to the washing process and follow it.

3.2.5 Power demand and load curves

The power demand curve of an average drying process needs to fit the average total energy consumption value of 2,46 kWh per cycle. Having a normal cotton programme as a guidance and splitting the power demand into ¼ hour steps this leads to an estimated power demand curve (Figure 3.2-2).

Figure 3.2-2 General pattern of a power demand curve of a tumble dryer in ¼ hour steps



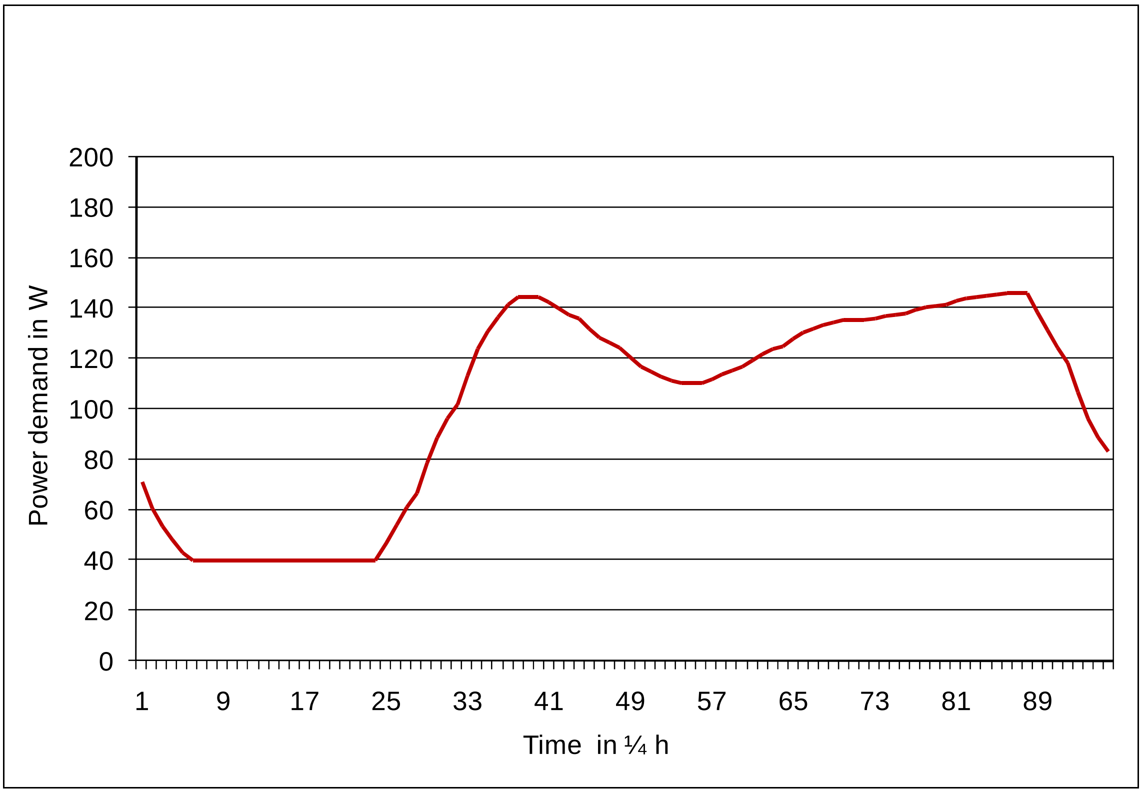
Source: University of Bonn

This power demand may vary from programme to programme and between machines. When the spinning efficiency of the washing machine or the desired final humidity is higher or the amount of textiles loaded is lower the curve will finish earlier and vice versa. Only if the consumer has activated a start time delay function this power demand is shifted by a defined number of hours.

Having asked how often and at what time consumers usually run their washing machines the survey of almost 2500 consumers from 10 European countries [EUP14 07b] reveals a very fragmented behaviour (see chapter on washing machines: Figure 3.1-10). This behaviour is transferred into information about the hour of the day the tumble dryer is operated by simply adding two hours to the point the washing cycle was started. These two hours are the usual time span between the start of the two devices.

Using the average behaviour of the consumers in these 10 countries to start a washing machine cycle and combining this with the average power demand of a tumble dryer cycle 2 hours later results in the average power demand which is needed for operating a tumble dryer (Figure 3.2-3) per day per household owning a tumble dryer. While during the night this power demand is low at about 40 W, during day two peak periods are seen at about 150 W: one in late morning and one in the evening.

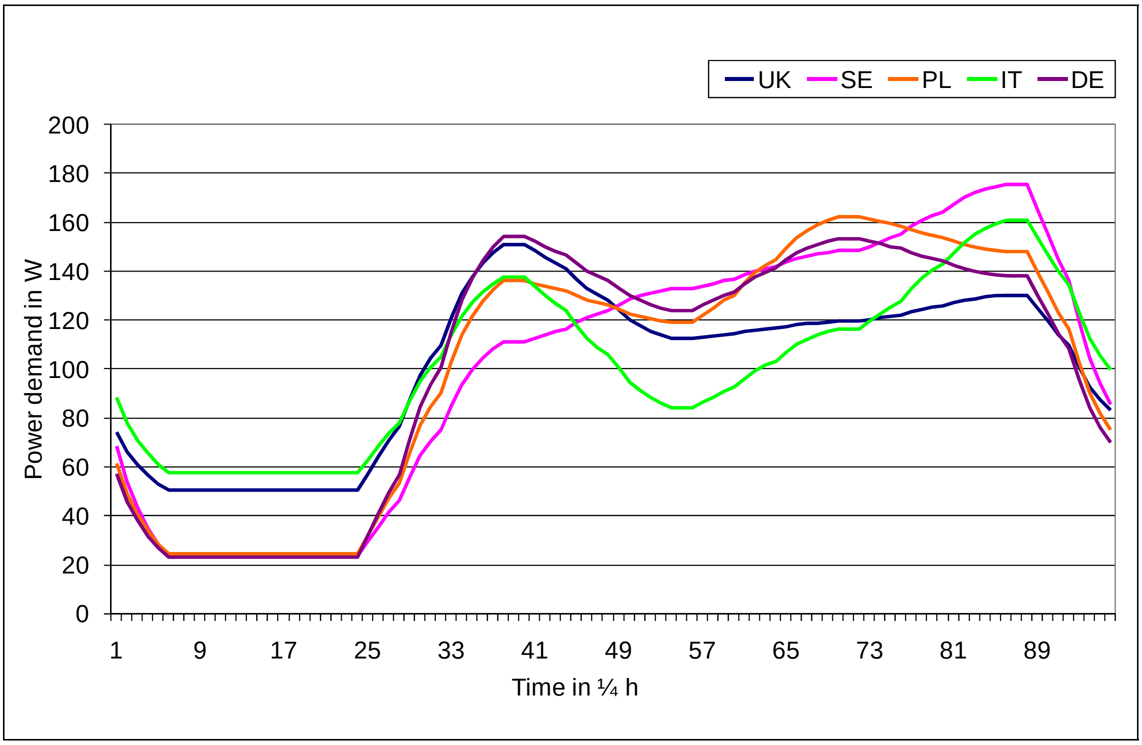
Figure 3.2-3 General pattern of a daily load curve of tumble dryers using average EU start time function



Source: University of Bonn

The shape of the curve varies due to the different behaviour of the consumers from country to country. The different curves for the regions selected in this study are shown in Figure 3.2-4.

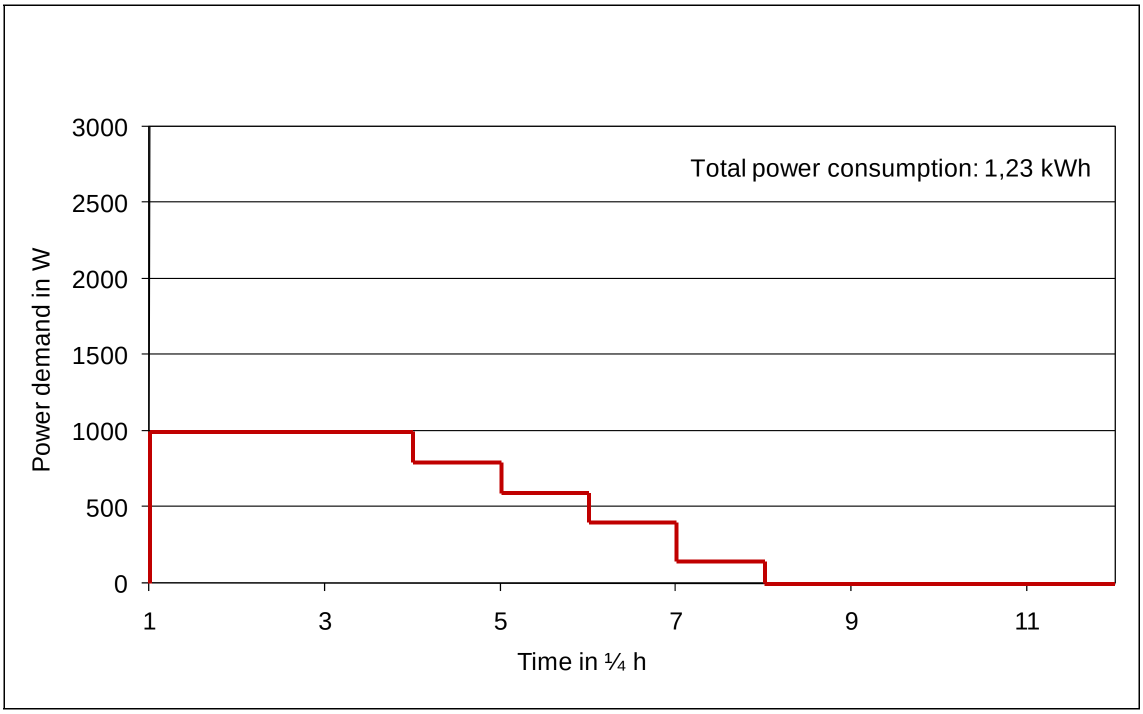
Figure 3.2-4 *General pattern of daily load curves for tumble dryers in the regions selected in this study*



Source: *University of Bonn*

Forecasting the development of tumble dryer power demand and energy consumption for year 2025 is mainly based on an expected increasing pressure for further reductions coming from overall CO2-saving requirements, backed in Europe by policies like Energy Labelling or other EuP measures. This may lead to a possible reduction of the energy consumption per cycle of about 50% (1,23 kWh per cycle), as the technology of using heat pumps is already available and just need to replace the conventional technology. This will cause a significant shift in the power demand curve (Figure 3.2-5). At the same time the penetration of tumble dryers in European households may be increasing from 34,4% today to about 50% in 2025 (roughly by 1% per year).

Figure 3.2-5 Estimated power demand curve for an average tumble dryer in year 2025



Source: University of Bonn

No other dramatic changes are expected to happen in a 'business as usual' scenario affecting the power demand of tumble dryers in 2025.

3.2.6 Synergistic potentials

Within this chapter it is tried to explore possible synergies when tumble dryers are somehow linked to sustainable energy sources, like solar or wind energy or heat from CHP processes. For each of these synergistic potentials it is described where the synergy comes from, what are possible constraints and what needs to be fulfilled to gain the potential. It is also estimated how many of the appliances might be affected and how these synergies might affect the power demand curve or the probability of operation of tumble dryers, including a possible recovery phase. As tumble drying is normally an activity immediately following the washing process, all synergistic actions on washing machines will affect also the operation of the tumble dryer. Described here are additional synergistic potentials only. As most of these synergies are not yet realised, they are somewhat hypothetical, but based on best engineering practise. If costs are given, they describe the expected additional prize the consumer has to pay for this feature. If ranges are given, the higher value normally corresponds to an implementation of this feature in a first introduction phase, while the lower value estimates how costs may develop at a large scale use. Results of the consumer survey will be added in a supplementary document to this report.

In the following synergy scenarios the complexity of technical adjustments on the device considered increases from level 1 (3.2.6.1) to level 4 (3.2.6.4) steadily. Whereas in level 1 the consumer still has the full control whether to use the described option or not, in level 2 some of that control was handed over to the machine which then reacts to incoming signals. In level 3 the full control is in the hands of an external manager (e.g. electric utility) who decides about when and how often the machine is being switched on or off after it was set in a ready mode by the consumer. Therefore signals are being transmitted in a bidirectional way. In level 4 additional options for storing energy or using other technologies are taken into account.

3.2.6.1 Shifting operation in time

Id and title: 1-1 Consumer shifts of operation in time
Description: The consumer receives a signal about the on the availability of renewable energy or energy from CHP plants. Depending on the signal, he shifts the operation of a tumble dryer to run at a time, where in relation to the expected load too much electricity is generated. The information about the availability may be communicated via radio (e.g. weather forecast), internet or remote control signals coming from the electricity provider. The consumer has to make his own decision whether to use this information or not. Available "start time delay" options may be used. Alternatively the consumer can chose the expected end of the drying process and the machine can start its operation at any time earlier.
Strategy for appliance control: This synergy option requires the active engagement of the consumer by transferring the information of shortage or surplus of renewable energy into the operation of the appliance. The broadcasting of the information may be randomized or varied in time locally to avoid that too many consumers are acting on the same signal at the same time.

Change in power demand curve of single appliance:

No change.

Change in day curve (of power demand of all appliances):

As at present about 8% of the washing machines are operated by using the start time delay function [EUP14 07b] and normally tumble drying is following the washing process, it is estimated that at maximum perhaps for 5% of the operations the described mode will be used. The option allows shifting the power demand at any time. A delay of the operation by up to 3 hours is estimated as the most likely scenario (even up to 9 h depending on the shift of the washing process), which will result in a reduction of the operation probability, followed by a recovery period (Figure 3.2-6). During the time of shift the drum and fan of the tumble dryer must operate at some intervals to avoid damping of the clothes.

Consumer benefits and drawbacks:

Enhanced use of renewable energy and CHP. But probably only accepted by convinced environmentalists or by people owning their own power or heat generation unit if the resource use is cheaper than if taken from other sources.

Demand management benefits and drawbacks:

Consumer acceptance may depend on the time of the day and season.

Impact on appliance design and service provided: (additional costs, limitations, additional energy consumption):

Delay start timer may be helpful. Already today available in about 30% of appliances in the stock.
Additional costs for consumer, if delay start time is not already included: 5 € - 25 €.

Additional energy consumption: 0 W - 4 W (depends on the use of a start time delay function).

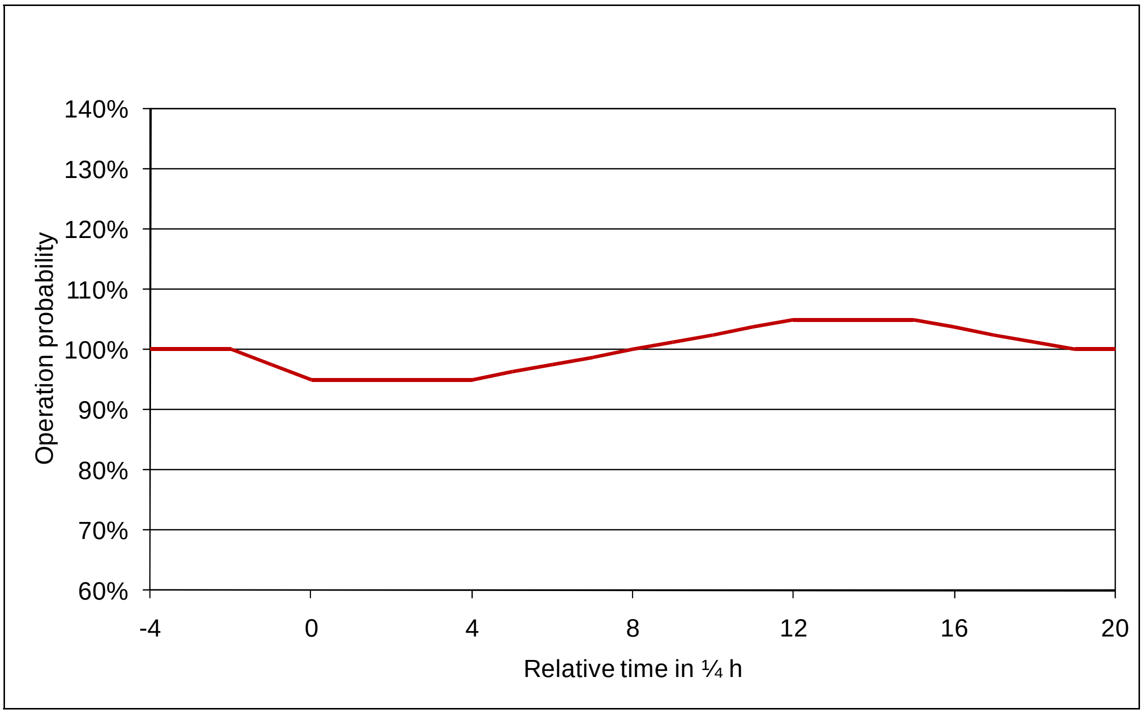
Consumer acceptance questions:

Willingness to accept this solution if additional costs are balanced by savings via energy bill.
Calculation (additional costs of 15 €):
251 kWh/a at 0,20 €/kWh = 50 €/a energy costs
Amortisation in 5 years: 3 €/a saving
Reduction of energy costs by 6% needed!

Strategies for success:

Increase environmental awareness and practise

Figure 3.2-6 *Example of a change in operation probability for synergy scenario 1-1*



Source: *University of Bonn*

3.2.6.2 Applying flexibility on appliance power demand

Id and title:
2-1 Power line triggered operation
Improbable scenario for this appliance. As the drying process follows immediately after the cleaning process, the acceptance among the consumers is assumed to be very low for this kind of scenario where the device waits for a signal to come and without any internal energy management within the machine.

Id and title:
2-2 Internal energy manager agent
Description: Triggered by an external signal about shortage of energy the tumble dryer may change its operation: - delay the start of the heating phase - interrupt the heating up to a certain time, without stopping drum rotation - reduce the power demand by choosing a lower heating power for the programme and prolonging the drying time.
Strategy for appliance control: The external signal should include information on the shortage of energy and how long it may last. The tumble dryers being in an appropriate state will then react by their own intelligence to find the appropriate answer.
Change in power demand curve of single appliance: Various. May shift heating time or heating power by seconds and minutes.

Change in day curve (of power demand of all appliances):

As most tumble dryers are operated in an automatic sensing mode detecting the right moment when the final humidity is reached, short term interruptions of the heating in a tumble dryer will hardly be noticed by the consumer. Therefore it may be well accepted by the consumer to interrupt the drying process for short time periods. It is estimated that about 30% of the tumble dryers (if equipped with an appropriate device and activated by the consumer) may be operated in this mode (Figure 3.2-7).

Consumer benefits and drawbacks:

Enhanced use of renewable energy and CHP. Possible irritation of consumers when machine stops must be avoided. But short term breaks may not be recognized at all. Too long breaks during heating period will cause a loss of energy.

Demand management benefits and drawbacks:

Influence on power demand by short term breaks. Programme end may be delayed.

Impact on appliance design and service provided: (additional costs, limitations, additional energy consumption):

Internal energy manager agent needs to be included in electronic unit of machine.
A harmonised signal of power shortage is needed.
Additional costs for consumer (signal recognition plus energy agent): 10 € - 100 €.
Additional power consumption:

- during operation: > 0 W - 4 W

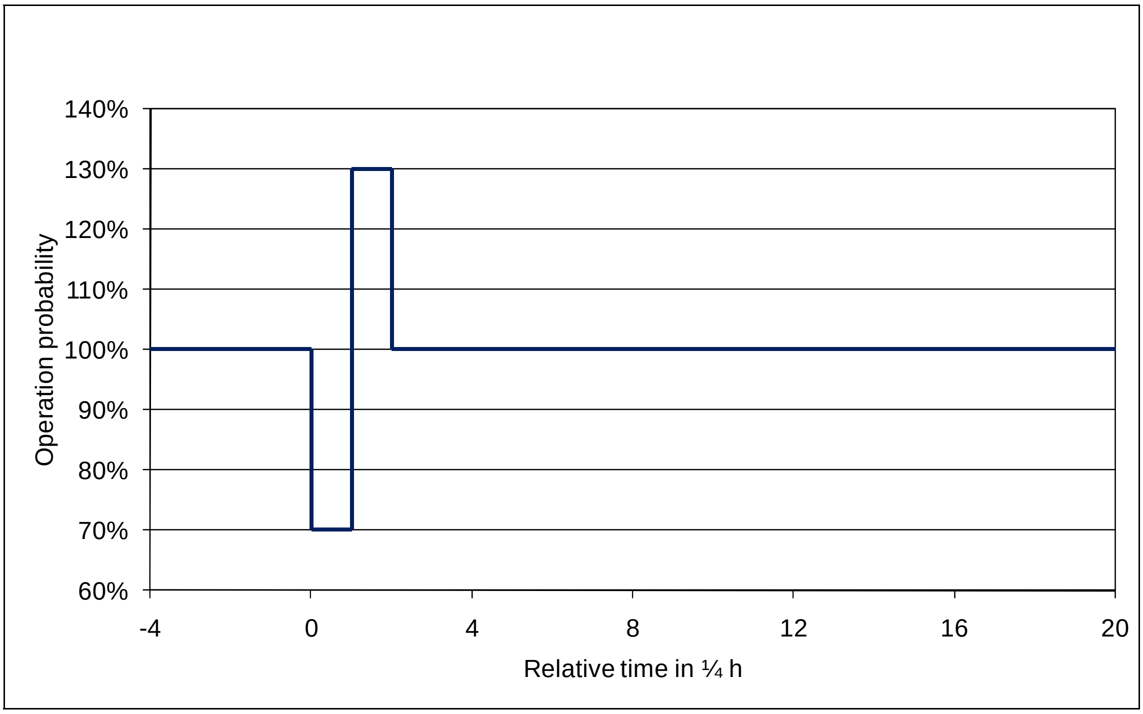
Consumer acceptance questions:

Willingness to accept this solution if additional costs are balanced by savings via energy bill.
Calculation (additional costs of 55 €):
251 kWh/a at 0,20 €/kWh = 50 €/a energy costs
Amortisation in 5 years: 11 €/a saving
Reduction of energy costs by 22% needed!

Strategies for success:

Define harmonised signal for shortage of power (CENELEC).
Define business model where energy utilities sponsor the implementation of these “Internal energy management agent” modules.

Figure 3.2-7 Example of a change in operation probability for synergy scenario 2-2



Source: University of Bonn

3.2.6.3 Managing the power on the grid

Id and title: 3-1 Energy demand manager
Description: The energy demand manager tries to harmonise the available power on the grid coming from conventional and renewable resources with the demand. Therefore the tumble dryer when started is set in a remote control mode which allows the energy demand manager to decide about the start of the machine within a predefined time interval. The energy demand manager is informed about the selected programme or at least the expected energy demand.
Strategy for appliance control: Knowing the demand for the next few hours the energy demand manager tries to use as much renewable energy and energy from CHP as possible and optimises the overall costs.
Change in power demand curve of single appliance: Unchanged.
Change in day curve (of power demand of all appliances): As tumble dryers are normally following a washing process the acceptance to delay the operation will be limited. But short term power demand management may be accepted, as it may not be noticed by the consumer. It is assumed that synergy scenarios 1-1 or 2-2 are applicable (Figure 3.2-8) managed by the energy demand manager. As the consumer is not involved in the operation of the device any more, the probability curve of scenario 1-1 (delayed start) stands for a second option of scenario 2-2.
Consumer benefits and drawbacks: Enhanced use of renewable energy and CHP. Cost benefits must be transferred to the consumer. Consumer remains in the position to decide whether he wants to use this option or not.

Demand management benefits and drawbacks:

Influence on power demand, especially short term. Influence only on those machines which are ‘online’.

Impact on appliance design and service provided: (additional costs, limitations, additional energy consumption):

Bidirectional communication needed. An additional switch is needed to signal ‘remote operation accepted’.
A harmonised communication protocol is needed.
Additional costs for consumer (communication module via power line): 30 € - 130 €.
Additional power consumption:

- during waiting for operation: > 0 W - 4 W

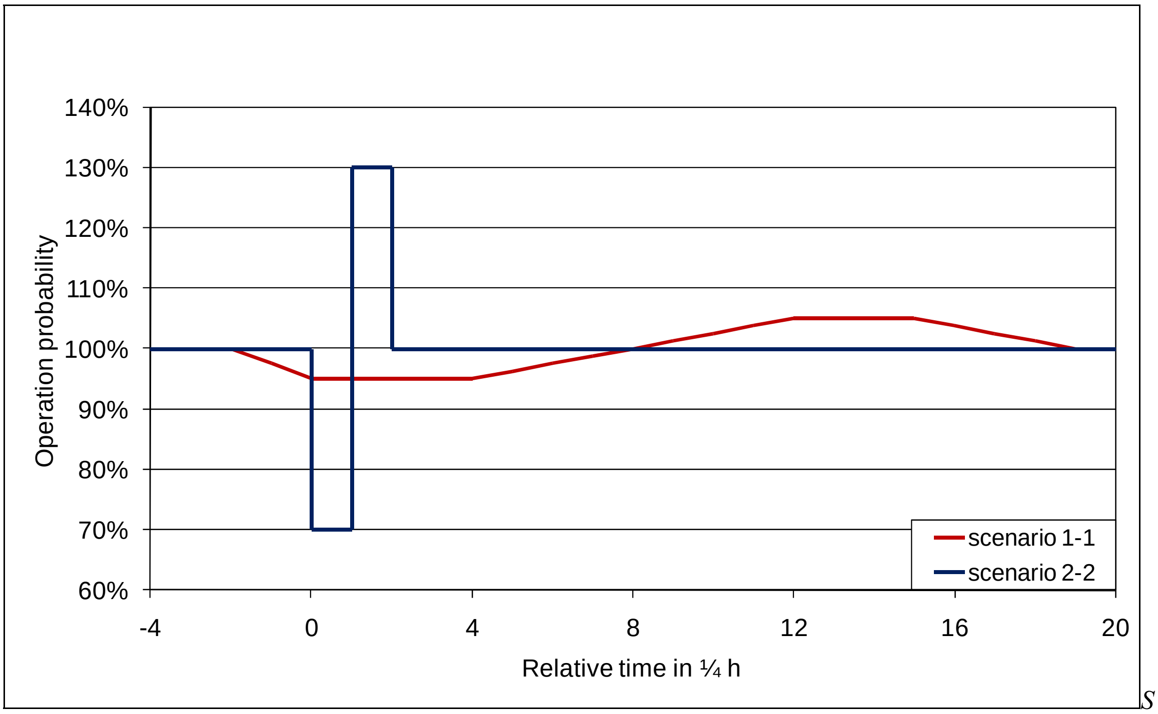
Consumer acceptance questions:

Willingness to accept this solution if additional costs are balanced by savings via energy bill.
Calculation (additional costs of 80 €):
251 kWh/a at 0,20 €/kWh = 50 €/a energy costs
Amortisation in 5 years: 16 €/a saving
Reduction of energy costs by 32% needed!

Strategies for success:

Define harmonised communication protocol (CENELEC).
Define business model where savings balance the additional costs for the appliance.

Figure 3.2-8 *Change in operation probability for synergy scenarios 3-1 (any of 1-1 and 2-2)*



Source: *University of Bonn*

3.2.6.4 Using energy storage capacity and other technologies

Id and title:

4-1 Heating by hot water

Description:

Using the warmth produced by a CHP unit, a solar plant or district heating for heating up the air in the tumble dryer may be done by hot water (at minimum 65°C needed). The heat is led directly into the heating rods within the machine which then heat up the air to the desired temperature. Therefore the total amount of electricity for the heating phase is replaced by the use of heat of other systems. Electricity is then only needed for the basic functions of the machine (fan, motor, electronic).

Strategy for appliance control:

Connect the tumble dryer to a CHP, solar plant or district heating.

Change in power demand curve of single appliance:

Heating power reduced by 100% - remaining electrical power consumption: 200 W for 2 hours per cycle (= 0,4 kWh = 16,2%)

Change in day curve (of power demand of all appliances):

No change.

Consumer benefits and drawbacks:

Enhanced use of renewable energy and CHP. Cost benefits.
Depending on the real hot water temperature the drying process may be considerably prolonged, especially for condensation dryers.

Demand management benefits and drawbacks:

Operation of the tumble dryer is linked to the availability of heat by the described suppliers. As the maximum temperature which may be reached is limited, drying time may be considerably longer.

Impact on appliance design and service provided: (additional costs, limitations, additional energy consumption):

Special heating rods are needed.
Programme must be adopted to ensure re-heating and appropriate drying times.
Additional costs for consumer: 100 € - 400 €.
Additional power consumption: 0 W

Consumer acceptance questions:

Willingness to accept this solution if additional costs are balanced by savings via energy bill.
Calculation without costs for heat from other systems (additional costs of 250 €):
251 kWh/a at 0,20 €/kWh = 50 €/a energy costs
Amortisation in 5 years: 50 €/a saving
Reduced energy consumption (16,2% of 251 kWh):
40,8 kWh/a at 0,20 €/kWh = 8 €/a energy costs
Reduction of energy costs by 16% needed!

Strategies for success:

Promotion of tumble dryer with direct use of renewable (or by CHP) produced heat.

3.3 Dishwasher

3.3.1 Technical description with regard to the use of water and energy

Automatic dishwashing machines consist of a square tub where dishes are placed in baskets on mainly two levels. Water is filled into the tub up to a defined quantity or low level which is maintained throughout the individual steps of the cleaning process. The dishes are sprayed with water through rotating spray arms located below the baskets. The cleaning is done at various temperatures (mainly 50/55°C, 60/65°C or 70/75°C), depending on the programme selected by the consumer. The water is heated up to the desired temperature by a resistant heating system of between 1800 W and 2500 W rated power. Heating may be interrupted for equalizing the temperatures in the water and in the load. When the desired temperature is reached, the cleaning process may be continued for some time, followed by one or several rinsing processes without heating. At the end in a final rinse cycle the water (and the dishes) is heated up again to a high temperature (normally higher than the cleaning cycle) to store sufficient heat in the dishes for the drying process. In this drying process water condenses at cold tub surfaces while water evaporates from the surface of the dishes. Short heating periods may be used to speed up or increase the drying effect.

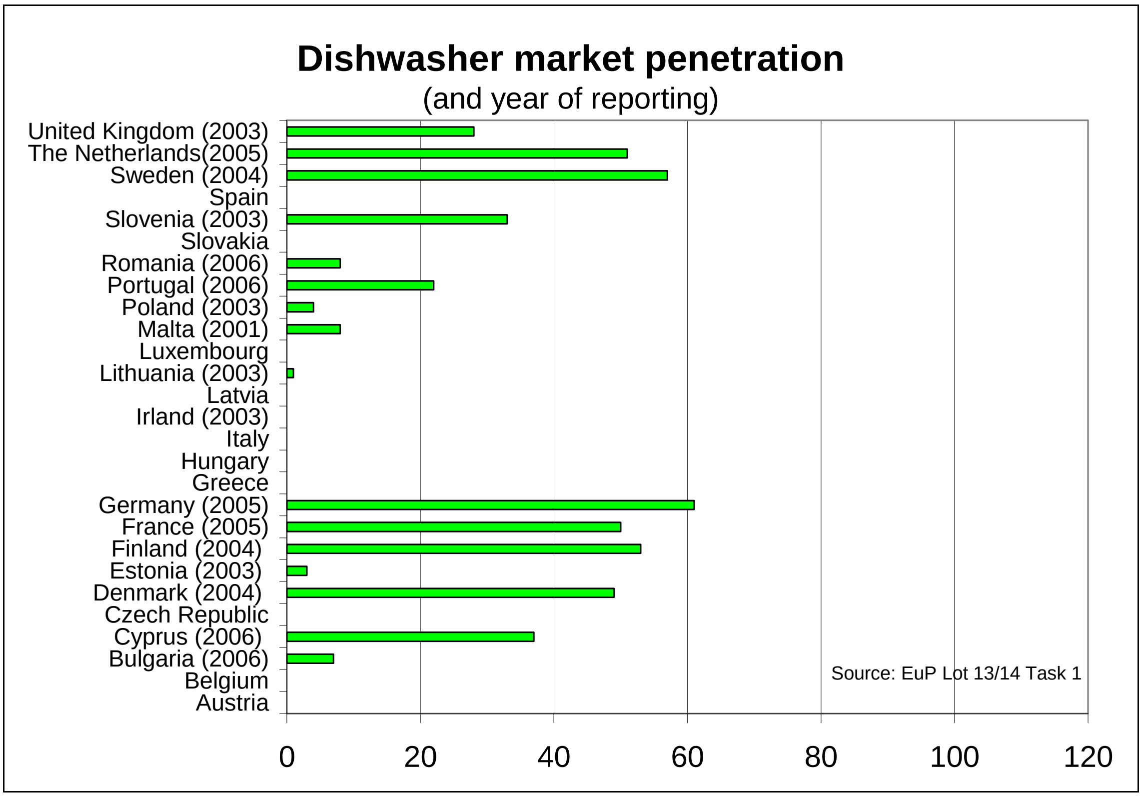
The whole process is controlled by a step timer or/and an electronic control device and lasts between about 15 minutes and up to 3 hours, depending on the programme and temperature chosen. Time delay functions are incorporated in some machines and allow either to shift the starting time by a defined number of hours or to end the process at a predefined time.

Electrical energy is used mainly for heating up the water to the desired temperature, thus also heating up the dishes and the tub. Additional electrical energy is used for driving the circulation pump motor and for the other electronic devices, including the user interface. But also after the end of the programme electricity is used by many machines (to a very small extend) to keep some safety functions alive, like water protection sensor systems or remote control systems. Regarding the total water consumption only about 1/4 to 1/2 of the water is being heated up, while the rest is used as cold water for pre-wash or rinsing.

3.3.2 Penetration in Europe

Automatic dishwashing machine penetration in the EU is reported to be very different from country to country, although detailed figures are not publicly available for all countries. Most recent source of information on dishwashing machines include also the new CEE countries which show penetration levels between about 0 and also 60% [EUP14 07a] (Figure 3.3-1). In Western European countries an average market penetration of 42% is reported [EUP14 07a], in Eastern European countries only of 3%. This penetration is increasing [EUP14 07a] in all countries.

Figure 3.3-1 Penetration of automatic dishwashing machines in EU-27 (where no data are shown, no data were available in [EUP14 07a])



Source: [EUP14 07a]

3.3.3 Consumption of energy and water in Europe

Only limited data are available regarding the amount of energy and water used for dishwashing in Europe. Anyhow in Western Europe, only 30 to 40% of the dishes are cleaned in an automatic dishwasher [EUP14 07a], the rest is done by manual dishwashing.

The European commission has published in its Green Book on Energy Efficiency [GRE 05] a total electricity consumption for dishwashing machines of 16,2 TWh for the EU-15 in 2003. As the EU-15 consisted of about 160 million households this leads to an annual energy consumption per household owning an automatic dishwasher of about 241 kWh (42% penetration of dishwashers assumed).

The Preparatory Studies for Eco-design Requirements of Energy-using Products (EuP) [EUP14 07a] have investigated in an online consumer questionnaire in 10 European countries the consumer behaviour with dishwashing and other household appliances. As a result the study shows that the average number of dishwashing cycles declared is at 4,06 per week. Per year (50 weeks) this would lead to 203 dishwashing cycles per household or 1,19 kWh per cycle (calculated with 241 kWh per household owing a dishwasher and year).

Regarding water consumption there are even less data available. The EuP study has reported an average consumption of 15,2 litre per cycle for an average machine produced in 2005, while in a former study (reported in [EUP14 07a], p.371) the average in 1995 was at 24 litre per cycle. As an average consumption of automatic dishwashers installed in European households 20 litres per cycle may be a fair assumption. This would lead to a total water consumption for automatic dishwashing of 4,06 m^3 per year per household.

3.3.4 Effects on energy and water consumption due to consumer usage

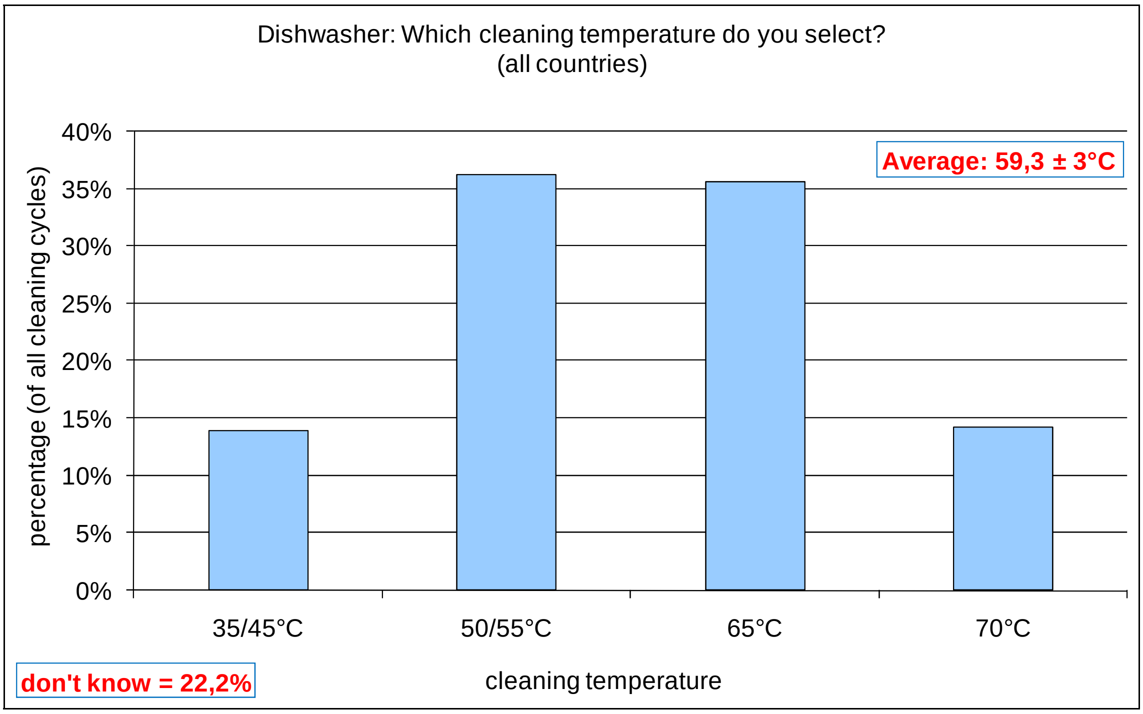
Automatic dishwashing machines are appliances which are operated on consumer demand only. Therefore the consumption of water and energy in the period of use is determined by the following, mainly consumer driven, factors:

- Ambient conditions (e.g. temperature…)
- Frequency of operation
- Selected programme and temperature in combination with amount (and type) of detergent
- Additional rinse option chosen
- Machine efficiency under real use conditions
- Load size used
- Low power mode (start delay + standby)

The frequency of operation mainly depends on the household size, as this defines the amount of dishes to be treated.

Investigating almost 2.500 consumers from 10 countries about their dishwashing behaviour the result of the EuP-Studies [EUP14 07a] does not show a clear preference for a certain programme temperature (Figure 3.3-2). There are about equal preferences to run a cleaning programme at a main wash temperature of 50/55°C or 60/65°C. This may be due to the missing communication about the correlation of the selected programme temperature and the associated energy consumption, but also due to some lacks in performance happening at lower wash temperature. The average of all these nominal dishwashing temperatures is calculated to be 59,3°C. Many consumers do not even know the temperature of a certain cleaning programme, as this may not be shown at the panel of the machine but just be contained in the instruction manual.

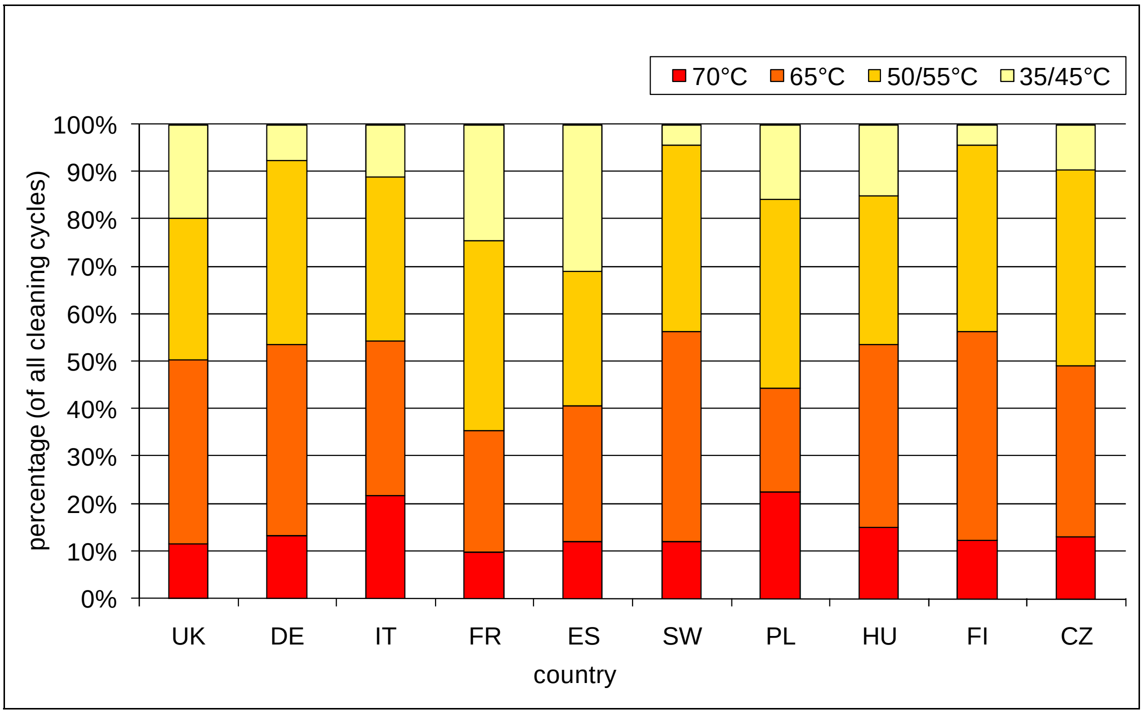
Figure 3.3-2 Relative occurrence of dishwashing temperatures in Europe (average of 10 countries)



Source: University of Bonn

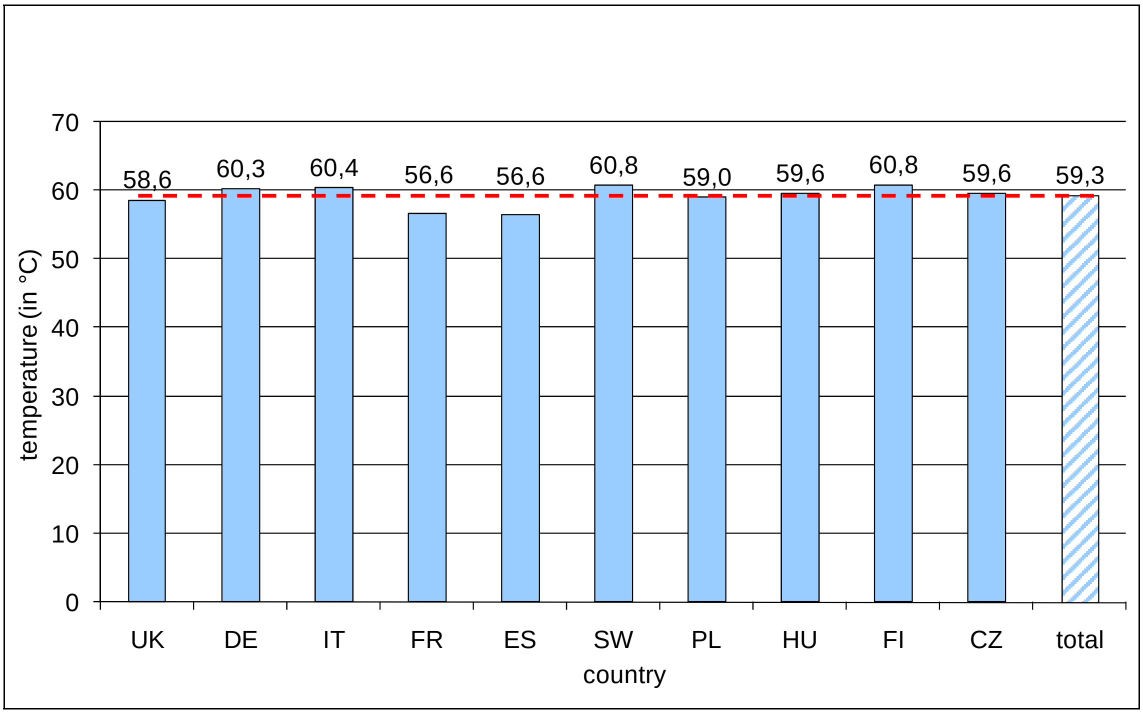
A closer view (Figure 3.3-3 and Figure 3.3-4) on the distribution of temperature in the 10 countries shows a relative homogenous distribution with lowest temperatures in France and Spain.

Figure 3.3-3 *Temperature distribution of dishwashing programmes for various countries*



Source: *University of Bonn*

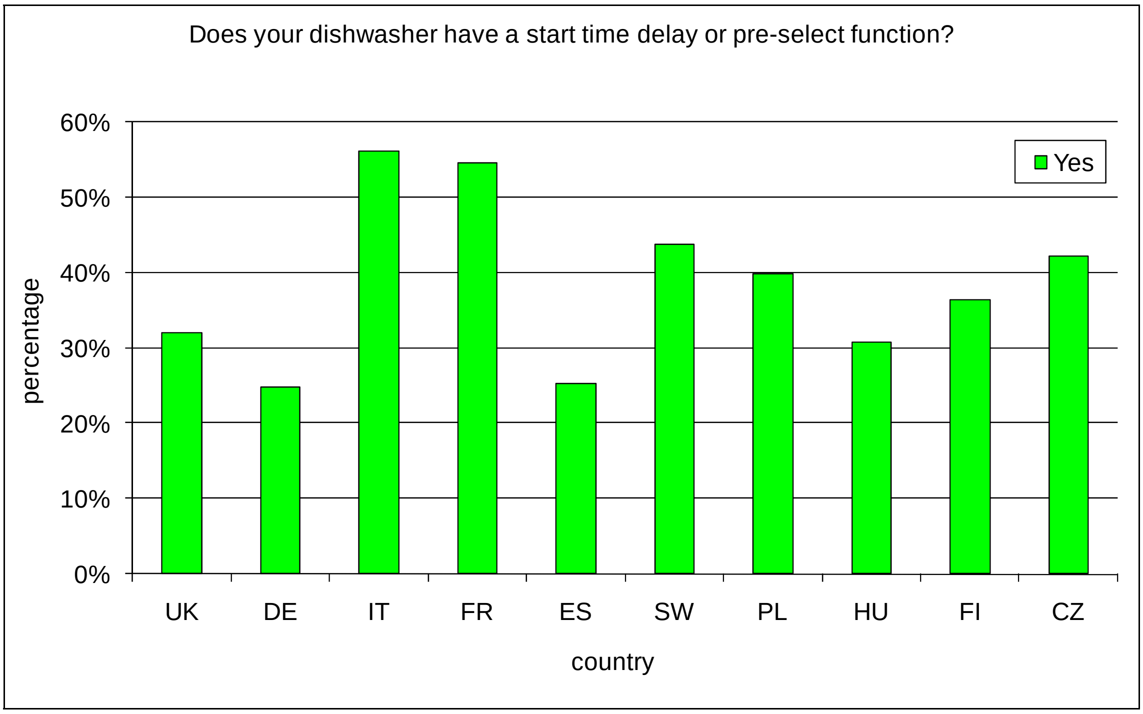
Figure 3.3-4 *Average nominal dishwashing temperature*



Source: *University of Bonn*

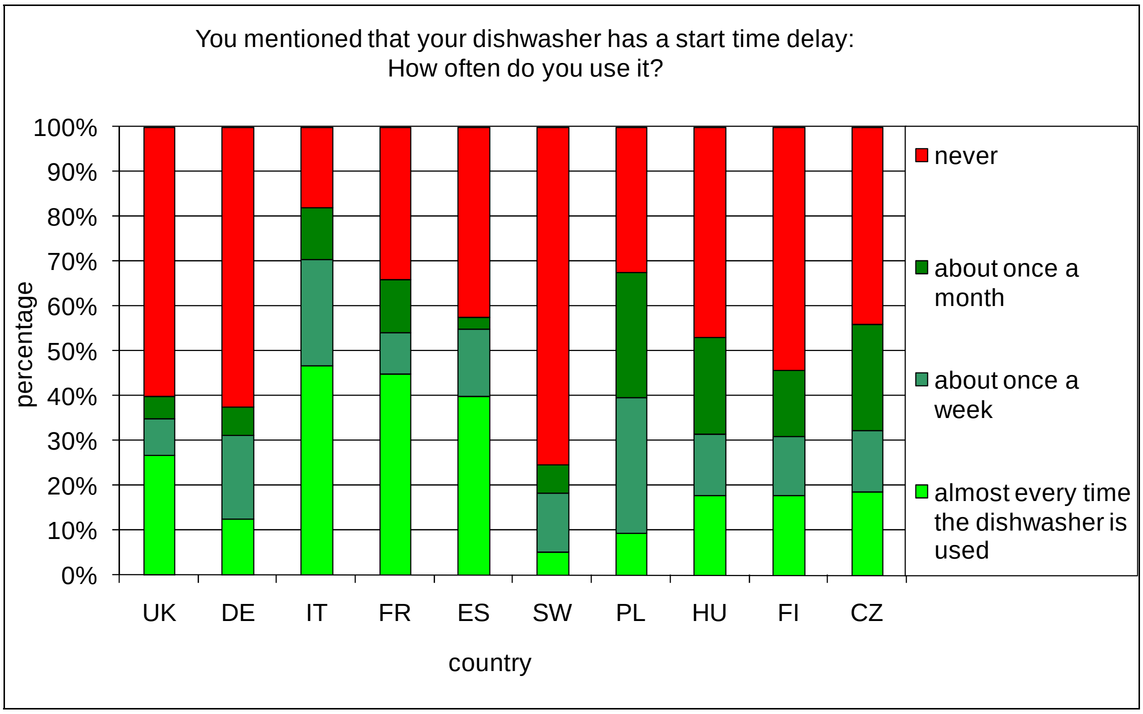
Another main issue of the same study [EUP14 07a] focused on the question whether or not a machine has a start time delay or pre-select function and how it is been used. This function allows shifting the starting time to any hour of the day or night when maybe cheaper tariffs are offered. Overall 39% of the dishwashing machines are equipped with such an option but differently in various countries (Figure 3.3-5).

Figure 3.3-5 Availability of start time delay or pre-select function



Source: University of Bonn

Figure 3.3-6 Usage frequency of the start time delay function

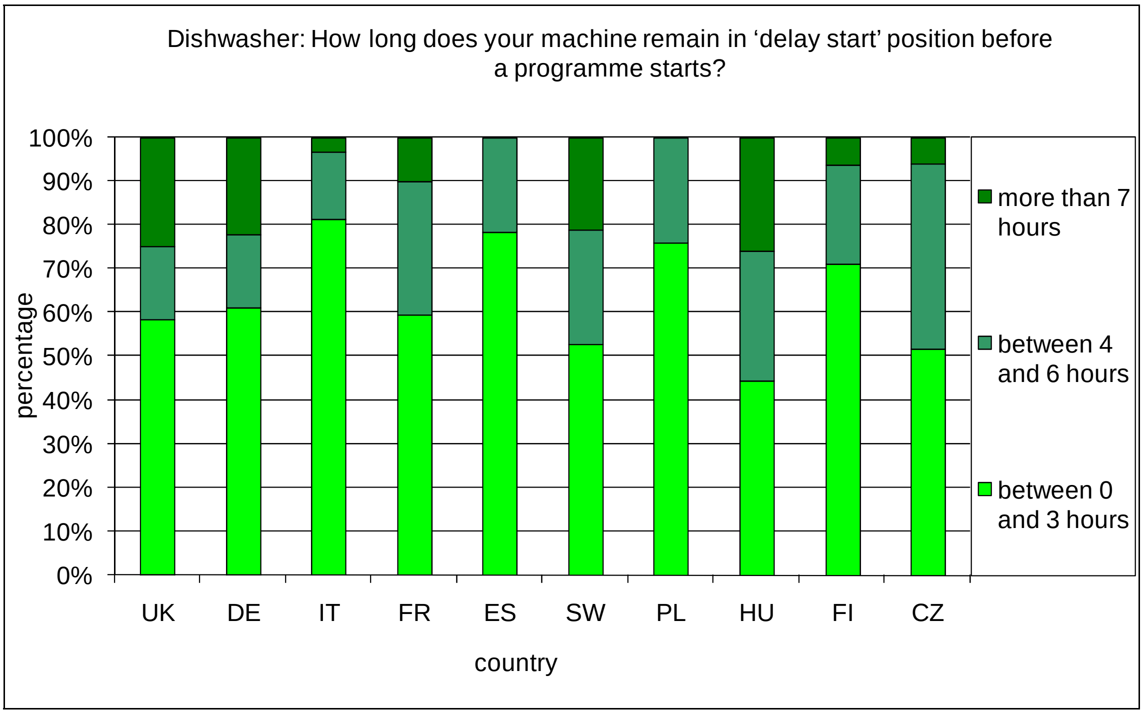


Source: University of Bonn

When asked about the frequency of usage of this start time delay option, most consumers confess (Figure 3.3-6) to 'never' use them (in average 45%). Only 27% say they almost always use this function and another 15% use it about once in a week.

This function also has a possible negative impact on the energy consumption, as the machine will consume a small amount of energy when waiting for the start time. Asking those consumers who have a start time delay function in their dishwashing machine and who make use of it about the selected start time delay, in average 66% choose a time between 0 and 3 hours (Figure 3.3-7) while 24% use it to delay the start time between 4 and 6 hours and 10% to delay it for more than 7 hours.

Figure 3.3-7 Frequency of start time delay hours

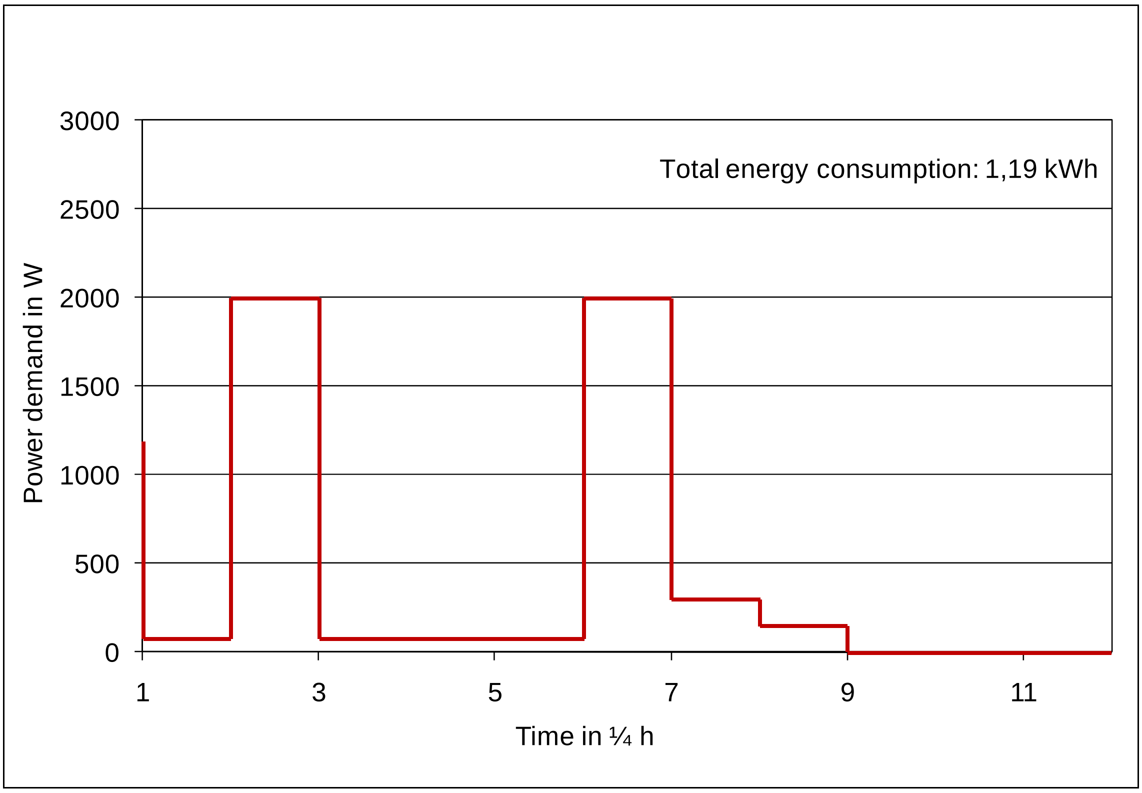


Source: University of Bonn

3.3.5 Power demand and load curves

The power demand curve of an average dishwashing process needs to fit the average total energy consumption value of 1,19 kWh per cycle. Having a normal cleaning programme as a guidance and splitting the power demand into ¼ hour steps this leads to an estimated power demand curve (Figure 3.3-8).

Figure 3.3-8 *General pattern of a power demand curve of a dishwashing machine in ¼ hour steps*

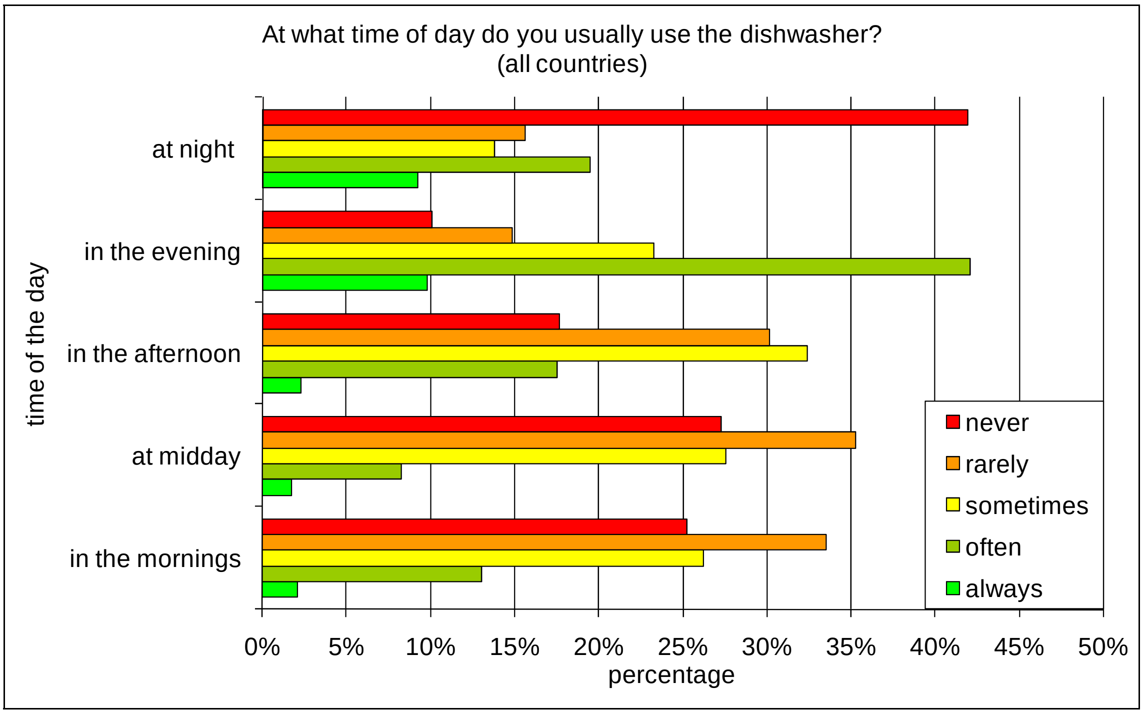


Source: *University of Bonn*

This power demand may vary from programme to programme and between machines. But when the machine is started by the consumer this kind of power demand will be drawn by the machine from the power line automatically. Only if the consumer has activated a start time delay function this power demand is shifted by a defined number of hours.

Having asked how often and at what time consumers usually run their dishwashing machines the survey of almost 2500 consumers from 10 European countries [EUP14 07a] reveals a very fragmented behaviour (Figure 3.3-9).

Figure 3.3-9 Frequency of operation of a dishwashing machine during the day



Source: [EUP14 07a]

To transfer this behaviour into information about the hour of the day the operation is started the data of the consumer survey were prepared as follows:

- Transforming the time of the day into hours of the day

Time of the day	**Hours**
Morning	6:00 - 9:59 h
Midday	10:00 - 13:59 h
Afternoon	14:00 - 17:59 h
Evening	18:00 - 21:59 h
Night	22:00 - 5:59 h

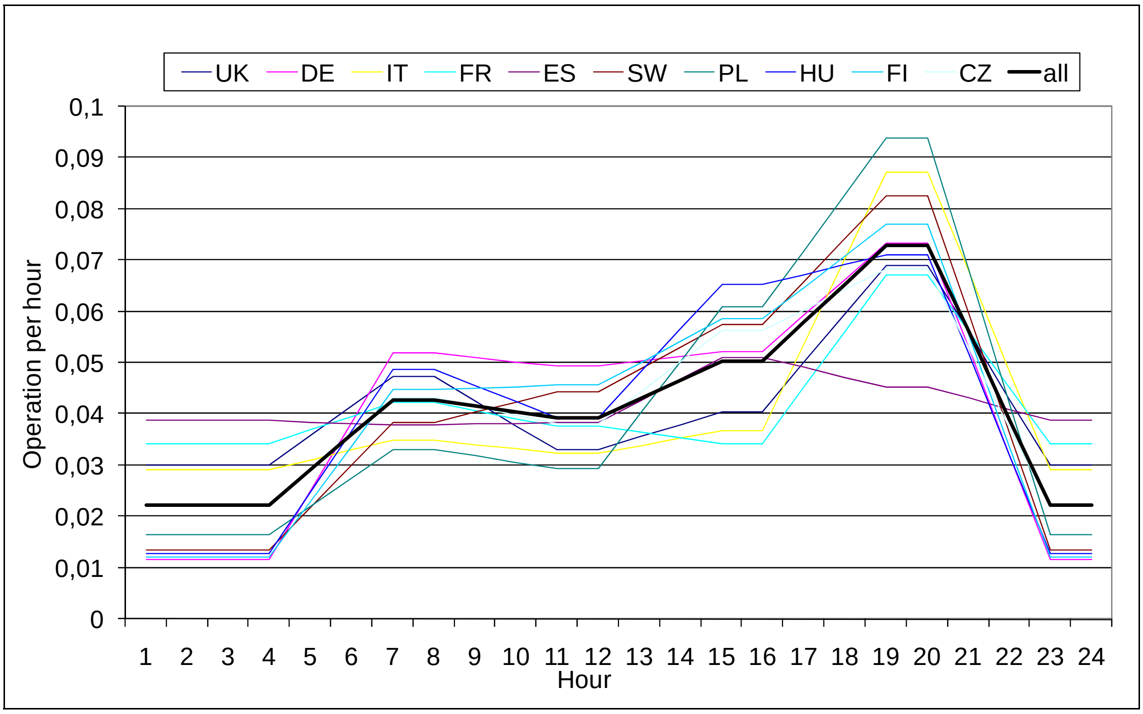
- Transforming the indication about the frequency into percentage information

Frequency	**Percentage**
Always	100%
Often	75%
Sometimes	20%
Rarely	25%
Never	0%

- Normalizing the sum of percentages per household to be at 100%
- Smoothing the curve by calculating the moving average over three hours.

This leads to a detailed estimation about the start time of the dishwashing machine operation for all 10 countries investigated (Figure 3.3-10).

Figure 3.3-10 Estimated probability of start time of dishwashing machine operation for 10 European countries

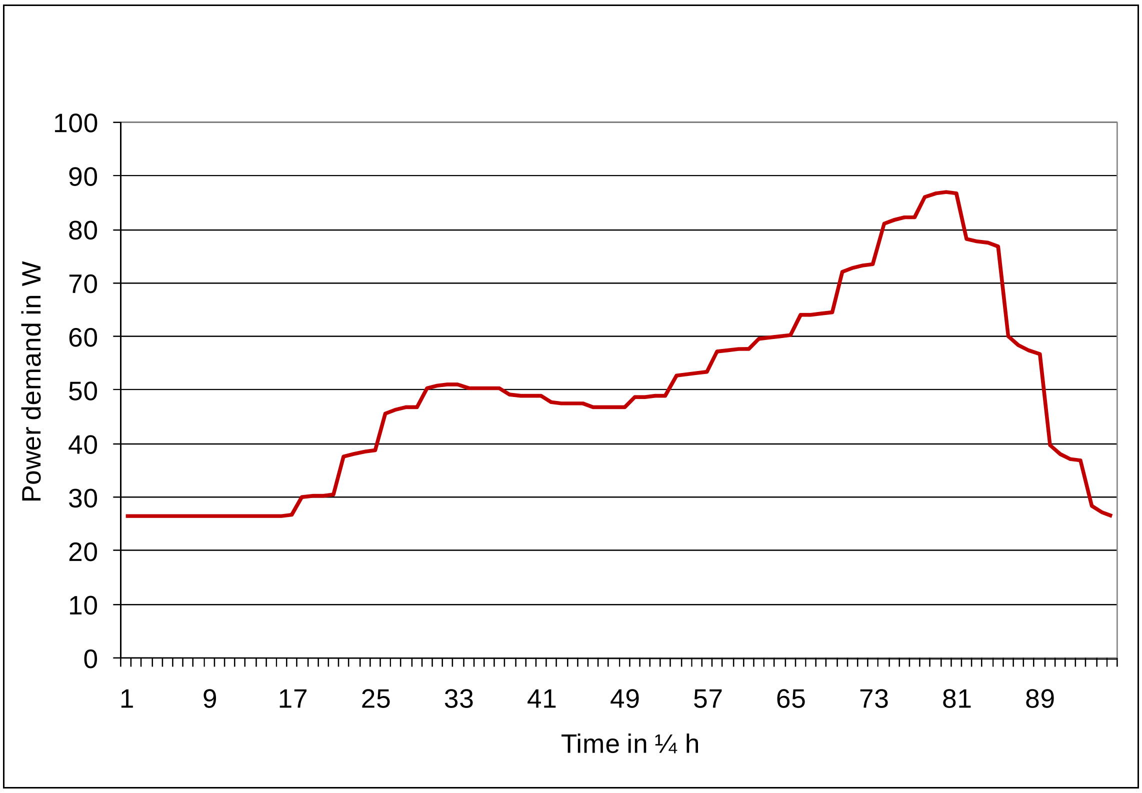


Source: University of Bonn

This analysis shows some significant behaviour as there is just one dominating period where dishwashing machines are being used: in the late afternoon/evening. There is one exception (Spain) where a significant amount of machines is operated in the night and no peak appears in the evening.

Using the average behaviour of the consumers to start a dishwashing machine cycle in these 10 countries and combining this with the average power demand a dishwashing machine cycle will take when started (Figure 3.3-8), results in the average power demand which is needed for operating a dishwashing machine (Figure 3.3-11) per day and household owning a dishwasher. While during the night this power demand is low at about 27 W, in the evening at about 20:00 h it peaks at about 87 W. This behaviour can be easily explained by a consumer behaviour which decides to start dishwasher operation after dinner. As dinner is used to be taken late in Spain, this also explains the shift of the day curve for Spanish consumers.

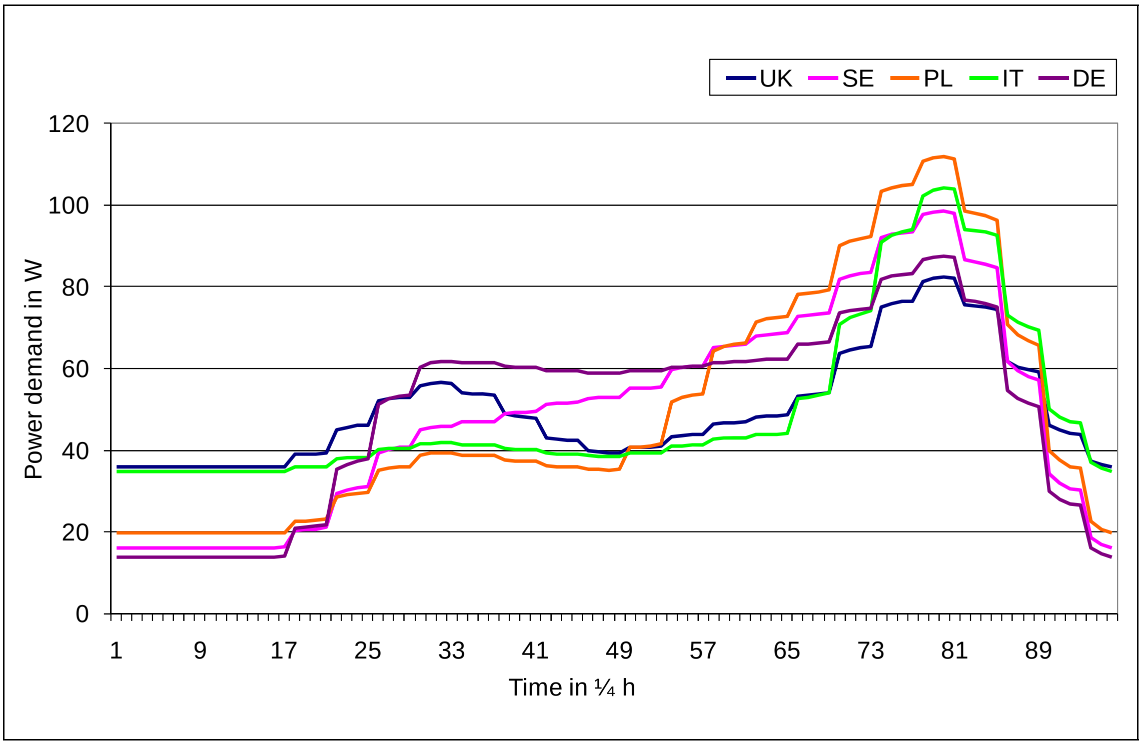
Figure 3.3-11 General pattern of a daily load curve of a dishwashing machine using average EU start time function



Source: University of Bonn

The shape of the curve varies due to the different behaviour of the consumers from country to country. The different curves for the regions selected in this study are shown in Figure 3.3-12.

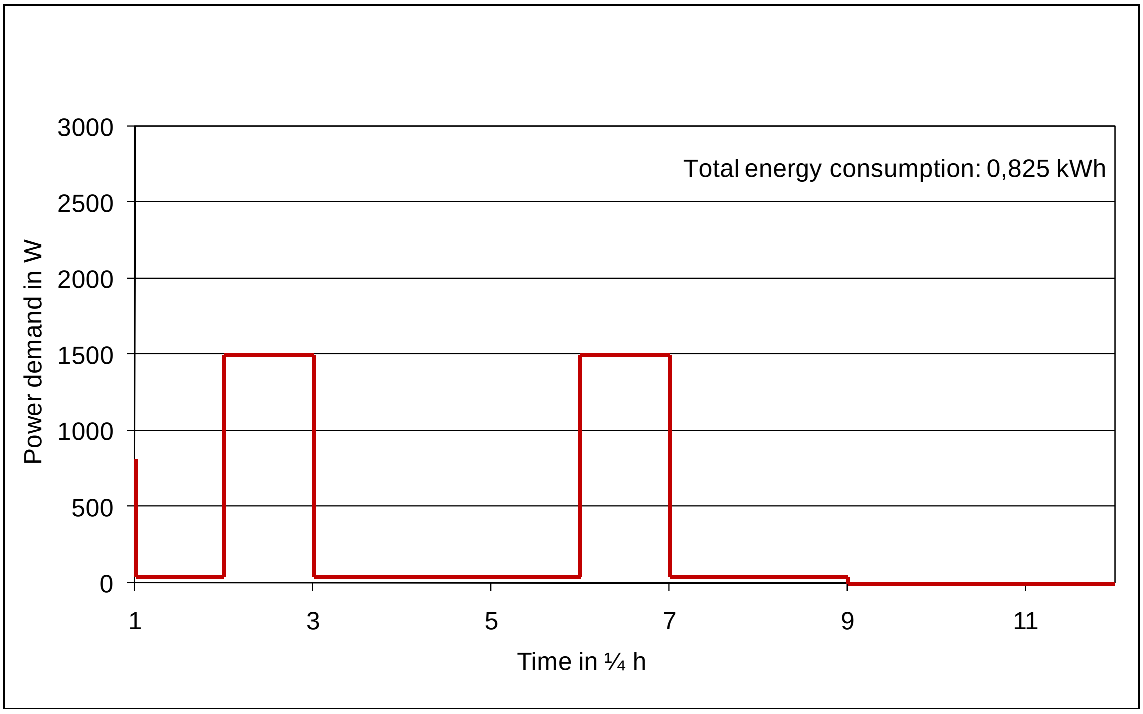
Figure 3.3-12 General pattern of daily load curves for dishwashers in the countries representing the regions selected in this study



Source: University of Bonn

Forecasting the development of dishwashing machine power demand and energy consumption for year 2025 is mainly based on an expected increasing pressure for further reductions coming from overall CO2-saving requirements, backed in Europe by policies like Energy Labelling or other EuP measures. This leads to a possible reduction of the energy consumption per cycle of about 30% (0,825 kWh per cycle). The energy saving will be realised by using lower dishwashing temperatures, but especially the temperature of the rinse cycle is expected to drop by introducing effective new rinse-aids. This will cause a significant shift in the power demand curve (Figure 3.3-13).

Figure 3.3-13 Estimated power demand curve of an average dishwashing machine in year 2025



Source: University of Bonn

No other dramatic changes are expected to happen in a 'business as usual' scenario affecting the power demand of dishwashing machines in 2025.

3.3.6 Synergistic potentials

Within this chapter it is tried to explore possible synergies when dishwashing machines are somehow linked to sustainable energy sources, like solar or wind energy or heat from CHP processes. For each of these synergistic potentials it is described where the synergy comes from, what are possible constraints and what needs to be fulfilled to gain the potential. It is also estimated how many of the appliances might be affected and how these synergies might affect the power demand curve or the probability of operation of dishwashing machines, including a possible recovery phase. As most of these synergies are not yet realised, they are somewhat hypothetical, but based on best engineering practise. If costs are given, they describe the expected additional prize the consumer has to pay for this feature. If ranges are given, the higher value normally corresponds to an implementation of this feature in a first introduction phase, while the lower value estimates how costs may develop at a large scale use. Results of the consumer survey will be added in a supplementary document to this report.

In the following synergy scenarios the complexity of technical adjustments on the device considered increases from level 1 (3.3.6.1) to level 4 (3.3.6.4) steadily. Whereas in level 1 the consumer still has the full control whether to use the described option or not, in level 2 some of that control was handed over to the machine which then reacts to incoming signals. In level 3 the full control is in the hands of an external manager (e.g. electric utility) who decides about when and how often the machine is being switched on or off after it was set in a ready mode by the consumer. Therefore signals are being transmitted in a bidirectional way. In level 4 additional options for storing energy or using heat from other sources are taken into account.

3.3.6.1 Shifting operation in time

Id and title: 1-1 Consumer shifts operation in time
Description: The consumer receives a signal about the availability of renewable energy or energy from CHP plants. Depending on the signal, he shifts the operation of a dishwashing machine cycle to run at a time, where in relation to the expected load too much electricity is generated. The information about the availability may be communicated via radio (e.g. weather forecast), internet or remote control signals coming from the electricity provider. The consumer has to make his own decision whether to use this information or not. Available “start time delay” options may be used.
Strategy for appliance control: This synergy option requires the active engagement of the consumer by transferring the information of shortage or surplus of renewable energy into the operation of the appliance. The broadcasting of the information may be randomized or varied in time locally to avoid that too many consumers are acting on the same signal at the same time.
Change in power demand curve of single appliance: No change.
Change in day curve (of power demand of all appliances): As at present about 10% of the dishwashing machines are operated by using the start time delay function [EUP14 07a] and most of them are running in the evening when there is no need to have the pro-

gramme finished quickly, it is estimated that at maximum perhaps for 20% of the operations the described mode will be used. The option allows shifting the power demand at any time in any direction. A delay of the operation of 3 hours is assumed for this scenario (with an estimated maximum of 19 hours), which will result in a reduction of the operation probability, followed by a recovery period (Figure 3.3-14).

Consumer benefits and drawbacks:

Enhanced use of renewable energy and CHP. But probably only accepted by convinced environmentalists or by people owning their own power or heat generation unit if the resource use is cheaper than if taken from other sources.

Demand management benefits and drawbacks:

Consumer behaviour is unpredictable. Experience may allow forecasting consumer behaviour. Consumer acceptance may depend on the time of the day.

Impact on appliance design and service provided: (additional costs, limitations, additional energy consumption):

Delay start timer may be helpful. Already today available in almost 40% of the appliances in the stock. As operation may occur over night, the noise level of the dishwasher must be low. Additional costs for consumer, if start time delay time is additionally needed: 5 € - 25 €.

Additional energy needed: 0 – 4 W (depends on the use of a start time delay function).

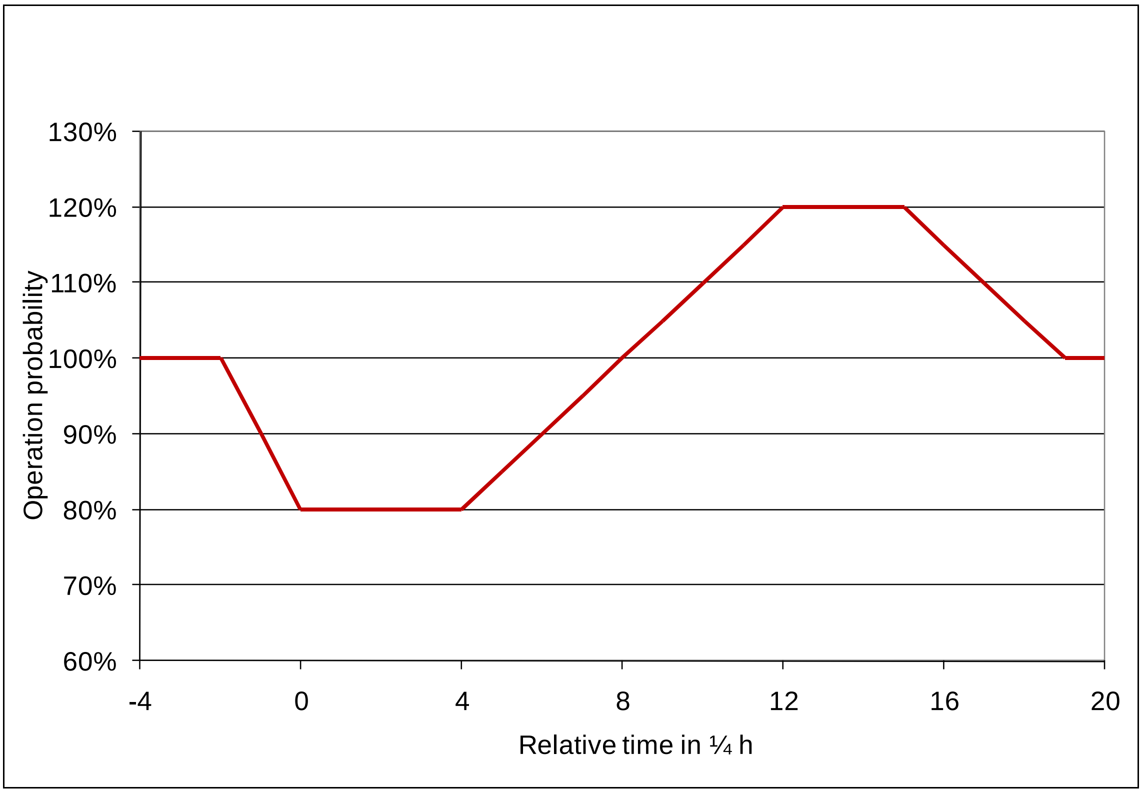
Consumer acceptance questions:

Willingness to accept this solution if additional costs are balanced by savings via energy bill.
Calculation (additional costs: 15 €):
241 kWh/a at 0,20 €/kWh = ~ 50 €/a energy costs
Amortisation in 5 years: 3 €/a saving
Reduction of energy costs by 6% needed!

Strategies for success:

Increase environmental awareness and practise.

Figure 3.3-14 Example of a change in operation probability for synergy scenario 1-1



Source: University of Bonn

3.3.6.2 Applying flexibility on appliance power demand

Id and title: 2-1 Power line triggered operation
Description: Signals via e.g. power line may be used to communicate about the availability of surplus power on the grid. This can be detected by the dishwasher and transferred into action. Action may be an immediate start as far as the machine is in a start time delay or in a special "ready for operation" mode. Alternatively other means like frequency sensing might be used as the frequency is changing with total load on the grid and high availability of energy will increase the load and thus the frequency.
Strategy for appliance control: Dishwashing machine start is anticipated when machine is in start time delay or special "ready for operation" mode. To avoid overload by too many machines starting the same time, the algorithm used to define the start time shall have a random factor including shifting the decision up to two hours.
Change in power demand curve of single appliance: No change.
Change in day curve (of power demand of all appliances): May allow to shift perhaps 10% of the operations at any time. As it is assumed that the machine is in start time delay operation mode, an anticipation of the operation will allow to increase the operation probability (Figure 3.3-15) short term, followed by a drop of the probability. A shift of the operation by up to 3 hours is estimated as the most likely scenario (at maximum a shift of up to 9h would be possible).

Consumer benefits and drawbacks:

Enhanced use of renewable energy and CHP. Possible irritation of consumers when machine starts at any time (e.g. also during night).

Demand management benefits and drawbacks:

Usage depends on the acceptance of a start time delay operation by the consumer.

Impact on appliance design and service provided: (additional costs, limitations, additional energy consumption):

Additional costs for consumer (start time delay or the like): 10 € - 50 €.
Additional power consumption:

- in start time delay mode: > 0 W - 4 W
- after programme end: 0 W - 4 W.

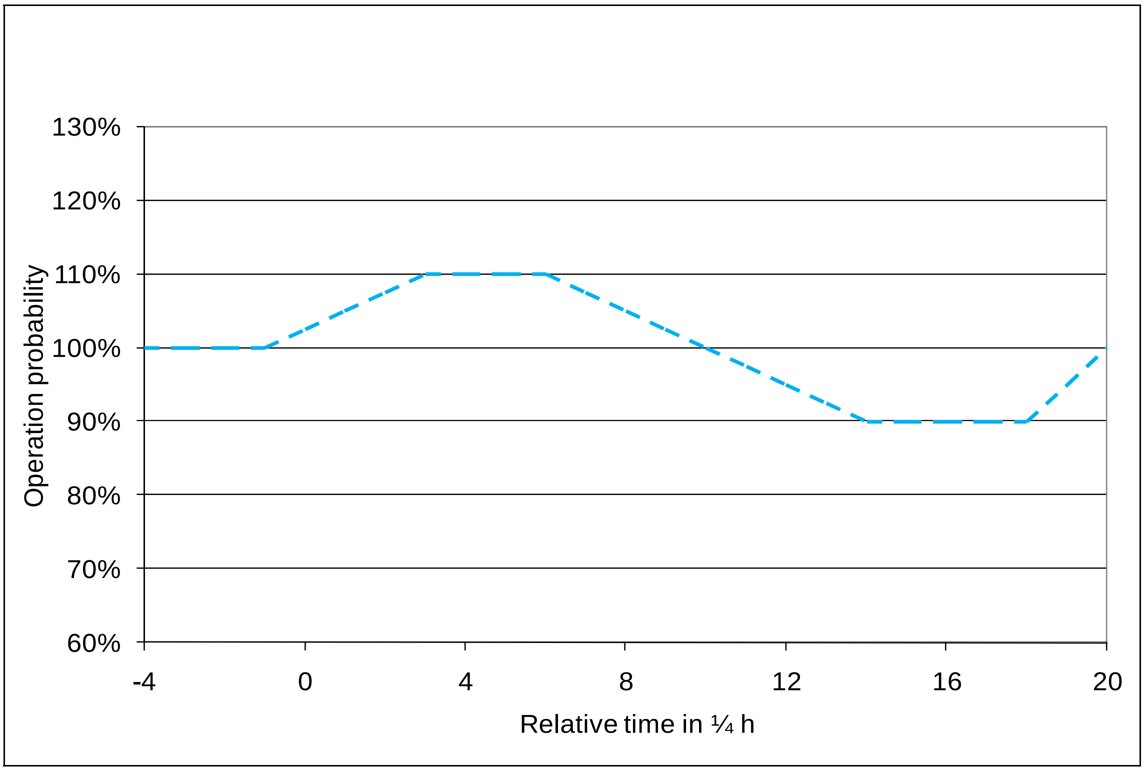
Consumer acceptance questions:

Willingness to accept this solution if additional costs are balanced by savings via energy bill.
Calculation (additional costs: 30 €):
241 kWh/a at 0,20 €/kWh = ~ 50 €/a energy costs
Amortisation in 5 years: 6 €/a saving
Reduction of energy costs by 12% needed!

Strategies for success:

Define business model where energy utilities sponsor the implementation of these “Power line triggered” modules.

Figure 3.3-15 Example of a change in operation probability for synergy scenario 2-1



Source: University of Bonn

Id and title:

2-2 Internal energy manager agent

Description:

Triggered by an external signal about shortage of energy the dishwashing machine may change its operation:

- delay the start of the heating phase
- interrupt the heating phase up to a certain time
- reduce the power demand by choosing a lower temperature for the programme and prolonging the cleaning time

Strategy for appliance control:

The external signal should include information on the shortage of energy and how long it may last. Dishwashing machines being in an appropriate state will then react by their own intelligence to find the appropriate answer.

Change in power demand curve of single appliance:

Various. May shift heating time or heating power by seconds and minutes.

Change in day curve (of power demand of all appliances):

As today 10% of the dishwashing machines are operated in the start time delay mode it is estimated that at maximum for 20% of the operations the described mode is used. The option allows shifting the operation by seconds and minutes. Assuming a shift of ¼ hour the operation probability will be changed as shown in Figure 3.3-16.

Consumer benefits and drawbacks:

Enhanced use of renewable energy and CHP. Possible irritation of consumers when machine stops. But short term breaks may not be recognized at all. Impact on dishwashing results must be limited. Too long breaks during heat-up period will cause a loss of energy.

Demand management benefits and drawbacks:

Influence on power demand by short term action. Effect will depend on the time of the day and the penetration of energy management agents in dishwashing machines.

Impact on appliance design and service provided: (additional costs, limitations, additional energy consumption):

Internal energy manager agent needs to be included in electronic unit of machine.
A harmonised signal of power shortage is needed.
Additional costs for consumer (signal recognition plus energy agent): 10 € - 100 €.
Additional power consumption:

- during operation: > 0 W - 4 W.

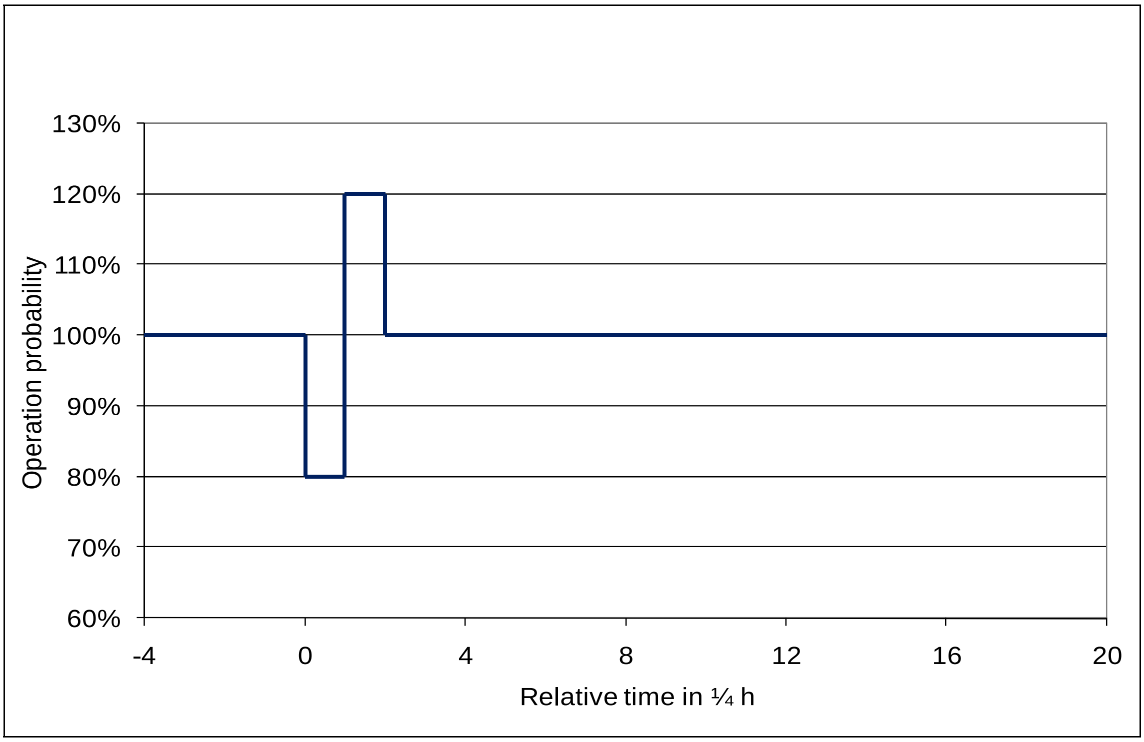
Consumer acceptance questions:

Willingness to accept this solution if additional costs are balanced by savings via energy bill.
Calculation (additional costs: 55 €):
241 kWh/a at 0,20 €/kWh = ~ 50 €/a energy costs
Amortisation in 5 years: 11 €/a saving
Reduction of energy costs by 22% needed!

Strategies for success:

Define harmonised signal for shortage of power (CENELEC).
Define business model where energy utilities sponsor the implementation of these “Internal energy management agent” modules.

Figure 3.3-16 Example of a change in operation probability for synergy scenario 2-2



Source: University of Bonn

3.3.6.3 Managing the power on the grid

Id and title: 3-1 Energy demand manager
Description: The energy demand manager tries to harmonise the available power on the grid coming from conventional and renewable resources with the demand. Therefore when the dishwashing machine is started, it is set in a remote control mode which allows the energy demand manager to decide about the start of the machine within a predefined time interval. The energy demand manager is informed about the selected programme or at least the expected energy demand.
Strategy for appliance control: Knowing the demand for the next few hours the energy demand manager tries to use as much renewable energy and energy from CHP as possible and optimises the overall costs.
Change in power demand curve of single appliance: Unchanged.
Change in day curve (of power demand of all appliances): As today 10% of the dishwashing machines are operated in the start time delay mode, it is assumed that at maximum 20% (except 2-1) of the operations - at full implementation of the described feature - might be shifted according to any of the probability curves as shown for the synergy scenarios 1-1, 2-1 or 2-2 in Figure 3.3-17 (managed by the energy demand manager). As the consumer is not involved in the operation of the device any more, the probability curve of scenario 1-1 (delayed start) stands for a second option of scenario 2-2.

Consumer benefits and drawbacks:

Enhanced use of renewable energy and CHP. Cost benefits must be transferred to the consumer. Consumer remains in the position to decide whether he wants to use this option or not.

Demand management benefits and drawbacks:

Influence on power demand by medium term action. Influence only on those machines which are ‘online’.

Impact on appliance design and service provided: (additional costs, limitations, additional energy consumption):

Bidirectional communication needed. Additional switch needed to signal ‘remote operation accepted’.
A harmonised communication protocol is needed.
Additional costs for consumer (communication module via power line): 30 € - 130 €.
Additional power consumption:

- during waiting for operation: > 0 W - 4 W

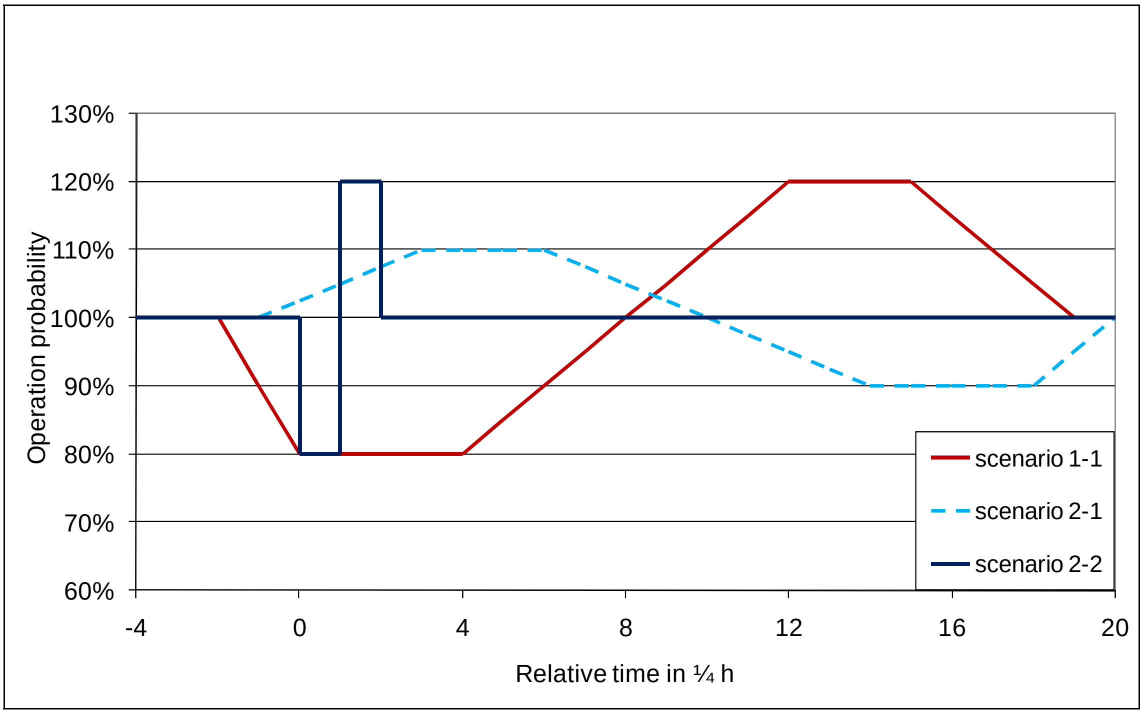
Consumer acceptance questions:

Willingness to accept this solution if additional costs are balanced by savings via energy bill.
Calculation (additional costs: 80 €):
241 kWh/a at 0,20 €/kWh = ~ 50 €/a energy costs
Amortisation in 5 years: 16 €/a saving
Reduction of energy costs by 32% needed!

Strategies for success:

Define harmonised communication protocol (CENELEC).
Define business model where savings balance the additional costs for the appliance.

Figure 3.3-17 Change in operation probability for synergy scenarios 3-1 (any of 1-1, 2-1, 2-2)



Source: University of Bonn

3.3.6.4 Using energy storage capacity and other technologies

Id and title:

4-1 Enhanced use of hot water

Description:

As dishwashing is done most frequently at 50°C and higher temperatures, hot water intake may be used to heat up the load and machine. Additional electrical heating is needed to reach the required temperature of the programme. Although intermediate water intakes could be with cold water, this is not beneficial, as this would cool down the dishes and more electricity would be needed to reach again a high temperature in the final rinse. Therefore only hot water intake could be a viable option. Programme structure may need to be adjusted to make optimal use of this hot water supply.

Strategy for appliance control:

Connect the dishwasher to a hot water supply. To avoid negative effects on structural elements of the machine, the maximum temperature of the water intake should be at 70°C. If water supplied is hotter, a mixing with cold water should be done. This should be done in a separate unit outside the dishwasher.

Change in power demand curve of single appliance:

Heating power reduced by about 50% - total energy consumption: 620 Wh (= 52%) (Figure 3.3-18).

Change in day curve (of power demand of all appliances):

No change.

Consumer benefits and drawbacks:

Enhanced use of renewable energy and CHP. Cost benefits.

Demand management benefits and drawbacks:

Operation of the dishwasher may be linked to availability of renewable hot water.

Impact on appliance design and service provided: (additional costs, limitations, additional energy consumption):

Hot water valve in the kitchen.
Programme must be adopted to ensure re-heating and appropriate dishwashing times.
Additional costs for consumer (valve): 150 € - 250 €.
Additional power consumption: 0 W

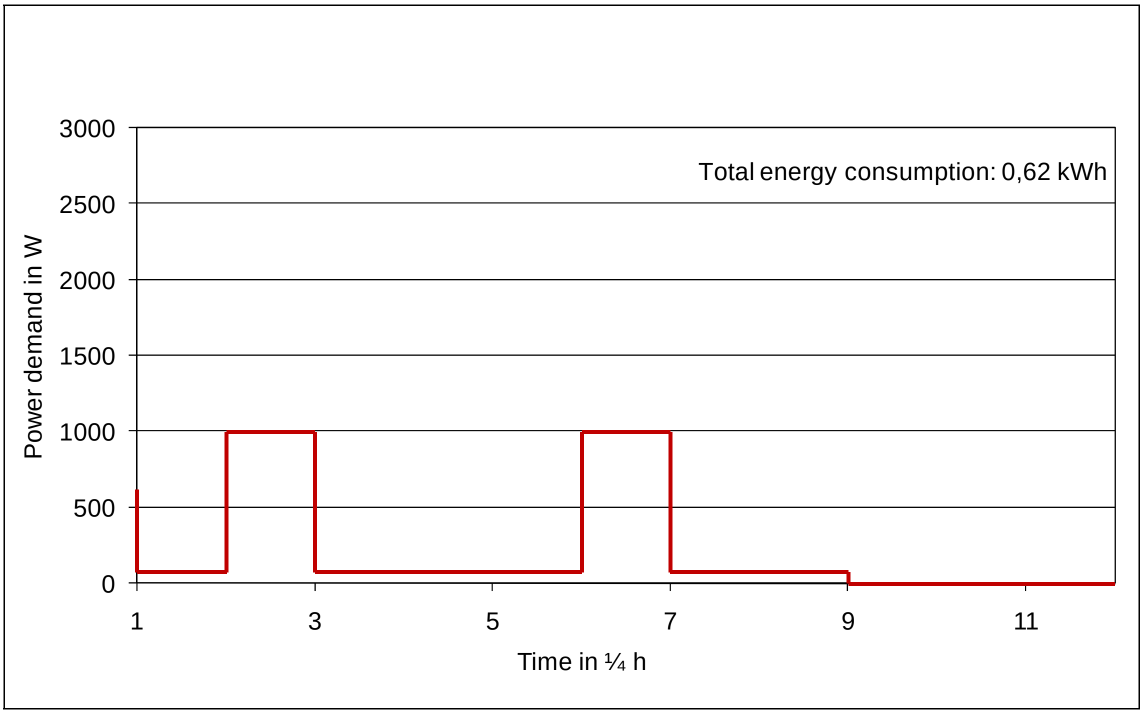
Consumer acceptance questions:

Willingness to accept this solution if additional costs are balanced by savings via energy/water bill.
Calculation (additional costs: 200 €):
241 kWh/a at 0,20 €/kWh = ~ 50 €/a energy costs
Amortisation in 5 years: 40 €/a saving
Reduced energy consumption (52% of 241 kWh):
125 kWh/a at 0,20 €/kWh = 25 €/a energy costs
Reduction of energy costs by 30% needed!

Strategies for success:

Promote use of dishwashers with hot-fill together with renewable (or by CHP) production of heat.
Promote development of dishwashing programmes which can work with water of > 60 °C water inlet temperature (also of programmes designed for 40°C!).

Figure 3.3-18 General pattern of a power demand curve of a dishwashing machine with H/C-fill



Source: University of Bonn

Id and title: 4-2 Heating by hot water
Description: Using the warmth produced by a CHP unit, a solar plant or district heating for heating up the water in the dishwashing machine. The heat is led directly into the heating rods within the machine which then heat up the water to the desired temperature. Water needs to be at least 60°C warm. The total amount of electricity for this heating phase is replaced by the use of heat of other systems. Electricity is here only needed for the basic functions of the machine (circulation pump, drain pump, electronic device).
Strategy for appliance control: Connect the dishwasher to a CHP, solar plant or district heating. To avoid negative effects on the cleaning result, the water temperature should be controlled by a sensor which stops the heat supply when the desired temperature is reached.
Change in power demand curve of single appliance: Heating power reduced by 100% - total electrical energy consumption: 160 Wh (= 13%) (Figure 3.3-19).
Change in day curve (of power demand of all appliances): No change.
Consumer benefits and drawbacks: Enhanced use of renewable energy and CHP. Cost benefits. Programme duration may be prolonged, depending on the temperature of the water and the heat exchange (size of heat exchanger).

Demand management benefits and drawbacks:

Operation of the dishwasher is linked to the availability of heat by the described suppliers.

Impact on appliance design and service provided: (additional costs, limitations, additional energy consumption):

Special heating rods are needed.
Programme must be adopted to ensure re-heating and appropriate cleaning times.
Additional costs for consumer: 50 € - 150 €.
Additional power consumption: 0 W

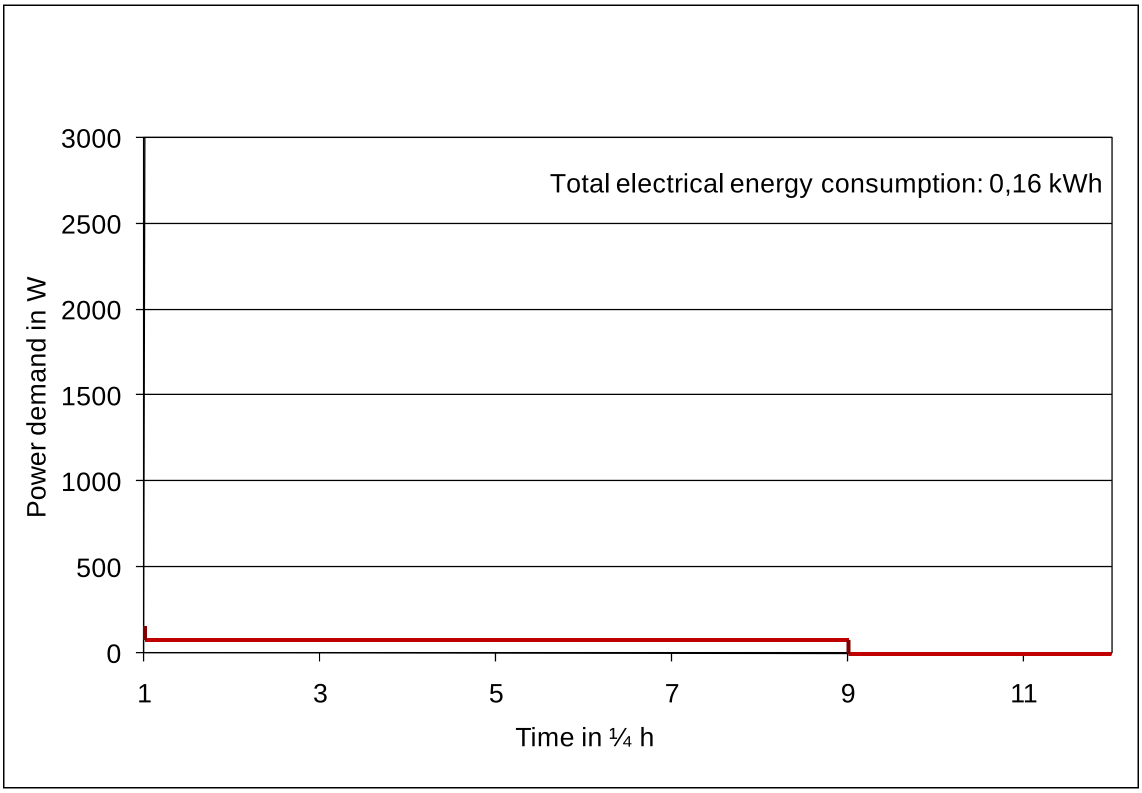
Consumer acceptance questions:

Willingness to accept this solution if additional costs are balanced by savings via energy/water bill.
Calculation without costs for heat from other systems (additional costs: 100 €):
241 kWh/a at 0,20 €/kWh = ~ 50 €/a energy costs
Amortisation in 5 years: 20 €/a saving
Reduced electrical energy consumption (13% of 241 kWh):
31,3 kWh/a at 0,20 €/kWh = 6 €/a energy costs
No reduction of energy price needed.

Strategies for success:

Promotion of dishwasher with direct use of renewable (or by CHP) produced heat.

Figure 3.3-19 General pattern of a power demand curve of a dishwashing machine heated by CHP



Source: University of Bonn

3.4 Oven and stove

Two types of energy are used by cooking appliances on the European market: gas and electricity. This report focuses only on the devices which are operated with the latter one. Even though the penetration of microwaves is increasing they are still not used for cooking major meals and therefore not considered here as well.

3.4.1 Technical description with regard to the use of energy

Electrical hobs (also called stoves) are either fitted with hot plates or with glass ceramics. The conventional model in stock is a sealed hob with usually four hot plates made of cast iron. The heat is being transferred through thermal conduction. In comparison to them ceramic stove tops using up to 20% less energy depending on the cooking process [STW 04]. The heat is transferred from the heating element to the cookware via thermal radiation and conduction. A halogen heating element leads the heat almost directly through the glass ceramic to the bottom of the cookware. In an induction hob the heat emerges through induction at the bottom of the cookware. Instead of a heating element a copper coil is being used which induces turbulent electric flow in the bottom of the cookware and thereby heats it up. The ceramic stove top is here not being heated up. As soon as the cooking pot is removed the heat input will stop and only a little residual heat will remain. When compared to other technologies of electrical cooking the induction hob is the most energy efficient one in almost all cooking processes.

Ovens consist of enamelled steel sheet and are insulated from inside to the housing. The temperature can vary between 50°C and 300°C and the heating systems range from top and bottom heat to fan heating, grill or combinations of some of them. The heat is transferred via radiation and to a small amount via natural convection. The use of a fan heating system intensifies the convection which quickens the cooking process, enables the use of a lower temperature and therefore decreases the consumption of energy. The energy consumed depends on the cooking time and on the chosen heating process which can reach a total power input of up to 3000 W. In test cycles for the European energy label [EEF 06] the energy consumption of electric ovens range from 0,8 kWh (best model class A) to 1,2 kWh (typical model) per cycle.

Beside an oven or hob as a single device combined devices called electric cookers are also available on the market.

A study investigating 100 households in France within the SAVE programme [ECUEL 99] stated that about 50% of the total cooking-related energy consumption was attributable to electric hobs and approximately 42% to ovens. As for all electric cooking appliances in one household it reported an average annual energy consumption of 568 kWh/a. But big variations between households and countries are subject of anecdotal reports.

3.4.2 Penetration in Europe

The data about the penetration ratio of cooking appliances in Europe is very fragmented and only partly available for one of the devices, i.e. only for hobs or only for ovens.

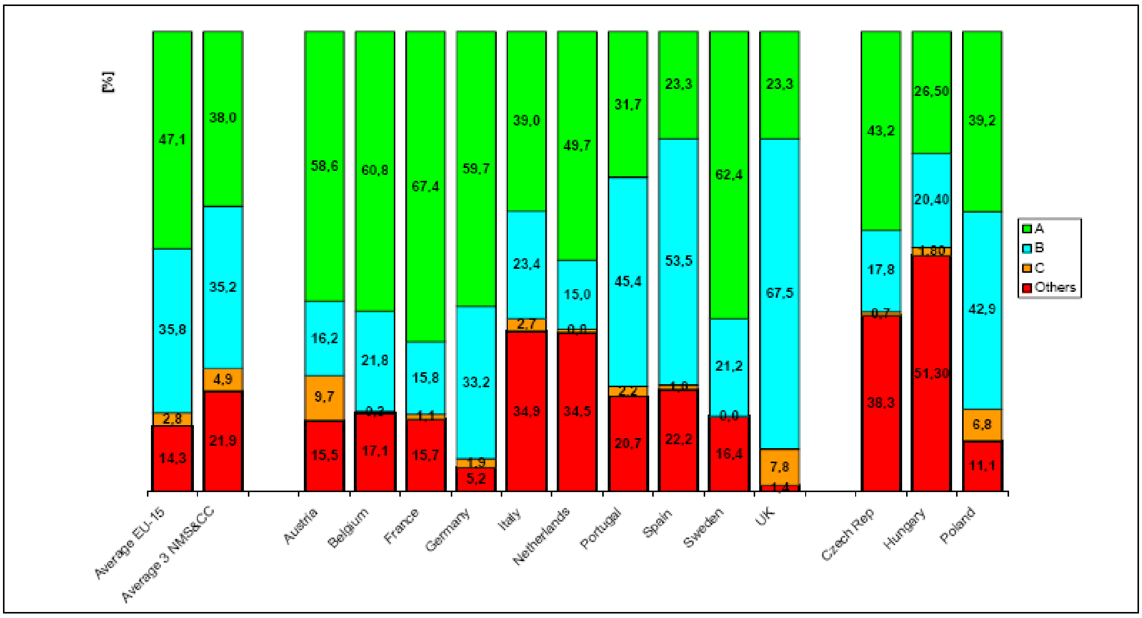
Within the SAVE II study [SAVE II] carried out in 1998-1999 a market penetration of 77% for electric ovens in the EU-15 was published. The countries in which relatively more gas ovens are owned by the households are France with 50%, the UK and Italy with 41,5% each. Germany, Austria and the Netherlands have an average penetration ratio of about 20% for gas ovens and in Scandinavia these models are practically non-existent.

As a more recent study of the European Commission [EEF 06] reported that electric ovens represent 97% of the overall oven sales in the year 2005 in the EU-15 as well as likewise in the 10 New Member States it seems that the preference for electric models is still increasing.

In the same report a share in sales of 34,5% for electrical free standing cookers and a share in sales among electric and gas of 58,4% for electric hobs is published. Similar to ovens the preferences for gas and electric hobs vary quite strongly from country to country, e.g. in Germany and Sweden almost 100% of the hobs are electrical whereas in Italy almost 100% are gas operated.

The same report [EEF 06] sees an impact of the mandatory energy label [EU 02], which covers only electric ovens (including ovens in free standing cookers), beginning to be visible on the efficiency of the devices in the European market (Figure 3.4-1). Although the sales of ovens with the A class level have reached an amount of almost 50% on average in the EU-15, this figure is still far from the sales of class A washing machines or dishwashers.

Figure 3.4-1 Sales of ovens in 2005, by energy class



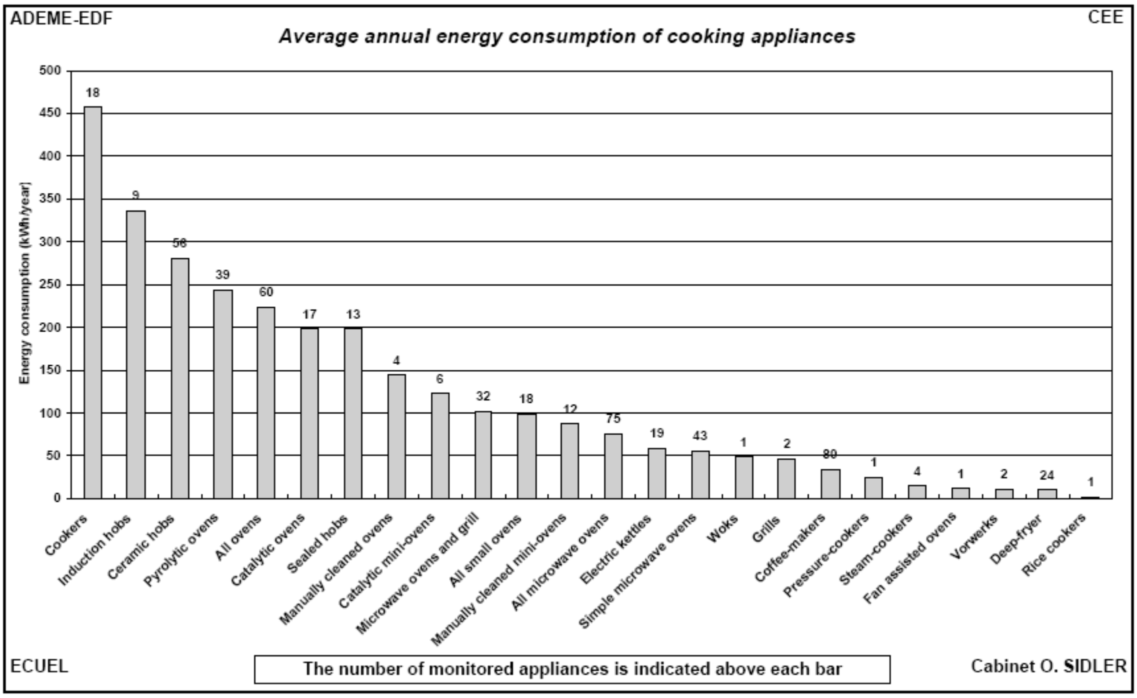
Source: GfK, [EEF 06]

3.4.3 Consumption of energy in Europe

In the Energy Efficiency Report [EEF 06] a total energy consumption in 2004 of 52 TWh in the EU-15 for electric cooking was published. Thereof an amount of 37 TWh was consumed by electric hobs and 15 TWh by electric ovens. With an estimated amount of 160 million households in the EU-15 this leads to an annual consumption of 120 kWh per household for electric ovens and 300 kWh for electric hobs (penetration ratio: 77%).

The SAVE project study [ECUEL 99] published an average annual energy consumption per household for electric cookers (combined hob and oven) of 457 kWh/a, for induction hobs of 337 kWh/a, 281 kWh/a for ceramic hobs and 224 kWh/a for ovens (Figure 3.4-2).

Figure 3.4-2 Annual average electricity consumption of electric cooking appliances



Source: Cabinet O. Sidler, 1999 [ECUEL 99]

A result of the same study was that induction hobs used the most energy in comparison to other models due to their standby power demand (between 8 – 18 W) and their heavy daily use (58 min/day). In respect of the energy consumption per hour of use however this type is the most efficient one (relative energy efficiency: 82 %) with a consumption of 588 Wh, ahead of ceramic hobs with a consumption of 999 Wh (relative energy efficiency: up to 70 %) and the least efficient sealed hobs (relative energy efficiency: 50 %) with 1161 Wh.

The study [ECUEL 99] pointed out that the most efficient technology of hobs and ovens from the perspective of energy saving was the one that exhibited the highest overall energy consumption due to their relatively heavier usage.

3.4.4 Effects on energy consumption due to consumer usage

Cooking appliances are devices which are operated in relatively small time slots during the day and on consumer demand only. Therefore the consumption of energy in the period of use is determined by the following, mainly consumer driven, factors:

- Frequency of operation
- Cooking process and its execution
- Type of hob (ceran, induction…)
- Device efficiency under real use conditions
- Cooking temperature
- Amount of hot plates or fields
- Heating option (top heat, grill…) of oven
- Frequency of oven door opening

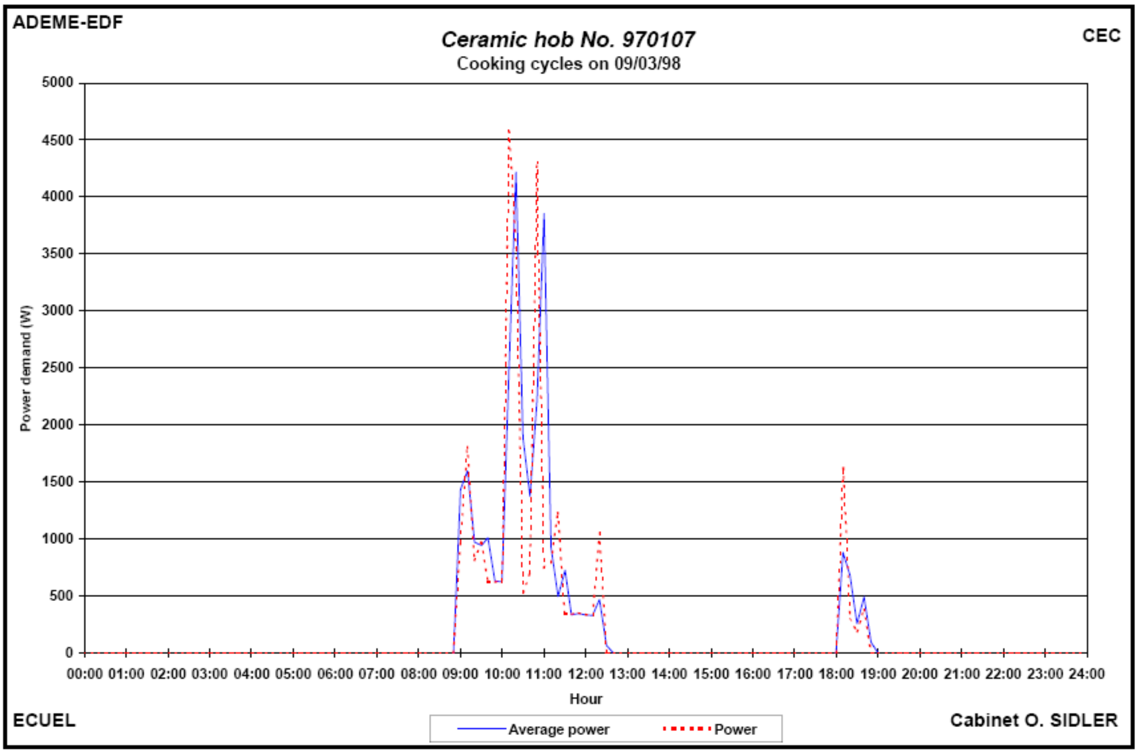
As a result of the SAVE II study [SAVE II] the average EU household uses its oven about 110 times a year, although there are huge differences between the countries. Consumers in the UK, France, Sweden, and Finland use their oven roughly more than 3 times a week, whereas in the Netherlands its used less than once a week. In Germany and Austria the frequency of usage is with 80 to 90 times per year just below the EU average and in Italy it is probably only around 23 times a year.

The frequency of operation mainly depends on the household size, as this defines the amount of meals to be cooked. Therefore a more or less linear increase of cooking processes with the number of persons living in the household may be assumed.

3.4.5 Power demand and load curves

The SAVE project study [ECUEL 99] published that during the day an electric hob is mainly used on midday and in the evening which is reflected in its power demand curve (Figure 3.4-3).

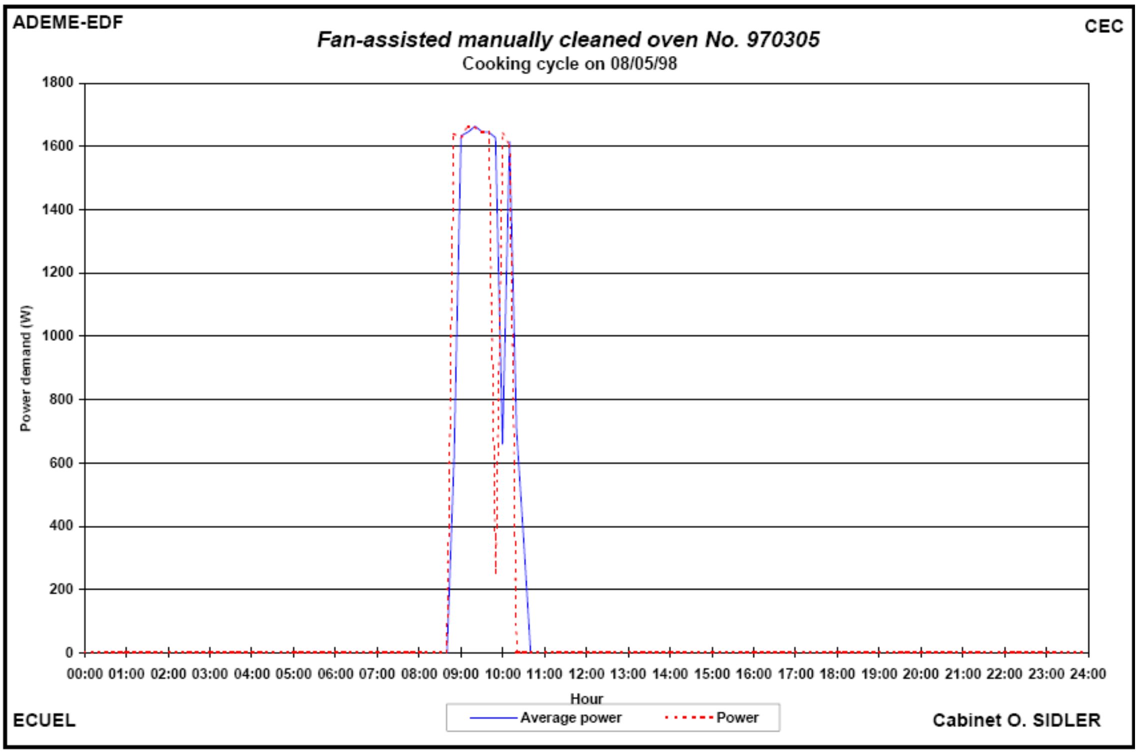
Figure 3.4-3 Daily power demand of an electric hob



Source: Cabinet O. Sidler, 1999 [ECUEL 99]

The power demand curve of an oven shows the heaviest use in a period of about 2 hours in the morning (Figure 3.4-4). As mentioned previously the average energy consumption of ovens per household was 224 kWh/a, whereas convection ovens used 233 kWh/a and fan-assisted ones 219 kWh/a. For one cooking period an average energy consumption of 889 Wh was reported. As average an energy consumption of 225 kWh per year per household or 617 Wh per day is calculated.

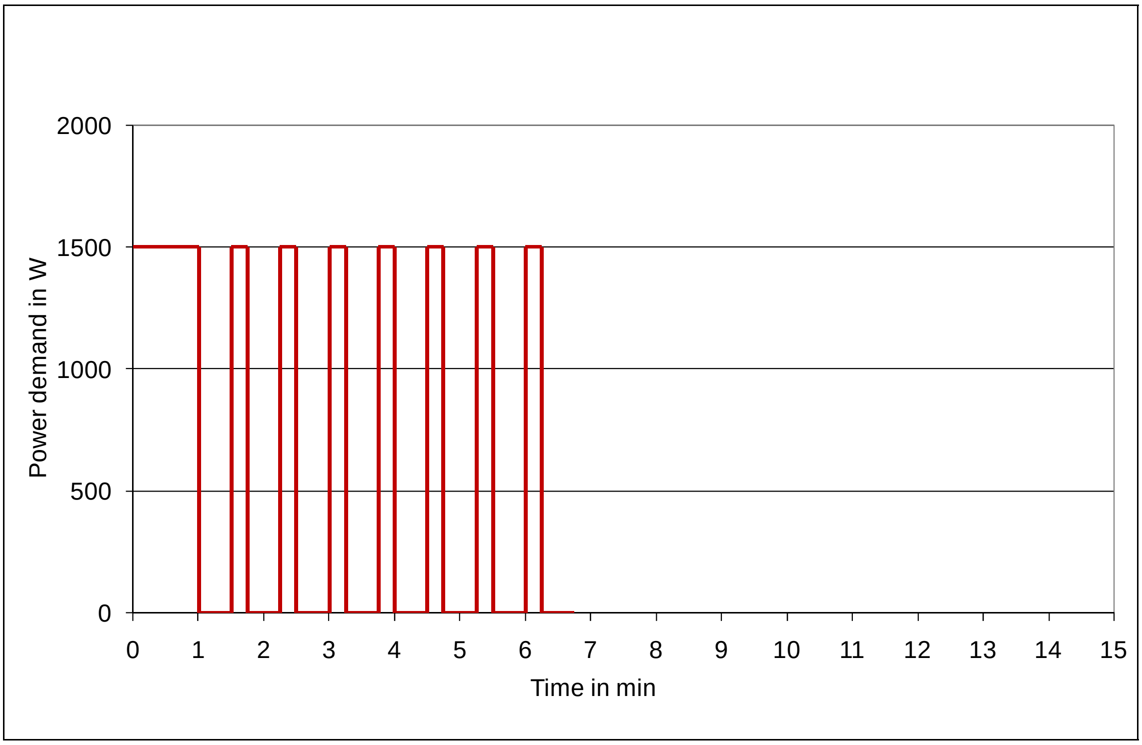
Figure 3.4-4 Daily power demand of an electric oven



Source: Cabinet O. Sidler, 1999 [ECUEL 99]

The power demand curve of an average cooking process needs to fit the energy consumption value of a sealed hob (1,1 kWh), a ceramic hob (0,9 kWh) or an induction hob (0,58 kWh), which is in average 0,92 kWh per cycle. Having a normal cooking process as a guidance and splitting the power demand into one minute steps this leads to an estimated power demand curve (Figure 3.4-5).

Figure 3.4-5 General pattern of a power demand curve of an electric hob

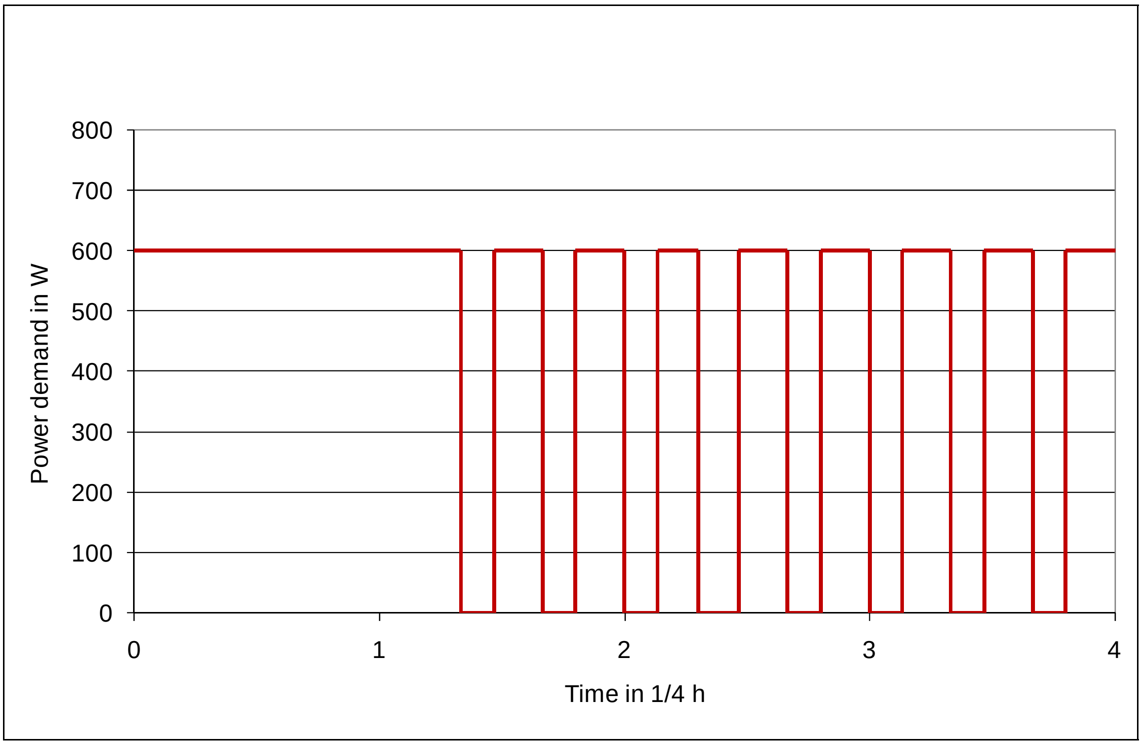


Source: University of Bonn

The exact shape of the curve will certainly vary depending on the type of hob and temperature chosen by the consumer. However the pattern of the curve will stay the same: after a somewhat longer period of full power consumption the ranges between switching the power on and off remain identically and every period of power consumption is much shorter than the starting one.

The formal shape of the power demand curve of an electric oven is quite similar to the one of a hob (Figure 3.4-6). Only the time needed for the starting period as well as for the several heating periods is a bit longer. The consumption of power depends here on the chosen heating process and temperature as well.

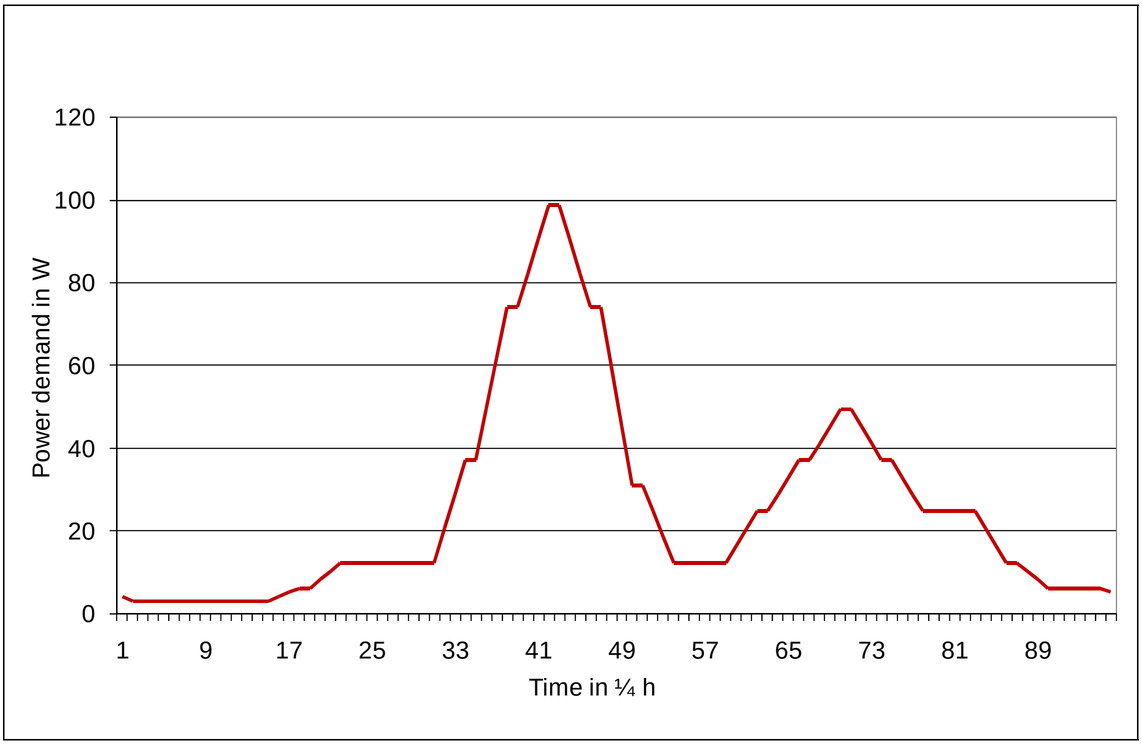
Figure 3.4-6 General pattern of a power demand curve of an electric oven



Source: University of Bonn

Breaking the average energy consumption of 225 kWh per year per household or 0,6 kWh per day down per day and assuming a concentration of cooking in the late morning hours, but some minor cooking activities also happening early in the morning and in the evenings a load curve (Figure 3.4-7) can be drafted.

Figure 3.4-7 General pattern of a daily load curve of an electric oven in an average European household



Source: University of Bonn

3.4.6 Synergistic potentials

Within this chapter it is tried to explore possible synergies when cooking appliances are somehow linked to sustainable energy sources, like solar or wind energy or heat from CHP processes. For each of these synergistic potentials it is described where the synergy comes from, what are possible constraints and what needs to be fulfilled to gain the potential. It is also estimated how many of the appliances might be affected and how these synergies might affect the power demand curve or the probability of operation of cooking appliances, including a possible recovery phase. As most of these synergies are not yet realised, they are somewhat hypothetical, but based on best engineering practise. If costs are given, they describe the expected additional prize the consumer has to pay for this feature. If ranges are given, the higher value normally corresponds to an implementation of this feature in a first introduction phase, while the lower value estimates how costs may develop at a large scale use. Results of the consumer survey will be added in a supplementary document to this report.

In the following synergy scenarios the complexity of technical adjustments on the device considered increases from level 1 (3.4.6.1) to level 4 (3.4.6.4) steadily. Whereas in level 1 the consumer still has the full control whether to use the described option or not, in level 2 some of that control was handed over to the machine which then reacts to incoming signals. In level 3 the full control is in the hands of an external manager (e.g. electric utility) who decides about when and how often the machine is being switched on or off after it was set in a ready mode by the consumer. Therefore signals are being transmitted in a bidirectional way. In level 4 additional options for storing energy or using other technologies are taken into account.

3.4.6.1 Shifting operation in time

Id and title:

1-1 Consumer shifts operation in time

Description:

The period of time for shifting the operation time of an oven or a hob to any time of the day when a huge amount of energy is available is very limited. The information about the availability may be communicated via radio (e.g. weather forecast), internet or remote control signals coming from the electricity provider. The consumer has to make his own decision if he is going to use this information or not.

Strategy for appliance control:

This synergy option requires the active engagement of the consumer by transferring the information of shortage or surplus of renewable energy into the operation of the appliance. The broadcasting of the information may be randomized or varied in time locally to avoid that too many consumers are acting on the same signal at the same time.

Change in power demand curve of single appliance:

No change.

Change in day curve (of power demand of all appliances):

It is estimated that maybe about 5% of the consumers will be willing to shift the start of their cooking process (Figure 3.4-8). But the range for shifting the start is assumed to be very narrow, due to the fact that eating times are more or less fixed to a specific time of the day. Therefore a shift of up to 30 min seems to be the maximum for any oven or hob operation.

Consumer benefits and drawbacks:

Enhanced use of renewable energy and CHP. But probably only accepted by convinced environmentalists.

Demand management benefits and drawbacks:

Consumer behaviour is unpredictable. Experience may allow forecasting consumer behaviour. Consumer acceptance may depend on the time of the day.

Impact on appliance design and service provided: (additional costs, limitations, additional energy consumption):

Additional costs for consumers: 0 €

Additional energy consumption: 0 W

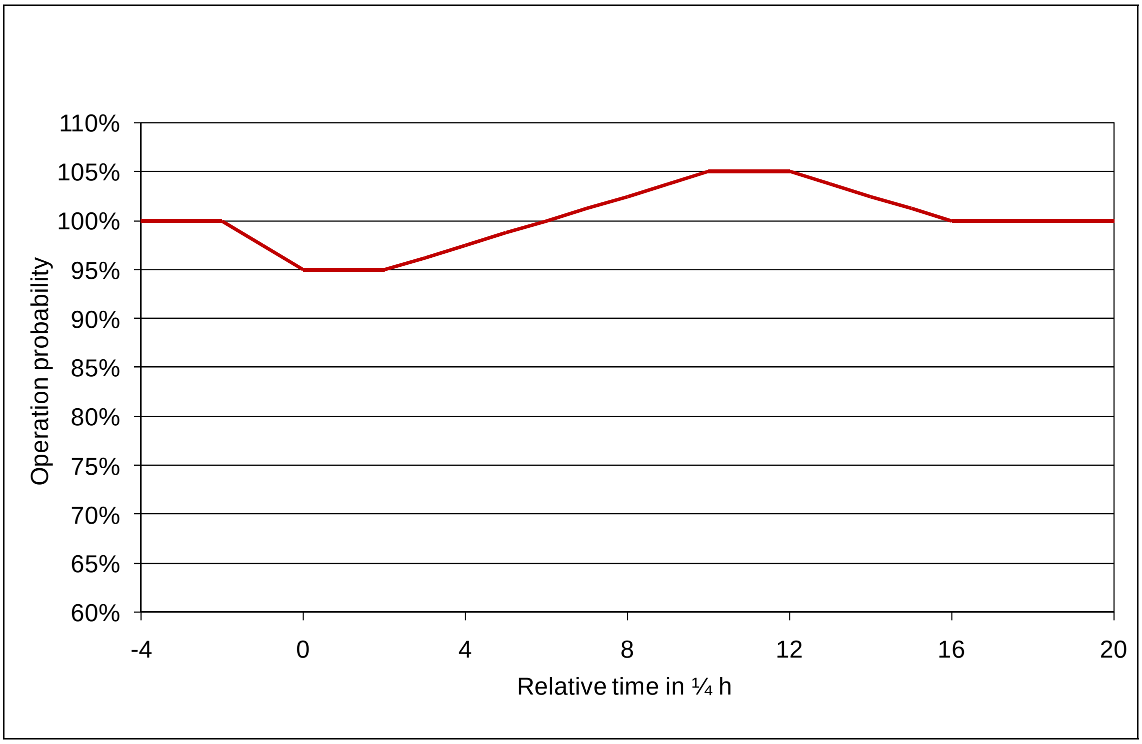
Consumer acceptance questions:

Willingness to accept without direct benefit.

Strategies for success:

Increase environmental awareness and practise.

Figure 3.4-8 Example of a change in operation probability for synergy scenario 1-1



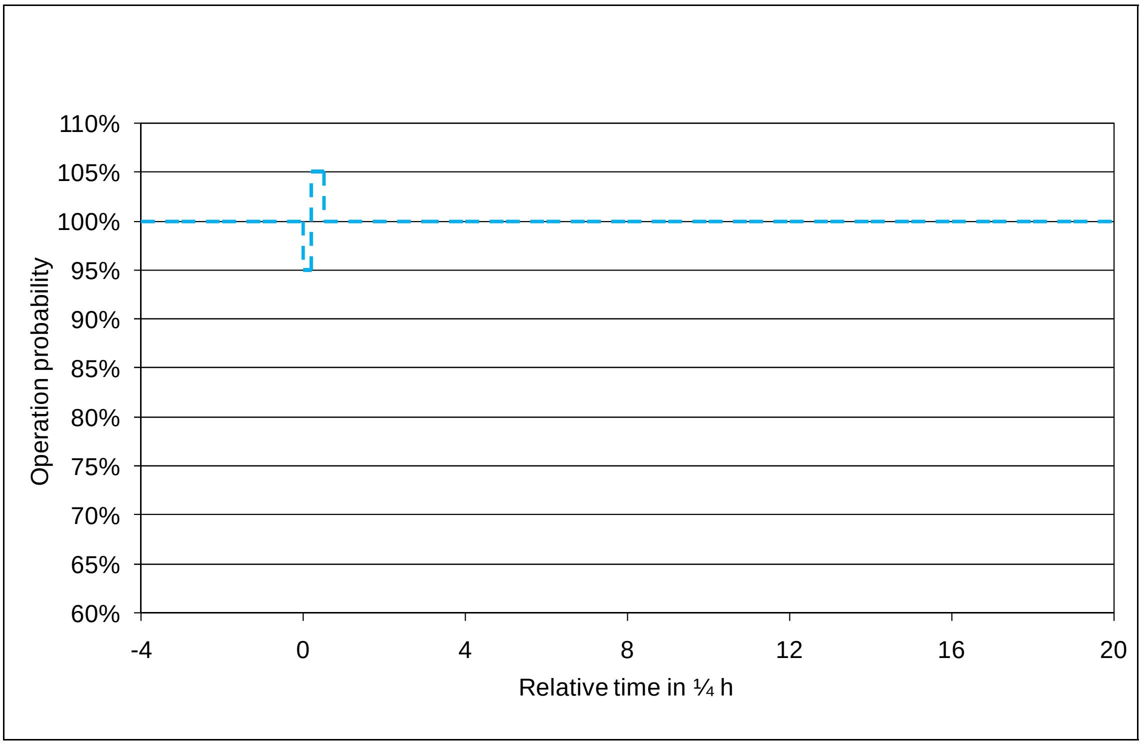
Source: University of Bonn

3.4.6.2 Applying flexibility on appliance power demand

Id and title: 2-1 Power line triggered operation
Description: Signals via e.g. power line may be used to communicate about the shortage of energy on the grid. This can be detected by the cooking appliance and transferred into action. Action may be an immediate interruption as far as the machine is in a special “ready for operation” mode. Alternatively other means like frequency sensing might be used as the frequency is changing with total load on the grid and low availability of energy will decrease the load and thus the frequency.
Strategy for appliance control: Device must contain a mechanism which allows very short breaks only during the cooking process and not shortly after the start.
Change in power demand curve of single appliance: No change.
Change in day curve (of power demand of all appliances): Although short breaks will probably not being recognised at all by the consumers during the operation, it is assumed that only perhaps 5% of them will be willing to accept that their operations may be interrupted even if it is only for a few seconds or minutes. The change of the operation probability for an estimated interruption of a few minutes is shown in Figure 3.4-9.
Consumer benefits and drawbacks: Enhanced use of renewable energy and CHP.

Demand management benefits and drawbacks: Consumer behaviour is unpredictable. Longer experience may allow forecasting consumer behaviour.
Impact on appliance design and service provided: (additional costs, limitations, additional energy consumption): Device needs a frequency sensor. Additional costs for consumer (frequency sensor): 10 € - 50 €. (depending on the need of additional electronic devices) Additional power consumption (in sensor mode): > 0 W - 4 W
Consumer acceptance questions: Willingness to accept this solution if additional costs are balanced by savings via energy bill. Calculation (additional costs: 30 €): 420 kWh/a at 0,20 €/kWh = 84 €/a energy costs Amortisation in 5 years: 6 €/a saving Reduction of energy costs by 7% needed!
Strategies for success: Define business model where energy utilities sponsor the implementation of these “Power line triggered sensor” module.

Figure 3.4-9 Example of a change in operation probability for synergy scenario 2-1



Source: University of Bonn

Id and title:

2-2 Internal energy manager agent

Description:

Triggered by an external signal about the shortage of energy the cooking appliance may change its operation and switches the power off for about a few seconds.

Strategy for appliance control:

The external signal should include information on the shortage of energy and how long it may last. The cooking appliance being in an appropriate state will then react due to their intelligence to find the appropriate answer.

Change in power demand curve of single appliance:

Prolonging the intervals between the heating phases or interrupting them for a few seconds or minutes.

Change in day curve (of power demand of all appliances):

In the first few minutes after the heating phase an interruption of a cooking process seems from an energy saving point of view not applicable. Only in the following period short breaks of these processes may be used to decrease the power demand for a short while (seconds or minutes). It is assumed that again maybe 5% of the consumers are willing to accept these interruptions (Figure 3.4-10).

Consumer benefits and drawbacks:

Enhanced use of renewable energy and CHP. Short term breaks may not be recognized at all. Impact on cooking results must be excluded.

Demand management benefits and drawbacks:

Influence on power demand by short term action. Effect will depend on the time of the day, the season and the penetration of energy management agents in cooking appliances.

Impact on appliance design and service provided: (additional costs, limitations, additional energy consumption):

Internal energy manager agent needs to be included in electronic unit of machine.
A harmonised signal of power shortage is needed.
Additional costs for consumer (signal recognition plus energy agent): 10 € - 100 €.
Additional power consumption:

- during operation: > 0 W - 4 W.

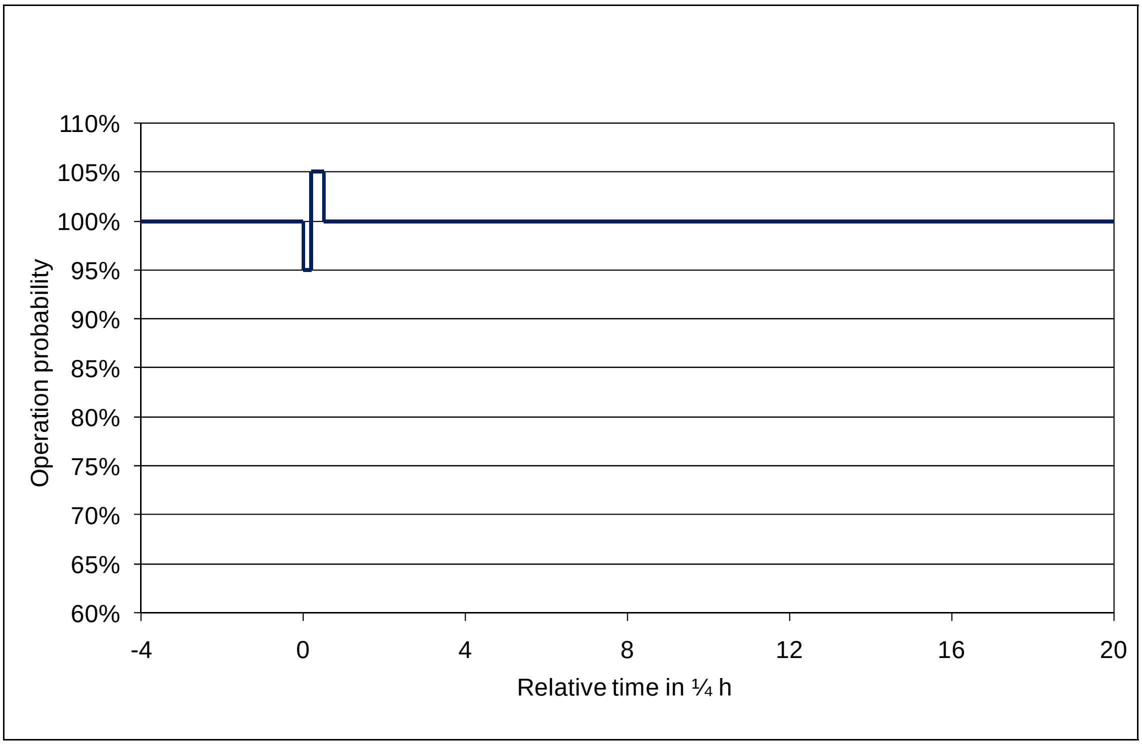
Consumer acceptance questions:

Willingness to accept this solution if additional costs are balanced by savings via energy bill.
Calculation (additional costs: 55 €):
420 kWh/a at 0,20 €/kWh = 84 €/a energy costs
Amortisation in 5 years: 11 €/a saving
Reduction of energy costs by 13% needed!

Strategies for success:

Define harmonised signal for shortage of power (CENELEC).
Define business model where energy utilities sponsor the implementation of these “Internal energy management agent” modules.

Figure 3.4-10 Example of a change in operation probability for synergy scenario 2-2



Source: University of Bonn

3.4.6.3 Managing the power on the grid

Id and title:

3-1 Energy demand manager

Description:

The energy demand manager tries to harmonise the available power on the grid coming from conventional and renewable resources with the demand. Therefore the device sends a signal at what time the consumer has chosen to use it later on. This allows the energy demand manager to decide about sending a signal back when energy is or will be available. The energy demand manager is informed about the selected cooking process and the expected energy demand.

Strategy for appliance control:

Knowing the demand for the next few hours the energy demand manager tries to use as much renewable energy and CHP as possible and optimises the overall costs.

Change in power demand curve of single appliance:

Unchanged.

Change in day curve (of power demand of all appliances):

Following the estimation made in 1-1, 2-1 and 2-2 it is assumed that at maximum 5% of the operations might be shifted according to any of the probability curves as shown for the synergy scenarios 1-1, 2-1 or 2-2 in Figure 3.4-11 (managed by the energy demand manager). As the consumer is not involved in the operation of the device any more, the probability curve of scenario 1-1 (delayed start) stands for a second option of scenario 2-2.

Consumer benefits and drawbacks:

Enhanced use of renewable energy and CHP. Cost benefits must be transferred to the consumer. Consumer remains in the position to decide whether he wants to use this option or not.

Demand management benefits and drawbacks:

Influence on power demand by medium term action. Influence only on those devices which are 'online'.

Impact on appliance design and service provided: (additional costs, limitations, additional energy consumption):

Bidirectional communication needed.
A harmonised communication protocol is needed.
Additional costs for consumer (communication module via power line): 30 € - 130 €.
Additional power consumption:

- during waiting for operation: > 0 W - 4 W

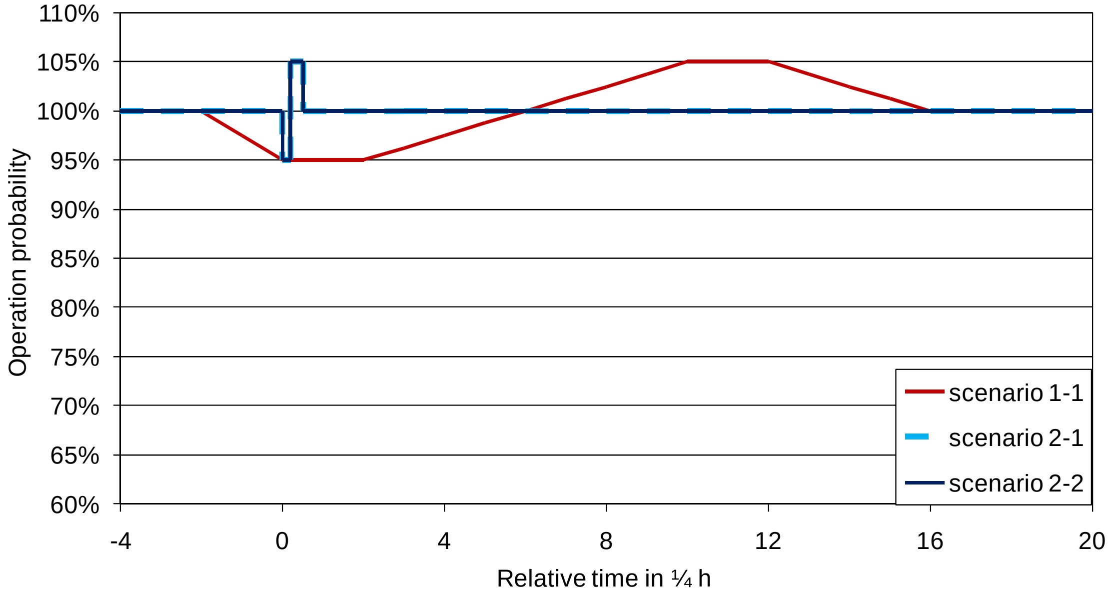
Consumer acceptance questions:

Willingness to accept this solution if additional costs are balanced by savings via energy bill.
Calculation (additional costs: 80 €):
420 kWh/a at 0,20 €/kWh = 84 €/a energy costs
Amortisation in 5 years: 16 €/a saving
Reduction of energy costs by 19% needed!

Strategies for success:

Define harmonised communication protocol (CENELEC).
Define business model where savings balance the additional costs for the appliance.

Figure 3.4-11 Change in operation probability for synergy scenarios 3-1 (any of 1-1, 2-1, 2-2)



Source: University of Bonn

3.4.6.4 Using energy storage capacity and other technologies

Any additional scenarios regarding the issues of this section did not seem to be very realistic for ovens and stoves at present.

3.5 Refrigerator

3.5.1 Technical description with regard to the use of energy

Refrigerators usually consist of a box type outer unit and an insulated inner compartment standing alone or built in a line of other kitchen units. The cooling device is mostly situated on the backside of the box.

The main technology is the compressor cooling machine. Evaporation of the liquid refrigerant (R12, R134a, etc.) creates the cold in the evaporator, which subsequently absorbs heat from the refrigerated inner space. The characteristics of the evaporator technology depend primarily on the required application and the type of cold source. After its full evaporation the refrigerant vapour is compressed by a compressor and than condensed while releasing the heat corresponding to the one absorbed at evaporator level and the thermal equivalent of the work of the compressor. After condensing, the refrigerant is expanded by an expansion valve which is used to throttle the refrigerant fluid back to the evaporator and to control the refrigerant flow. In this appliance the circulation of the refrigerant is driven by a compressor, which demands a motor and electrical energy.

Thermodynamic energy can also be used directly. The absorber cooling process uses ammoniac as refrigerant. A mixture of ammoniac gas and hydrogen flows from the evaporator into the absorber, where the ammoniac vapour is suspended in water. The insoluble hydrogen flows back into the evaporator. The mixture of ammoniac and water is then heated by the boiler while the refrigerant vaporises by absorbing heat from the box. The refrigerant vapour gets into the condenser and the water flows back into the absorber. The ammoniac vapour is condensed while evacuating the heat with a ratio of about 1:3 (cooling effect : heat input). At last the fluid ammoniac streams back to the hydrogen containing evaporator. As there are no mechanical processes in this appliance, absorption-refrigerators operate almost noiseless. Nevertheless those appliances are also operated with electricity instead of natural gas or other heating sources.

Other technologies like Pelletier-Elements are not relevant for household sector apart from the use for mobile purposes.

The whole process of cooling is controlled by a mechanical or/and an electronic thermostat control device. The compressor operates under normal conditions (no new load, normal ambient temperature) only 20 to 35% of the time the refrigerator is connected to the supply (power using factor), but may increase up to 100% e.g. when a lot of items are loaded into the refrigerator box which need to be cooled.

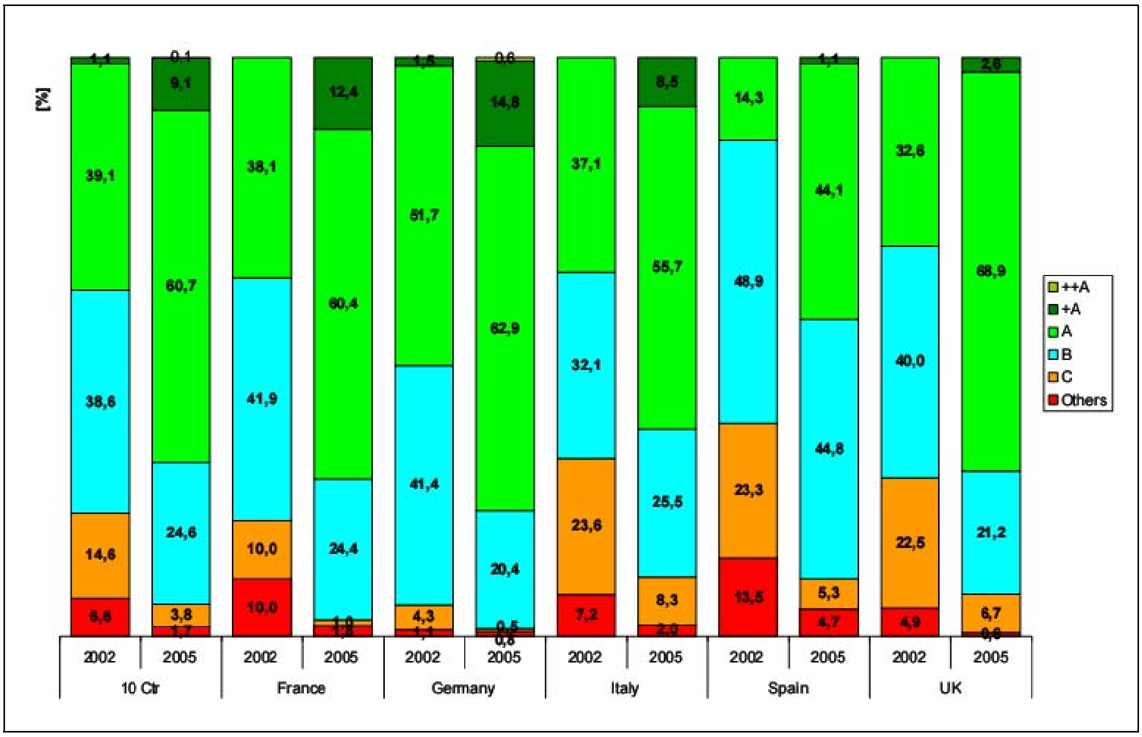
3.5.2 Penetration in Europe

The energy efficiency for refrigerators and freezers has improved continuously. For domestic refrigerators the Energy Efficiency Index (EEI) is defined in the “Cold Appliances” labelling Directive [EEF 06] and was at a value of 102% for an average model on the market in year 1992. This EEI is also used to define the labelling classes A to G. In

2002 additional classes A+ and A++ had been introduced to indicate superior EEIs to the consumer [EEF 06].

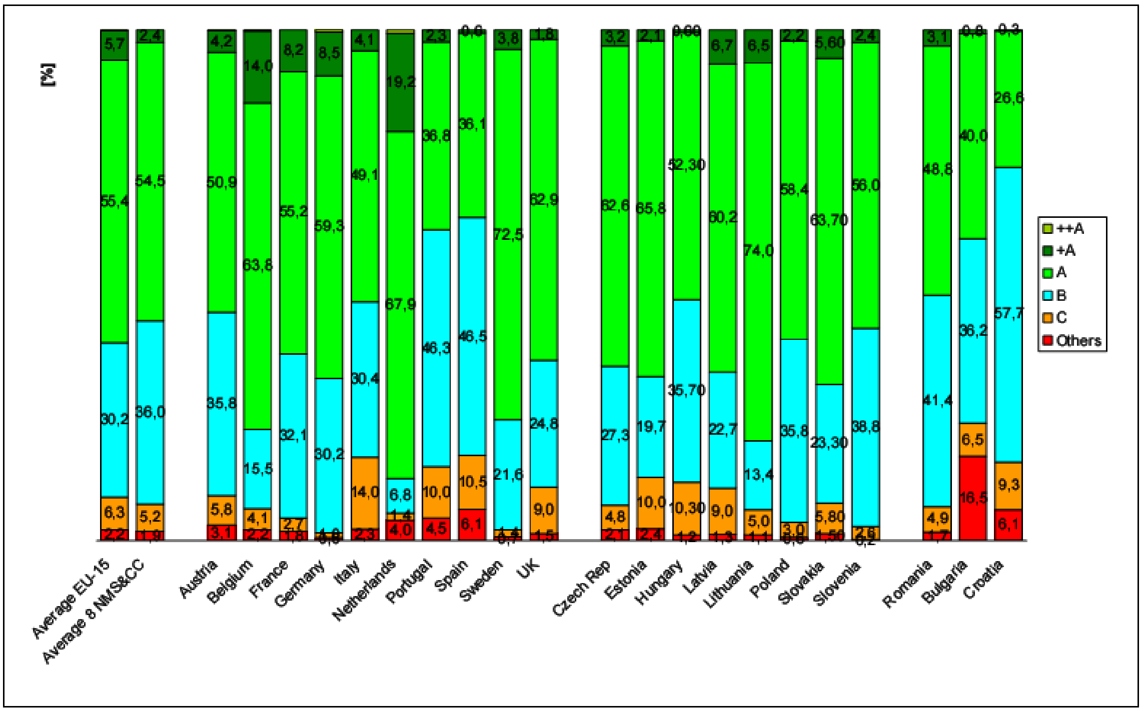
The sales data for 2005 for cold appliances show [EEF 06] that in some markets the A+ appliances are starting to have an important market share (14,8% market share of A+ class in Germany), while at European level the share of A class has reached 60% of the sales, with 9% in A+ class. In all countries the share of A and A+ appliances has strongly increased in 2005 compared with previous years (Figure 3.5-1). Large differences still exist between countries due to different national and regional policies and programmes. The lowest share in sales of A class refrigerators in the Western European countries covered by the "Gesellschaft für Konsumforschung" (GfK) panel 2004 is in Spain (36,1%), while the highest share is in the Netherlands (67,9% in A class plus 19,2% in A+ class), this remarkable high share is due in particular to incentives for very high efficient appliances. Also worth noticing in Figure 3.5-2 is that the share of A class appliances in new refrigerators sales is higher in the New Member States, comparing only among the countries covered by the GfK panel. The strongest progress in the period of 2002 to 2005 happened in the UK mainly due to the Energy Efficiency Commitment under which about 1 million efficient cold appliances have been sold per year [EEF 06].

Figure 3.5-1 Sales of cold appliances: comparison for the 5 large countries of sales in 2002 and 2005 by energy class



Source: [SOR 05]

Figure 3.5-2 Sales of refrigerators in 2004 by energy class



Source: [SOR 05]

For refrigerators (including fridge-freezers) the market is already oversaturated with an average saturation level of 106%, meaning that in all households there is one device and in 6% there are two. It is assumed that this remains more or less unchanged in the future, perhaps supported by policies to avoid second lives of discarded products [ECC 01].

According to a consumer survey conducted within the Preparatory Study for Eco-design Requirements of Refrigerators and Freezers [EUP13 07] 21% of the households own a second refrigerator. It was not investigated if these units are always connected to the mains or just used for special events. In the same study the use of second hand purchased refrigerators was only 4,9%.

3.5.3 Consumption of energy in Europe

Only limited data are available regarding the amount of energy used for refrigeration in Europe. In most sources no differentiation between refrigerators and freezers is made.

The European Commission has published in its Green Book on Energy Efficiency (2005) a total electricity consumption for cooling appliances (no distinction between refrigerators and freezers has been made) of 103 TWh for the EU-15 in 2003 [GRE 05].

The European Committee of Domestic Equipment Manufacturers (CECED) calculates in a stock model for 2005 the amount of energy consumption only for refrigerators including fridge freezers up to 66,1 TWh [ECC 01]. As in the study at hand it is assumed that the EU-15 consists of about 154,55 million households with a saturation of 106% the annual energy consumption per household owning a refrigerator is about 403,5 kWh.

3.5.4 Effects on energy consumption due to consumer usage

Refrigerators are appliances which are operated as long as they are connected to the supply. Therefore the consumption of energy in the period of use is determined by the following, partly consumer driven, partly environment driven factors:

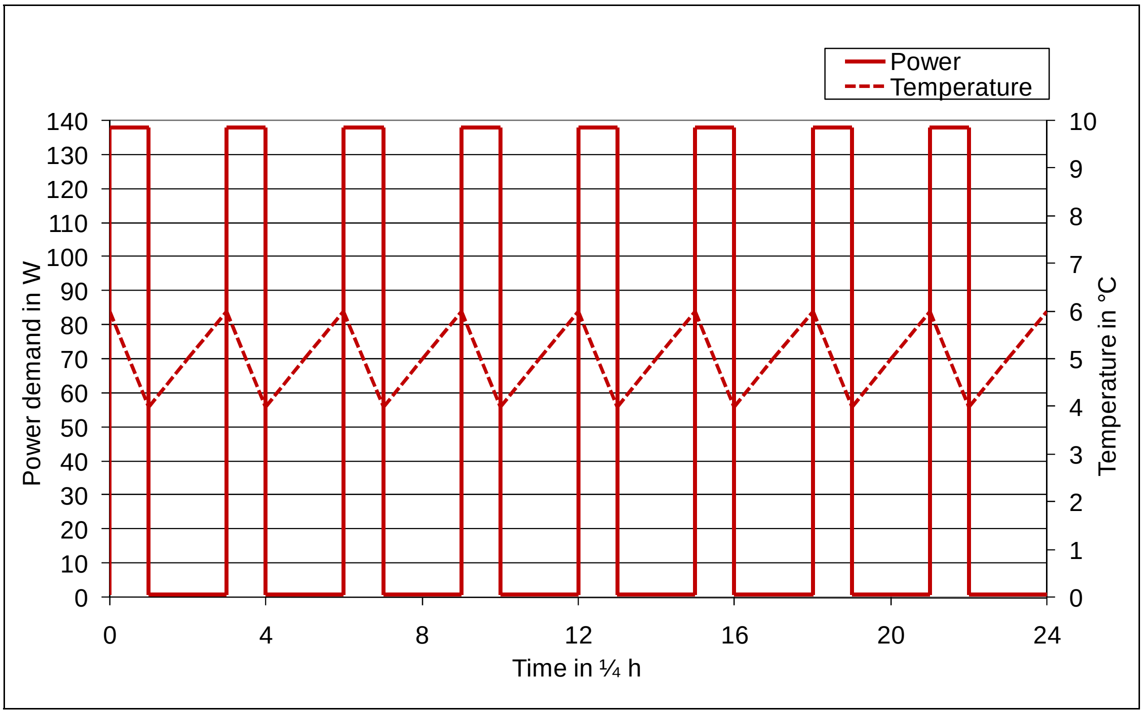
- Ambient conditions, e.g. temperature
- Place of installation in the kitchen
- Frequency of door opening
- Temperature setting
- Capacity
- Exchange of cooled load by warm load
- Components of the load, water content
- Machine efficiency under real use conditions

Refrigerators in average European households vary largely in terms of box size, inside temperature and the main ambient temperature in the kitchen or installation room.

3.5.5 Power demand and load curves

The actual power demand of refrigerators varies according to their size in a range of 50 to 300 W. With an average energy consumption of 403,5 kWh per appliance and year (see above) and a power using factor of 33,3% (i.e. in 1/3 of the time the appliance is connected to the grid the compressor is working) an average power demand of 138,2 W per appliance can be calculated. A standardised curve to illustrate the mainly time depending progress of the power demand and the temperature inside the refrigerator is shown in Figure 3.5-3. As the pattern of the curve includes already the consumer behaviour opening the door of a fridge and replacing new load to cool down no differentiation in terms of the behaviour at specific times of the day are visible any more.

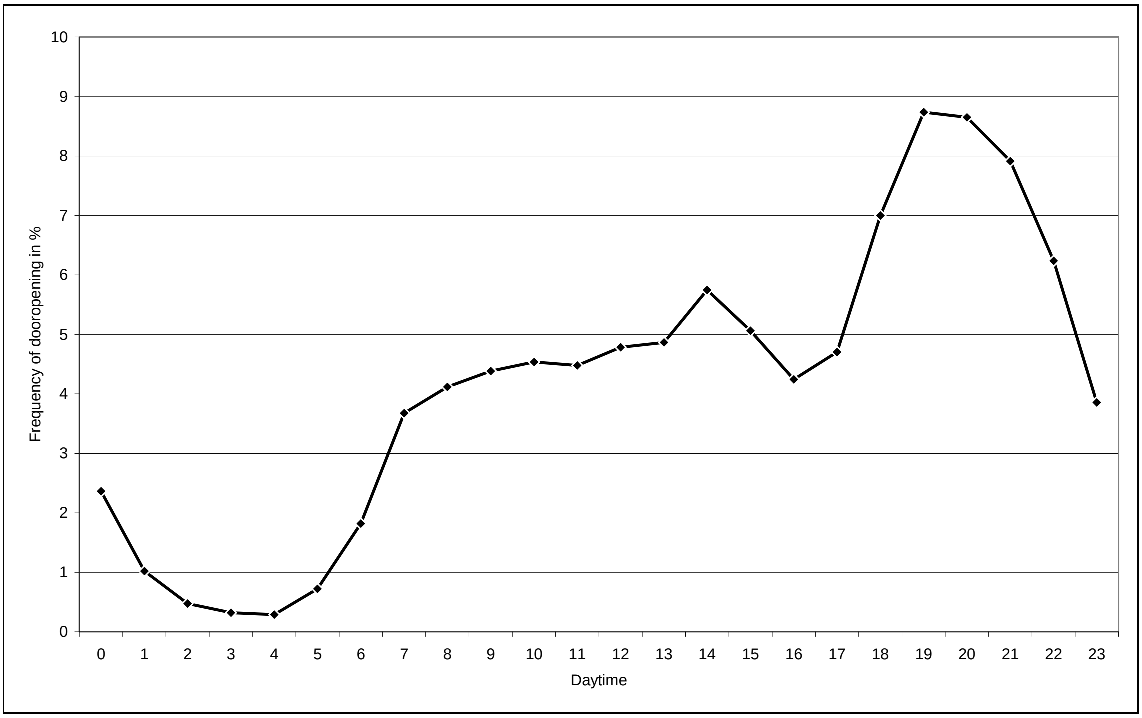
Figure 3.5-3 General pattern of a power demand curve of a refrigerator in ¼ hour steps



Source: University of Bonn

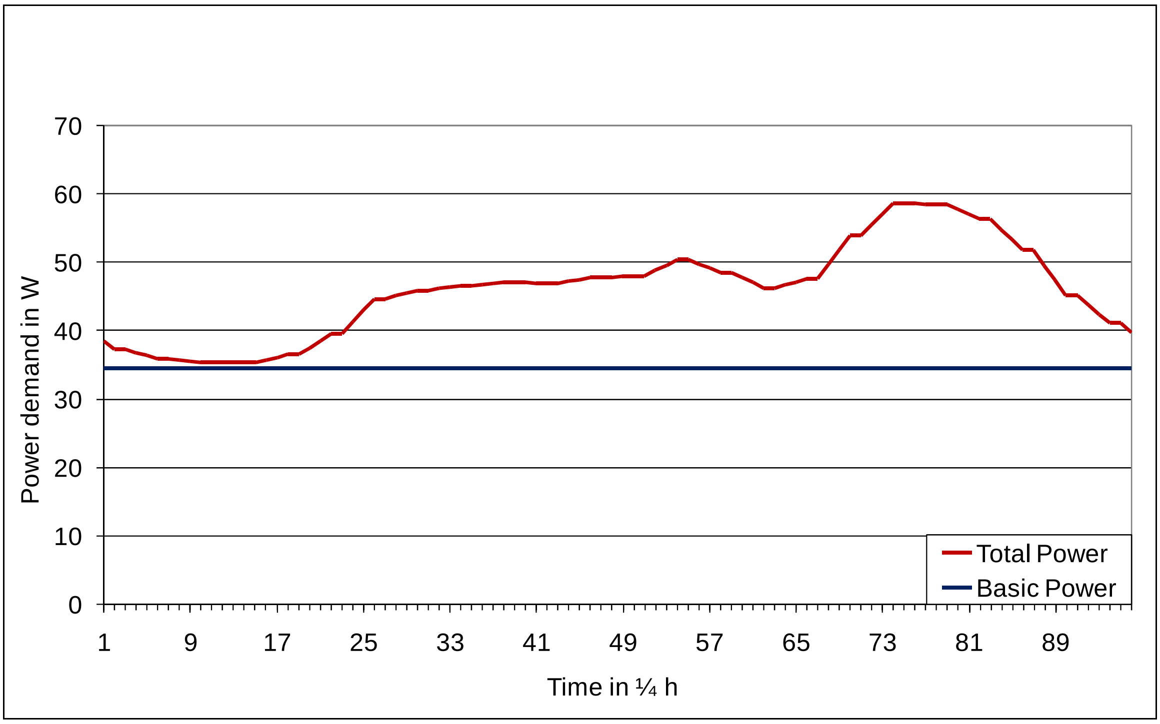
Looking at the day load curve of all refrigerators the time and frequency of door openings for an exchange of items have to be taken into account. Regarding this issue a recent investigation of the University of Bonn [THO 07] on different European households is shown in Figure 3.5-4. The energy-consumption is correlated to the frequency of door-openings because of the heat-input of exchanging air as well as food and beverage to be cooled. We assume 25% of the total energy consumption of fridges is induced by the consumer behaviour of opening the door and exchanging things to be cooled. Therefore the power demand curve of all appliances will follow the same shape (Figure 3.5-5).

Figure 3.5-4 Frequency of door-openings per day



Source: [THO 07]

Figure 3.5-5 General pattern of a daily load curve of a refrigerator in an average European household



Source: University of Bonn

3.5.6 Synergistic potentials

Within this chapter it is tried to explore possible synergies when refrigerators are somehow linked to sustainable energy sources, like solar or wind energy or heat from CHP processes. For each of these synergistic potentials it is described where the synergy comes from, what are possible constraints and what needs to be fulfilled to gain the potential. It is also estimated how many of the appliances might be affected and how these synergies might affect the power demand curve or the probability of operation of refrigerators, including a possible recovery phase. As most of these synergies are not yet realised, they are somewhat hypothetical, but based on best engineering practise. If costs are given, they describe the expected additional prize the consumer has to pay for this feature. If ranges are given, the higher value normally corresponds to an implementation of this feature in a first introduction phase, while the lower value estimates how costs may develop at a large scale use. Results of the consumer survey will be added in a supplementary document to this report.

In the following synergy scenarios the complexity of technical adjustments on the device considered increases from level 1 (3.5.6.1) to level 4 (3.5.6.4) steadily. Whereas in level 1 the consumer still has the full control whether to use the described option or not, in level 2 some of that control was handed over to the machine which then reacts to incoming signals. In level 3 the full control is in the hands of an external manager (e.g. electric utility) who decides about when and how often the machine is being switched on or off after it was set in a ready mode by the consumer. Therefore signals are being transmitted in a bidirectional way. In level 4 additional options for storing energy or using other technologies are taken into account.

3.5.6.1 Shifting operation in time

Id and title: 1-1 Consumer shifts loading of food or beverage to cool down in time
Description: Triggered by a signal or indication that regenerative energy is rare the consumer avoids placing new items inside the refrigerator for some time. This will avoid operation of the compressor at this time.
Strategy for appliance control: Strategy is limited to spread out the information. This may be organised locally by spreading information about energy-consumption depending on consumer behaviour.
Change in power demand of single appliance curve: The operation of the compressor will be postponed as shown in Figure 3.5-6. As the usual exchange of items already is included in the pattern of the power demand curve, the time for the compressor operation stays always the same. Depending on the prolongation of the start of the refrigeration process the mean power demand will be lowered for this period, but recovered later when the items are finally placed into the refrigerator.
Change in day curve (of power demand of all appliances): It is estimated that maybe about 5% of the consumers will be willing to shift the door opening of their fridge (Figure 3.5-7). But the range for shifting is assumed to be very narrow, due to the fact that eating times and recreation are more or less fixed to a specific time of the day. Therefore a shift of up to 30 min seems to be the maximum.

Consumer benefits and drawbacks:

Enhanced use of renewable energy and CHP. But the time to use it is short, depending on the way the consumer is informed about availability or shortage of renewable energy or CHP.

Demand management benefits and drawbacks:

Consumer behaviour is unpredictable. Longer experience may allow forecasting consumer behaviour. It may depend much on the time of the day and season as well as on the demand to consume cooled food and beverages.

Impact on appliance design and service provided: (additional costs, limitations, additional energy consumption):

No changes in design but means to inform about the opportunity to use renewable energies and CHP in a certain period of time are necessary.

Additional costs for consumers: 0 €

Additional energy consumption: 0 W

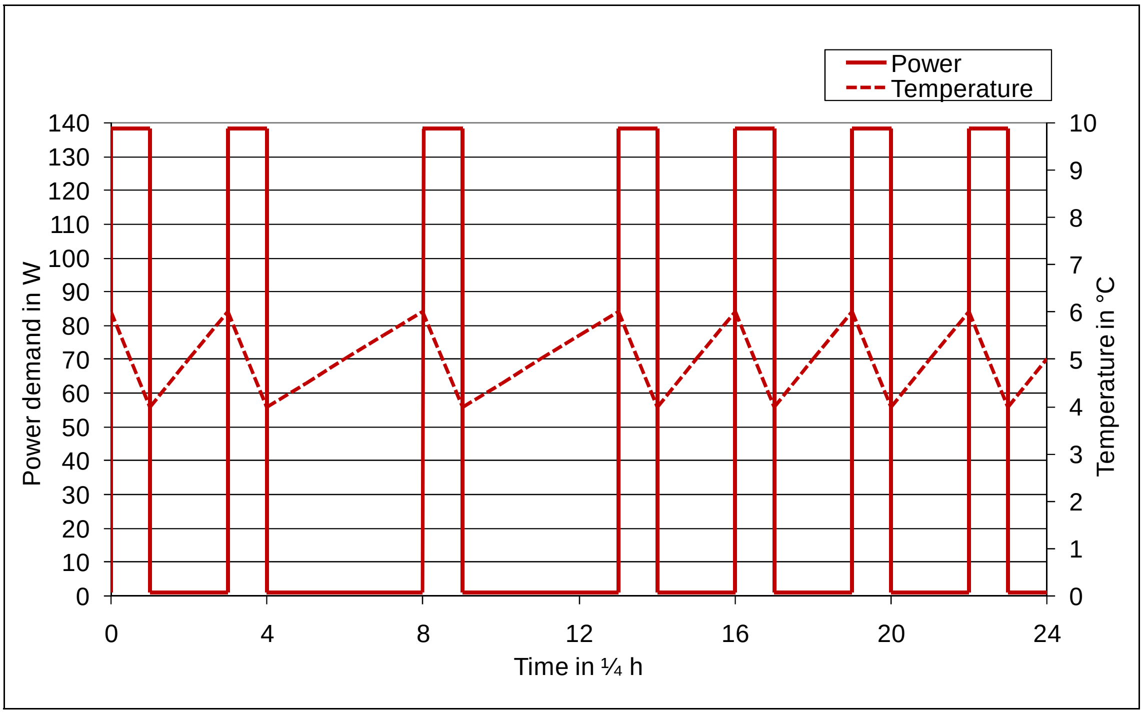
Consumer acceptance questions:

Willingness to accept without direct benefit

Strategies for success:

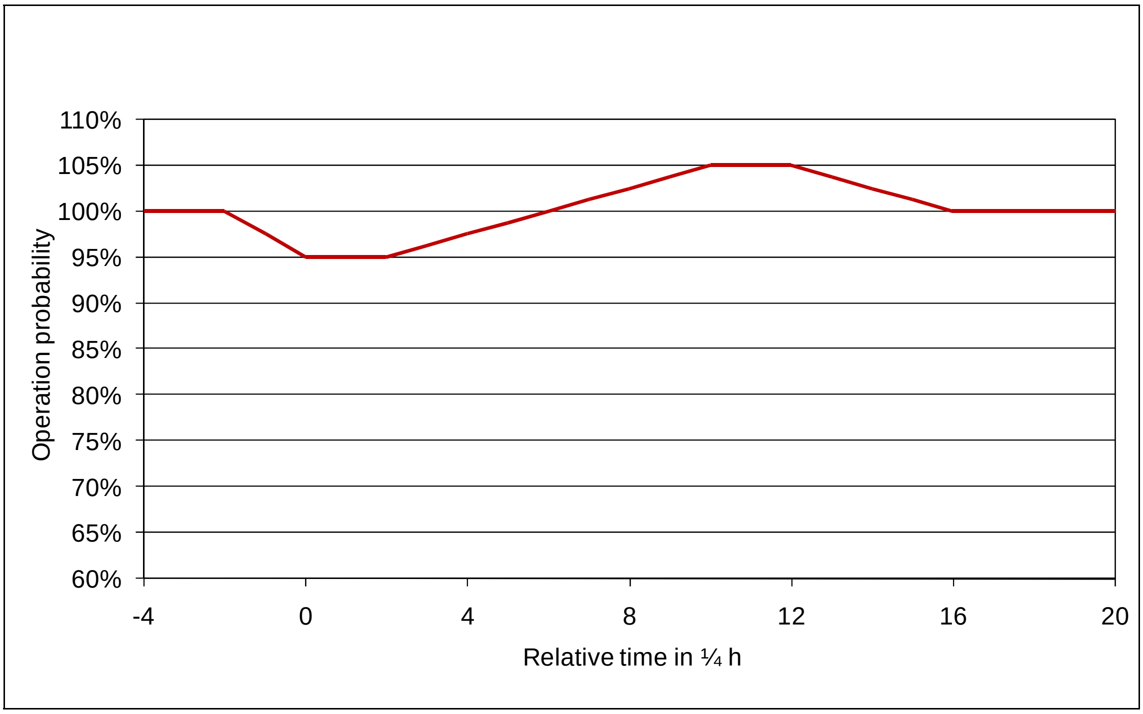
Increase environmental awareness and practise

Figure 3.5-6 *General pattern of a power demand curve of a refrigerator with postponed start of compressor in ¼ hour steps*



Source: *University of Bonn*

Figure 3.5-7 Example of a change in operation probability for synergy scenario 1-1



Source: University of Bonn

3.5.6.2 Applying flexibility on appliance power demand

Id and title: 2-1 Power line triggered operation
Description: Power line frequency is changing with total load on the grid. High availability or shortage of renewable energy and CHP will influence the load and thus the frequency. This can be detected by the appliance and transferred into action (Dynamic Demand Control - DDC). Mains frequency varies in central Europe within 50 +/- 0,2 Hz achieved by switching on or off additional power units or exchanging load with other regions. In the UK the grid is more isolated why the alteration of frequency may be up to +/- 1,5 Hz. In both cases the frequency decreases with more load and increases with less load on the grid. Therefore the situation in central Europe should be considered as different to the UK. Here the implementation of frequency sensing units in refrigerators is relatively simple [DDC 07] and should cost almost nothing in refrigerators already controlled by an electronic device. In central Europe a more sophisticated frequency sensing unit is needed resulting in a higher cost to the consumer.
Strategy for appliance control: The operation of the compressor may be interrupted or the start of the compressor may be delayed. For reasons of food safety cool box temperature must determine the time of delay.
Change in power demand curve of single appliance: Operation time may be prolonged. Compare Figure 3.5-6.
Change in day curve (of power demand of all appliances): DDC can modify the on-off cycle of a refrigerator in response to the overall load on the grid. By defini-

tion DDC operation is fully automatic, no consumer intervention is required.

Short breaks or a shifting of the compressor start will probably not even be recognised at all by the consumers during the operation. For the UK it is assumed that 100% of them will be willing to accept an implementation of DDC whereas in central Europe the amount will be only about 10% due to higher costs of more sensitive frequency detection. The probability curves are shown in Figure 3.5-8.

Consumer benefits and drawbacks:

Enhanced use of renewable energy and CHP.

Demand management benefits and drawbacks:

Renewable energies and CHP may be easily provided for the grid system. The wider temperature range may influence food quality while stored.

Impact on appliance design and service provided: (additional costs, limitations, additional energy consumption):

Operation interruption and start delay unit needs including frequency sensing or other detection means.

Additional costs for consumer in UK: 2 € - 5 €

Additional costs for consumers in central Europe: 10 € - 50€

Additional energy consumption: > 0 W - 4 W

Consumer acceptance questions:

Willingness to accept this solution if additional costs are sponsored by energy utility.

The wider temperature range in operation may influence food quality while stored, will this be accepted?

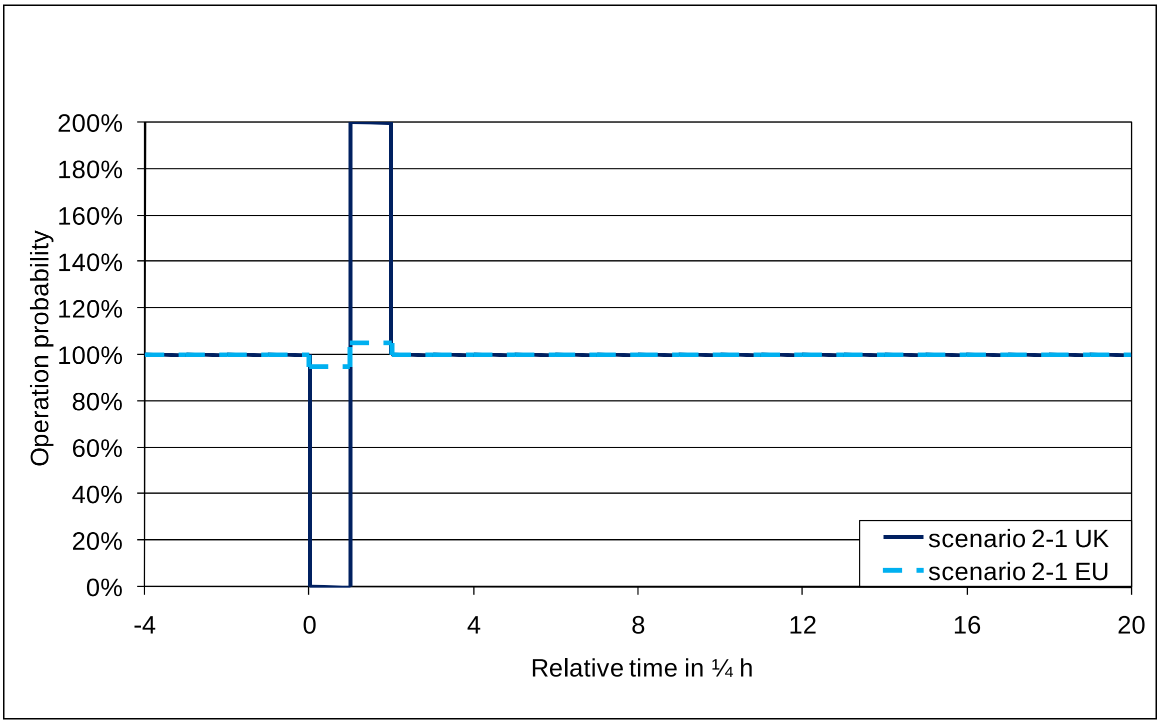
Calculation UK (additional costs: 3,50 €):
403 kWh/a at 0,20 €/kWh = 80 €/a energy costs
Amortisation in 5 years: 0,70 €/a saving
Reduction of energy costs by ~1% needed.

Calculation central Europe (additional costs: 30 €):
403 kWh/a at 0,20 €/kWh = 80 €/a energy costs
Amortisation in 5 years: 6 €/a saving
Reduction of energy costs by 8% needed.

Strategies for success:

Define business model where energy utilities sponsor the implementation of these “Power line triggered operation” modules.

Figure 3.5-8 *Example of a change in operation probability for synergy scenario 2-1*



Source: *University of Bonn*

Id and title: 2-2 Internal energy manager agent
Description: The availability of regenerative power may be communicated by other signals (like power line signal, mobile phone) and may be used to communicate and influence the start or interruption of the compressor in a more sophisticated way as in 2-1. This technique requires more information from the grid but is still a one-way communication. The external signal should include information on the shortage of energy and how long it may last. There is no feedback concerning the actual situation of the refrigerator. Triggered by such a signal the refrigerator may change its operation: • interrupt or delay the start of the cooling process • prolong the cooling process by reducing the speed of the motor. • change of temperature setting • change of temperature variation
Strategy for appliance control: Knowing the actual inner temperature of the cool compartment the signal about the availability or shortage of renewable energy and CHP can be used to either anticipate or postpone the operation of the compressor. The hysteresis of the thermostat may be enlarged.
Change in power demand curve of single appliance: Various. May shift operating time or motor power by seconds and minutes (Figure 3.5-9).
Change in day curve (of power demand of all appliances): May allow to shift perhaps 5% of the individual operations at any time by seconds and minutes. Due to the characteristics of each appliance the changes in the overall power demand vary in the same manner as shown in scenario 2-1.

Consumer benefits and drawbacks:

Enhanced use of renewable energy and CHP. Short term breaks may not be recognised at all.

The wider temperature range in operation may influence food quality while stored. Impact on food quality must be limited.

Demand management benefits and drawbacks:

Influence on power demand by short term action. Effect will depend on the time of the day, the season and the penetration of energy management agents in refrigerators.

Impact on appliance design and service provided: (additional costs, limitations, additional energy consumption):

Internal energy manager agent needs to be included in the electronic unit of machine.

A harmonised signal of availability or shortage of renewable energy and CHP is needed.

Additional costs for consumer (signal recognition plus energy agent): 10 € - 100 €.

Possible additional energy consumption:

- for communication device during operation: > 0 W - 4 W

Consumer acceptance questions:

Willingness to accept this solution if additional costs are sponsored by energy utility.

The wider temperature range in operation may influence food quality while stored, will this be accepted?

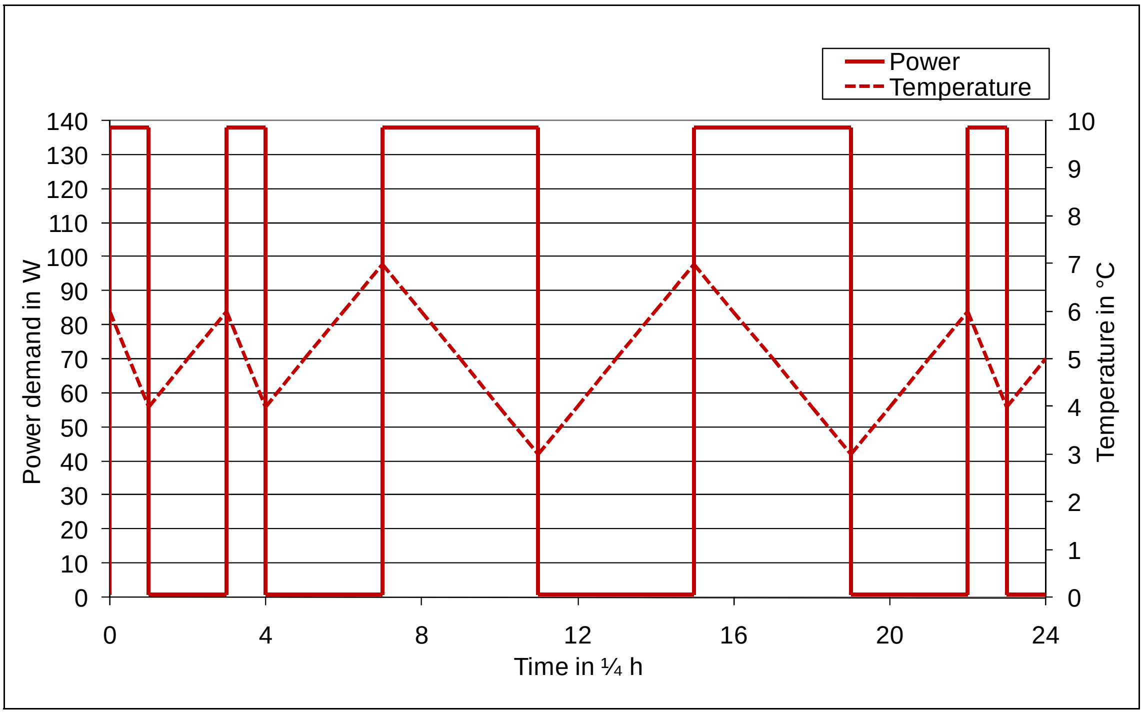
Calculation (additional costs: 55 €):
403 kWh/a at 0,20 €/kWh = 80 €/a energy costs
Amortisation in 5 years: 11 €/a saving
Reduction of energy costs by ~14% needed.

Strategies for success:

Define harmonised signal for availability or shortage of renewable energy and CHP (CENELEC).

Define business model where energy utilities sponsor the implementation of these “Internal energy management agent” modules.

Figure 3.5-9 *General pattern of a power demand curve of a refrigerator with postponed start of compressor and rising temperature in ¼ hour steps*



Source: *University of Bonn*

3.5.6.3 Managing the power on the grid

Id and title: 3-1 Energy demand manager
Description: The energy demand manager tries to harmonise the available power on the grid coming from conventional and renewable resources with the demand. The refrigerator needs to be equipped with remote facilities like start delay of the compressor, different electrical power levels or different hysteresis of the temperature control unit. The energy demand manager is informed about the temperature and the expected energy demand.
Strategy for appliance control: Knowing the demand for the next few hours the energy demand manager tries to use as much renewable energy and CHP as possible and optimises the overall costs. It anticipates or postpones the operation of as many refrigerators as necessary and available for remote control.
Change in power demand curve of single appliance: In the same way as shown in scenario 1-2, 2-1, 2-2.
Change in day curve (of power demand of all appliances): May allow to shift perhaps 5 % of the operations at any time by minutes. Harmonisation of certain groups of refrigerators may allow shifting for longer time periods. The sequential operation of different refrigerators will lower the total power demand of the refrigerators for some time (hours) but power demand will need to be recovered (Figure 3.5-10). As the consumer is not involved in the operation of the device any more, the probability curve of scenario 1-1 (delayed start) stands for a second option of scenario 2-2.

Consumer benefits and drawbacks:

Enhanced use of renewable energy and CHP. Cost benefits must be transferred to the consumer.

Demand management benefits and drawbacks:

Influence on power demand by medium term action. Influence only on those appliances which are ‘online’.

Impact on appliance design and service provided: (additional costs, limitations, additional energy consumption):

Bidirectional communication needed. Additional switch needed to signal ‘remote operation accepted’.

A harmonised communication protocol is needed.

Additional costs for consumer (communication module via power line): 30 - 130 €.

Additional energy consumption:

- during operation: > 0 W - 4 W.

Consumer acceptance questions:

Willingness to accept this solution if additional costs are balanced by savings via energy bill.

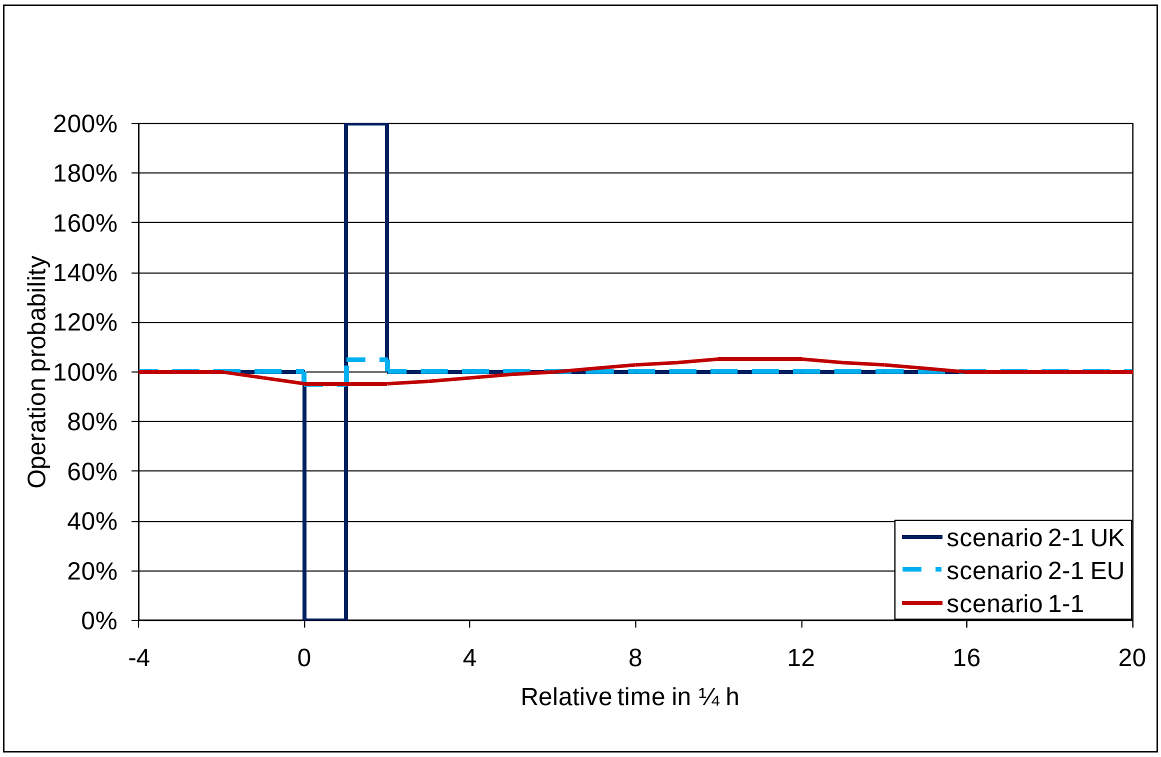
Calculation (additional costs: 80 €):
403 kWh/a at 0,20 €/kWh = 80 €/a energy costs
Amortisation in 5 years: 16 €/a saving
Reduction of energy costs by 20% needed.

Strategies for success:

Define harmonised communication protocol (CENELEC).

Define business model where savings balance the additional costs for the appliance.

Figure 3.5-10 *Change in operation probability for synergy scenarios 3-1(any of 1-1, 2-1, 2-2 is same as 2-1)*



Source: *University of Bonn*

3.5.6.4 Using energy storage capacity and other technologies

Id and title:

4-1 Energy storage capacity

Description:

Due to food safety reasons the increase of pathogen micro-organisms has to be avoided. Therefore refrigerators need to provide a relatively small range of temperature depending on the sensitivity of the food. Storage of cooling energy is difficult because of the risks to freeze the food in the fridge.

Nevertheless a refrigerator filled with material of high heat capacity may be able to balance interruptions in energy supply for a longer period of time, as a temperature rise will be slowed down.

This option may be especially beneficial when combined with smart operations as described in options 2-1, 2-2 and 3-1.

Strategy for appliance control:

No.

Change in power demand curve of single appliance:

The rise of temperature in the cool box is lowered and the start of the cooling process prolonged (Figure 3.5-11).

Change in day curve (of power demand of all appliances):

Shifting volume depends on availability of refrigerators with additional heat storage capacity.

Consumer benefits and drawbacks:

Enhanced use of renewable energy and CHP when operation is linked to the availability of renewable energy and CHP.

Demand management benefits and drawbacks:

Consumer behaviour is unpredictable. Longer experience may allow forecasting consumer behaviour.

Impact on appliance design and service provided: (additional costs, limitations, additional energy consumption):

Additional space for material with high heat capacity will reduce the usable capacity for household purpose.

Additional costs for heat storage materials or possible ventilation: 40 € - 50 €

Additional energy consumption: 0 W.

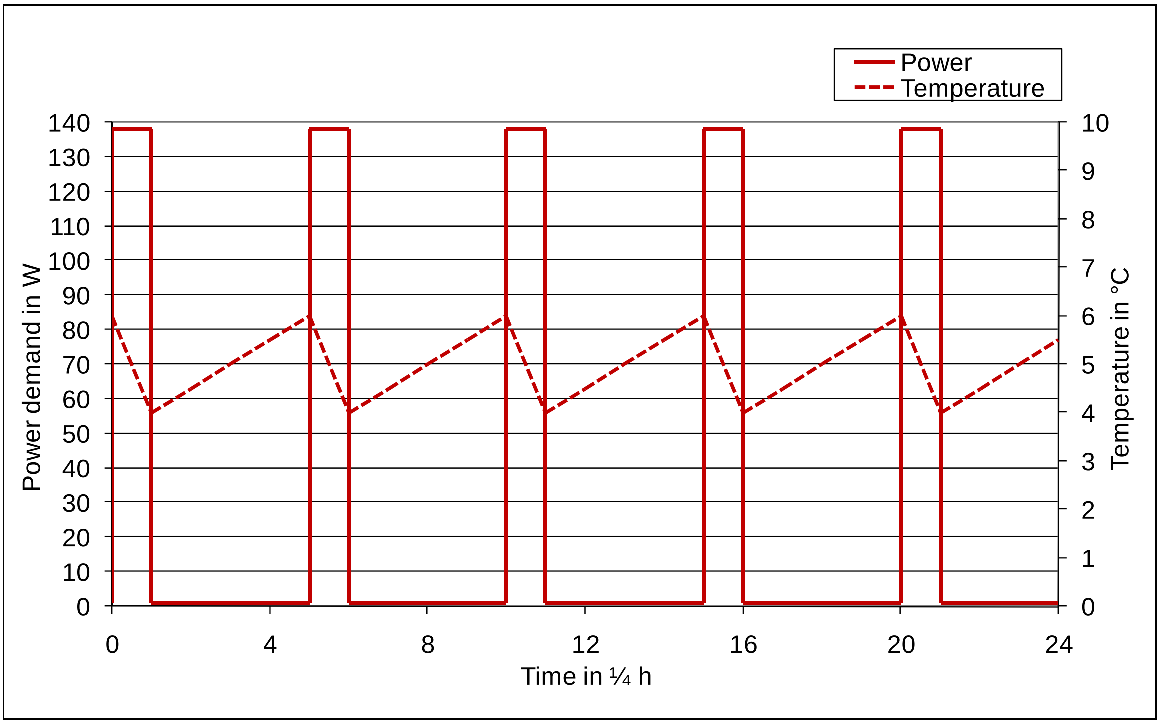
Consumer acceptance questions:

Willingness to accept this solution if additional costs are balanced by savings via energy bill.
Calculation (additional costs: 45 €):
403 kWh/a at 0,20 €/kWh = 80 €/a energy costs
Amortisation in 5 years: 9 €/a saving
Reduction of energy costs by ~11% needed.

Strategies for success:

Define business model where savings balance the additional costs for the appliance.

Figure 3.5-11 *General pattern of a power demand curve of a refrigerator with postponed start of compressor due to cool storage capacity*



Source: *University of Bonn*

Id and title:

4-2 Implementing absorber technology

Description:

Instead of running the cooling cycle by electrical energy, absorber cooling technology can be used. This cooling circle is driven by heat from an external source which can be provided by solar collectors or by a combined heat and power unit.

Strategy for appliance control:

No.

Change in power demand curve of single appliance:

Reduction of electricity demand by 95% (5% needed for electronic control and perhaps ventilator).

Change in day curve (of power demand of all appliances):

Reduction of electricity demand by 95% at any time.

Consumer benefits and drawbacks:

The operation of the refrigerator is nearly for free as long as the required heat can be taken from already existing solar collectors or combined heat and power units which are traditionally used to deliver warm water and electricity all year and warmth during winter time.

Demand management benefits and drawbacks:

Almost no electrical energy needed.

Impact on appliance design and service provided: (additional costs, limitations, additional energy consumption): Absorber technology is still quite expensive for any appliances. Consumer benefit probably can only be realised if solar collectors or a combined heat and power unit is already available.
Consumer acceptance questions: Might be accepted by people who can use thermodynamic power from solar collectors and combined heat and power units.
Strategies for success: Improvement of absorber technology also for domestic appliances. Increase application of solar collectors and combined heat and power units in households.

3.6 Freezer

3.6.1 Technical description with regard to the use of energy

Freezers usually consist of a box type insulated compartment standing alone or built in a line of other kitchen units or in combination with a refrigerator. Parts of the cooling device are mostly situated on the backside of the box or inside its outer shell.

The so called chest-freezers have a lid on the top whereas the so called up-right freezers have a front-door similar to refrigerators. In direct comparison of both types of freezers with the same freezing capacity chest-freezers have small advantages regarding energy-consumption because of their favourable geometric relation surface to volume. Additionally during time of openings the air and heat exchange in case of an up-right-freezer is higher than in case of an up-right freezer.

The main cooling technology is the compressor cooling machine. Evaporation of the liquid refrigerant (R12, R134a, etc.) creates the cold in the evaporator, which subsequently absorbs heat from the freezing inner space. After its full evaporation the refrigerant vapour is compressed by a compressor and than condensed while releasing the heat corresponding to the one absorbed at evaporator level and the thermal equivalent of the work of the compressor. After condensing, the refrigerant is expanded by an expansion valve which is used to throttle the refrigerant fluid back to the evaporator and to control the refrigerant flow. In this appliance the circulation of the refrigerant is driven by a compressor, which demands a motor and electrical energy.

Thermodynamic energy can also be used directly. The absorber cooling process uses ammoniac as refrigerant. A mixture of ammoniac gas and hydrogen flows from the evaporator into the absorber, where the ammoniac vapour is suspended in water. The insoluble hydrogen flows back into the evaporator. The mixture of ammoniac and water is then heated by the boiler while the refrigerant vaporises by absorbing heat from the box. The refrigerant vapour gets into the condenser and the water flows back into the absorber. The ammoniac vapour is condensed while evacuating the heat with a ratio of about 1:3 (cooling effect : heat input). At last the fluid ammoniac streams back to the hydrogen containing evaporator. As there are no mechanical processes in this appliance, absorption freezers operate almost noiseless. Nevertheless those appliances are also operated with electricity instead of natural gas or other heating sources.

Other principles like Pelletier-Elements are not suitable for the freezing processes.

The whole process of cooling and freezing is controlled by a mechanical or/and an electronic thermostat control device. The compressor operates under normal conditions (no new load, normal ambient temperature) during 20 to 35% of the time the freezer is connected to the supply (power using factor), but may increase up to 100% e.g. when a lot of items are loaded into the freezer box and needed to be cooled down. In order to avoid warming up frozen goods being already stored in the freezer, consumers are asked to prepare the process of new load by setting the freezer to a lower temperature. This “super frost” function is set by pressing a special button which leads to a mean temperature of -25°C instead of the normal storage temperature of -18°C.

3.6.2 Penetration in Europe

In 2005 the penetration rate for freezers was at a value of 52% based on 15 European member states. Realistic scenarios expect no changes in the penetration rate for EU-15. Regarding the new member states a fast process of assimilation takes place starting from a currently lower level [ECC 01].

The energy efficiency of refrigerators and freezers has improved continuously. For domestic freezers the Energy Efficiency Index (EEI) is defined in the “Cold Appliances labelling Directive” [EEF 06] and was at a value of 102% for an average model on the market in year 1992. This EEI is also used to define the labelling classes A to G. In 2002 additional classes A+ and A++ had been introduced to indicate superior EEIs to the consumer [EEF 06]. The average EEI in 2005 was at a value of 70% based on the improvements in insulation and optimisation of the refrigerating cycle.

3.6.3 Consumption of energy in Europe

Only limited data is available regarding the amount of energy used for freezing processes in Europe. In most sources no differentiation between refrigerators and freezers is made.

The European Commission has published in its Green Book on Energy Efficiency (2005) a total electricity consumption of cooling appliances (no distinction between refrigerators and freezers has been made) of 103 TWh for the EU-15 in 2003 [GRE 05].

The European Committee of Domestic Equipment Manufacturers (CECED) calculates in a differentiated stock model for 2005 the amount of energy consumption of freezers alone up to 33,3 TWh [ECC 01]. As in the study at hand it is assumed that the EU-15 consists of about 154,55 million households with a penetration of freezers of 52%, the annual energy consumption per household owning a freezer is about 414 kWh. This average freezer has a capacity of 230 litres.

3.6.4 Effects on energy consumption due to consumer usage

Freezers are appliances which operate as long as they are connected to the mains. Therefore the consumption of energy in the period of use is determined by the following, partly consumer driven, partly environment driven factors:

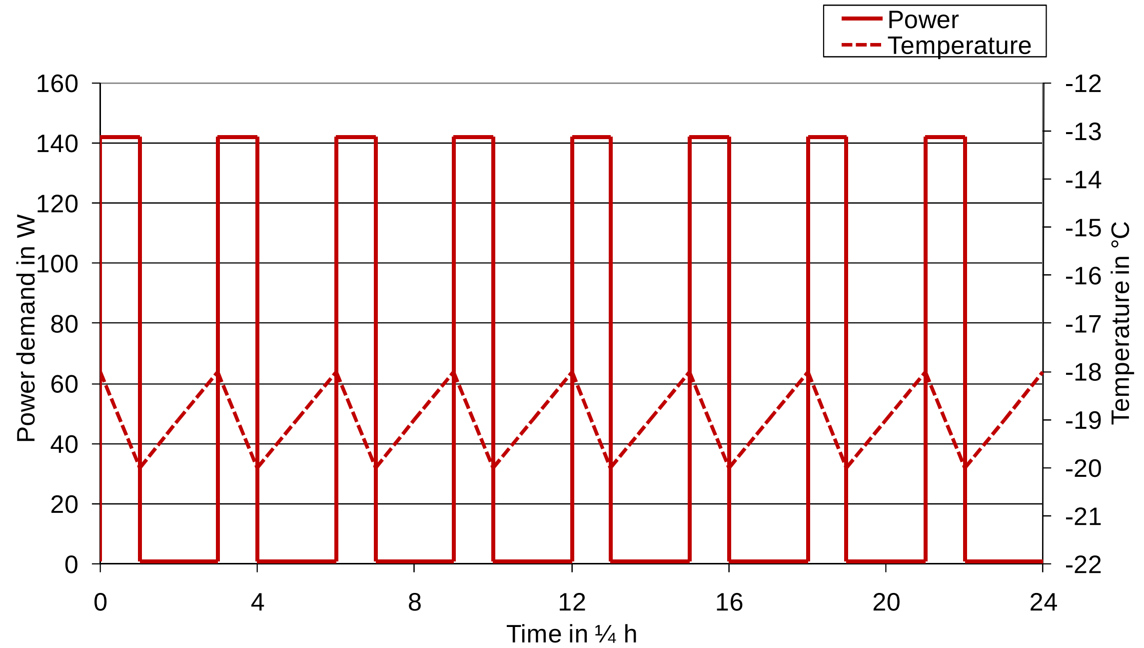
- Ambient conditions, e.g. temperature
- Place of installation in the house
- Frequency of door opening
- Temperature setting
- Capacity
- Storage of new frozen or unfrozen load
- Components of the load, water content
- Machine efficiency under real use conditions

Freezers in average European households vary in terms of box size, inside temperature and the main ambient temperature in the installation room.

3.6.5 Power demand and load curves

The actual power demand of freezers varies according to their size in a range of 50 to 200 W. Assuming an average energy consumption of 414 kWh per year and a power-using factor of 33,3% due to the switching of the thermostat/compressor in the freezer a mean power demand of 105,5 W per appliance is calculated. A standardised curve to illustrate the mainly time depending progress of the power demand and the temperature inside is shown in Figure 3.6-1.

Figure 3.6-1 General pattern of a power demand curve of a freezer in ¼ hour steps



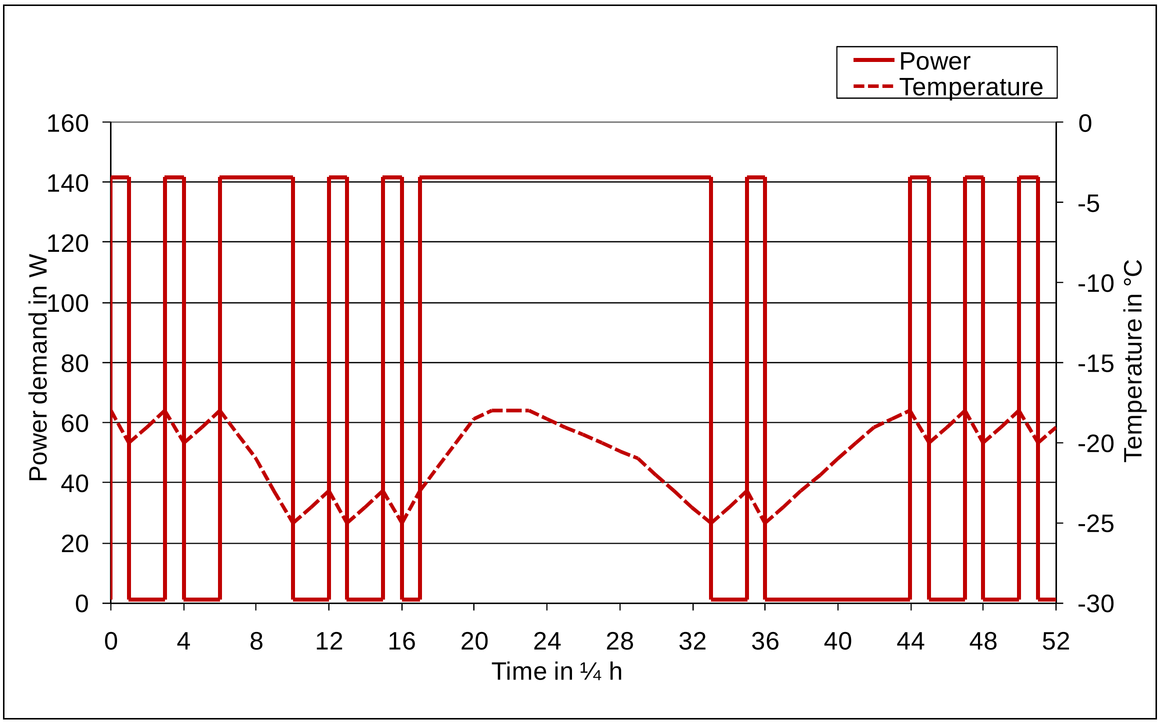
Source: University of Bonn

In contradiction to refrigerators where door-openings mean replacing food or beverage to be cooled the freezer using habits are different: taking out frozen goods for consumption occurs relatively seldom per day, maybe about one or two times. The frequency of placing new goods to be frozen into the freezer may be only on one to three times per week.

Only by opening the door of a freezer for taking out something won't affect the power demand to a relevant extent because of the large cool capacity inside. In case of placing things to be cooled down and frozen however the duration of compressor operation will increase. This behaviour is illustrated in Figure 3.6-2: to prepare the freezer the user set it to "super frost" mode to reach -25°C. Then the freezer stays at this temperature until new goods are stored. The temperature increases and in the meantime the compressor starts, nevertheless temperature inside keeps increasing. Depending on the mass of the new load the system will remove the heat and the temperature decreases again down to -25°C. As soon as the consumer switches off the "super frost" mode the temperature raises back to -18°C.

The changes in power demand and day curve will be lower, if the consumer only places already frozen food into the device.

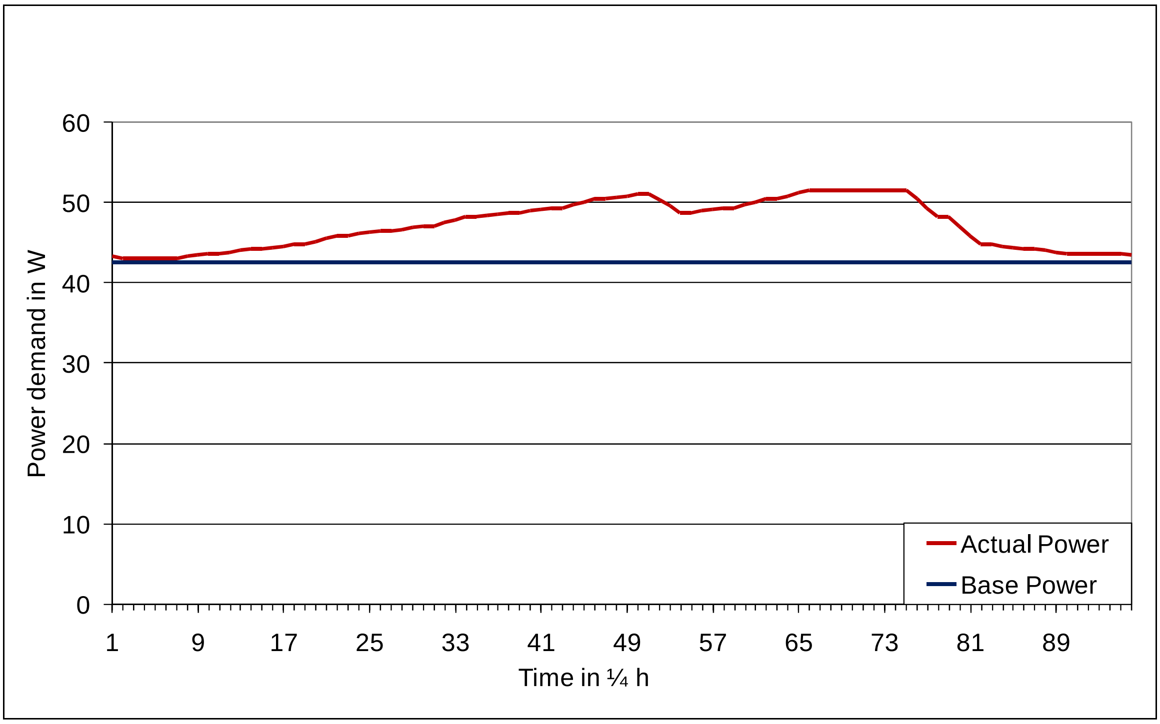
Figure 3.6-2 General pattern of a power demand curve of a freezer during storage of new goods to be frozen in ¼ hour steps



Source: University of Bonn

Regarding the day curve of all appliances the actual user behaviour has to be taken into account. It is assumed that in average 10% of the total energy consumption of freezers is induced by the consumer behaviour of opening the door and exchanging items to be frozen. Therefore a power demand curve of all appliances will follow a shape shown in Figure 3.6-3 where the base power is the amount of energy which is not being influenced by the behaviour of the consumers.

Figure 3.6-3 *General pattern of a daily load curve of an average freezer in ¼ hour steps*



Source: *University of Bonn*

3.6.6 Synergistic potentials

Within this chapter it is tried to explore possible synergies when freezers are somehow linked to sustainable energy sources, like solar or wind energy or heat from CHP processes. For each of these synergistic potentials it is described where the synergy comes from, what are possible constraints and what needs to be fulfilled to gain the potential. It is also estimated how many appliances might be affected and how these synergies might affect the power demand curve or the probability of operation of freezers, including a possible recovery phase. As most of these synergies are not yet realised, they are somewhat hypothetical, but based on best engineering practise. If costs are given, they describe the expected additional prize the consumer has to pay for this feature. If ranges are given, the higher value normally corresponds to an implementation of this feature in a first introduction phase, while the lower value estimates how costs may develop at a large scale use. Results of the consumer survey will be added in a supplementary document to this report.

In the following synergy scenarios the complexity of technical adjustments on the device considered increases from level 1 (3.6.6.1) to level 4 (3.6.6.4) steadily. Whereas in level 1 the consumer still has the full control whether to use the described option or not, in level 2 some of that control was handed over to the machine which then reacts to incoming signals. In level 3 the full control is in the hands of an external manager (e.g. electric utility) who decides about when and how often the machine is being switched on or off after it was set in a ready mode by the consumer. Therefore signals are being transmitted in a bidirectional way. In level 4 additional options for storing energy or using other technologies are taken into account.

3.6.6.1 Shifting operation in time

Id and title: 1-1 Consumer shifts loading of food to freeze or store in time
Description: Triggered by a signal or indication that regenerative energy is not available the consumer avoids placing new load into the freezer for some time. This will avoid additional operation of the compressor at this time.
Strategy for appliance control: Strategy is limited to spread out the information. This may be organised locally by spreading information about the relation of energy consumption and consumer behaviour using freezers
Change in power demand of single appliance curve: The operation of the compressor will be unchanged. Depending on the prolongation of the start of the freezing process the mean power demand will be lowered for this period, but recovered later when the items are finally placed into the freezer.
Change in day curve (of power demand of all appliances): It is estimated that maybe about 5% of the consumers will be willing to shift the freezing process (Figure 3.6-4). After food preparation by cooking, baking etc. the goods need to cool to ambient temperature. Therefore a shift of up to 30 min seems to be the maximum.

Consumer benefits and drawbacks:

Enhanced use of renewable energy and CHP. But the time to use it is short, depending on the way the consumer is informed about availability or shortage of renewable energy and CHP.

Demand management benefits and drawbacks:

Consumer behaviour is unpredictable. Longer experience may allow forecasting consumer behaviour. It may depend much on the time of the day and season as well as on the demand of frozen food .

Impact on appliance design and service provided: (additional costs, limitations, additional energy consumption):

No changes in design but means of information about the opportunity to use renewable energies and CHP in a certain period of time are necessary.

Additional costs for consumer: 0 €
Additional energy consumption: 0 W.

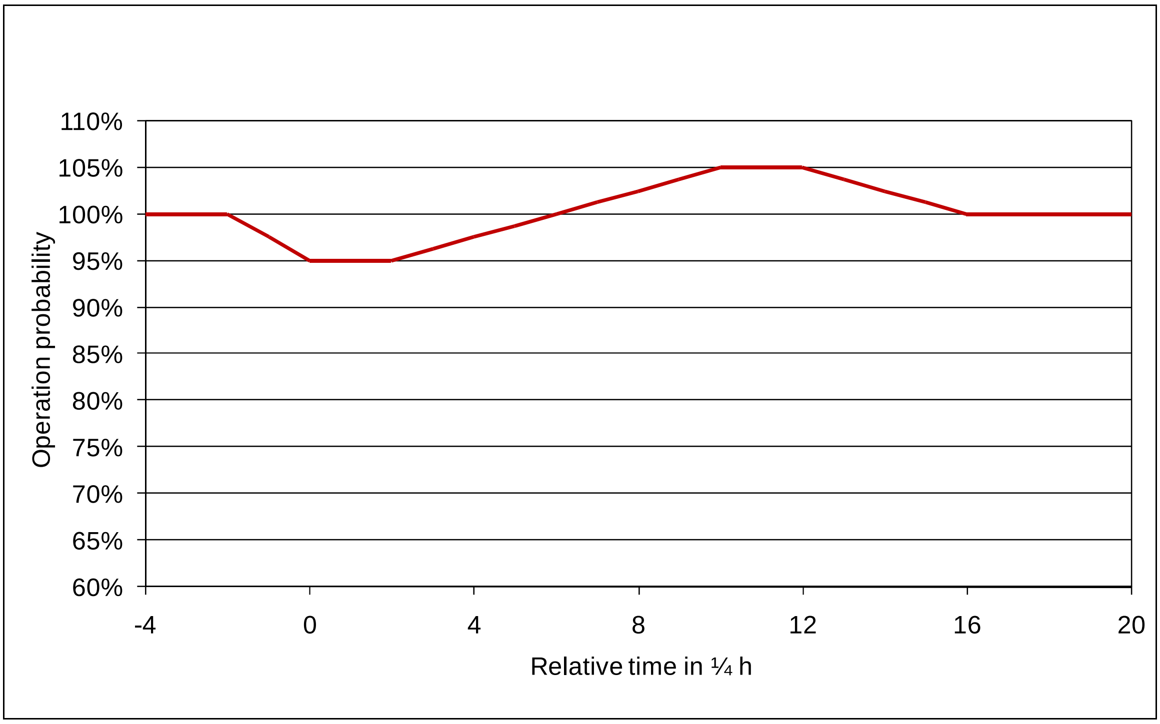
Consumer acceptance questions:

Willingness to accept without direct benefit.

Strategies for success:

Increase environmental awareness and practise.

Figure 3.6-4 Example of a change in operation probability for synergy scenario 1-1



Source: University of Bonn

3.6.6.2 Applying flexibility on appliance power demand

Id and title:

2-1 Power line triggered operation

Description:

Power line frequency is changing with the total load on the grid. High availability or shortage of renewable energy and CHP will influence the load and thus the frequency. This can be detected by the appliance and transferred into action DDC (Dynamic demand control).

Mains frequency varies in central Europe within 50 +/-0,2 Hz achieved by switching on or off additional power units or exchanging load with other regions. In the UK the grid is more isolated why the alteration of frequency may be up to +/-1,5 Hz. In both cases the frequency decreases with more load and increases with less load on the grid. Therefore the situation in central Europe should be considered as different to the UK. Here the implementation of frequency sensing units in freezers is relatively simple due to less expense [DDC 07].

Strategy for appliance control:

The operation of the compressor may be interrupted or the start of the compressor may be delayed. For reasons of food safety the freezer box temperature must determine the time of the delay.

Change in power demand curve of single appliance:

Operation time may be prolonged.

Change in day curve (of power demand of all appliances):

DDC can modify the on-off cycle of a freezer in response to the overall load on the grid. By definition DDC operation is fully automatic, no consumer intervention is required.

Short breaks or a shift of the compressor start will probably not even be recognised at all by the consumers during the operation. For the UK it is assumed that 100% of them will be willing to accept an implementation of DDC whereas in central Europe the amount will be only about 5%, because of higher costs for the implementation and additional frequency sensing. The probability curve in case of a shortage of renewable energy and CHP is shown in Figure 3.6-5.

Consumer benefits and drawbacks:

Enhanced use of renewable energy and CHP. No deterioration of the quality of frozen food must happen.

Demand management benefits and drawbacks:

Renewable energies and CHP may be easily provided for the grid system. Simple way to influence power demand on the grid, but only in an unpredictable way.

Impact on appliance design and service provided: (additional costs, limitations, additional energy consumption):

Operation interruption and start delay unit needs including frequency sensing or other detection means.

Additional costs for consumer in UK: 2 € - 5 €

Additional costs for consumers in central Europe: 10 € - 50 €

Additional energy consumption: > 0 W - 4 W.

Consumer acceptance questions:

Willingness to accept this solution if additional costs are balanced by savings via energy bill.

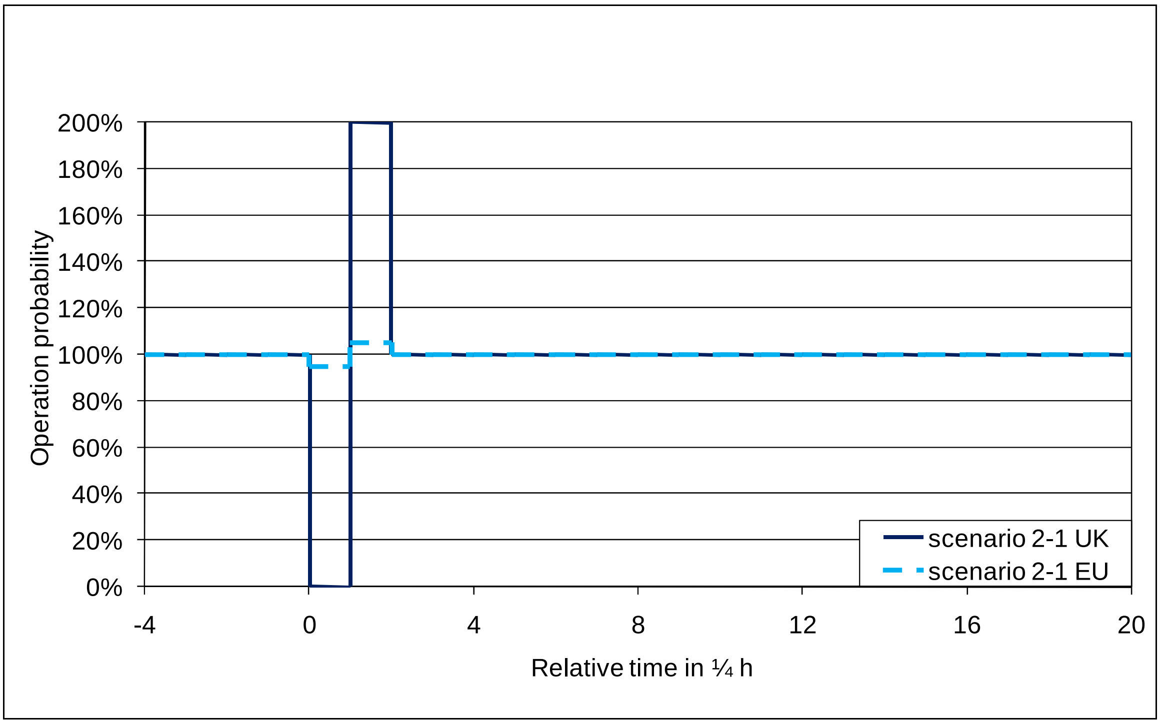
Calculation UK (additional costs: 3,50 €):
414 kWh/a at 0,20 €/kWh = 83 €/a energy costs
Amortisation in 5 years: 0,70 €/a saving
Reduction of energy costs by ~1% needed.

Calculation central Europe (additional costs: 30 €):
414 kWh/a at 0,20 €/kWh = 83 €/a energy costs
Amortisation in 5 years: 6 €/a saving
Reduction of energy costs by ~7% needed.

Strategies for success:

Define business model where energy utilities sponsor the implementation of these "Power line triggered operation " modules.

Figure 3.6-5 Example of a change in operation probability for synergy scenario 2-1



Source: University of Bonn

Id and title:

2-2 Internal energy manager agent

Description:

The availability or shortage of regenerative power may be communicated by other signals (like power line signal, mobile phone) and may be used to communicate and influence the start or interruption of the compressor in a more sophisticated way as in 2-1. This technique requires more information from the grid but is still a one-way communication. The external signal should include information on the availability or shortage and how long it may last. There is no feedback concerning the actual situation of the freezer.

Triggered by such a signal the freezer may change its operation:

- interrupt or delay the start of the freezing process
- prolong the freezing process by reducing the speed of the motor.
- change of temperature setting
- change of temperature variation

Strategy for appliance control:

Knowing the actual temperature inside the freezer a signal about the availability or shortage of renewable energy and CHP can be used to either anticipate or postpone the operation of the compressor. The hysteresis of the thermostat may be enlarged.

Change in power demand curve of single appliance:

Various. May shift operating time or motor power by seconds and minutes (Figure 3.6-6).

Change in day curve (of power demand of all appliances):

May allow shifting perhaps 5% of the individual operations at any time by seconds and minutes. Due to the characteristics of each appliance the changes in the overall power demand vary in the same manner as shown in scenario 2-1.

Consumer benefits and drawbacks:

Enhanced use of renewable energy and CHP. Short term breaks may not be recognised at all. Impact on food quality must be limited.

Demand management benefits and drawbacks:

Influence on power demand by short term action. Effect will depend on the time of the day, the season and the penetration of energy management agents in freezers.

Impact on appliance design and service provided: (additional costs, limitations, additional energy consumption):

Internal energy manager agent needs to be included in the electronic unit of machine.

A harmonised signal of availability or shortage of renewable energy and CHP is needed.

Additional costs for consumer (signal recognition plus energy agent): 10 € - 100 €.

Possible additional energy consumption:

- for communication device during operation: > 0 W - 4 W

Consumer acceptance questions:

Willingness to accept this solution if additional costs are balanced by savings via energy bill.

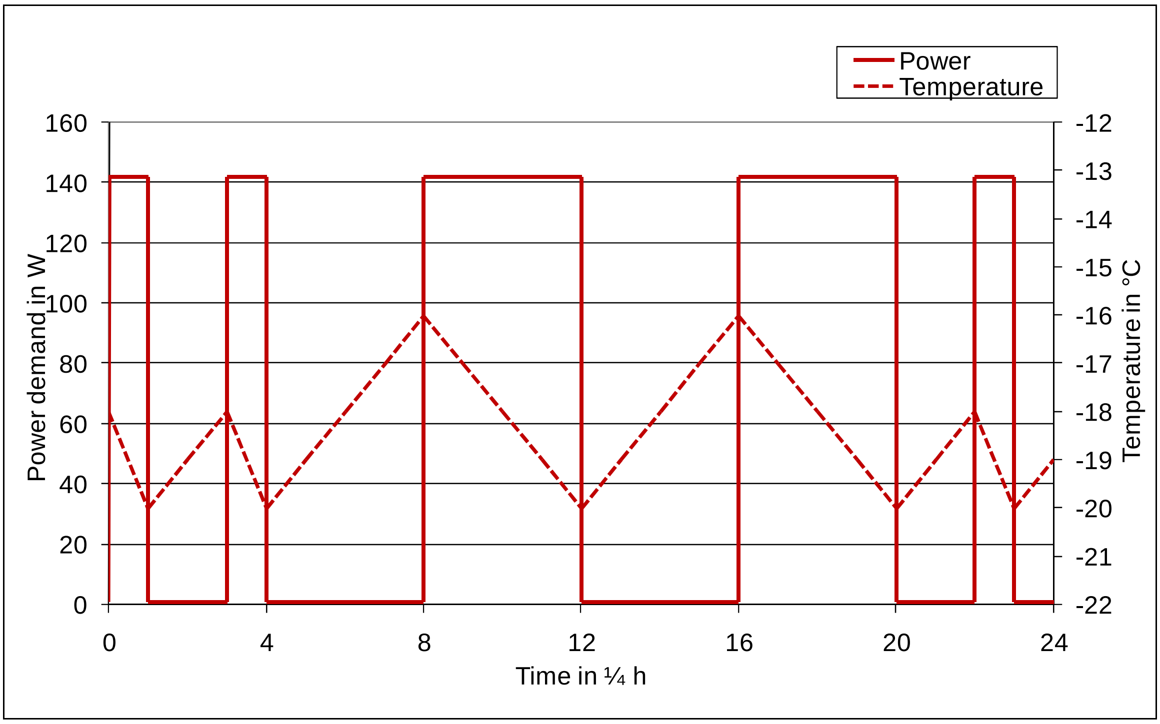
Calculation (additional costs: 55 €):
414 kWh/a at 0,20 €/kWh = 83 €/a energy costs
Amortisation in 5 years: 11 €/a saving
Reduction of energy costs by ~ 13% needed.

Strategies for success:

Define harmonised signal for availability or shortage of renewable energy and CHP (CENELEC).

Define business model where energy utilities sponsor the implementation of these “Internal energy management agent” modules.

Figure 3.6-6 *General pattern of a power demand curve of a freezer with postponed start of compressor and rising temperature in ¼ hour steps*



Source: *University of Bonn*

3.6.6.3 Managing the power on the grid

Id and title: 3-1 Energy demand manager
Description: The energy demand manager tries to harmonise the available power on the grid coming from conventional and renewable resources with the demand. The freezer needs to be equipped with remote facilities like start delay of the compressor, different electrical power levels or different hysteresis of the temperature control unit. The energy demand manager is informed about the temperature and the expected energy demand.
Strategy for appliance control: Knowing the demand for the next few hours the energy demand manager tries to use as much renewable energy and CHP as possible and optimises the overall costs. It anticipates or postpones the operation of as many freezers as necessary and available for remote control.
Change in power demand curve of single appliance: In the same way as shown in scenario 1-1, 2-1, 2-2.
Change in day curve (of power demand of all appliances): It is assumed that about 5% in Central Europe and 100% in the UK might be shifted according to any of the probability curves as shown for the synergy scenarios 1-1, 2-1 or 2-2 in Figure 3.6-7 (managed by the energy demand manager). Harmonisation of certain groups of freezers e.g. in different dwellings of a building or groups of houses may allow shifting for longer time periods. The sequential operation of different freezers will lower the total power demand of the freezers for some time (hours) but power demand will need to be recovered. As the consumer is not involved in the operation of the device any more, the probability curve of scenario 1-1 (delayed start) stands for a second option of scenario 2-2.

Consumer benefits and drawbacks:

Enhanced use of renewable energy and CHP. Impact on food quality must be limited. Cost benefits must be transferred to the consumer.

Demand management benefits and drawbacks:

Influence on power demand by medium term action. Influence only on those machines which are 'online'.

Impact on appliance design and service provided: (additional costs, limitations, additional energy consumption):

Bidirectional communication needed. Additional switch needed to signal 'remote operation accepted'.

A harmonised communication protocol is needed.

Additional costs for consumer (communication module via power line): 30 € - 130 €.

Additional energy consumption:

- For communication during operation: > 0 W - 4 W

Consumer acceptance questions:

Willingness to accept this solution if additional costs are balanced by savings via energy bill.

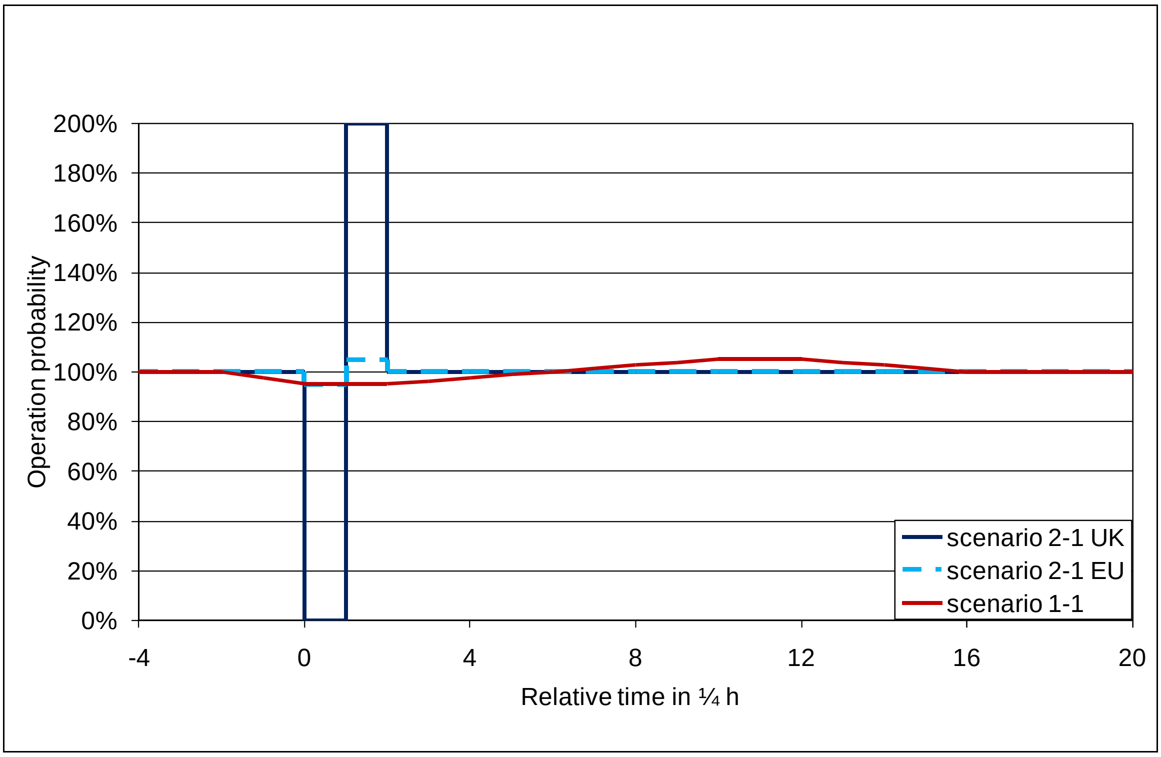
Calculation (additional costs: 80 €):
414 kWh/a at 0,20 €/kWh = 83 €/a energy costs
Amortisation in 5 years: 16 €/a saving
Reduction of energy costs by 19% needed.

Strategies for success:

Define harmonised communication protocol (CENELEC).

Define business model where savings balance the additional costs for the appliance.

Figure 3.6-7 Change in operation probability for synergy scenarios 3-1 (any of 1-1, 2-1, 2-2 is same as 2-1)



Source: University of Bonn

3.6.6.4 Using energy storage capacity and other technologies

Id and title:

4-1 Energy storage capacity

Description:

Freezer with additional material of high heat (cool) capacity may be able to slow down rise of temperature.

This option may be especially beneficial when combined with smart operations as described in options 2-1, 2-2 and 3-1.

Strategy for appliance control:

No.

Change in power demand curve of single appliance:

The rise of temperature in the freezer box is lowered and the start of the cooling process prolonged (Figure 3.6-8).

Change in day curve (of power demand of all appliances):

Shifting volume depends on availability of freezers with additional cool storage capacity.

Consumer benefits and drawbacks:

Enhanced use of renewable energy and CHP when operation is linked to the availability of renewable energy and CHP.

Demand management benefits and drawbacks:

Use of renewable energy and CHP in different ways, depending on the availability.

Impact on appliance design and service provided: (additional costs, limitations, additional energy consumption):

Additional space for material with high heat capacity will reduce the usable capacity for household purpose.

Additional costs for heat storage materials and possible ventilation including additional energy consumption: 40 € - 200 €

Consumer acceptance questions:

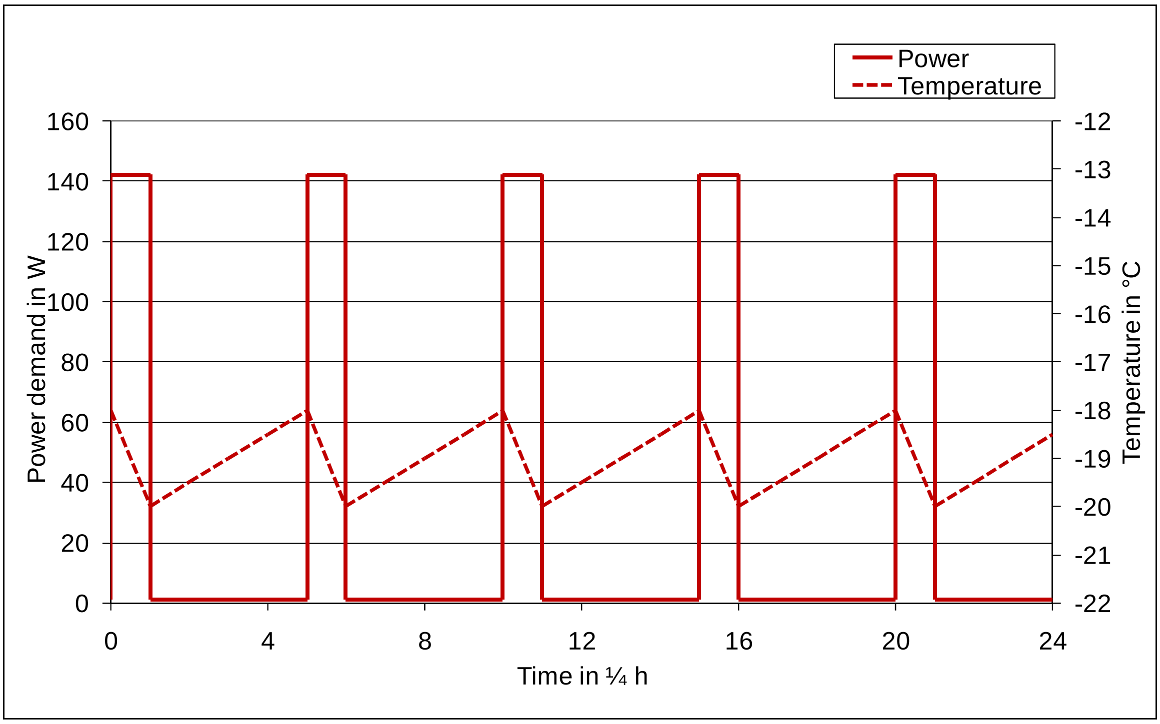
Willingness to accept this solution if additional costs are balanced by savings via energy bill.

Calculation (additional costs: 120 €):
414 kWh/a at 0,20 €/kWh = 83 €/a energy costs
Amortisation in 5 years: 24 €/a saving
Reduction of energy costs by ~29% needed.

Strategies for success:

Define business model where savings balance the additional costs for the appliance.

Figure 3.6-8 *General pattern of a power demand curve of a freezer with postponed start of compressor due to cool storage capacity*



Source: *University of Bonn*

Id and title:
4-2 Energy storage by phase change material
Description:
Freezer with additional phase change material may be able to balance interruptions in energy supply for a longer period of time. Phase change material is designed to keep the temperature of the freezer at the point, where this material alters its physical state of aggregation. All energy penetrating the freezer is used until all of the substance has changed from crystallized to liquid phase. In the next period of compressor operation the phase change material has to be 'charged' again, which needs additional energy. This option may be especially beneficial when combined with smart operations as described in options 2-1, 2-2 and 3-1.
Strategy for appliance control:
No.
Change in power demand curve of single appliance:
See next paragraph
Change in day curve (of power demand of all appliances):
The shifting volume depends on the availability of freezers with additional phase change material. In Figure 3.6-9 the power demand is divided in four equal periods over the whole day. The situation is characterised by long periods of low power demand and long periods of high power demand. The amount of power is calculated for a mean appliance consuming 414 kWh per year (see chapter "Consumption of energy in Europe"). Figure 3.6-10 shows the situation when the whole energy is provided during daytime when e.g. solar energy

is available. The amount of power is calculated for a mean appliance consuming 414 kWh per year (see chapter “Consumption of energy in Europe”).

Figure 3.6-11 shows the situation when the whole energy is provided during the night when other power demand is minimized and free capacities of power generation may be used. The amount of power is calculated for a mean appliance consuming 414 kWh per year (see chapter “Consumption of energy in Europe”).

Consumer benefits and drawbacks:

Enhanced use of renewable energy and CHP when operation is linked to the availability of renewable energy and CHP.

Demand management benefits and drawbacks:

Use of renewable energy and CHP in different ways, depending on the availability. Demand of energy and generation of renewables and CHP can be adjusted.

Impact on appliance design and service provided: (additional costs, limitations, additional energy consumption):

Additional space for phase change-material will reduce the usable capacity for household purpose.

Additional costs for heat storage materials and possible ventilation including additional energy consumption: 40 € - 200 €

Consumer acceptance questions:

Willingness to accept this solution if additional costs are balanced by savings via energy bill.

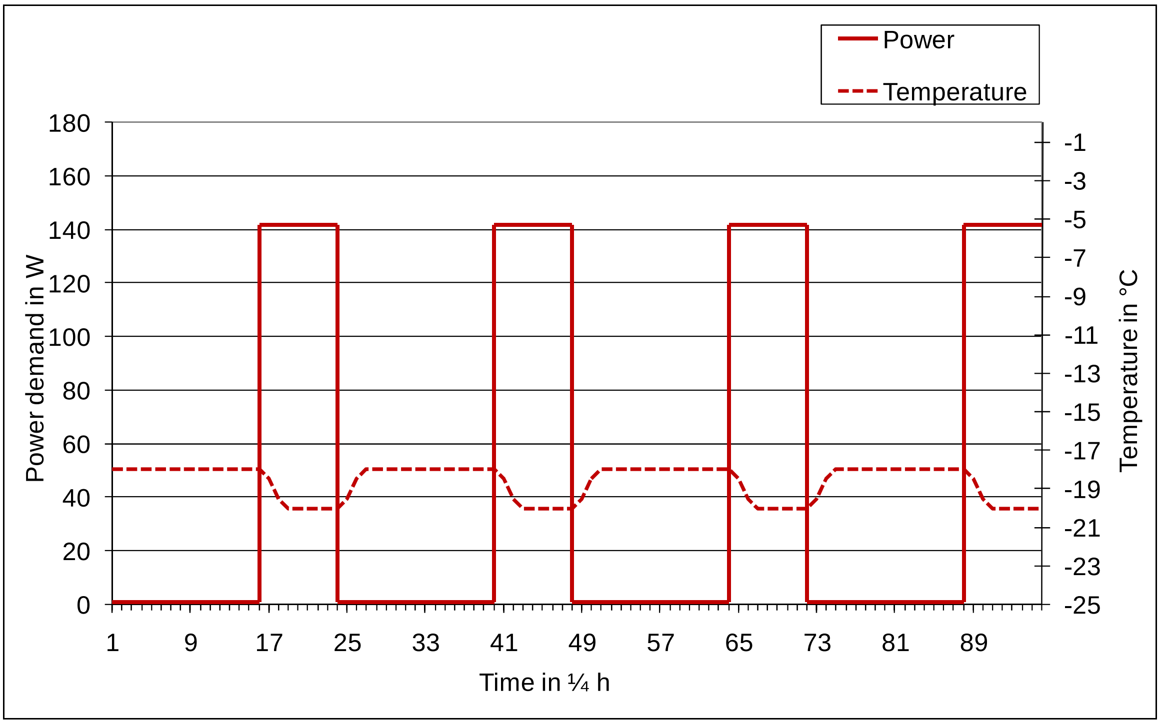
Calculation (additional costs: 120 €):
414 kWh/a at 0,20 €/kWh = 83 €/a energy costs
Amortisation in 5 years: 24 €/a saving
Reduction of energy costs by ~29% needed.

Strategies for success:

Suppliers offer special tariffs: overnight rate, solar rate, wind rate etc.

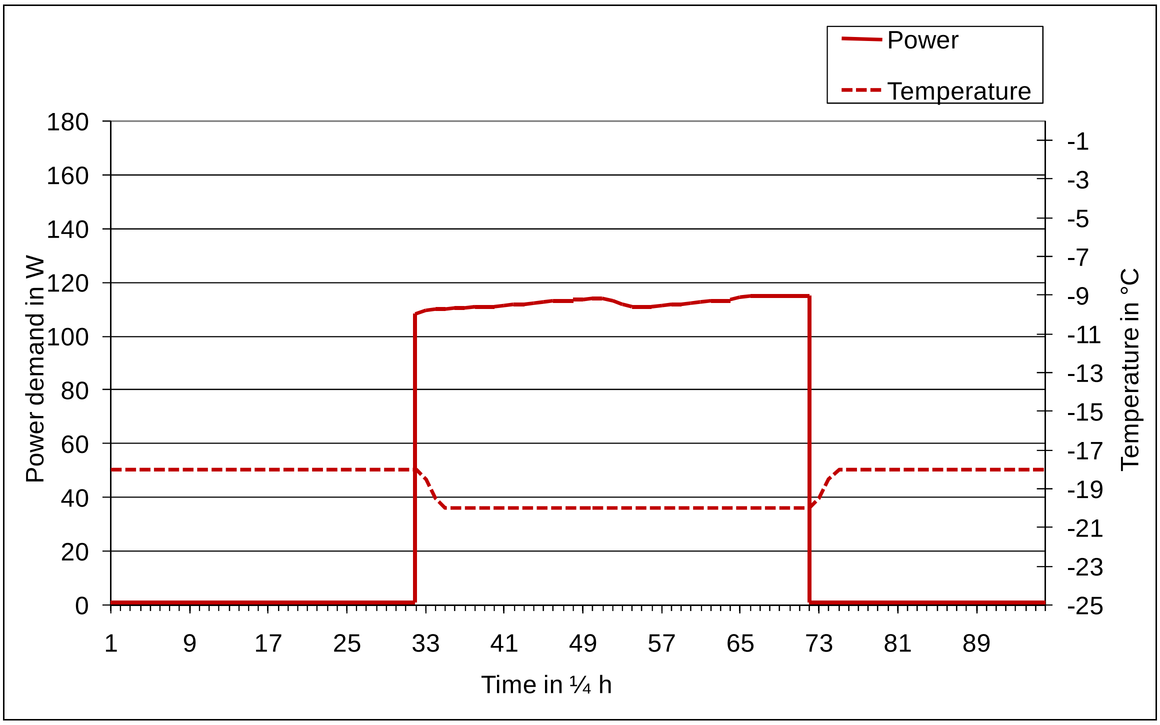
Define business model where savings balance the additional costs for the appliance.

Figure 3.6-9 *General pattern of a power demand curve per day of an average single freezer due to phase-change-material, multiple cycles per day*



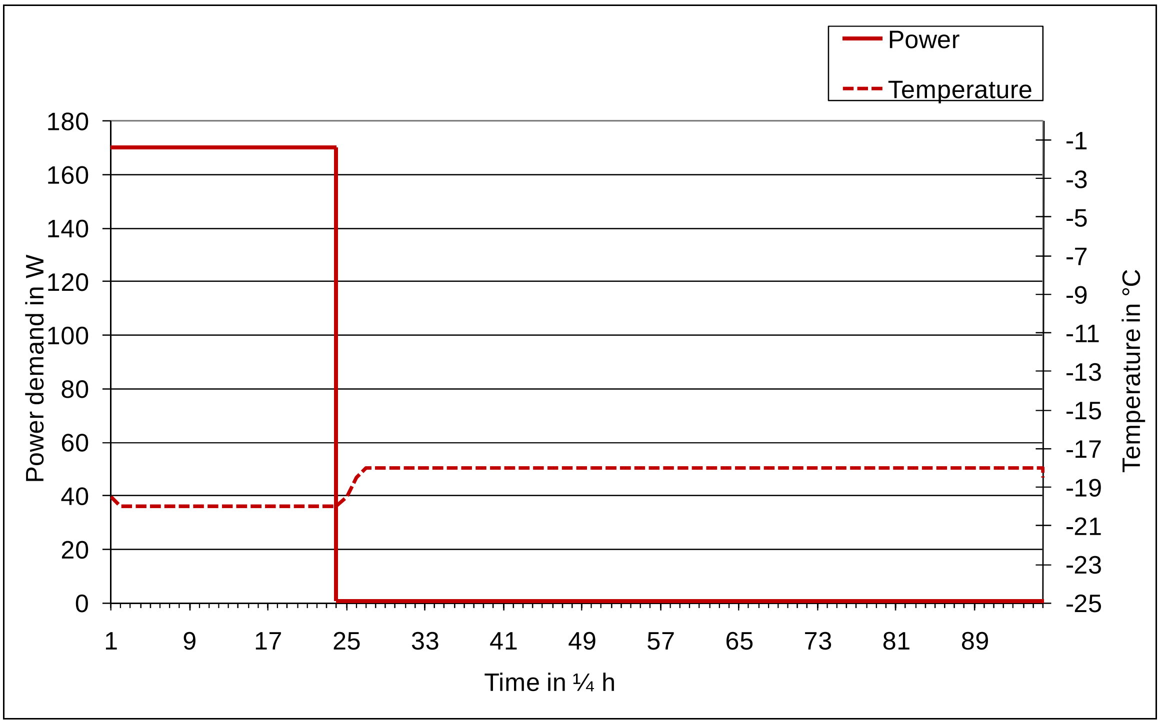
Source: *University of Bonn*

Figure 3.6-10 *General pattern of a power demand curve per day of an average single freezer due to phase-change-material, one cycle per daytime*



Source: *University of Bonn*

Figure 3.6-11 *General pattern of a power demand curve per day of an average single freezer due to phase-change-material, one cycle per night time*



Source: *University of Bonn*

Id and title: 4-3 Implementing absorber technology
Description: Instead of running the freezing cycle by electrical energy, absorber freezing technology can be used. This circle is driven by heat from an external source which can be provided by solar collectors or by a combined heat and power unit.
Strategy for appliance control: No.
Change in power demand curve of single appliance: Reduction of electricity demand by 95% (5% needed for electronic control and perhaps ventilator).
Change in day curve (of power demand of all appliances): Reduction of electricity demand by 95% at any time.
Consumer benefits and drawbacks: The operation of the freezer is nearly for free as long as the required heat can be taken from already existing solar collectors or combined heat and power units which are traditionally used to deliver warm water and electricity all year and warmth during winter time.
Demand management benefits and drawbacks: Almost no electrical energy needed.
Impact on appliance design and service provided: (additional costs, limitations, additional energy consumption): Absorber technology is still quite expensive for any appliances. Consumer benefit probably can only be

realised if solar collectors or a combined heat and power unit is already available.
Consumer acceptance questions: Might be accepted by people who can use thermodynamic power from solar collectors and combined heat and power units.
Strategies for success: Improvement of absorber technology also for domestic appliances. Increase application of solar collectors and combined heat and power units in households.

3.7 Room air conditioner

Air conditioning is a technology supported by thermodynamic and physical science, intended to change and improve the conditions (mainly temperature and moisture content) of the indoor air. Room air conditioners applied in the residential sector are designed in order to improve the well-being of the human presence [JA 03]. The main designs available on the European market are portable single duct room air conditioners, single package room air conditioners for window or through-wall mounting, single-split package room air conditioners with indoor and outdoor unit and multi-split package room air conditioners consisting of one outdoor unit and a variable number of indoor units [VHK 05].

3.7.1 Technical description with regard to the use of energy

The most simple air conditioning system cools the space by rejecting the heat outside the room, with a limited or complete control of the room humidity and air quality. The energetic process is described by the load to be extracted (also called cooling effect) which is the thermodynamic quantity necessary to maintain the defined comfort conditions. The desired comfort conditions may include thermal comfort, which is expressed in terms of a mix of air flow, humidity control and indoor air quality which is usually obtained through ventilation, i.e. by the change of indoor air and filtration components. Cooling only systems extract heat from inside the room (P_c) approximately equivalent to the value of the load, through the use of electricity (P_e). Usually the heat rejected outside (P_r) has an energetic value equivalent to $P_e + P_c$ [JA 03].

The main technology for cold production is the compressor cooling machine. Evaporation of the liquid refrigerant (R22, R407C, R134a, etc.) creates the cold in the evaporator, which subsequently absorbs heat from the refrigerated space. The characteristics of the evaporator technology depend primarily on the required application and the type of cold source. After its full evaporation the refrigerant vapour is compressed by a compressor and than condensed while evacuating the heat corresponding to the one absorbed at evaporator level and the thermal equivalent of the work of the compressor to the outer space. After condensing, the refrigerant is expanded by an expansion valve which is used to throttle the refrigerant fluid back to the evaporator and to control the refrigerant flow. The circulation of the refrigerant is driven by a compressor, which demands electrical energy.

Instead of electricity thermodynamic energy can be used (absorber cooling process). This process uses ammoniac as refrigerant. A mixture of ammoniac gas and hydrogen flows from the evaporator into the absorber, where the ammoniac vapour is suspended in water. The insoluble hydrogen flows back into the evaporator. The mixture of ammoniac and water is then heated by the boiler while the refrigerant vaporizes. The refrigerant vapour gets into the condenser and the water flows back into the absorber. The ammoniac vapour is condensed while evacuating the heat with a ratio of about 1:3 (cooling effect: heat input). At last the fluid ammoniac streams back to the hydrogen containing evaporator. As there are no mechanical processes in this appliance, the absorber operates completely noiseless.

3.7.2 Penetration in Europe

Recent Eurostat statistics on production, import, export and penetration rate are not very detailed nor complete. Eurostat publishes production figures for Jan-Dec 2002 while not differentiate between room air conditioners and other types of air conditioners (Table 3.7-1).

Table 3.7-1 Production of air conditioners by country Jan – Dec 2002

COUNTRY	**PRODUCTION 1000 units**		**COUNTRY**	**PRODUCTION 1000 units**
Italy	705		Austria	8
France	55		Hungary	1
Germany	48		Poland	1
Spain	25		TOTAL	843

Source: [VHK 2005]

The Japan Refrigeration and Air Conditioning Industry Association (JRAIA) estimates the world demand for air conditioners at almost 60 million units. About 80% (40-45 million units) are room air conditioners. The global market value, according to the Building Services Research and Information Association (BSRIA) is 34 billion dollar, rising with 4% per annum which makes the future demand of room air conditioners an interesting economical fact.

The yearly European (geographical area not indicated) demand for room air conditioners is estimated at some 4,5 million units or 10% of the world total in 2004 and expected to be at 5,5 million units per year in 2008 [VHK 05].

Eurovent presents historical and future sales data for the three main markets in Europe: France, Spain and Italy (Table 3.7-2).

Table 3.7-2 Sales and penetration rates of air conditioners in France, Spain, Italy

Year	2004	2006	2008	2010
EUROVENT			expected	expected
sales Italy (‘000 units) penetration ratio (%)	1800 20%	2150 28%	2400 35%	2500 45%
sales Spain (‘000 units) penetration ratio (%)	1000 24%	1200 30%	1420 35%	1580 42%
sales France (‘000 units) penetration ratio (%)	460 4%	720 7%	800 9%	900 12%
sales EU-25 (‘000 units) (estimated 142% of above)	4657	5814	6600	7114
JRAIA			expected	expected
sales Europe (‘000 units)	4324	4861	5543	6500
annual growth rate	10%	6%	8%	8%
DIFFERENCE JRAIA/EUROVENT	7%	7%	6%	9%

Source: [VHK 05]

More figures concerning the European stock of room air conditioners are published by the Energy Efficiency of Room Air Conditioners study (EERAC) which presents stock figures of room air conditioners in European households for different years: 1,17 million units in 1990, 7,4 million units in 1996, 21,02 million units estimated for 2010 and 33 million units estimated for 2025. The interpolation of these figures results in a 2004 stock of approximately 17 million units (VHK 05].

Comparing the EERAC stock forecast with a forecast based upon the sales figures published by JRAIA and Eurovent it seems that EERAC underestimates the market (which has been confirmed by EERAC). A recalculated estimate of 2004 stock is therefore 25 million units [VHK 05].

3.7.3 Consumption of energy in Europe

Only limited data are available regarding the amount of energy consumption used for room cooling in European households. Estimating a stock of 25 million room air conditioners in Europe 2004, VHK calculates a total energy consumption for room cooling of 22,5 TWh per year [VHK 05]. This calculation is based on an average cooling capacity of 4,6 kW per room air conditioner and 500 hours of operation per year. The European Commission publishes an energy consumption of 5,8 TWh per year for the residential sector in EU-15 in its Green Paper on Energy Efficiency in 2005 [GRE 05]. For EU-25 Bartoldi and Atanasin estimate the electricity consumption for air cooling in private households to be in a range between 7 TWh and 10 TWh per year [EEF 06].

3.7.4 Effects on energy consumption due to consumer usage

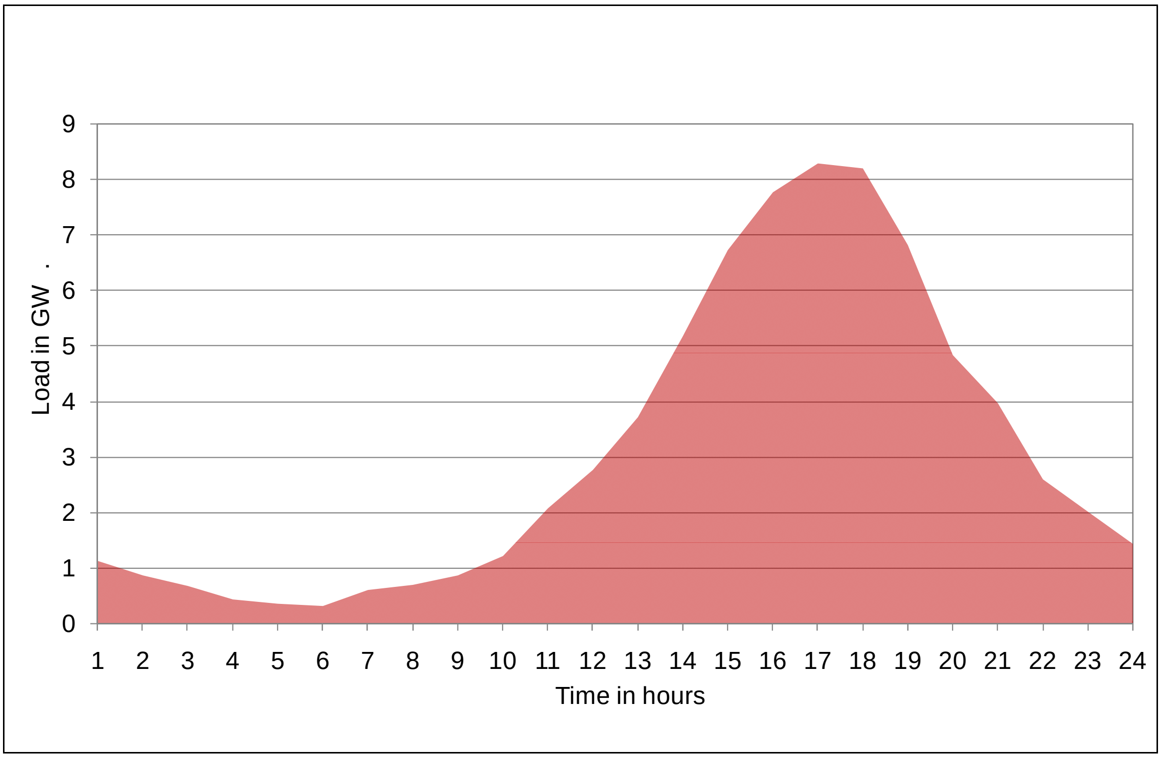
As room air conditioners in the residential sector are operated on consumer demand only, the electricity consumption for room air conditioning is determined by following mainly consumer driven factors:

- Ambient conditions
- Frequency of operation
- Temperature settings
- Appliance efficiency under real use conditions
- Maintenance
- Additional functions like high or low airflow, air purifiers
- Standby / timer settings.

The running hours and desired temperature are not only influenced by the preference of the user but also by the local climate (temperature/humidity), the physical characteristics of the room (insulation, heat gain) and by the design of the unit, the way it is installed and the measures taken to prevent warm air entering the room [VHK 05]. In any case the comfort level to be reached should reflect the nature and quality of the activity which takes place in the conditioned space. Comfort conditioning requirements can vary between natural cooling and total cooling. While natural cooling is obtained by forced ventilation, when outdoor conditions permit, total cooling includes full control of temperature and provision of the minimum ventilation rate for hygienic purposes. Total cooling requires a degree of dehumidification meeting the cooling effect, which is a very frequent comfort level today although natural cooling or partial cooling may be felt as comfortable in North and Central European countries [JA 03].

It is already known from households in the US that the electricity consumption for room conditioning varies during daytime. The following diagram (Figure 3.7-1) shows times of low and high electricity consumption within 24 hours.

Figure 3.7-1 *USA, load peaks due to room air conditioners (California, summer 1999)*



Source: *[CAD 02]*

Obviously the highest peak in electricity consumption occurs at about 5 pm. As the temperature rise in Europe during daytime is similar to that in the USA this curve should be adaptable for European countries.

The desired indoor temperature should correspondent with the real outdoor temperature to avoid health problems. Following the German DIN 1946 the maximum temperature and the relative humidity should be as given in Table 3.7-3.

Table 3.7-3 Desirable maximum indoor air temperature and humidity as per DIN 1946

Outdoor Air	Indoor Air	
Temperature °C	Temperature °C	Relative humidity %
18	22	35 – 65
20	22	35 – 65
25	23	35 – 65
30	25	35 - 60
32	26	35 - 55

Source: German DIN 1946

According to heating appliances which are only used in wintertime in order to provide warmth, room air conditioners are mainly needed during summertime. Only very few information about actual running hours is available. A study testing a solar driven absorber chiller shows a cooling demand of 60 days in Stuttgart during one year [VB 05]. The eco-design report for room air conditioners assumes 500 operating hours per year [VHK 05]. The EECCAC Report 2003 publishes 400 – 800 h/a as equivalent usage duration at full load. Due to different climate zones in Europe the real demand of room cooling varies a lot between the countries. For the calculation of operation hours, the cooling degree days [WRI 03] respectively cooling days of each country are used. Most people feel comfortable in a surrounding of about 20°C therefore “cooling days” are determined as days on which the average temperature is higher than 20°C. Cooling degree days are summations of positive differences between the mean daily temperature and the room (base) temperature of 18°C. With data of average temperatures per month for each country published by Eurometeo [EM 07] the average temperature of the cooling period can be determined (Table 3.7-5). As cooling period those months are chosen which reach average temperatures ≥ 20°C. For example for Portugal an average temperature of the cooling period (outside temp. ≥ 20°C) of 21,75 °C is calculated (Table 3.7-4).

Table 3.7-4 Cooling days and average temperature of the cooling period (e.g. Portugal)

Month	**°C**	The number of cooling days Z [d] is calculated by the following formula: Z[d] = G/(tz - ti) G [Kd] = number of cooling degree days ti = 18°C (base temperature) tz = average outside temperature during the cooling period
January	11	
February	12	
March	14	
April	15	
May	17	
June	20	
July	22	
August	23	
September	22	
October	19	
November	15	
December	12	
average temp. cooling period	**21,75**	

Source: University of Bonn

With the cooling degree days' data published by World Resources Institute in 2003 [WRI 03] the cooling days are determined as shown in Table 3.7-5.

Table 3.7-5 Cooling degree days and cooling days

countries	**cooling degree days**	**cooling days**	**cooling hours**	**average outside temp. (cooling period)**
	G	**Z**	**T**	**tz**
	[Kd]	**[d]**	**[h]**	**[°C]**
Austria	173	87	522	20,0
Bulgaria	430	215	1290	20,0
Croatia	418	209	1254	20,0
France	241	69	414	21,5
Greece	923	128	768	25,2
Hungary	256	85	510	21,0
Italy	600	109	654	23,5
Portugal	345	92	552	21,7
Romania	290	97	582	21,0
Spain	702	187	1122	21,7

Source: Calculations by the University of Bonn based on data from [EM 07]

Taking into consideration that room air conditioners are mostly run in the afternoon and early evening six operating hours per cooling day might be estimated (15.00 h – 21.00 h). Based on this estimation the number of cooling hours per year can be calculated (Table 3.7-5).

In some North and Middle European countries the average temperature doesn't exceed 18°C and therefore a cooling period can't be determined. But anyway hot periods in which room cooling is desired might also occur in those regions. The World Resources Institute has published cooling degree days (CDD) also for countries without a cooling period (Table 3.7-6).

Table 3.7-6 Cooling degree days for countries without a determined cooling period

	Belgium	**Denmark**	**Finland**	**Germany**	**Poland**	**Switzerland**	***Great Britain***
CDD	*102*	*40*	*48*	*122*	*100*	*137*	*66*

Source: [WRI 03]

The experience of the last years shows that the number of days with an average outside temperature above 20°C rises in those countries. Therefore it might be fair to estimate that room air conditioning becomes necessary at about 10 – 20 days per year which is not yet caused by the climate but by special weather circumstances.

3.7.5 Power demand and load curves

For the calculation of the cooling capacity of an average room air conditioner in stock or on sale the weighted average capacity of an air cooled 230 V appliance is calculated (Table 3.7-7). Figures are the same for stock and sales.

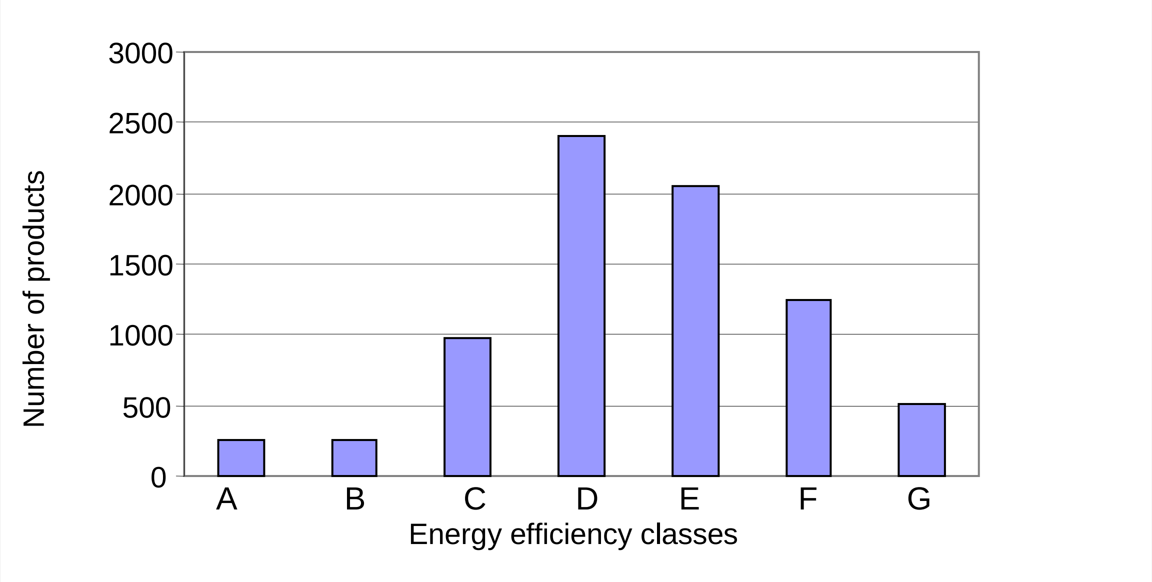
Table 3.7-7 Average cooling capacity by air conditioner type

Type	Average cooling capacity	% of sales / stock	Weighted stock average
single duct	1,7 kW	9 %	4,6 kW
packaged	4,92 kW	7 %	
Split	4,87 kW	70 %	
Multi-split	5,23 kW	14%	

Source: [VHK 05]

Due to the Eurovent database 2002 recent data about the distribution of energy classes of room air conditioners below 12 kW is available (Figure 3.7-2).

Figure 3.7-2 Energy efficiency of room air conditioners by label



Source: [VHK 05]

In 2002 the average energy efficiency class for all types of room air conditioners below 12 kW was D, which corresponds with an energy efficiency rate (EER) of 2,5 concerning the appliances in stock and 2,7 regarding units on sale. The EER is the ratio between the cooling capacity and the electric power of the device. Assuming an average compressor operation time of 500 hours (with 6 cooling hours per day) the average energy consumption per air conditioner per year can be calculated as shown in Table 3.7-8.

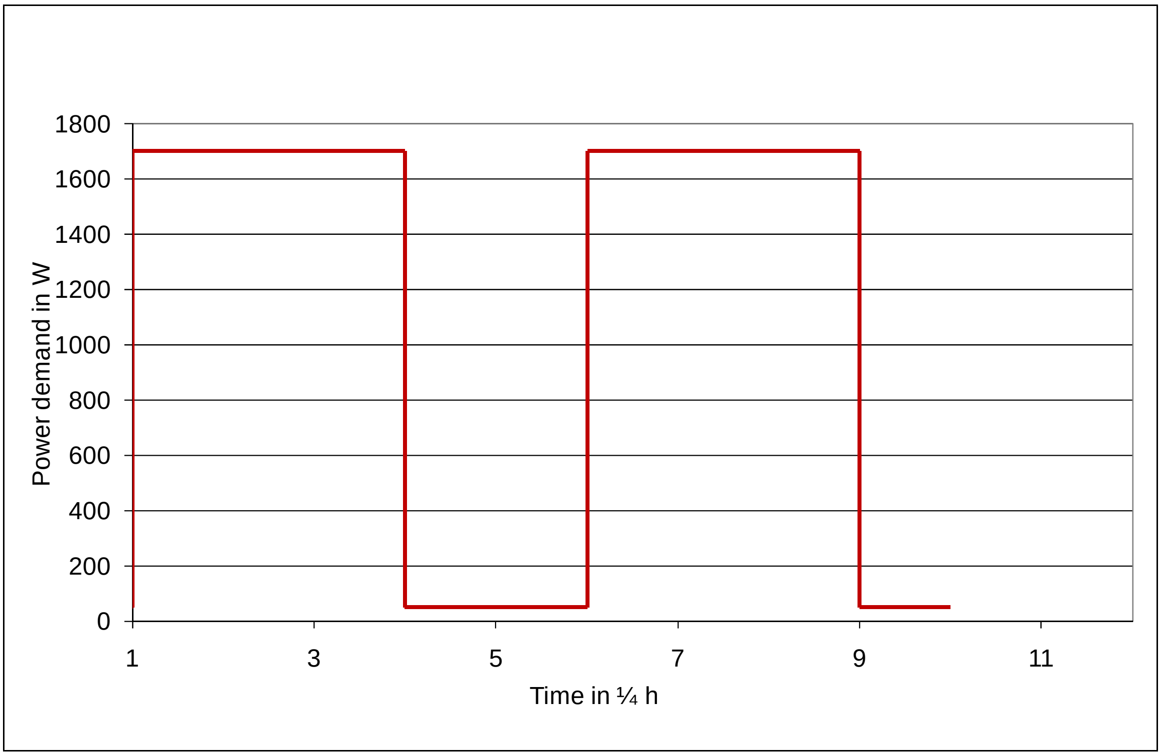
Table 3.7-8 Average electricity consumption per European room air conditioner per year

	Cooling capacity	Energy efficiency rate	$P_{electric}$ (kW)	kWh/a
Stock 2004	4.6 kW	2.5	1.8 kW	900 kWh/a
Sales 2004	4.6 kW	2.7	1.7 kW	850 kWh/a

Source: [VHK 05]

The power demand (Figure 3.7-3) may vary from air conditioner to air conditioner and also depends on the outdoor air temperature and humidity. But when the air conditioner is started by the consumer this kind of power demand will be drawn by the appliance automatically. Only if the consumer has activated a timer or start time delay function this power demand is shifted by a defined number of hours.

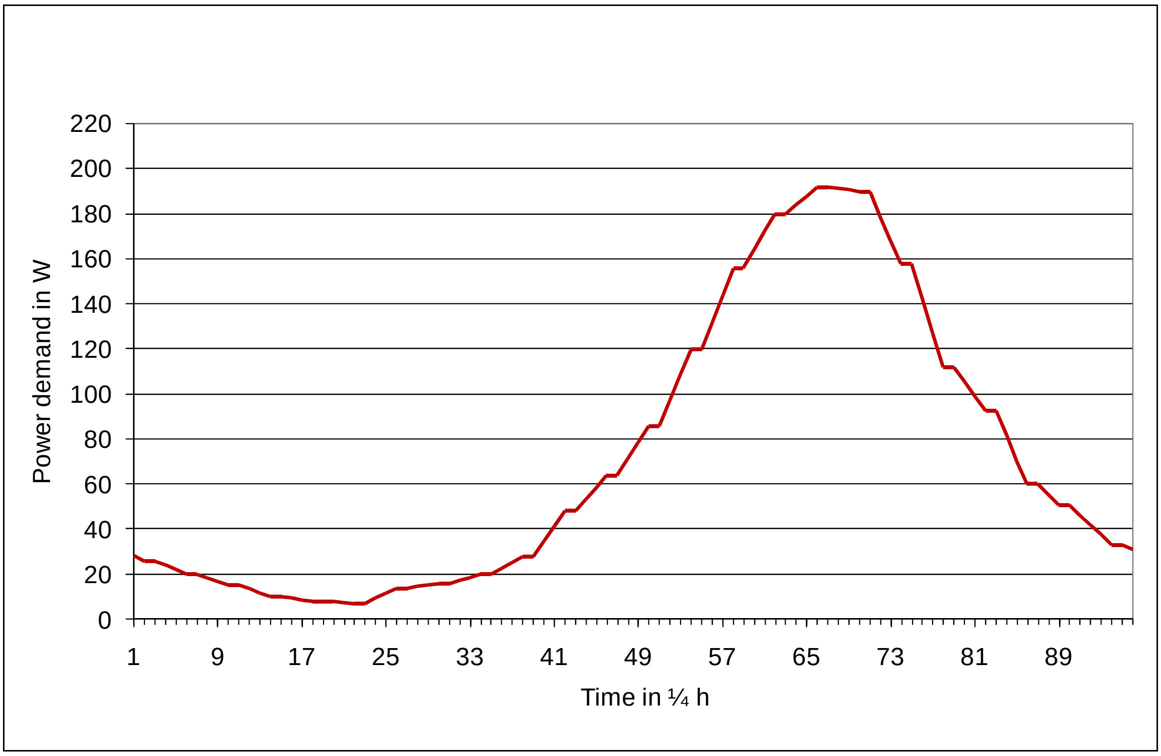
Figure 3.7-3 General pattern of a power demand curve of an average air conditioner in ¼ hour steps



Source: University of Bonn

Using the average room cooling demand as presented in Figure 3.7-1 and combining it with the power demand of a 1,7 kW room air conditioner leads to an average load curve as shown in Figure 3.7-4.

Figure 3.7-4 General pattern of a daily load curve per day of an average air conditioner in ¼ hour steps



Source: University of Bonn

3.7.6 Synergistic potentials

Within this chapter it is tried to explore possible synergies when room air conditioners are somehow linked to sustainable energy sources, like solar or wind energy or heat from CHP processes. For each of these synergistic potentials it is described where the synergy comes from, what are possible constraints and what needs to be fulfilled to gain the potential. It is also estimated how many appliances might be affected and how these synergies might affect the power demand curve or the probability of operation of room air conditioners including a possible recovery phase. As most of these synergies are not yet realised, they are somewhat hypothetical, but based on best engineering practise. If costs are given, they describe the expected additional prize the consumer has to pay for this feature. If ranges are given, the higher value normally corresponds to an implementation of this feature in a first introduction phase, while the lower value estimates how costs may develop at a large scale use. Results of the consumer survey will be added in a supplementary document to this report.

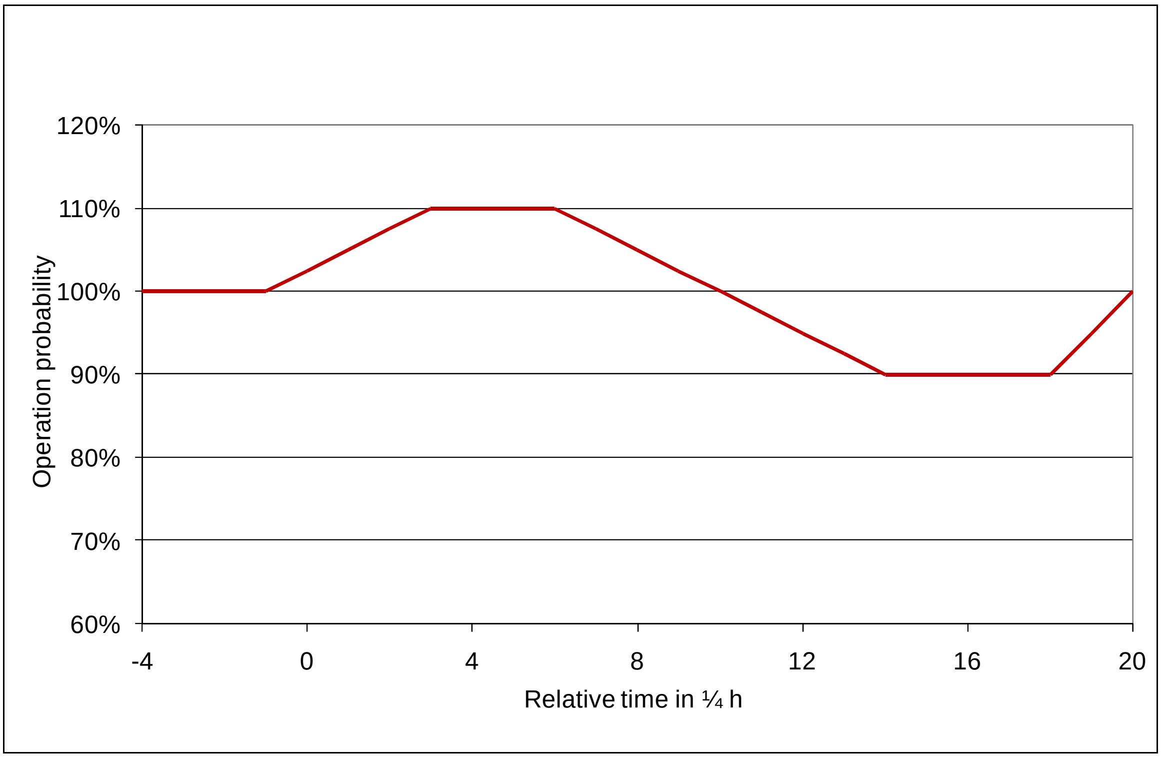
In the following synergy scenarios the complexity of technical adjustments on the device considered increases from level 1 (3.7.6.1) to level 4 (3.7.6.4) steadily. Whereas in level 1 the consumer still has the full control whether to use the described option or not, in level 2 some of that control was handed over to the machine which then reacts to incoming signals. In level 3 the full control is in the hands of an external manager (e.g. electric utility) who decides about when and how often the machine is being switched on or off after it was set in a ready mode by the consumer. Therefore signals are being transmitted in a bidirectional way. In level 4 additional options for storing energy or using other technologies are taken into account. Options for storage of thermal energy in building structures are not included in the scenarios, even though it might be more beneficial in some cases to use these rather than air conditioners with storage.

3.7.6.1 Shifting operation in time

Id and title: 1-1 Consumer shifts operation in time
Description: The consumer receives a signal about the availability of renewable energy or energy from CHP plants. Depending on the signal, he shifts the operation of a room air conditioner to run at a time, where in relation to the expected load too much electricity is generated. The information about the availability may be communicated via radio (e.g. weather forecast), internet or remote control signals coming from the electricity provider. The consumer has to make his own decision whether to use this information or not. Available timer or "start time delay" options may be used.
Strategy for appliance control: This synergy option requires the active engagement of the consumer by transferring the information of shortage or surplus of renewable energy into the operation of the appliance. The broadcasting of the information may be randomized or varied in time locally to avoid that too many consumers are acting on the same signal at the same time.
Change in power demand curve of single appliance: No change
Change in day curve (of power demand of all appliances): As an additional technical implementation on the appliance is not necessary, the start of all room air conditioners could be shifted up to one hour earlier. Actually it can't be assumed that all consumers are interested and willing to use and follow the information about high availability of (renewable) energy and CHP. It is estimated that perhaps only 10% of the consumers (to be verified by WP 5) will shift the start of their appliance (Figure 3.7-5). A time shift of more than 1 hour doesn't seem to be reasonable because longer operation time might cause additional electricity consumption unless combining this strategy with the inverter technology (Figure 3.7-9).
Consumer benefits and drawbacks: Enhanced use of renewable energy and CHP. But probably only accepted by convinced environmentalists or by people owning their own power or heat generation unit if the resource use is cheaper than the one taken from other sources.
Demand management benefits and drawbacks: Consumer behaviour is unpredictable. Longer experience may allow forecasting consumer behaviour.
Impact on appliance design and service provided: (additional costs, limitations, additional energy consumption): Delay start timer may be helpful. Additional costs for consumer: 5 € - 25 € Additional power consumption: 0 W - 4 W.
Consumer acceptance questions: Willingness to accept this solution if additional costs are balanced by savings via energy bill.

Calculation (additional costs: 15 €): 900 kWh/a at 0,20 €/kWh = 180,00 €/a energy costs. Amortisation in 5 years: 3 €/a saving Reduction of energy costs by ~ 2 % needed.
Strategies for success: Increasing environmental awareness and practise.

Figure 3.7-5 Example of a change in operation probability for synergy scenario 1-1



Source: University of Bonn

3.7.6.2 Applying flexibility on appliance power demand

Id and title: 2-1 Power line triggered operation
Description: Signals via e.g. power line may be used to communicate about the availability of surplus power on the grid. This can be detected by the room air conditioner and transferred into action. Action may be an immediate start as far as the device is in a start time delay or in a special "ready for operation" mode. Alternatively other means like frequency sensing might be used as the frequency is changing with total load on the grid and high availability of energy will increase the load and thus the frequency.
Strategy for appliance control: Room air conditioner start is anticipated when the appliance is in start time delay or special "ready for operation" mode. To avoid overload by too many machines starting the same time, the algorithm used to define the start time shall have a random factor including shifting the decision by up to 1 hour in advance.
Change in power demand curve of a single appliance: No change.

Change in day curve (of power demand of all appliances):

The necessary technical impacts might mostly be implemented to higher standard types like single split or multi split air conditioners, these made up about 64% of all appliances in the 1990 stock and about 80% in the 2000 stock [VHK 05]. The product life of an average air conditioner is estimated to be 12 years [VHK 05], the average growth rate per year is estimated to be 15% [VHK 05]. Therefore it might be fair to assume that in the near future (perhaps until 2010) about 50% of the appliances in stock could have the necessary intelligence. Reliable data about how many consumers run their air conditioner in a timer or start time delay mode is unknown, therefore it can only be estimated that perhaps more consumers will use the comfortable start time delay mode than switching the appliance on and off by hand. But if it is estimated that about 20% of the consumers who own a device with the necessary technology run their appliance in start time delay mode, this will lead to the estimation that about 10% of all appliances will cause a shift in the operation by seconds and minutes to an earlier start (to be verified by WP 5). As far as the appliance is in start time delay mode, an anticipation of the operation will allow to increase the operation probability short term, followed by a drop of the probability (Figure 3.7-6).

Consumer benefits and drawbacks:

Enhanced use of renewable energy and CHP. Possible irritation of consumers when machine starts at any time.

Demand management benefits and drawbacks:

Usage depends on the acceptance of a start time delay operation by the consumer.

Impact on appliance design and service provided: (additional costs, limitations, additional energy consumption):

Additional costs for consumer (start time delay or the like): 10 € - 50 €.

Additional power consumption (in start time delay mode): > 0 W - 4 W

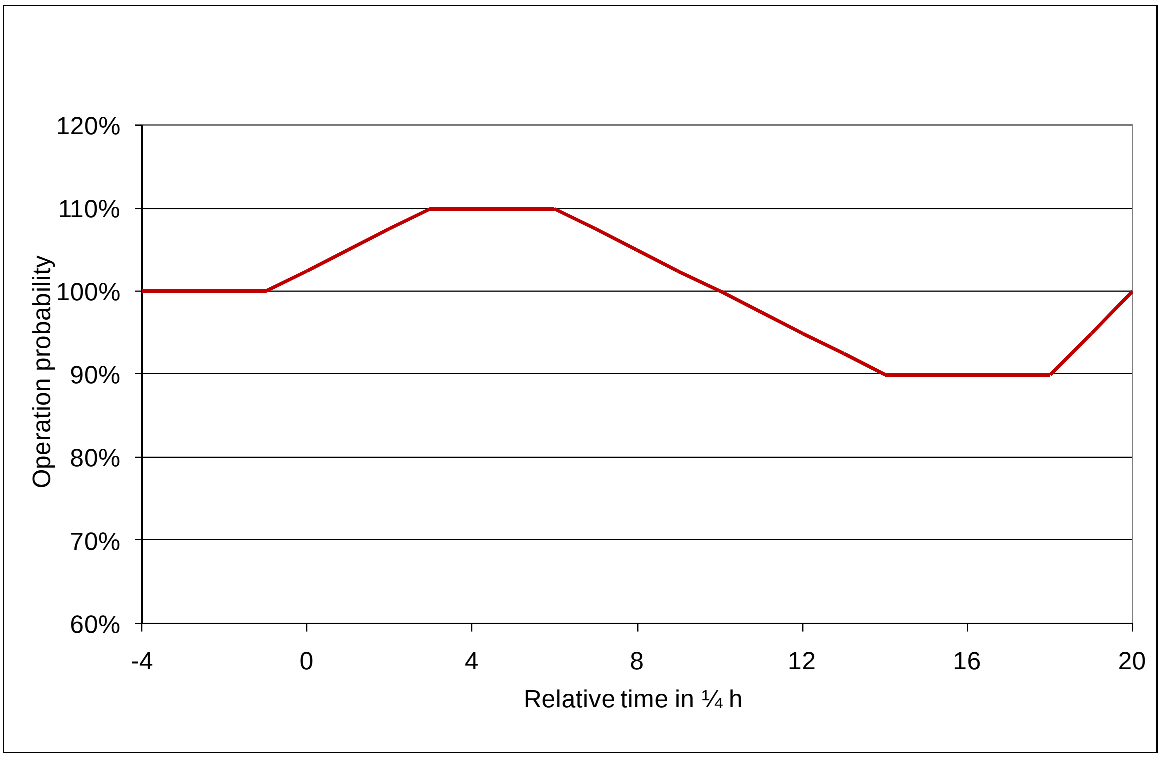
Consumer acceptance questions:

Willingness to accept this solution if additional costs are balanced by savings via energy bill.
Calculation (additional costs: 30 €):
900 kWh/a at 0,20 €/kWh = 180,00 €/a energy costs.
Amortisation in 5 years: ~ 6,00 €/a saving
Reduction of energy costs by ~3% needed.

Strategies for success:

Define business model in which energy utilities sponsor the implementation of these “Power line triggered” modules.

Figure 3.7-6 *Example of a change in operation probability for synergy scenario 2-1*



Source: *University of Bonn*

Id and title: 2-2 Internal energy manager agent
Description: Triggered by an external signal about shortage of energy the room air conditioner may change its operation: - shift the start of the cooling phase to an earlier start - interrupt the cooling phase for a certain time - reduce the power demand by choosing a higher desired room temperature
Strategy for appliance control: The external signal should include information on the shortage of energy of energy and how long it may last. Room air conditioners being in an appropriate state will then react by their own intelligence to find the appropriate answer.
Change in power demand curve of single appliance: Various. May shift cooling time between seconds and minutes.
Change in day curve (of power demand of all appliances): Similar to scenario 2-1 it is estimated that 10% of the operations may be used in the described mode and allow to shift the operation by seconds and minutes. Assuming a shift of ¼ hour (at maximum 1 h) the operation probability will be changed as shown in Figure 3.7-7.
Consumer benefits and drawbacks: Enhanced use of renewable energy and CHP. Short term breaks and temperature rise of 1°C or 2°C may not be recognised at all. Too long breaks during the cooling period will cause a reduction in the comfort of the consumer.

Demand management benefits and drawbacks:

Influence on power demand by short term action. Effect will depend on daytime, season and penetration of energy management agents in room air conditioners.

Impact on appliance design and service provided: (additional costs, limitations, additional energy consumption):

Internal energy manager agent has to be included in the electronic unit of the appliance.
A harmonised signal of power shortage is needed.
Additional costs for consumer (signal recognition plus energy agent): 10 € - 100 €.
Additional power consumption (during operation): > 0 W - 4 W.

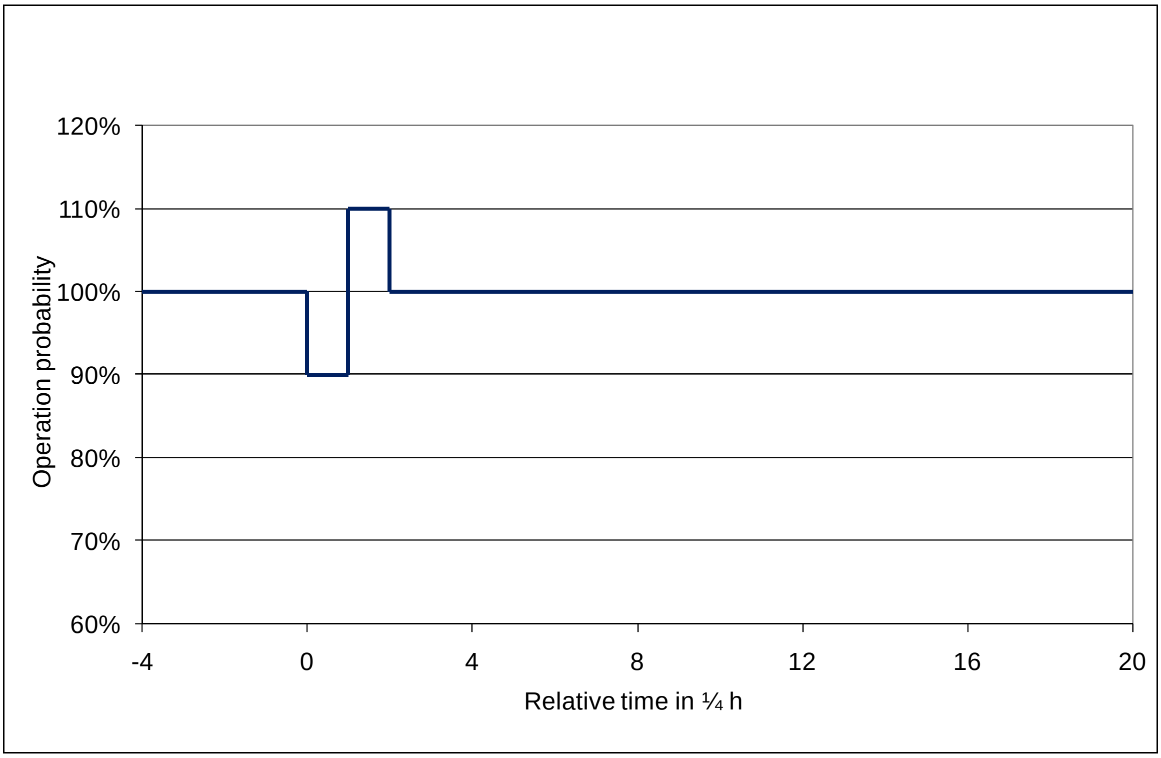
Consumer acceptance questions:

Willingness to accept this solution if additional costs are balanced by savings via energy bill.
Calculation (additional costs: 55 €):
900 kWh/a at 0,20 €/kWh = 180,00 €/a energy costs.
Amortisation in 5 years: ~ 11,00 €/a saving
Reduction of energy costs by ~ 6 % needed.

Strategies for success:

Define harmonised signal for shortage of power (CENELEC).
Define business design in which energy utilities sponsor the implementation of the “internal energy management agent” modules.

Figure 3.7-7 Example of a change in operation probability for synergy scenario 2-2



Source: University of Bonn

3.7.6.3 Managing the power on the grid

Id and title:

3-1 Energy demand manager

Description:

The energy demand manager tries to harmonise the available power on the grid coming from conventional and renewable resources with the demand. Therefore the room air conditioner when started is set in a remote control mode which allows the energy demand manager to decide about the start of the appliance within a predefined time interval. The energy demand manager is informed about the actual room air temperature or at least the expected energy demand.

Strategy for appliance control:

Knowing the demand for the next hours the energy demand manager tries to use as much renewable energy and CHP as possible and optimises the overall costs.

Change in power demand curve of single appliance:

No change.

Change in day curve (of power demand of all appliances):

Following the estimation made in 1-1, 2-1 and 2-2 it is assumed that at maximum 10% of the operations might be shifted according to any of the probability curves as shown for the synergy scenarios 1-1, 2-1 or 2-2 in Figure 3.7-8 (managed by the energy demand manager) As the consumer is not involved in the operation of the device any more, the probability curve of scenario 1-1 (advanced start) stands for a second option of scenario 2-2..

Consumer benefits and drawbacks:

Enhanced use of renewable energy and CHP. Cost benefits must be transferred to the consumer. Consumer remains in the position to decide whether he wants to use this option or not.

Demand management benefits and drawbacks:

Influence on power demand by medium term action. Influence only on those room air conditioners which are 'online'.

Impact on appliance design and service provided: (additional costs, limitations, additional energy consumption):

Bidirectional communication needed. Additional switch needed to signal 'remote operation accepted'.
A harmonised communication protocol is needed.
Additional costs for consumer (communication module via power line): 30 € - 130 €.
Additional power consumption (during waiting for operation): > 0 W - 4 W.

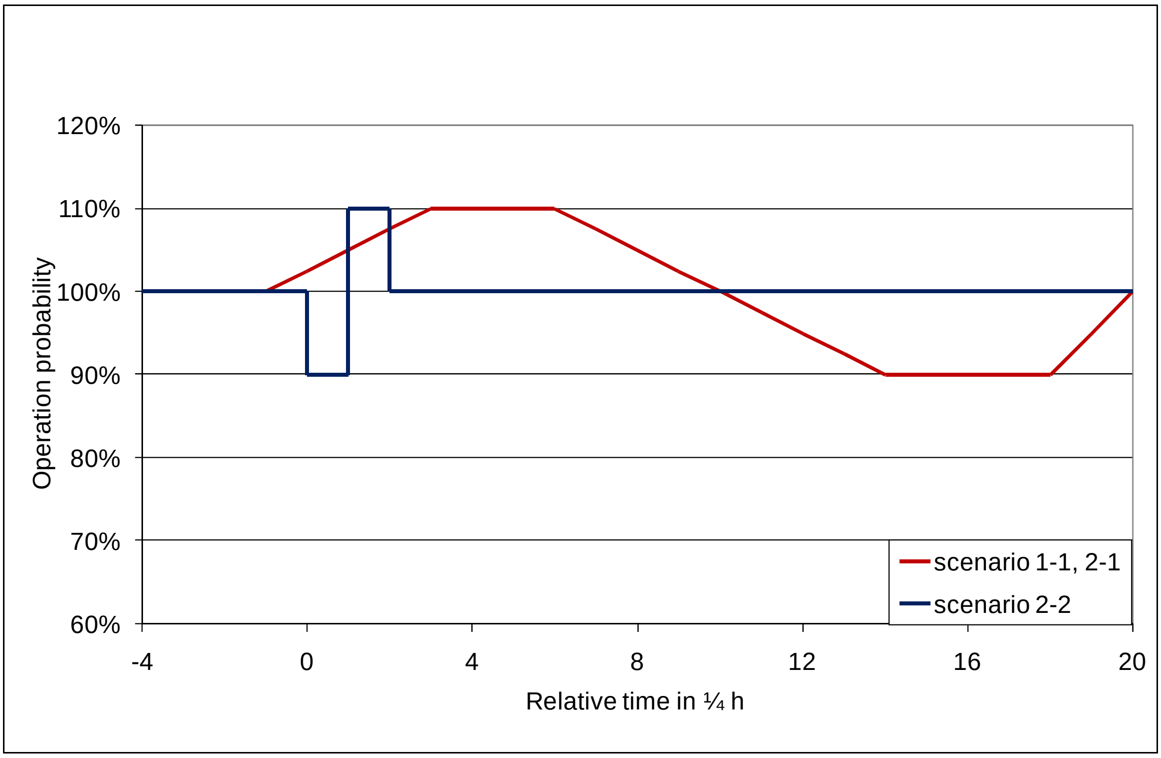
Consumer acceptance questions:

Willingness to accept this solution if additional costs are balanced by savings via energy bill.
Calculation (additional costs: 80 €):
900 kWh/a at 0,20 €/kWh = 180 €/a energy costs
Amortisation in 5 years: 16 €/a saving
Reduction of energy costs by ~ 9% needed.

Strategies for success:

Define harmonised communication protocol (CENELEC).
Define business design in which savings balance the additional costs for the appliance.

Figure 3.7-8 Change in operation probability for synergy scenarios 3-1 (any of 1-1, 2-1, 2-2)



Source: University of Bonn

3.7.6.4 Using energy storage capacity and other technologies

Id and title: 4-1 Implementing cold storage
Description: On the availability of energy the room air conditioner starts operating although there is no need for cooling. The produced cold is stored in a heat exchanger. Most simple would be freezing water to ice in a special water tank within the air conditioner, higher efficiency might be achieved by using special heat exchange materials or other technology like drying of Lithium Chloride [WIS 07]. As soon as air cooling is desired a ventilator transports warm outdoor air via the cool surface of the ice or heat exchanging material - similar to adiabatic cooling.
Strategy for appliance control: The air conditioner start is anticipated when the appliance is in start time delay mode. To avoid overload by too many appliances starting the same time, the algorithm used to define the start time shall have a random factor including shifting the decision by up to two hours in advance or depending on heat exchanging material even longer.
Change in power demand curve of single appliance: No change.
Change in day curve (of power demand of all appliances): May allow shifting of operations about two hours in advance when using water and ice and even longer periods if other heat exchanging materials are implemented. Shifting volume depends on availability of air conditioners with storage capacity.

Consumer benefits and drawbacks:

Enhanced use of renewable energy and CHP. But probably only accepted by convinced environmentalists or by people who own their own power or heat generation unit if the resource use is cheaper than the one of other sources.

Demand management benefits and drawbacks:

Consumer behaviour is unpredictable. Longer experience may allow forecasting consumer behaviour.

Impact on appliance design and service provided: (additional costs, limitations, additional energy consumption):

Additional heat exchanger and ventilator have to be applied. The bulk of the appliance might be of insulating material. Start timer including frequency sensing means needed.

Additional costs for start timer: 8 € - 12 €

Costs for heat exchanger and ventilator: 80 € - 120 €

Consumer acceptance questions:

Willingness to accept this solution if additional costs are balanced by savings via energy bill.
Calculation (additional costs: 100 €):
900 kWh/a at 0,20 €/kWh = 180,00 €/a energy costs.
Amortisation in 5 years: ~ 20,00 €/a saving
Reduction of energy costs by ~ 11 % needed.

Strategies for success:

Define business model where energy utilities sponsor the implementation of energy storing material.

Id and title:

4-2 Inverter technology

Description:

Applying an inverter technology to the device which controls the room temperature and humidity continually. The desired room temperature is reached quicker because the power is over drift during the first cooling phase, which means that for a short time the real power demand of the device is higher than the nominal power demand. After the desired room temperature is reached, the air conditioner keeps the temperature in a very close range by comparing the target temperature with the actual room temperature. Devices with implemented inverter technology are able to adapt their power demand to the actual cooling demand which leads to a decrease of energy consumption.

Strategy for appliance control:

The appliance controls the room temperature and humidity continually and starts operating depending on the changes more often than a conventional appliance. The start of the operation is shifted to a time when renewable energy and CHP is available. The appliance might be started by the consumer himself (1-1), the operation might be power line triggered (2-1) or started by an internal energy manager agent (2-2) or an external energy demand manager (3-1).

Change in power demand curve of single appliance:

After high energy consumption (~ 10% more than conventional technology) at the beginning of the operation the appliance consumes less electricity for keeping the room temperature within a narrow range (Figure 3.7-9).

Change in day curve:

Allows shifting operations at any time to an earlier start, volume depending on penetration of inverter technology.

Consumer benefits and drawbacks:

Room climate comfort is improved due to more constant temperature and humidity and to quicker achievement of the desired temperature. Higher price of appliance will be paid back by less expenditure on electricity.

Demand management benefits and drawbacks:

Inverter technology is believed to achieve average efficiency gains of 10-12% [VHK 05] although gains up to 40% in specific classes have been reported [STE 07].

Impact on appliance design and service provided: (additional costs, limitations, additional energy consumption):

Room air conditioner has to be provided with inverter technology. Inverter technology appliances are already on sale but penetration rate is unknown.
Additional costs for consumer: 140 € - 160 €

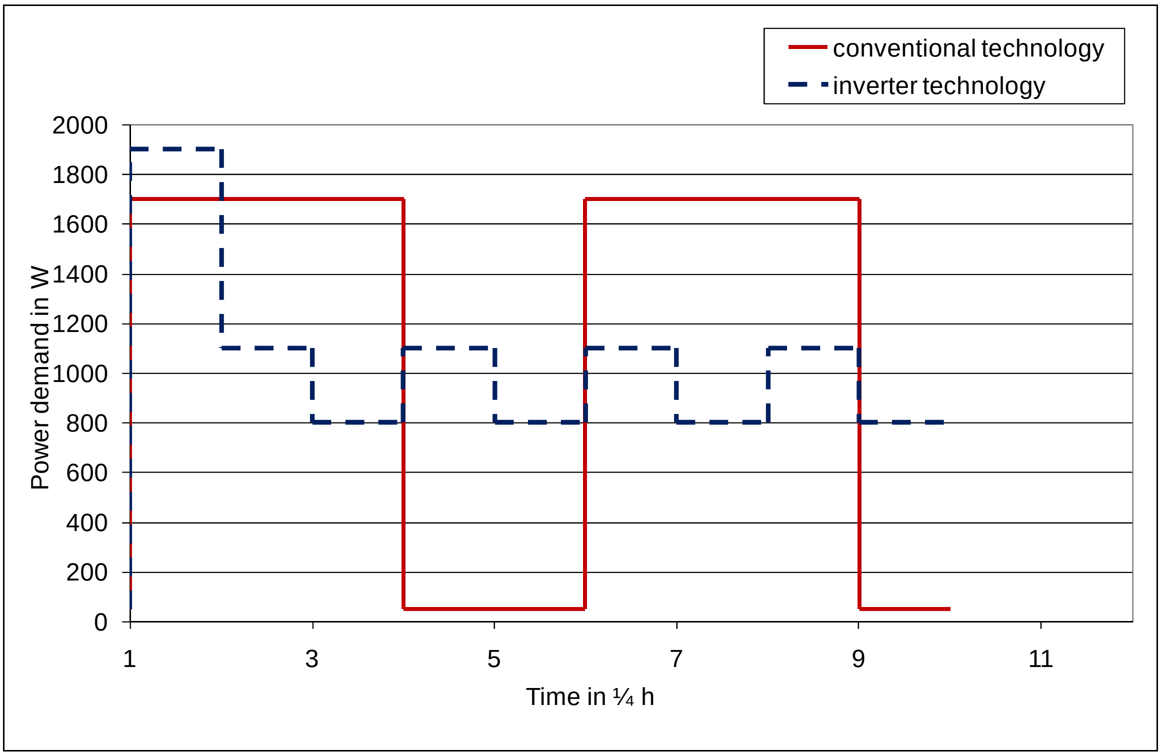
Consumer acceptance questions:

Inverter technology appliances are about 10-20% more expensive than usual air conditioners. Consumers might appreciate higher comfort and will perhaps accept also longer terms of amortisation. Longer experience may allow forecasting of consumer behaviour.
Calculation (additional costs: 150 €):
900 kWh/a at 0,20 €/kWh = 180,00 €/a energy costs
Amortisation in 5 years: ~30,00 €/a saving
Reduction of energy costs by ~17% needed

Strategies for success:

Define business model where energy utilities sponsor the implementation of inverter technology. Make inverter technology visible on energy label. Improve consumer's information about inverter technology.

Figure 3.7-9 General pattern of a power demand curve of an inverter type air conditioner in ¼ hour steps



Source: University of Bonn

Id and title:

4-3 Using cool outdoor air

Description:

The room air conditioner controls the indoor temperature and starts automatically when the temperature rises higher than a defined temperature. Instead of starting the cooling operation immediately, the appliance first checks the outdoor temperature. If the outdoor temperature is lower than the indoor temperature a ventilator starts shovelling the cooler outdoor air into the room. If the outdoor temperature rises or the indoor temperature doesn't decrease within a defined time the ventilator stops and the air conditioner starts working. Especially during the night – when it is cool outside and stuffy inside the room – this option is more comfortable for the consumer than having to get up for opening the window in the middle of the night.

Strategy for appliance control:

Additional sensor for measuring the outdoor temperature is needed.

Change in power demand curve of single appliance:

In times of advantageous conditions energy demand might be reduced by 100%.

Change in day curve (of power demand of all appliances):

May reduce the energy demand especially during night time.

Consumer benefits and drawbacks:

Enhanced use of renewable energy and CHP but possibly only accepted by convinced environmentalists.

Demand management benefits and drawbacks:

Reduced power demand from cooling process in general.

Impact on appliance design and service provided: (additional costs, limitations, additional energy consumption):

Outdoor temperature sensor needed, solar cell and battery needed.
Additional costs for consumer: 50 € - 70 €

Consumer acceptance questions:

Willingness to accept this solution if additional costs are balanced by savings via energy bill.
Calculation (additional costs: 60 €):
900 kWh/a at 0,20 € /kWh = 180,00 €/a energy costs
Amortisation in 5 years: 12,00 €/a saving
Reduction of energy costs by ~ 7% needed.

Strategies for success:

Define business design in which savings balance the additional costs for the appliance.

Id and title:

4-4 Implementing absorber technology

Description:

Instead of running the cooling cycle by electrical energy, absorber cooling technology can be used. This cooling circle is driven by heat from an external source which can be provided by solar collectors or by a combined heat and power unit. Absorber cooling technology allows enhanced usage of those energies during times when the heat is produced but not needed for heating.

Strategy for appliance control:

No.

Change in power demand curve of single appliance:

Reduction of electricity demand by 95% (5 % needed for electronic control and ventilator).

Change in day curve (of power demand of all appliances):

Reduction of electricity demand by 95% at any time.

Consumer benefits and drawbacks:

The operation of the room air conditioner is nearly for free as long as the needed heat can be taken from already existing solar collectors or combined heat and power units which are traditionally used to deliver warm water and electricity all year and warmth during winter time. The technology operates nearly noiseless which avoids disturbances especially in sleeping rooms.

Demand management benefits and drawbacks:

Almost no electrical energy needed. During summertime when air cooling is needed solar collectors and combined heat and power units are often over dimensioned. The unneeded capacities can be used to provide heat for the absorber chiller.

Impact on appliance design and service provided: (additional costs, limitations, additional energy consumption):

Absorber technology is still quite expensive for small appliances. Consumer benefit probably can only be realised if solar collectors or a combined heat and power unit is already available.

Consumer acceptance questions:

Might be accepted by people who can use thermodynamic power from solar collectors and combined heat and power units.

Strategies for success:

Improvement of absorber technology also for smaller appliances. Increase application of solar collectors and combined heat and power units in households.

3.8 Electric water heater

In European households the availability of hot water at any time is a widely spread standard and appreciated by all consumers. Hot water is drinking water, which is heated up to temperatures up to 95°C by water heating appliances [THKT 05/06]. The standard classification Production Comunautaire (PRODCOM) assesses 3 different categories for water heaters: electric instantaneous water heaters, electric water heaters with storage and non-electric water heaters differentiated in instantaneous and storage [VHK 06].

3.8.1 Technical description with regard to the use of energy

Hot water in different rooms of a dwelling can be provided by centralised or decentralised heating systems. In centralised systems the water is heated in one device and distributed to the different places of tapping points. A huge disadvantage of centralised systems is the loss of energy due to large distribution distances despite a thorough insulation of the pipe system. A suitable solution for central water heating is the electric storage water heater. As there is no need for connecting the electric device to a chimney it can be located in a way that avoids long transportation distances. Due to the water storage capacity the water can be heated during times of low total energy demand e.g. during night time [OT]. Decentralised heating means that the water is heated next to the place of demand either by an instantaneous water heater (e.g. in the bathroom) or by appliances with a small water storage tank (e.g. in the kitchen next to the sink) [OT]. So-called closed appliances are made for the supply of several tapping points and have to stand the normal water supply pressures inside the storage tank. Open devices are made for single use only and the pressure inside the storage tank is the atmospheric pressure. [THKT 05/06].

Electric water heaters with storage are heated by an electric resistance heating element which is located near the bottom of the storage. Cold water streams into the insulated tank and is heated up. The warm water ascends from the bottom to the top of the tank and streams via insulated pipes as soon as hot water is required on one of the connected taps [THKT 05/06]. Water heaters with small water storage capacity from 5 to 30 litres can be connected to the usual residential voltage supply and have an electric power of about 2000 W. Water temperatures up to 95°C can be chosen. The time for heating up the water from 10°C to 95°C depends on the volume of water and varies between 2 minutes for 0,5 litres and 15 minutes for 5 litres [VA 05]. For larger volumes of water, tanks of up to 400 litres are available for residential use. The devices can be connected to high voltage current or to the usual residential voltage current. The electric power mostly varies from 2000 W to 6000 W. Water temperatures of up to 85°C can be chosen. The heating time depends on the electric power of the device and the volume of water. Heating 50 litres of water from 10°C up to 60°C with an electric power of 2000 W takes about 1 hour 45 minutes (=3,5 kWh). The heating of 400 litres of water from 10°C up to 60°C with an electric power of 2000 W takes about 17 hours (=34 kWh) while it takes only about 6 hours when heated by an electric power of 6000 W. In addition to the power demand for heating up the water, devices with large storage tanks have a standby energy consumption between about 1,8 and 2,6 kWh within 24 hours to maintain the desired water temperature [VA 05].

Instantaneous water heaters heat up the required volume of water just in the moment of tapping. According to the water flow a pressure difference sensor communicates the energy demand. The streaming water is directly heated by a heater rod made of bare wire [THKT 05/06]. Instantaneous water heaters use high voltage current and usually vary between 18 and 27 kW of power demand. A water temperature in a range of mostly 30°C to 60°C can be chosen [VA 05].

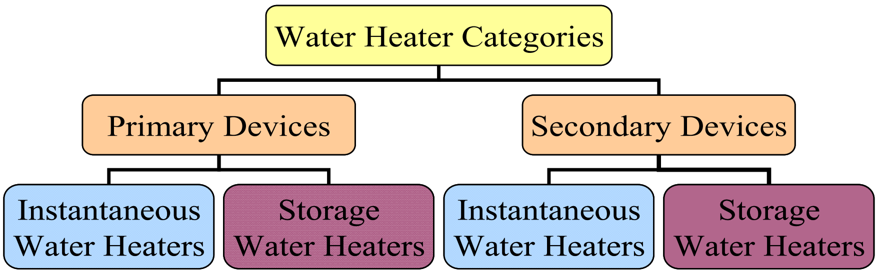
3.8.2 Penetration in Europe

Concerning the stock data of water heating appliances only little information is available. The Business Research Group Consult (BRGC) has prepared a report on the market and stock data. BRGC has developed a methodology to estimate and elaborate parameters which are far unknown. This leads to a more approximate approach than with e.g. white goods, where parameters can be assessed at the point of sales or by questionnaires [VHK 06]. As already described water heating appliances can be divided into two main groups: instantaneous water heating devices which heat the water on demand and storage water heating devices which preheat and store the water in a tank. To describe the market and stock data of water heating BRG Consult distinguishes also between another two main groups [VHK 06]:

- Primary water heating to describe appliances that provide the main supply of sanitary hot water to the dwelling.
- Secondary water heating to describe water heaters that have a supplementary role (usually in supplying hot water to just one room or location in dwellings that already have a primary water heating appliance).

An overview of these categories is given in Figure 3.8-1.

Figure 3.8-1 Overview of water heater categories

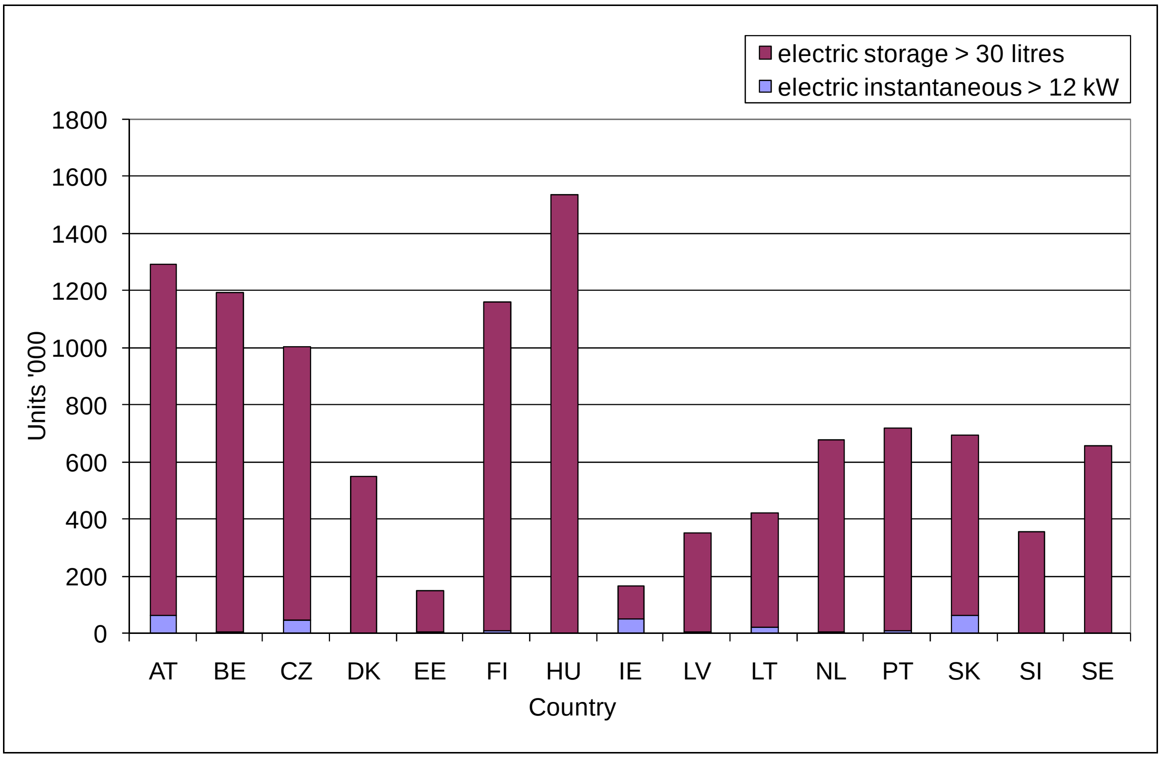


Source: University of Bonn

The total EU domestic water heater park has been calculated by BRG Consult in 2004 for 22 countries which are the EU member countries except Cyprus, Luxembourg, Malta, Bulgaria and Romania. For 2004 a total of 236 million water heaters has been calculated of which 2,6 million (1,5% of primary water heaters) were based on district heating, 87 million units were linked to a central heating boiler (48,9 % of primary water heaters) and 146 million were dedicated water heaters (49,6 % of primary and 100% of secondary water heaters) [VHK 06]. The market penetration of water heaters in the same year was 132,4 % meaning that 32,4 % of EU households owned a secondary water heater, usually a small electric storage water heater for the kitchen (18,5 %), a second electric instantaneous unit (7,9 %) or a small gas-fired instantaneous unit (5,9 %) [VHK 06].

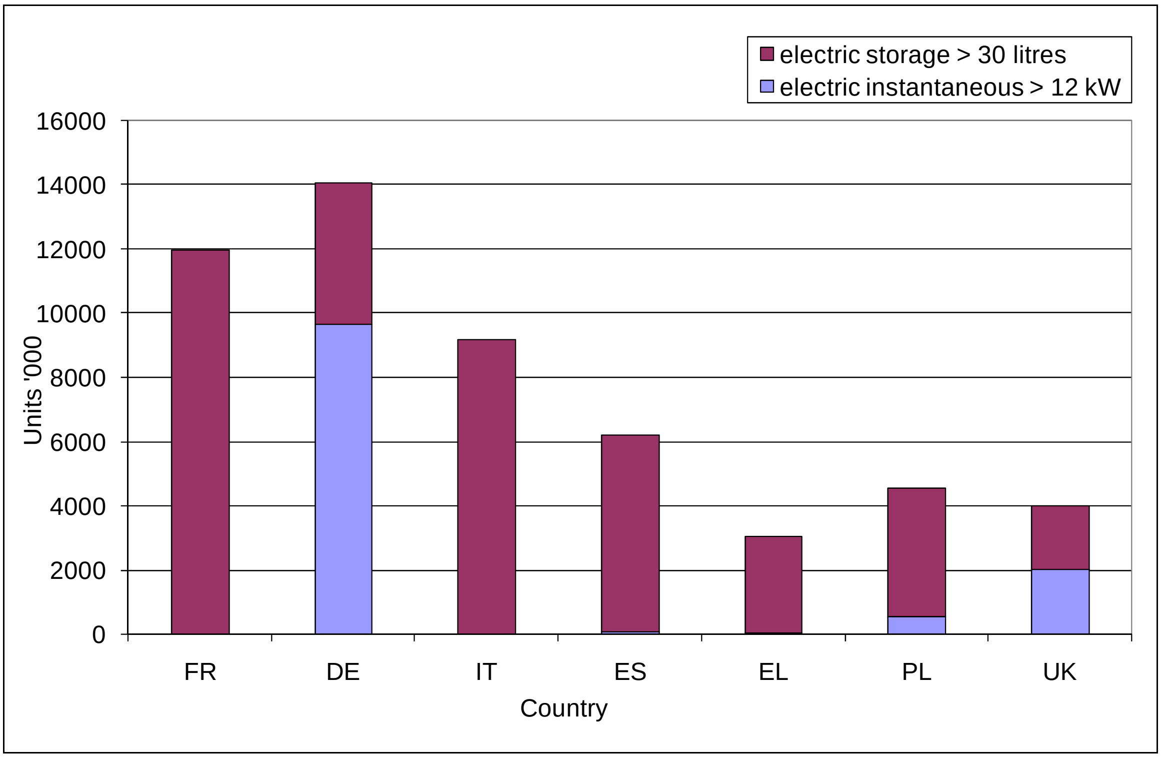
The total number of primary water heating devices in EU-22 is about 178 million units. Within this group electric instantaneous water heaters > 12 kW make about 7,1 %, which is about 12,7 million units. The number of electric storage water heaters with more than 30 litres is about 51,3 million units which is about 28,8% [VHK 06]. As there are large differences concerning the number of appliances in different countries, Figure 3.8-2 shows all countries with less than 2 million units, while Figure 3.8-3 shows all countries with more than 2 million units.

Figure 3.8-2 Primary water heating countries with less than 2 million units



Source: [VHK 06]

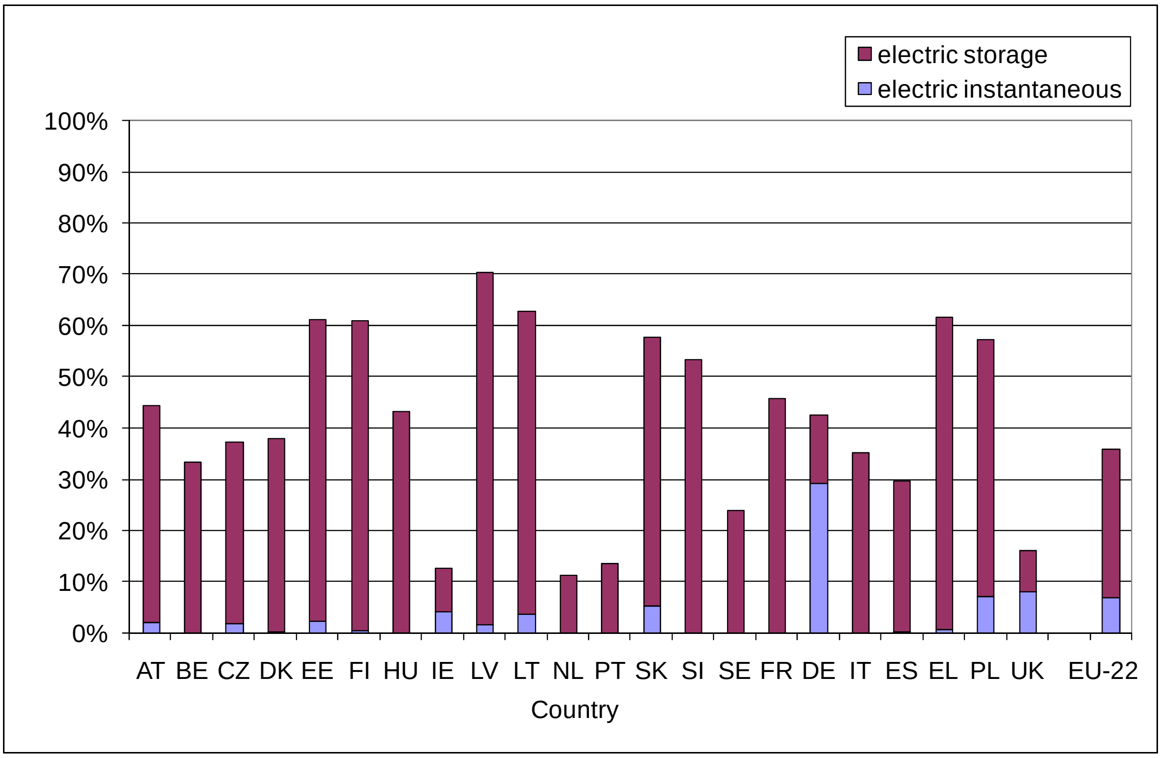
Figure 3.8-3 Primary water heating countries with more than 2 million units



Source: [VHK 06]

The importance of the primary electric water heaters becomes more obvious by regarding their share of all primary water heating devices (Figure 3.8-4).

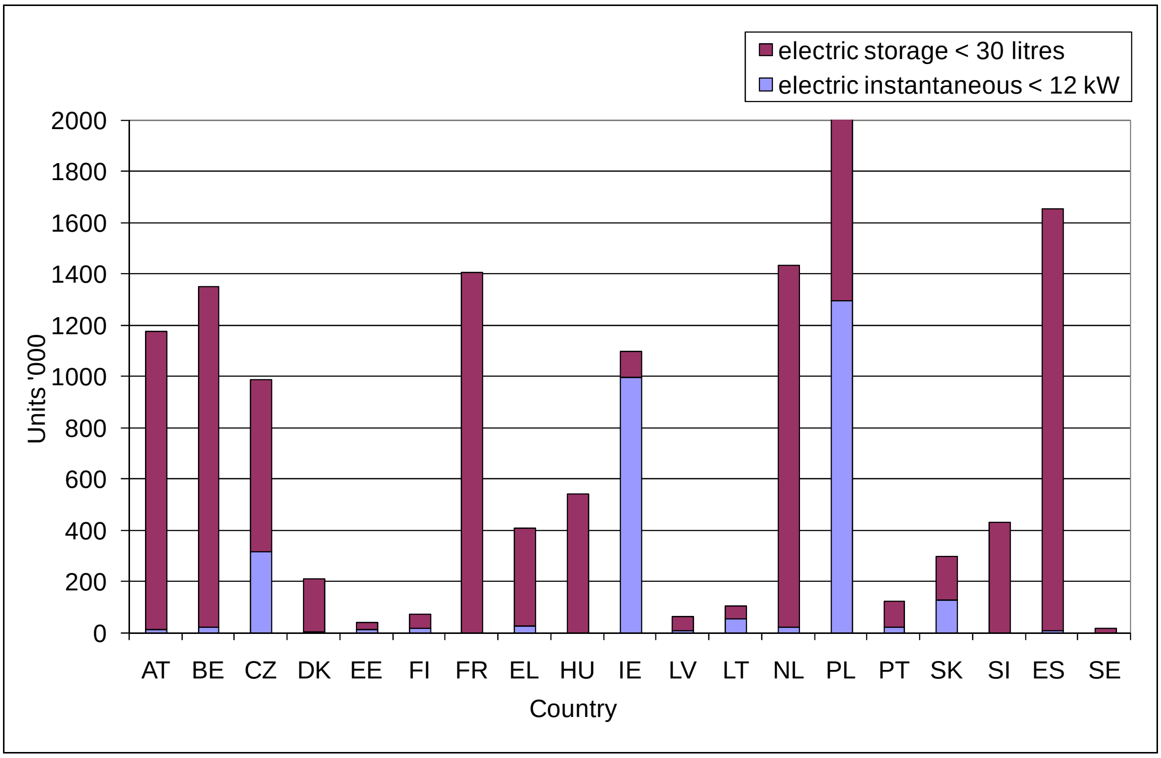
Figure 3.8-4 *Share of primary electric water heaters based on all primary water heating devices in EU-22*



Source: *University of Bonn based on data [VHK 06]*

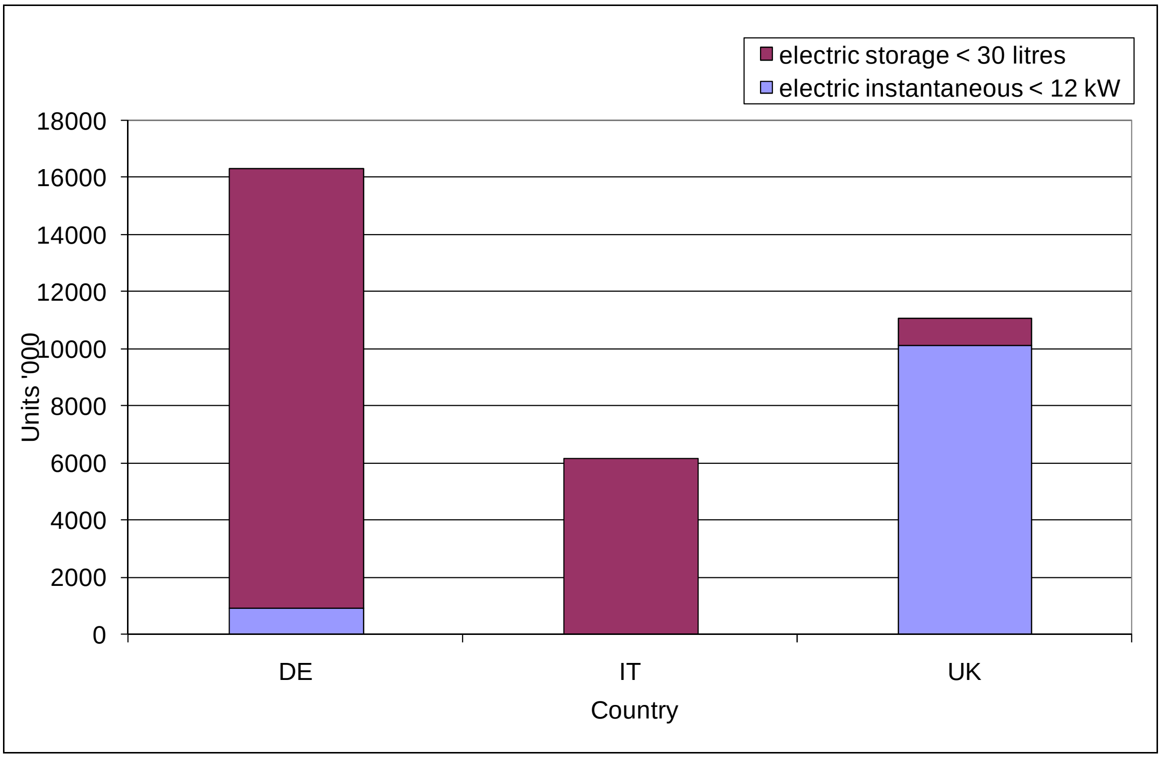
The total number of secondary water heating devices in EU-22 is about 57,7 million units. Secondary water heaters mainly are electric instantaneous heaters with less than 12 kW and storage water heaters with less than 30 litres. [VHK 06]. Within this group electric instantaneous water heaters < 12 kW make about 7,9 %, which is about 14 million units. The number of electric storage water heaters with less than 30 litres is about 33 million units which is about 18,5 % [VHK 06]. As there are large differences concerning the number of appliances in different countries Figure 3.8-5 shows all countries with less than 2 million units while Figure 3.8-6 shows all countries with more than 2 million units.

Figure 3.8-5 Secondary water heating - countries with less than 2 million units



Source: *[VHK 06]*

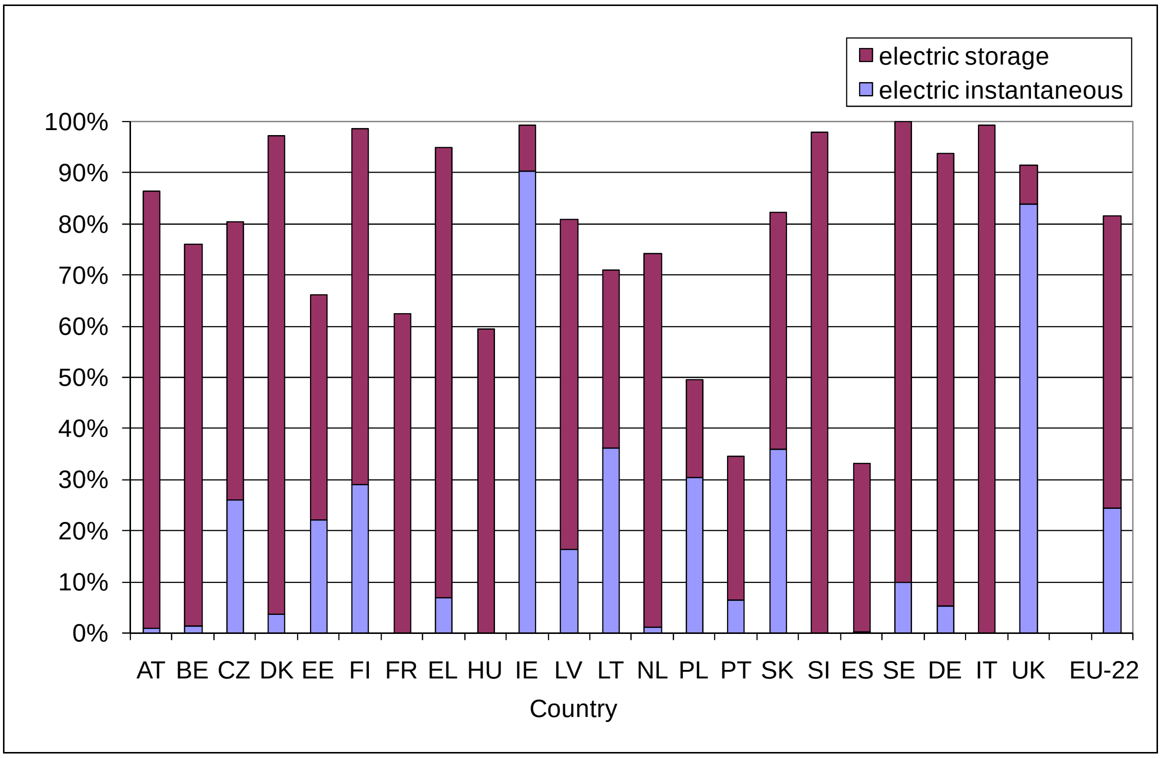
Figure 3.8-6 Secondary water heating - countries with more than 2 million units



Source: *[VHK 06]*

The importance of the secondary electric water heaters becomes more obvious by regarding their share of all secondary water heating devices (Figure 3.8-7).

Figure 3.8-7 *Share of secondary electric water heaters based on all secondary water heating devices in EU-22*



Source: *University of Bonn based on data [VHK 06]*

3.8.3 Consumption of energy in Europe

The European commission has published in its Green Book on Energy Efficiency a total electricity consumption for water heating and storage of 67 TWh in EU-15 in 2003 [GRE 05]. The Energy Efficiency Report [EEF 06] shows a total electricity consumption for electric storage water heaters of 65 TWh in EU-15 for 2003/2004 and estimates the share of electricity consumption for heating water to be about 9% of the total electricity consumption of households. In 2004 a total electricity consumption of the residential sector of 744,7 TWh has been published by Eurostat for EU-25. Calculating with a share of 9 %, the electricity consumption for heating water in EU-25 would be about 67 TWh. Ökotec estimates the share of electricity consumption to be 11 % of the total electricity consumption [OT]. Calculating with a share of 11 %, the consumption in EU-25 would be about 81 TWh. EU-15 members own about 90% of all primary heating appliances and about 85% of all secondary heating appliances of EU-22 [VHK 06]. Therefore the above mentioned figures published for EU-15 cover the main part of the electricity consumption for heating water in Europe.

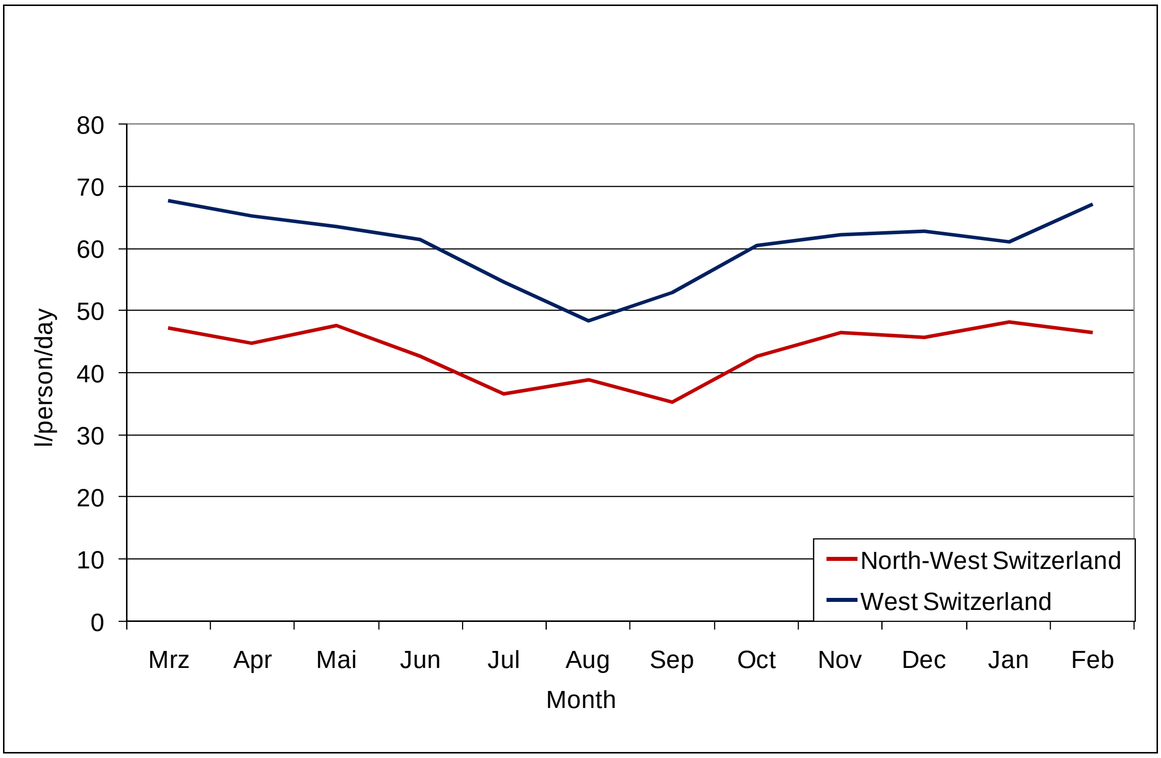
3.8.4 Effects on energy consumption due to consumer usage

Space heating has traditionally been the dominant component of domestic energy usage in cold countries, but in newer houses with improved standards of insulation, water heating exceeds it [EE 03]. The demand of warm water relates to different issues [VHK 06]:

- Family size
- Frequency, duration, timing, etc. of baths or showers
- Typical kitchen use, e.g. hot-fill dishwashers
- Bathroom use, e.g. sinks and bidet

The Bavarian Ministry of Economics publishes an average warm water demand per person of 35 litres per day in Germany [BME]. For Switzerland a consumption of 45 litres per Person has been published in 2007 [ECH 07] and 48,5 litres where published in 1993 [BfK 93]. Although there are reasonable figures for average hot water consumption, averages are a poor guide to usage in individual dwellings [EE 03]. In 1993 16 multi-family houses with in total 939 occupants have been surveyed during 1 year in two Swiss regions. The water temperature measured next to the storage tank was about 60°C all year. Differences up to 33% in consumption of hot water have been recognized, depending on season, weekday and daytime [BfK 93]. Seasonal variations shown in Figure 3.8-8 are caused by changes in consumer behaviour due to different outside temperatures and variations in the cold water temperature of up to 5°C during the year.

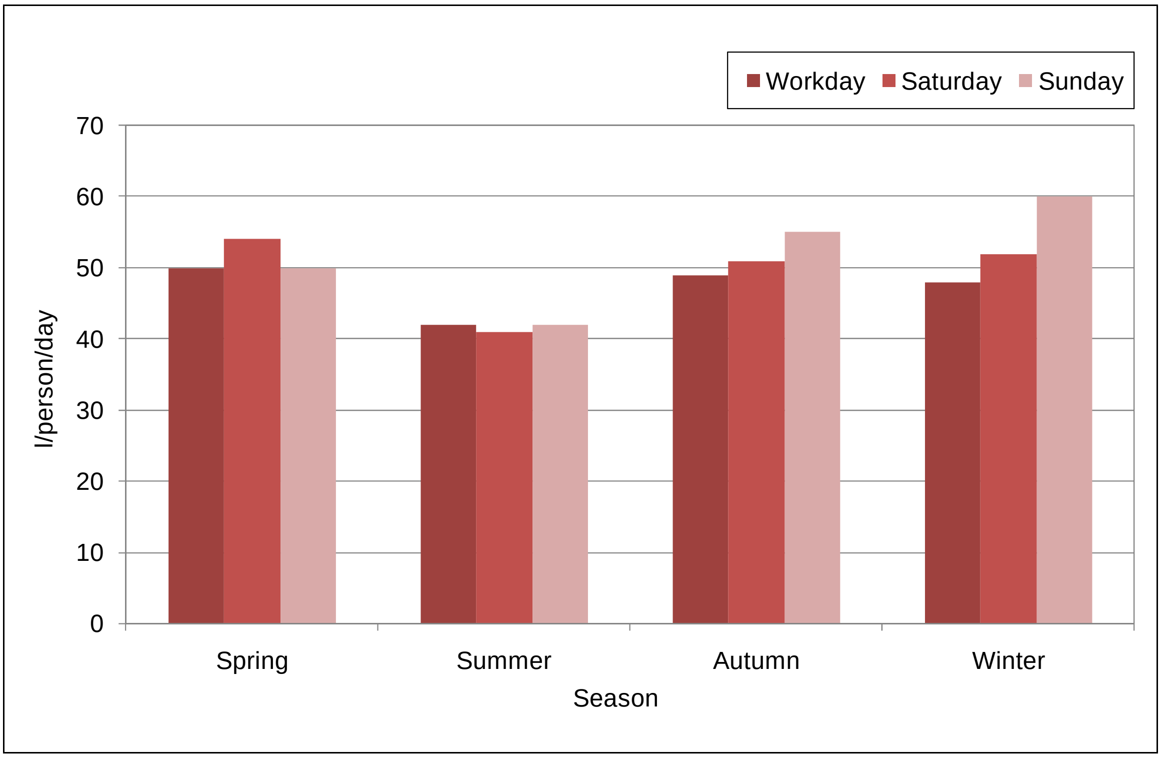
Figure 3.8-8 Yearly hot water consumption



Source: [BfK 93]

The seasonal variation of consumption of 60°C hot water represented by Figure 3.8-9 shows that the consumption during summertime is visibly lower than during colder seasons. On Saturdays and Sundays the hot water consumption per person is obviously higher than on workdays especially in autumn and winter. The average consumption per person is 48,5 l per day. In relation to this figure the scattering of the average water consumption on workdays and Saturdays respectively Sundays is between -14% and + 23% [BfK 93].

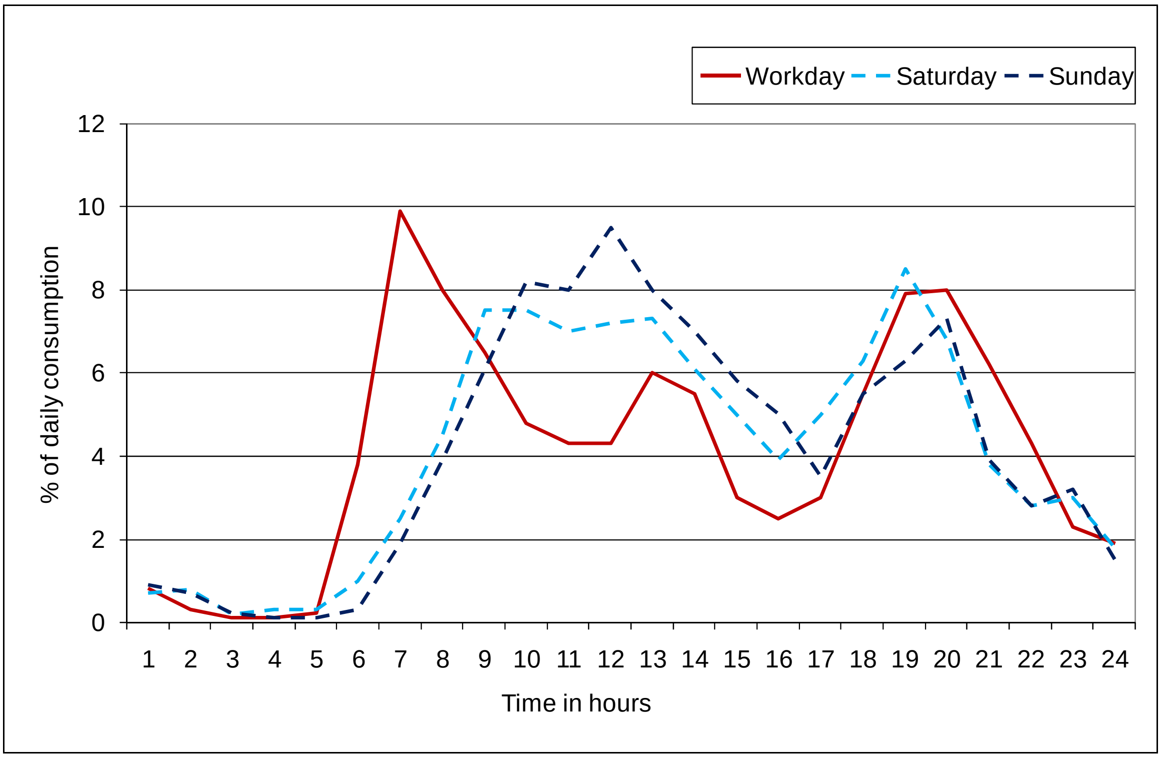
Figure 3.8-9 Daily hot water consumption by season and weekday



Source: [BfK 93]

The change in hot water demand during the day is represented by Figure 3.8-10. The morning peak does only appear from Monday to Friday, on Saturdays and Sundays demand peaks can only be recognized during lunchtime and in the evening [BfK 93].

Figure 3.8-10 Profile of daily hot water consumption



Source: [BfK 93]

3.8.5 Power demand and load curves

Regarding the power demand of large electrical storage water heaters it has to be distinguished between two large groups of devices:

- Storage water heaters which heat during night time and thus operate at times of high availability of power. These devices are controlled by external signals of the electricity provider.
- Storage water heaters which heat continuously also during day time.

Only few information is available about the distribution of the two different types of storage water heaters in European countries. Stiebel Eltron, a producer of water heaters estimates following figures for some European countries (Table 3.8-1).

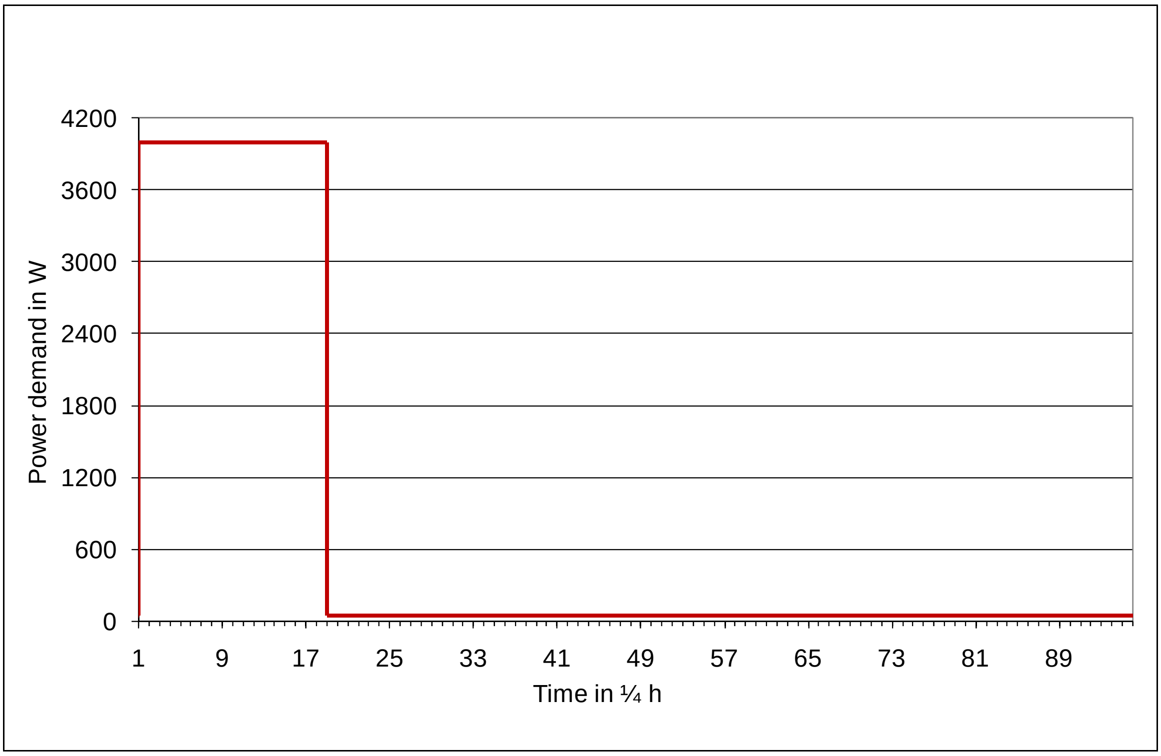
Table 3.8-1 Distribution of storage water heaters – night and day heating

Country	Share of storage water heaters > 50 litres / night heating only	Share of storage water heater > 50 litres / continuous heating
Germany	> 95 %	< 5 %
France	> 90 %	< 10 %
UK	> 50 %	< 50%
Spain	very low	high
Italy	very low	high
Sweden	unknown but both types available (in general only few electric units)	
Czech Republic	low	high
Hungary	low	high
Poland	low	high

Source: [STEL 07]

Water heaters over 50 litres and often much more than 50 litres of storage capacity e.g. in Germany generally operate during night time without maintaining the desired water temperature during day time [LK 07]. A water heater with an electrical capacity of 4 kW will for example need 4,4 hours to heat up 300 litres of water. The power demand curve needs to fit the total energy consumption for heating the respective volume of water. The time it will take to reach the desired temperature depends on the electrical capacity of the device. The device is controlled by an external signal of the electricity supplier Figure 3.8-11.

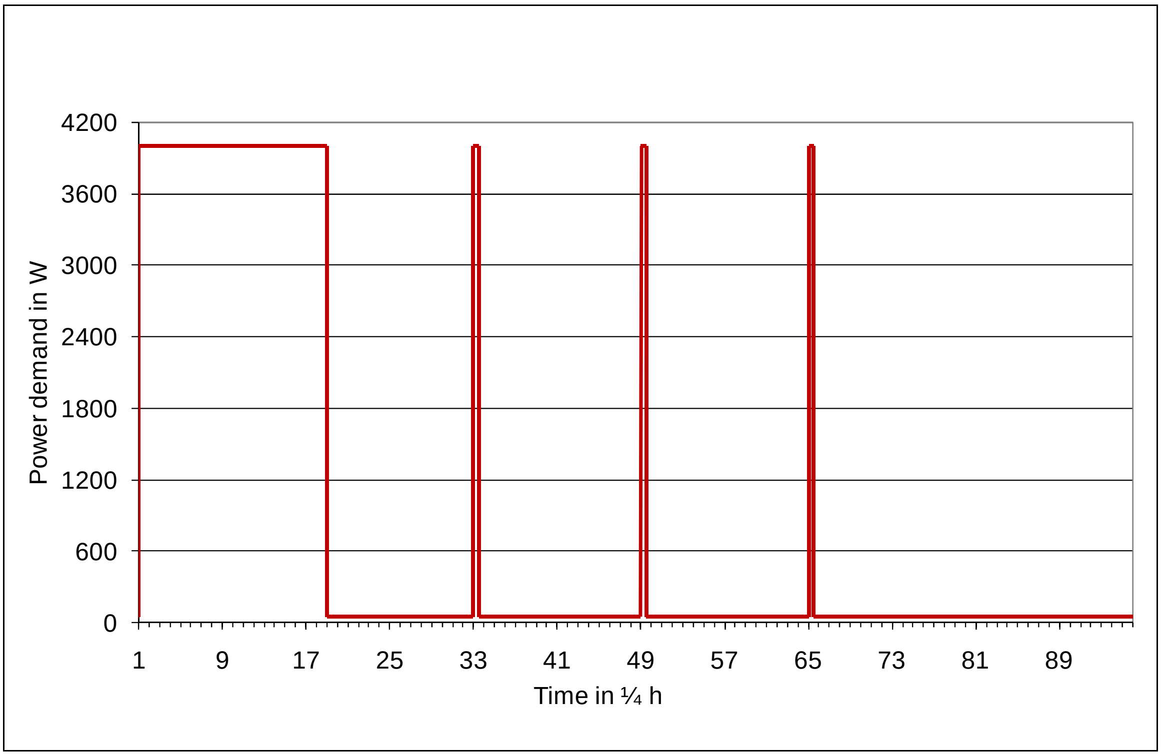
Figure 3.8-11 General pattern of a power demand curve of a storage water heater operating during night time only (for heating 300 l of water by a 4 kW appliance without day maintenance)



Source: University of Bonn

To increase the comfort for the user, some devices (amount unknown) maintain the desired temperature during the day. These water heaters are rather used in small businesses like hairdresser or barber shops than in private households. As explained above the power demand curve needs to fit the total energy consumption depending on the electrical capacity of the device and the amount of water to be heated. Assuming that the water is heated up during the night and the temperature has to be maintained from heating period to heating period the appliance will draw a power demand curve within 24 hours as shown in Figure 3.8-12.

Figure 3.8-12 General pattern of a power demand curve of a storage water heater operating during night time and maintaining the temperature during day time (for heating 300 l of water by a 4 kW)



Source: University of Bonn

The performance of electric storage water heaters over 50 litres which heat continuously during the day is best expressed through their recovery rates [VHK 07] which is the amount of hot water the device can produce in a specified period and with specified temperature raise. The main determinant for the continuous recovery rate is the capacity of the electric heaters. The recovery rate starting with a fully charged storage is of course higher than the continuous recovery rate [VHK 07]. The table below presents some data for typical electric storage water heaters over 50 litres [VHK 07] (Table 3.8-2).

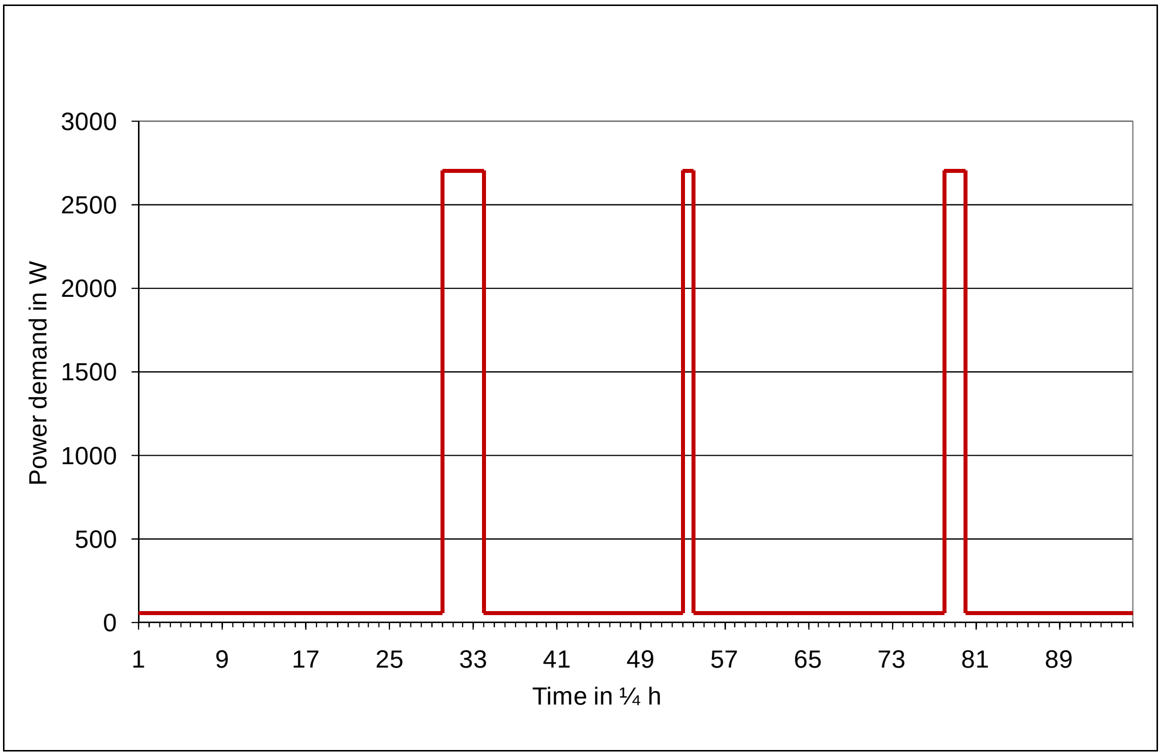
Table 3.8-2 Recovery rates of electric storage water heaters over 50 litres

Volume	l	55	75	115	155	190	250	300	450
Electric power	kW	1,8	1,8	2,7	2,7	2,7	2,7	2,7	2,7
Current	A	8	8	11-13	11-13	11-13	11-13	11-13	11-13
#Elements	-	1	1	2	2	2	2	2	2
Max. set temperature	°C	77	77	77	77	77	77	77	77
30 min. Δ T=28°	l	108	138	211	271	323	413	488	713
60 min. Δ T=28°	l	136	166	253	313	366	456	531	758
90 min. Δ T=28°	l	164	194	295	355	408	498	573	798
120 min. Δ T=28°	l	193	223	338	398	450	540	615	840
Continu Δ T=28°	l/h	56	56	85	85	85	85	85	85
Full Δ T=28°	min	58	80	81	110	135	177	212	319
30 min. Δ T=50°	l	60	77	118	152	181	231	273	399
60 min. Δ T=50°	l	76	93	142	175	205	255	297	423
90 min. Δ T=50°	l	92	109	165	199	228	279	321	447
120 min. Δ T=50°	l	108	125	189	223	252	303	345	471
Continu Δ T=50°	l/h	32	32	47	47	47	47	47	47
Full Δ T=50°	min	104	142	145	196	240	316	379	569

Source: [VHK 07]

Presuming that the average hot water consumption per person and day is about 40 litres, 160 litres of water have to be reheated for a 4 person household (Δ T=28°), which causes an electricity consumption of 5,2 kWh per day. The temperature difference of only 28 °C is based on the assumption that water from the tap has an average temperature of 15 °C. Water which is used for household purposes or personal care has mostly a temperature of more or less 40 °C. Therefore it seems to be reasonable that a hot water temperature of 43 °C is sufficient. Taking the power demand during day time into consideration as presented in Figure 3.8-10 a storage water heater with 2,7 kW of electric power will in general draw the power demand curve shown in Figure 3.8-13.

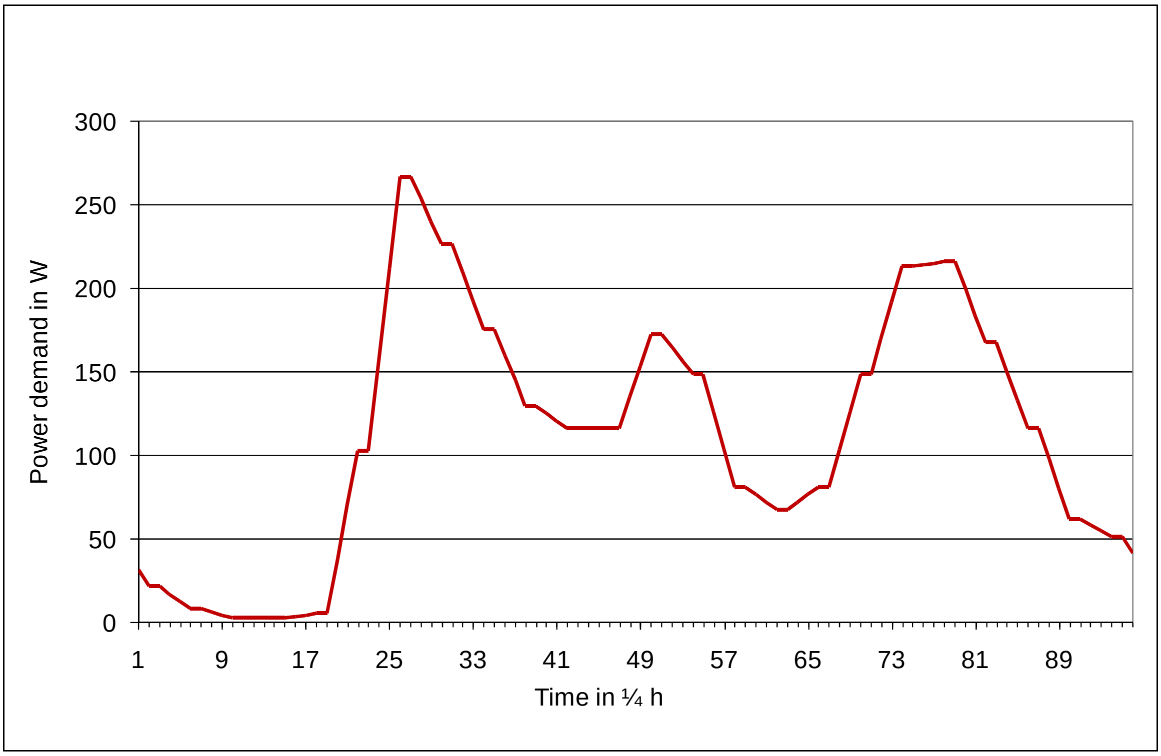
Figure 3.8-13 General pattern of a power demand curve of a storage water heater over 50 litres continual heating (total power consumption 5,2 kWh)



Source: University of Bonn

Using the average behaviour of hot water demand on a work day as presented in Figure 3.8-10 and combining it with the power demand of a continuously heating 2,7 kW device leads to an average power demand curve as shown in Figure 3.8-14.

Figure 3.8-14 General pattern of a daily load curve of a 2,7 kW storage water heater continual heating



Source: University of Bonn

For electric water heaters under 30 litres the recovery rate is often not indicated in product brochures, only the reheat time is published [VHK 07]. In the example in Table 3.8-3 reheat times and standing losses for some smaller electric storage water heaters are shown. The difference between the two types of 10 l and 15 l devices is the standing loss and therefore in their insulation.

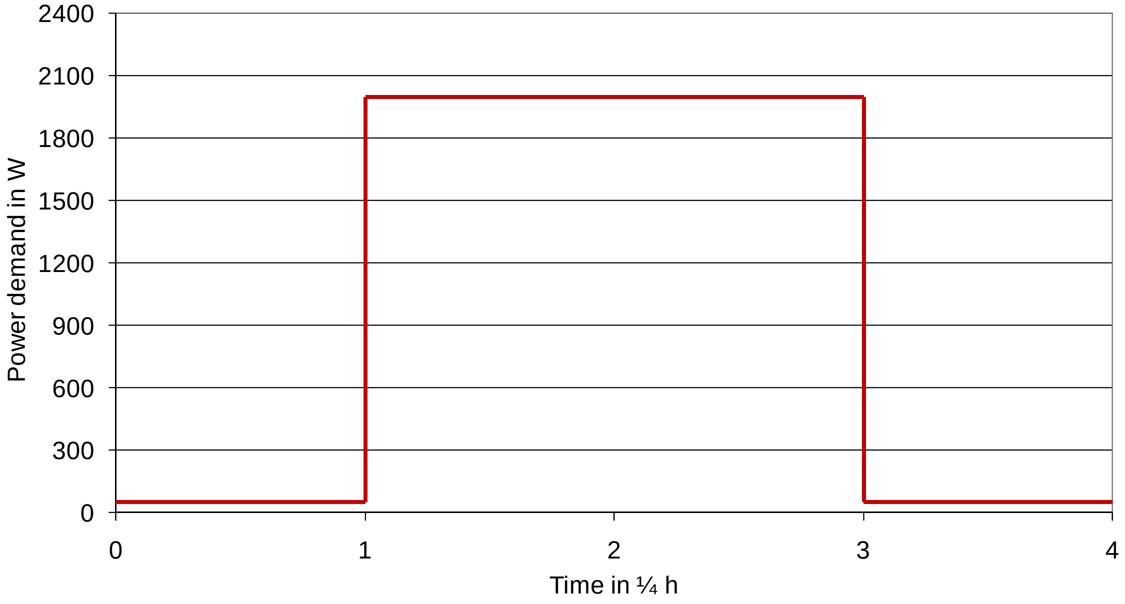
Table 3.8-3 Reheat times of electric storage water heaters under 50 litres

Volume	l	10	10	15	15	30
Reheat time (from 10°C to 60°C with 2 kW element)	min	20	20	30	30	60
Standing losses (kWh per 24 hrs at 65°C)	kWh	0,57	0,43	0,69	0,53	0,69

Source: [VHK 07]

The power demand curve needs to fit the energy consumption for heating up the refilled water and depends on the volume of water and the electrical power of the appliance but as soon as the device starts operating a power demand curve similar to that shown in Figure 3.8-15 is drawn.

Figure 3.8-15 General pattern of a power demand curve of an electric water heater under 30 litres (for heating 15 l of water by a 2 kW appliance)



Source: University of Bonn

Heating 1 litre of water from 10° to 55°C by an instantaneous water heater consumes about 0,04 kWh of electricity, depending on the electric power of the appliance. The higher the capacity of the device the more hot water is available within 1 minute. An example for the availability of hot water in dependence of the energy power is given in Table 3.8-4.

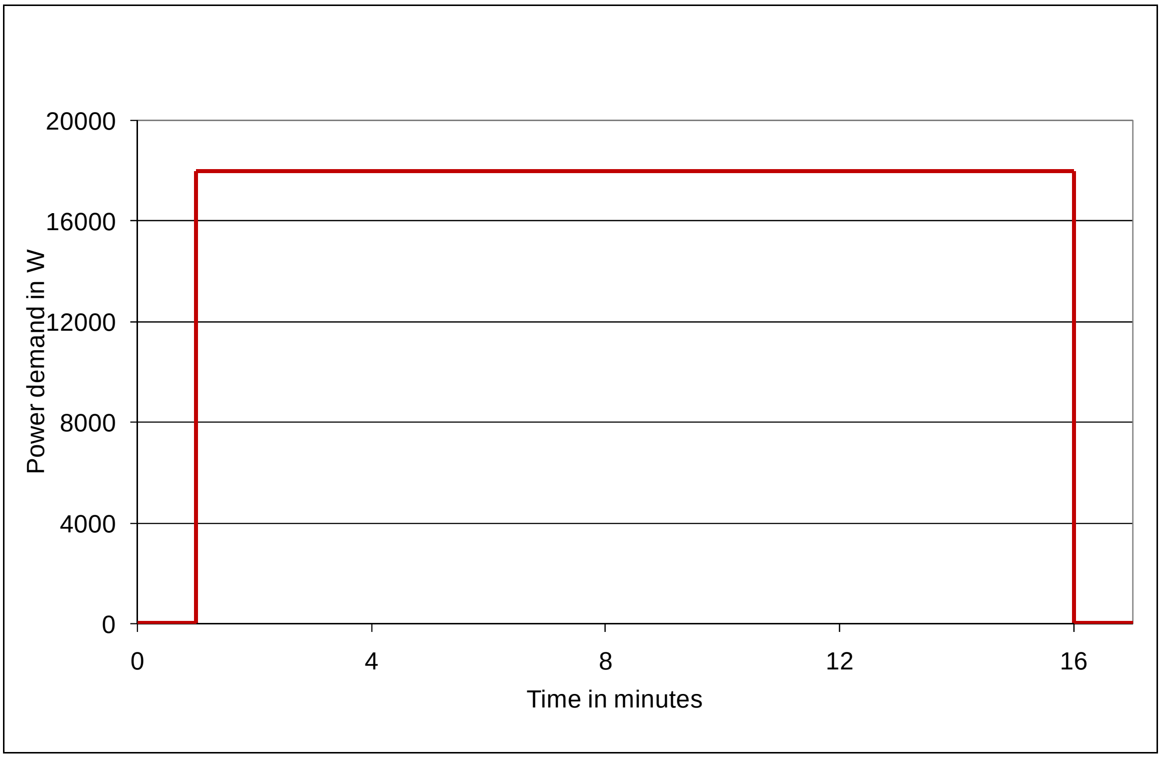
Table 3.8-4 Availability of hot water depending on the electric power of an instantaneous water heater

Partial capacity	**kW**	**6**	**9**	**10,5**	**12**	**13,5**
Water temperature	°C	40	40	40	40	40
Hot water available	l/min	2,7	3,8	4,4	5,1	5,7
Energy consumption	kWh/l	0,037	0,039	0,039	0,039	0,039
Full capacity	**kW**	**12**	**18**	**21**	**24**	**27**
Water temperature	°C	55	55	55	55	55
Hot water available	l/min	3,8	5,8	6,7	7,7	8,8
Energy consumption	kWh/l	0,053	0,052	0,052	0,052	0,051

Source: [VA 05]

The power demand of an instantaneous water heater starts in the moment of hot water tapping. The power demand curve of for example filling a bathtub with 150 litres of 37°C warm water needs to fit the average energy consumption of about 4,5 kWh. Assuming the bathtub is filled by a 18 kW device, the operation time is 15 minutes, which leads to a power demand curve as shown in Figure 3.8-16.

Figure 3.8-16 General pattern of a power demand curve of an instantaneous water heater



Source: University of Bonn

3.8.6 Synergistic potentials

Within this chapter it is tried to explore possible synergies when water heating appliances are somehow linked to sustainable energy sources, like solar or wind energy or heat from CHP processes. For each of these synergistic potentials it is described where the synergy comes from, what are possible constraints and what needs to be fulfilled to gain the potential. It is also estimated how many of the appliances might be affected and how these synergies might affect the power demand curve or the probability of operation of water heating appliances, including a possible recovery phase. As most of these synergies are not yet realised, they are somewhat hypothetical, but based on best engineering practise. If costs are given, they describe the expected additional prize the consumer has to pay for this feature. If ranges are given, the higher value normally corresponds to an implementation of this feature in a first introduction phase, while the lower value estimates how costs may develop at a large scale use. Results of the consumer survey will be added in a supplementary document to this report.

In the following synergy scenarios the complexity of technical adjustments on the device considered increases from level 1 (3.8.6.1) to level 4 (3.8.6.4) steadily. Whereas in level 1 the consumer still has the full control whether to use the described option or not, in level

2 some of that control was handed over to the machine which then reacts to incoming signals. In level 3 the full control is in the hands of an external manager (e.g. electric utility) who decides about when and how often the machine is being switched on or off after it was set in a ready mode by the consumer. Therefore signals are being transmitted in a bidirectional way. In level 4 additional options for storing energy or using other technologies are taken into account.

Due to the large differences in the synergistic potentials of the three main types of water heaters the description of the scenarios is given separately for each device. The devices are assigned to the characters A-C:

A	primary electric storage water heaters with more than 50 litres
B	secondary electric storage water heaters with less than 50 litres
C	primary electric instantaneous water heaters

As the synergy scenarios for primary and secondary electric instantaneous water heaters are similar and in addition most scenarios are improbable for instantaneous devices, only primary electric instantaneous water heaters are taken into consideration in the following.

3.8.6.1 Shifting operation in time

Id and title: 1-1 A: Consumer shifts operation in time
Improbable scenario for this appliance.

Id and title: 1-1 B: Consumer shifts operation in time
Improbable scenario for this appliance.

Id and title: 1-1 C: Consumer shifts operation in time
Description: The consumer receives a signal about the availability of renewable energy or energy from CHP plants. Depending on the signal, he shifts the operation of a instantaneous water heater to run at a time, where in relation to the expected load too much electricity is generated. The information about the availability may be communicated via radio (e.g. weather forecast), internet or remote control signals coming from the electricity provider. The consumer has to make his own decision whether to use this information or not. Available “timer mode” options may be used.
Strategy for appliance control: This synergy option requires the active engagement of the consumer by transferring the information of shortage or surplus of renewable energy into the operation of the appliance. The broadcasting of the information may be randomized or varied in time locally to avoid that too many consumers are acting on the same signal at the same time.
Change in power demand curve of single appliance: No change.

Change in day curve (of power demand of all appliances)

There is only low potential for shifting the operation of an electric instantaneous water heater because it might be inconvenient for the consumer to change his habits and for example shift his demand for warm water to another time of the day. Therefore it is assumed that not more than 1% of the consumers will accept this solution. As the consumer probably has a rough time schedule for his day, a delay of the operation by up to 30 minutes is estimated as the most likely scenario, which will result in a reduction of the operation probability, followed by a recovery period (Figure 3.8-17).

Consumer benefits and drawbacks:

Enhanced use of renewable energy and CHP. But probably only accepted by convinced environmentalists or by people owning their own power or heat generation unit if the resource use is cheaper than the one taken from other sources**.**

Demand management benefits and drawbacks:

Consumer behaviour is unpredictable. Longer experience may allow forecasting consumer behaviour.

Impact on appliance design and service provided: (additional costs, limitations, additional energy consumption):

Delay start timer may be helpful. Additional costs for consumer: 5 € - 25 €.

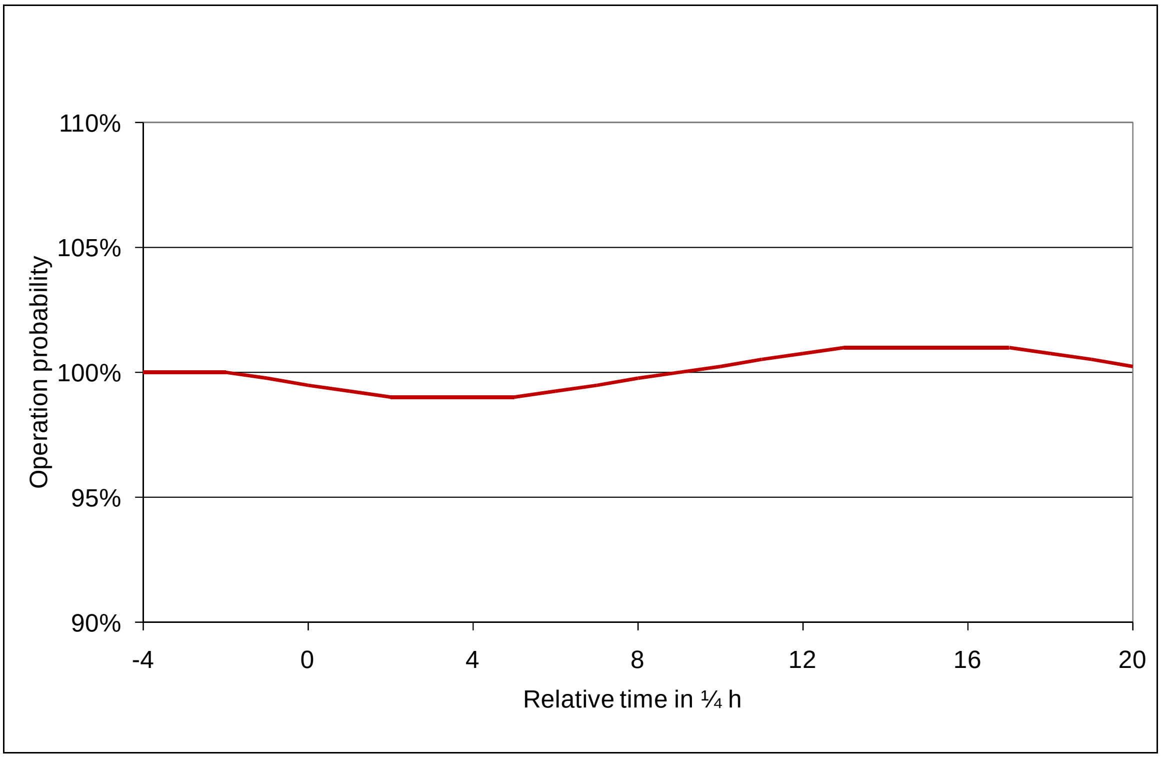
Consumer acceptance questions:

Willingness to accept this solution if additional costs are balanced by savings via energy bill.
Calculation (additional costs: 15 €):
1900 kWh/a at 0,20 €/kWh = 380,00 €/a energy costs.
Amortisation in 5 years: 3 €/a saving
Reduction of energy costs by ~ 1 % needed.

Strategies for success:

Increasing environmental awareness and practise.

Figure 3.8-17 Example of a change in operation probability for synergy scenario 1-1 C



Source: University of Bonn

3.8.6.2 Applying flexibility on appliance power demand

Id and title:

2-1 A: Power line triggered operation

Description:

Signals via e.g. power line may be used to communicate about the shortage of power on the grid. This can be detected by the water heater and transferred into action. Action may be a delayed start as far as the machine is in a start time delay or in a special “ready for operation” mode. Alternatively other means like frequency sensing might be used as the frequency is changing with total load on the grid and low availability of energy will decrease the load and thus the frequency.

Strategy for appliance control:

The water heater start is delayed when the appliance is in start time delay or special “ready for operation” mode. To avoid overload by too many machines recovering at the same time, the algorithm used to define the start time shall have a random factor.

Change in power demand curve of a single appliance:

No change.

Change in day curve (of power demand of all appliances):

The necessary technical impacts might mostly be implemented in higher standard types and new models. The product life of an average storage water heater is estimated to be about 15 years [VHK]. 3,9 Million water heaters over 30 litres were sold in EU 22 in 2004 while about 51 Million units were on stock [VHK 06] of which about 60% are located in Germany, France and UK, which are the countries with high share of night heating appliances. This leads to the assumption that not more than 40% of all electric storage appliances in stock heat continuously during the day, which is a stock of about 20,5 Million units. If during the next 10 years about 15 million continuously heating devices are sold, about 75% of the continuously heating devices could have the necessary intelligence to be run in a timer mode. Presuming that the consumer is not able to change the operation performance of the device it can be assumed that all water heaters with the necessary technical equipment are run in start time delay mode. This strategy may allow shifting about 75% of the operation by seconds, minutes and up to hours. But also if the consumer would have the possibility to change the operation mode of the device it can be expected that due to reluctance only a few consumers will use this function (to be verified by WP 5). When the machine is in start time delay mode a delay of the operation will allow decreasing the operation probability short term, followed by a recovery of the probability (Figure 3.8-18).

Consumer benefits and drawbacks:

Enhanced use of renewable energy and CHP.

Demand management benefits and drawbacks:

Usage depends on the acceptance of a start time delay operation by the consumer.

Impact on appliance design and service provided: (additional costs, limitations, additional energy consumption):

Additional costs for consumer (time mode or the like): 10 - 50 €.
Additional power consumption (timer mode): > 0 W - 4 W.

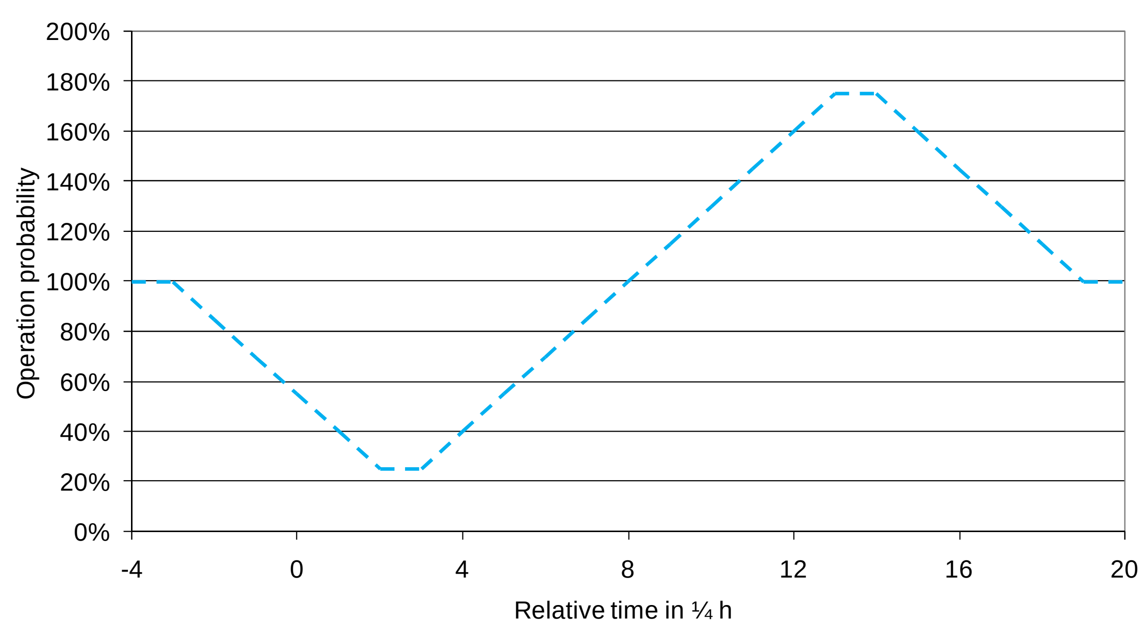
Consumer acceptance questions:

Willingness to accept this solution if additional costs are balanced by savings via energy bill.
Calculation (additional costs: 30 €):
1900 kWh/a at 0,20 €/kWh = 380,00 €/a energy costs.
Amortisation in 5 years: ~ 6,00 €/a saving
Reduction of energy costs by ~ 2 % needed.

Strategies for success:

Define business model in which energy utilities sponsor the implementation of these “Power line triggered” modules.

Figure 3.8-18 *Example of a change in operation probability for synergy scenario 2-1 A*

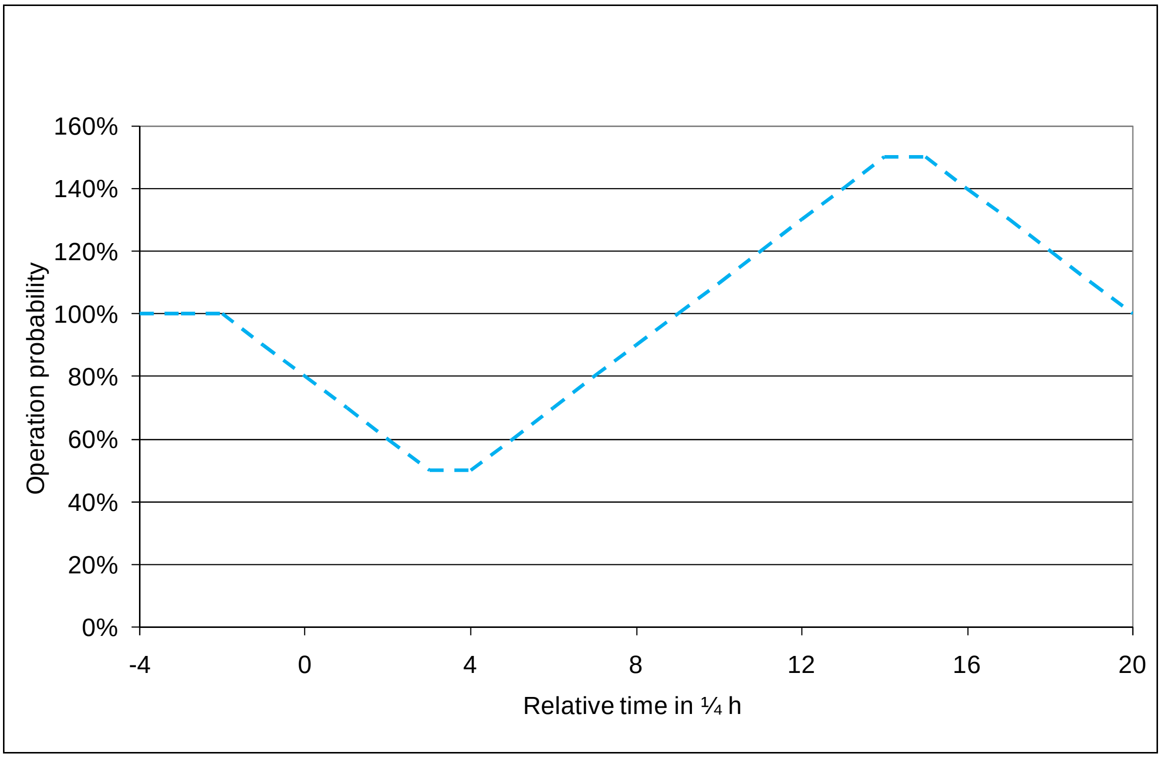


Source: *University of Bonn*

Id and title: 2-1 B Power line triggered operation
Description: Signals via e.g. power line may be used to communicate about the shortage of power on the grid. This can be detected by the water heater and transferred into action. Action may be a delayed start as far as the machine is in a start time delay or in a special “ready for operation” mode. Alternatively other means like frequency sensing might be used as the frequency is changing with total load on the grid and low availability of energy will decrease the load and thus the frequency.
Strategy for appliance control: The water heater start is delayed when the appliance is in start time delay or special “ready for operation” mode. To avoid overload by too many machines recovering at the same time, the algorithm used to define the start time shall have a random factor.
Change in power demand curve of a single appliance: No change.
Change in day curve (of power demand of all appliances): The necessary technical impacts might mostly be implemented to higher standard types and new models. The product life of an average small water heater is estimated to be about 15 years [VHK]. 1,9 million water heaters under 30 litres were sold in EU 22 in 2004 while about 33 million units were on stock [VHK 06]. Therefore it might be fair to assume that in the next 10 years about 50% of the appliances in stock could have the necessary intelligence. Presuming that the consumer is not able to change the operation performance of the device it can be assumed that all water heaters with the necessary technical equipment are run in start time delay mode. This strategy may allow shifting about 50% of the operation by seconds and minutes. When the machine is in start time delay mode a delay of the operation will allow decreasing the operation probability short term, followed by a recovery of the probability (Figure 3.8-19).

Consumer benefits and drawbacks:
Enhanced use of renewable energy and CHP.
Demand management benefits and drawbacks:
Usage depends on the acceptance of a start time delay operation by the consumer.
Impact on appliance design and service provided: (additional costs, limitations, additional energy consumption):
Additional costs for consumer (start time delay or the like): 10 € - 50 €. Additional power consumption (in start time delay mode): > 0 W - 4 W
Consumer acceptance questions:
Willingness to accept this solution if additional costs are balanced by savings via energy bill. Calculation (additional costs: 30 €): 950 kWh/a at 0,20 €/kWh = 190,00 €/a energy costs. Amortisation in 5 years: ~ 6,00 €/a saving Reduction of energy costs by ~ 3% needed.
Strategies for success:
Define business model in which energy utilities sponsor the implementation of these “Power line triggered” modules.

Figure 3.8-19 Example of a change in operation probability for synergy scenario 2-1 B



Source: University of Bonn

Id and title:
2-1 C: Power line triggered operation
Improbable scenario for this appliance.

Id and title:

2-2 A: Internal energy manager agent

Description:

Triggered by an external signal about shortage of energy the electric storage water heater may change its operation:

- delay the start of the heating phase
- interrupt the heating phase for a certain time
- reduce the power demand by choosing a lower desired water temperature

Strategy for appliance control:

The external signal should include information on the shortage of energy and how long it may last. Electric water heaters being in an appropriate state will then react by their own intelligence to find the appropriate answer.

Change in power demand curve of single appliance:

Various. May shift operation time between seconds and minutes.

Change in day curve (of power demand of all appliances)

As explained before (see 2-1 A) it is estimated that 75% of the devices may be used in the described mode and allow to shift the operation by seconds, minutes and up to hours. Assuming a shift of ¼ hour the operation probability will be changed as shown in Figure 3.8-20.

Consumer benefits and drawbacks:

Enhanced use of renewable energy and CHP.

Demand management benefits and drawbacks:

Influence on power demand by short term action. Effect will depend on daytime and penetration of internal energy manager agent.

Impact on appliance design and service provided: (additional costs, limitations, additional energy consumption):

Internal energy manager agent has to be included in the electronic unit of the appliance.

A harmonised signal of power shortage is needed.

Additional costs for consumer (signal recognition plus energy agent): 10 € - 100 €.

Additional power consumption (during operation): > 0 W - 4 W

Consumer acceptance questions:

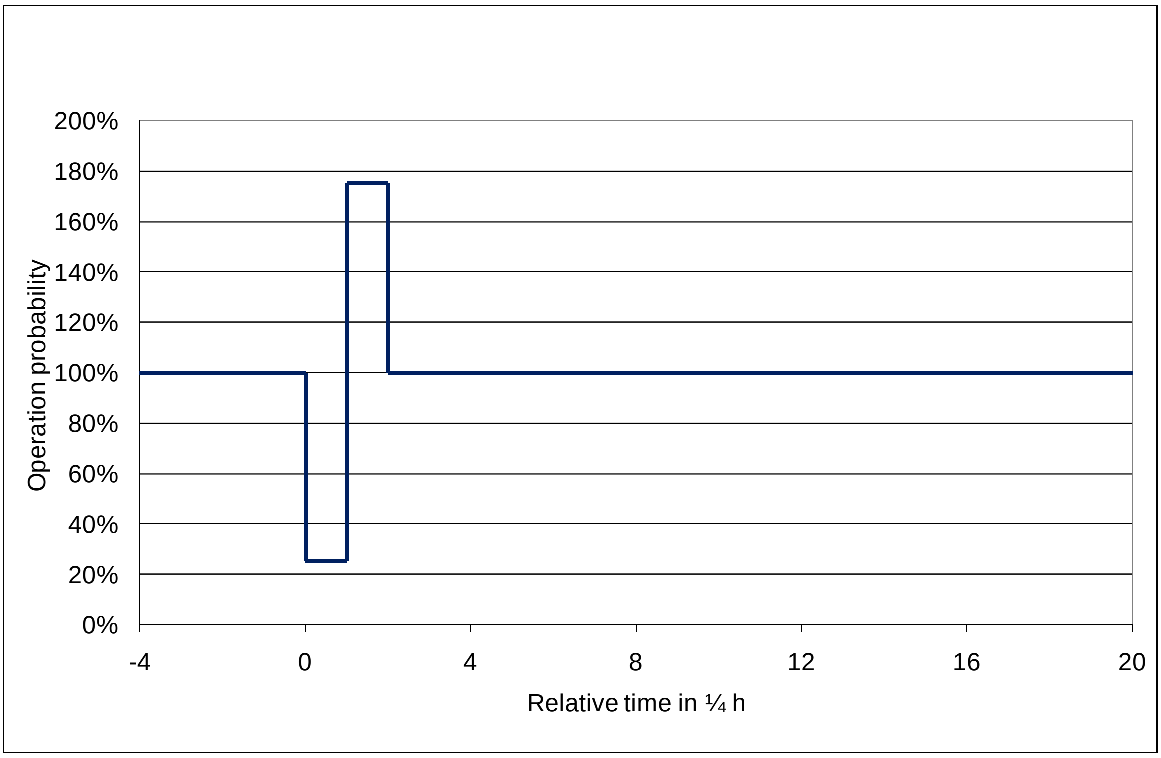
Willingness to accept this solution if additional costs are balanced by savings via energy bill.
Calculation (additional costs: 55 €):
1900 kWh/a at 0,20 €/kWh = 380,00 €/a energy costs.
Amortisation in 5 years: ~ 11,00 €/a saving
Reduction of energy costs by ~ 3% needed.

Strategies for success:

Define harmonised signal for shortage of power (CENELEC).

Define business design in which energy utilities sponsor the implementation of the “internal energy management agent” modules.

Figure 3.8-20 Example of a change in operation probability for synergy scenario 2-2 A



Source: University of Bonn

Id and title: 2-2 B: Internal energy manager agent
Description: Triggered by an external signal about shortage of energy the electric water heater may change its operation: - delay the start of the heating phase - interrupt the heating phase for a certain time - reduce the power demand by choosing a lower desired water temperature
Strategy for appliance control: The external signal should include information on the shortage of energy and how long it may last. Electric water heaters being in an appropriate state will then react by their own intelligence to find the appropriate answer.
Change in power demand curve of single appliance: Various. May shift heating time between seconds and minutes.
Change in day curve (of power demand of all appliances) As explained before (see 2-1 B) it is estimated that 50% of the operations may be used in the described mode and allow to shift the operation by seconds and minutes. Assuming a shift of ¼ hour the operation probability will be changed as shown in Figure 3.8-21.
Consumer benefits and drawbacks: Enhanced use of renewable energy and CHP.
Demand management benefits and drawbacks: Influence on power demand by short term action. Effect will depend on daytime, season and penetration of energy management agent in electric water heaters.

Impact on appliance design and service provided: (additional costs, limitations, additional energy consumption):

Internal energy manager agent has to be included in the electronic unit of the appliance.

A harmonised signal of power shortage is needed.

Additional costs for consumer (signal recognition plus energy agent): 10 € - 100 €.

Additional power consumption (during operation): > 0 W - 4 W

Consumer acceptance questions:

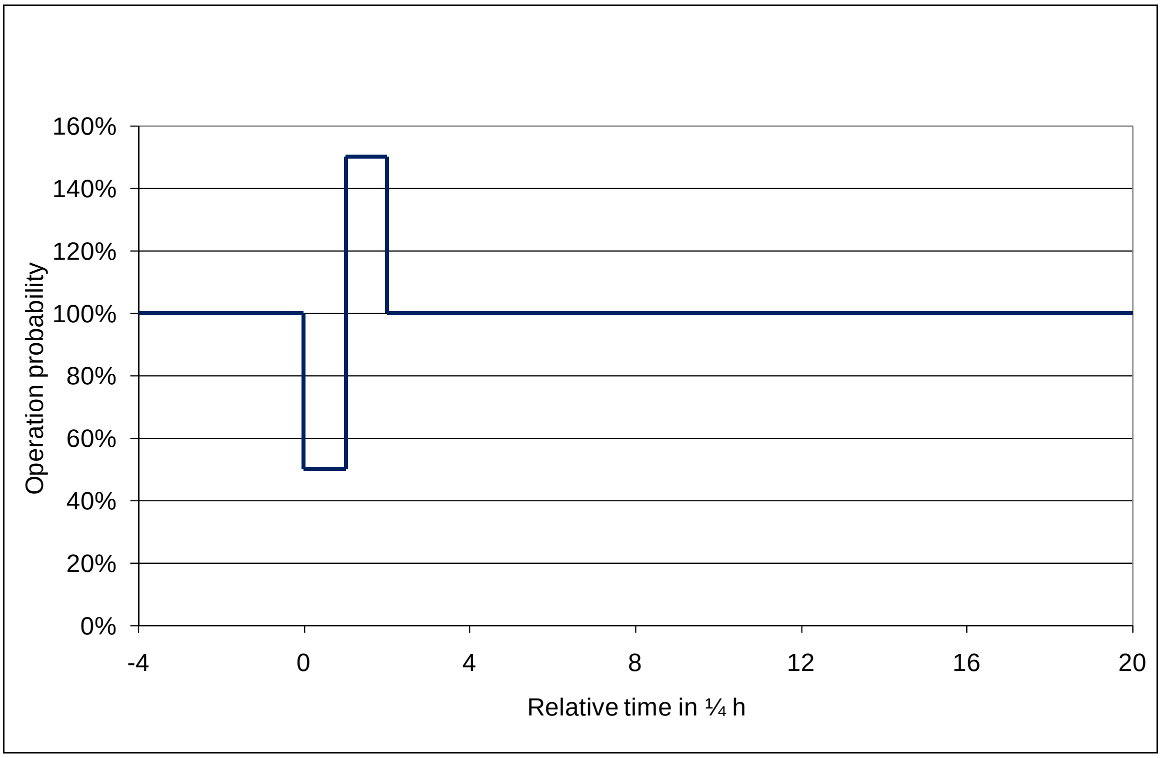
Willingness to accept this solution if additional costs are balanced by savings via energy bill.
Calculation (additional costs: 55 €):
950 kWh/a at 0,20 €/kWh = 190,00 €/a energy costs.
Amortisation in 5 years: ~ 11,00 €/a saving
Reduction of energy costs by 6% needed.

Strategies for success:

Define harmonised signal for shortage of power (CENELEC).

Define business design in which energy utilities sponsor the implementation of the “internal energy management agent” modules.

Figure 3.8-21 Example of a change in operation probability for synergy scenario 2-2 B



Source: University of Bonn

Id and title:

2-2 C Internal energy manager agent

Improbable scenario for this appliance.

3.8.6.3 Managing the power on the grid

Id and title:

3-1 A: Energy demand manager

Description:

The energy demand manager tries to harmonise the available power on the grid coming from conventional and renewable resources with the demand. Therefore the electric water heater when started is set in a remote control mode which allows the energy demand manager to decide about the start of the appliance within a predefined time interval. The energy demand manager is informed about the selected programme or at least the expected energy demand.

Strategy for appliance control:

Knowing the demand for the next hours the energy demand manager tries to use as much renewable energy and CHP as possible and optimises the overall costs.

Change in power demand curve of single appliance:

No change.

Change in day curve (of power demand of all appliances):

May allow shifting perhaps 75% of the operations at any time by seconds, minutes and up to hours (estimation see 2-1 A) according to the probability curves as shown for the synergy scenarios 2-1 A and 2-2 A (Figure 3.8-22)

Consumer benefits and drawbacks:

Enhanced use of renewable energy and CHP. Cost benefits must be transferred to the consumer.

Demand management benefits and drawbacks:

Influence on power demand by medium term action. Influence only on those water heaters which are ‘online’.

Impact on appliance design and service provided: (additional costs, limitations, additional energy consumption):

Bidirectional communication needed.

Additional switch needed to signal ‘remote operation accepted’.

A harmonised communication protocol is needed.

Additional costs for consumer (communication module via power line): 30 € - 130 €.

Additional power consumption: > 0 W - 4 W

Consumer acceptance questions:

Willingness to accept this solution if additional costs are balanced by savings via energy bill.

Calculation (4 person household with an electricity consumption of 5,2 kWh per day for water heating and additional costs of 50 €):

1900 kWh/a at 0,20 €/kWh = 380 €/a energy costs

Amortisation in 5 years: 10 €/a saving

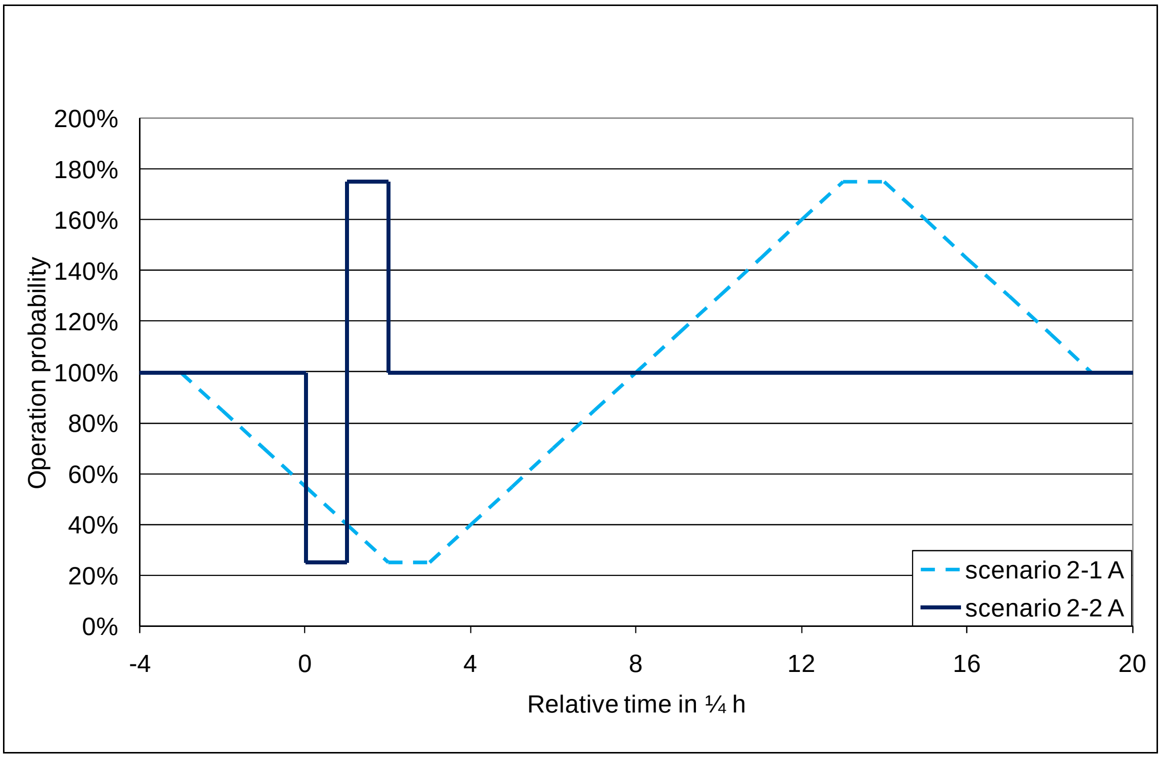
Reduction of energy costs by ~3% needed

Strategies for success:

Define harmonised communication protocol (CENELEC).

Define business design in which savings balance the additional costs for the appliance.

Figure 3.8-22 Change in operation probability for synergy scenario 3-1 A (any of 2-1 A and 2-2 A)



Source: University of Bonn

Id and title: 3-1 B: Energy demand manager
Description: The energy demand manager tries to harmonise the available power on the grid coming from conventional and renewable resources with the demand. Therefore the electric water heater when started is set in a remote control mode which allows the energy demand manager to decide about the start of the appliance within a predefined time interval. The energy demand manager is informed about the selected programme or at least the expected energy demand.
Strategy for appliance control: Knowing the demand for the next hours the energy demand manager tries to use as much renewable energy and CHP as possible and optimises the overall costs.
Change in power demand curve of single appliance: No change.
Change in day curve (of power demand of all appliances): Perhaps 50 % of the operations might be shifted at any time by seconds and minutes (estimation see 2-1 B) according to the probability curves as shown for the synergy scenarios 2-1 B and 2-2 B (Figure 3.8-23).
Consumer benefits and drawbacks: Enhanced use of renewable energy and CHP. Cost benefits must be transferred to the consumer.
Demand management benefits and drawbacks: Influence on power demand by medium term action. Influence only on those water heaters which are ‘online’.

Impact on appliance design and service provided: (additional costs, limitations, additional energy consumption):

Bi-directional communication needed.

Additional switch needed to signal ‘remote operation accepted’.

A harmonised communication protocol is needed.

Additional costs for consumer (communication module via power line): 30 € - 130 €.

Additional power consumption: > 0 W - 4 W

Consumer acceptance questions:

Willingness to accept this solution if additional costs are balanced by savings via energy bill.

Calculation (2 person household with a consumption 2,6 kWh per day for water heating and additional costs of 50 €):

950 kWh/a at 0,20 €/kWh = 190 €/a energy costs

Amortisation in 5 years: 10 €/a saving

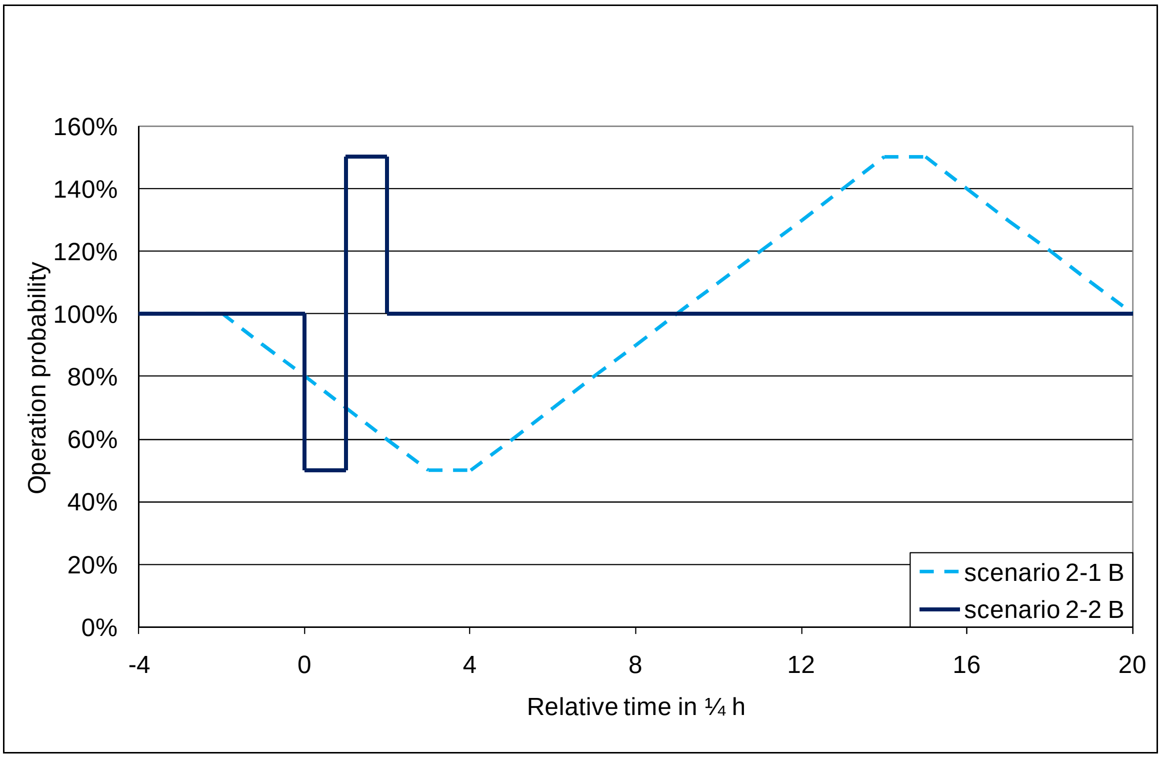
Reduction of energy costs by ~ 5% needed

Strategies for success:

Define harmonised communication protocol (CENELEC).

Define business design in which savings balance the additional costs for the appliance.

Figure 3.8-23 Change in operation probability for synergy scenario 3-1 B (any of 2-1 B and 2-2 B)



Source: University of Bonn

Id and title:

3-1 C: Energy demand manager

Improbable scenario for this appliance.

3.8.6.4 Using energy storage capacity of appliances and other technologies

Id and title:

4-1 A: Heating by hot water

Description:

Using the warmth produced by a CHP, solar plant or district heating for heating up the water in the water heater. The heat is led directly into the heating rods within the machine which then heats up the water to the desired temperature. Therefore the total amount of electricity for the heating phase is replaced by the use of heat of other systems. Electricity is only needed for the basic functions of the device and the pump.

Strategy for appliance control:

Connect the water heater to a CHP, solar plant or district heating. To avoid overheating, the water temperature should be controlled by a sensor which stops the heat supply when the desired temperature is reached.

Change in power demand curve of single appliance:

Heating power reduced by 100 %. Total power consumption depending on the size of pump, etc. is estimated to be about 1 kWh per day.

Change in day curve (of power demand of all appliances):

No change.

Consumer benefits and drawbacks:

Enhanced use of renewable energy and CHP. Cost benefits.

Demand management benefits and drawbacks:

Operation of the water heater is linked to the availability of heat by the described suppliers.

Impact on appliance design and service provided: (additional costs, limitations, additional energy consumption):

Special heating rods are needed.

Additional costs for consumer: 80 € - 120 €

Additional power consumption: 0 W

Consumer acceptance questions:

Willingness to accept this solution if additional costs are balanced by savings via energy bill.

Calculation (4 persons household with an electricity consumption of 5,2 kWh for water heating per day and additional costs of 100 €):

1900 kWh/a at 0,20 €/kWh = 380,00 €/a energy costs

Amortisation in 5 years: 20 €/a saving

Reduced energy consumption (80 % of 1900 kWh):

1520 kWh/a at 0,20 kWh = 304 €/a

No reduction of energy price needed.

Strategies for success:

Promotion of water heaters with direct use of alternatively produced heat.

Id and title:

4-1 B: Heating by hot water

Description:

Using the warmth produced by a CHP, solar plant or district heating for heating up the water in the water heater. The heat is led directly into the heating rods within the machine which then heats up the water to the desired temperature. Therefore the total amount of electricity for the heating phase is replaced by the use of heat of other systems. Electricity is only needed for the basic functions of the device and the pump.

Strategy for appliance control:

Connect the water heater to a CHP, solar plant or district heating. To avoid overheating, the water temperature should be controlled by a sensor which stops the heat supply when the desired temperature is reached.

Change in power demand curve of single appliance:

Heating power reduced by 100 % - total power consumption depending on basic operations of the device, is estimated to be about 200 Wh per day.

Change in day curve (of power demand of all appliances):

No change.

Consumer benefits and drawbacks:

Enhanced use of renewable energy and CHP. Cost benefits.

Demand management benefits and drawbacks:

Operation of the water heater is linked to the availability of heat by the described suppliers.

Impact on appliance design and service provided: (additional costs, limitations, additional energy consumption):

Special heating rods are needed.

Additional costs for consumer: 80 € - 120 €

Additional power consumption: 0 W

Consumer acceptance questions:

Willingness to accept this solution if additional costs are balanced by savings via energy bill.

Calculation (2 person household with an electricity consumption of 2,6 kWh for water heating per day and additional costs of 100 €):

950 kWh/a at 0,20 €/kWh = 190 €/a energy costs

Amortisation in 5 years: 20 €/a saving

Reduced energy consumption (90 % of 950 kWh):

850 kWh/a at 0,20 kWh = 170 €/a

No reduction of energy price needed. No rise in energy price possible.

Strategies for success:

Promotion of water heaters with direct use of renewable (or by CHP) produced heat.

Id and title:

4-1 C: Heat of CHP, district heating or solar plant

Improbable scenario for this appliance.

3.9 Electric heating (storage unit)

Electric space heating systems can mainly be divided into two categories: storage and direct heating. As there are various technologies on the market (e.g. floor heating, cylinder central heating etc.) not all of them are investigated separately but being summarized under the topic “electric heating”. The section about the synergy potential only focuses on electric heating systems with the ability to store heat for a later use.

3.9.1 Technical description with regard to the use of energy

An electric heater is an electrical appliance that converts electrical energy into heat. The heating element inside every electric heater is simply an electrical resistor, and works on the principle of Joule heating: an electric current flowing through a resistor converts electrical energy into heat energy. Although all electric heaters use this physical principle to generate heat, they differ in the way they deliver that heat to the environment. Several types are described in the paragraphs below.

Direct heating systems:

There are different types of direct heating systems on the market with technologies like convection, radiation, air conditioning etc. In these systems the heating energy is immediately available as soon as the electrical currant is led through the resistance wire. The way of heat transmission is different in the various technologies.

In a convection heater, the heating element heats the air next to it by conduction. Hot air is less dense than cool air, so it rises due to buoyancy, allowing more cool air to flow in to take its place. This sets up a constant current of hot air that leaves the appliance through vent holes and heats up the surrounding space.

A special type of convection heater is a fan heater which includes an electric fan to speed up the airflow. The air is being heated up on its way through a bundle of heating wires and blown in the room.

Radiative heaters contain a heating element that reaches a high temperature. The element is usually packaged inside a glass envelope resembling a light bulb and with a reflector to direct the energy output away from the body of the heater. The element emits infrared radiation that travels through air or space until it hits an absorbing surface, where it is partially converted to heat and partially reflected. This heat directly warms people and objects in the room, rather than warming the air.

Storage heating systems:

A storage heater is an electrical appliance that charges heat during periods of cheaper off-peak power and saves the heat for a later use. The inside of a standard storage heater contains a storage core (ceramic or other material) with high heat retention capacity. Heating elements within the storage core convert electrical energy into heat almost without loss. The core is being heated up to temperatures between 600°C and 700°C and is surrounded by a high-grade insulating material which reduces the heat losses. A connected room temperature controller comes into play when the actual room temperature falls below the required level. In that event a fan is started to ingest compartment air which is being heated up on its way through the hot storage core of the heating element and then blown into the entire room. The temperature of the expelled air is regulated by a thermally controlled mixing valve. The power input depends on the size of the heating unit and ranges up to 7 kW [FE 04].

Electrical underfloor heating are available as direct or storage heating systems. The heating power of a direct underfloor heating varies between 80 W/m^2 and about 180 W/m^2. The floor is used as storage material for the heat in a storage underfloor heating system. For a room temperature of 27°C a power input of 70 W/m^2 is needed [FE 04].

3.9.2 Penetration in Europe

A study within the SAVE II project [SA4 02] reported that the use of electric heating in the EU occurred already in the 1960's – at this time mainly through storage heaters – as a means to utilize surplus power generation at night; it became very popular in the 1970's e.g. linked to the rise of nuclear energy. The present (year 2002) level of electric heating is around 13-14%. The study stated that electric heating systems are diminishing in cold and moderate climate zones, whereas they are becoming popular in warm climate zones in Southern Europe as a cheap way to generate heat in short heating seasons and/or as the 'the other side' of reversible air conditioners. In Scandinavia, where electrical heating traditionally holds a strong position, they are replaced by district heating or (still electrical) heat pumps. The study sees the overall trend in ownership of electrical systems declining: in a stock model it was calculated that in 2005 already 60% (compare '95: 46%) of the 155 million dwellings have heating systems that are gas-fired, 20% are oil-fired ('95: 22%), 8-9% electric ('95: 14%), 7% solid ('95: 8%) and 7% on district heating (unaltered).

Another study within the SAVE II project [SA1 02] reported in 2002 a high presence of electric heating in Finland, France, Sweden and the UK. In France 22% of households have electrical central heating, convective and storage heaters installed throughout the home. Sales of central electric heating for 1998 were: convectors 76%, storage heaters 20%, radiant panels 4%. In many households the individual heaters are centrally controlled ("integrated" systems). In Germany practically all electrical central heating employs storage heaters (Table 3.9-1). In Sweden, electric central heating is used in 19% of households; 1/3 of systems are hydronic (i.e. use of water as the heat-transfer medium). In Finland the proportion of homes using electricity for heating reached 21,2%. The study stated for 0,3% of the Dutch homes the use of electrical radiant panels as secondary heating for extra comfort reasons (e.g. warm floor in the bathroom and/or in the kitchen).

Table 3.9-1 Estimate of penetration of heat emitter types used in electric central heating, (author in [SA1 02]). Figures are percentages of households and from years 1998 to 2002.

	DK	FI	FR	DE	IE	NL	SE	UK
Storage			4,44	6,1				8
Convective			16,9				12,9	
Hydronic							6,5	
Other (inc. radiant panels)			0,9	0,1				2
Total	0,7	21,2	22,2	6,2	8,8	0,3	19,4	10

Source: Following [SA1 02]

A recent study about the energy efficiency potentials by substituting electric heating systems in Germany [IZ 07] reported about initiatives to minimise the use of electric heating in the following European countries: Denmark, Norway and Sweden. As the study considered the power consumption for electrically heated households in Germany as increasing recommendations for a similar initiatives are given. In 2002 about 1,44 million households are heated electrically which is about 4% of all households which is contradictory to the figures of the SAVE II study mentioned earlier.

For OECD Europe the International Energy Agency anticipated in their study [IEA 03] in 2003 that from 2006 to 2010 a major retrofit of existing electric space heating systems will be initiated. In Europe the study assumed that 80% of electric resistance space heating will have been substituted by heat pump units by 2010.

3.9.3 Consumption of energy in Europe

In the energy efficiency study [EEF 06] a share of 22% of the overall electricity consumption among residential end-use equipment in the EU-15 in 2004 was published for residential electric heating. That means a total amount of around 150 TWh was consumed by electric heating units. It has been indicated that there is still a substantial difference between the former EU-15, where the largest electricity use is still space heating, followed by refrigerators and freezers and lighting, and the New Member States, where refrigerators and freezers and lighting are more or less on the same level and are the largest electricity end-users, and where very little electricity is used for space heating and cooling.

A recent study [IZ 07] reported for Germany an increase in the power consumption for electric resistance heating of 5,7% from 1995 until 2004 caused mainly by the installation of new resistance heating systems in German households. A total amount of 24,4 TWh was reported to be consumed in 2004 for electrical space heating by about 1,4 million electric heating units of which an amount of around 1,3 million units are off-peak storage heaters. The calculation of the average power consumption of an electric heating unit in Germany per year results in an amount of about 15532 kWh. The duration of the heating period is assumed with 264 heating days [EUP13 07] which leads to a daily power consumption of about 59 kWh per unit in average.

3.9.4 Effects on energy consumption due to consumer usage

Electric heating units are appliances which are operating usually automatically and on the demand for warmth in the home of the consumer. Therefore the consumption of energy in the period of use is determined by following factors:

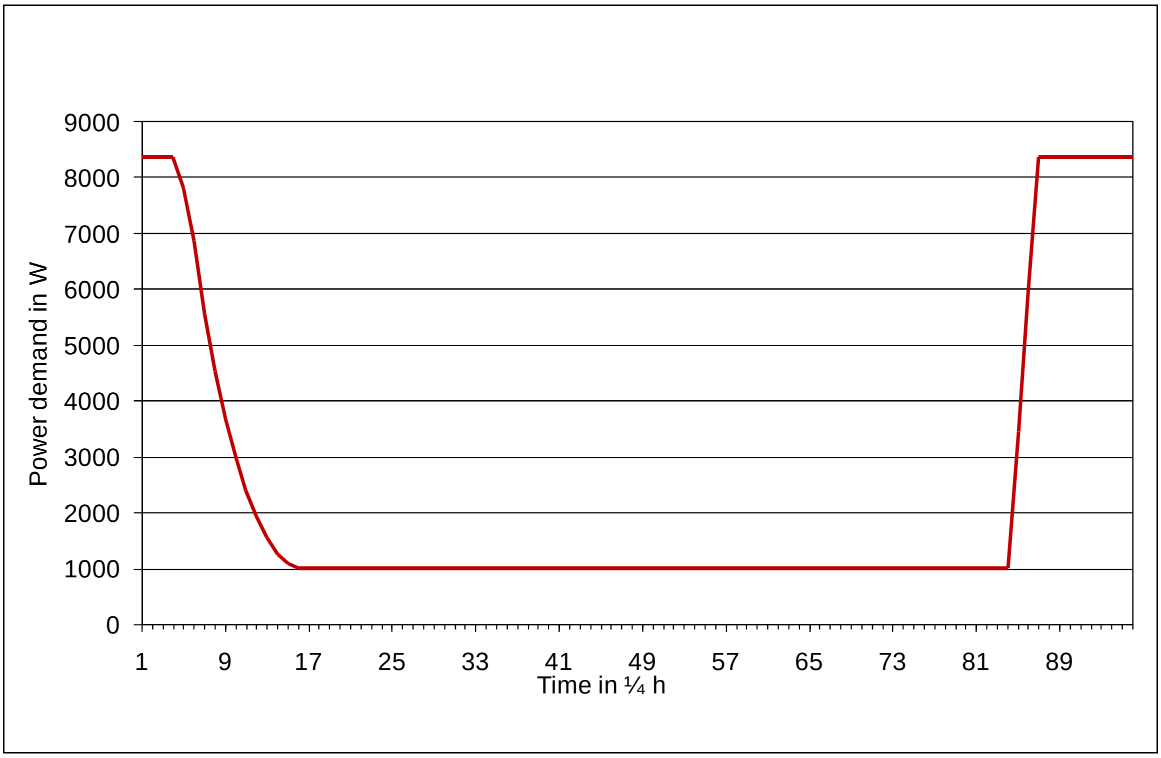
- Type and size of storage heater
- Duration of the heating period
- Adjustment of the heating system
- Outside temperature

The energy consumption of electrical heating systems also depends on the personal sense for warmth of the consumer which determines the duration of the heating period in one year.

3.9.5 Power demand and load curves

As storage heaters usually operate at off-peak periods the time of their energy consumption ranges usually from 22:00 until 6:00 (sometimes periods during the day are also possible depending on the offers of the supplier). Therefore in general a power demand curve per day of a storage heater might follow the pattern as shown in Figure 3.9-1. As there is only limited data available for the average energy consumption of electric heating units for the whole of Europe the curve is based on the figures calculated for storage heaters in Germany.

Figure 3.9-1 General pattern of a daily load curve of an average storage heater in ¼ hour steps



Source: University of Bonn

3.9.6 Synergistic potentials

Within this chapter it is tried to explore possible synergies when electric storage heating units are somehow linked to sustainable energy sources, like solar or wind energy or heat from CHP processes. For each of these synergistic potentials it is described where the synergy comes from, what are possible constrains and what needs to be fulfilled to gain the potential. It is also estimated how many appliances might be affected and how these synergies might affect the power demand curve or the probability of operation of electric storage heating units, including a possible recovery phase. As most of these synergies are not yet realised, they are somewhat hypothetical, but based on best engineering practise. If costs are given, they describe the expected additional prize the consumer has to pay for this feature. If ranges are given, the higher value normally corresponds to an implementation of this feature in a first introduction phase, while the lower value estimates how costs may develop at a large scale use. Results of the consumer survey will be added in a supplementary document to this report.

In the following synergy scenarios the complexity of technical adjustments on the device considered increases from level 1 (3.9.6.1) to level 4 (3.9.6.4) steadily. Whereas in level 1 the consumer still has the full control whether to use the described option or not, in level 2 some of that control was handed over to the machine which then reacts to incoming signals. In level 3 the full control is in the hands of an external manager (e.g. electric utility) who decides about when and how often the machine is being switched on or off after it was set in a ready mode by the consumer. Therefore signals are being transmitted in a bidirectional way. In level 4 additional options for storing energy or using other technologies are taken into account.

3.9.6.1 Shifting operation in time

Id and title: 1-1 Consumer shifts operation in time
Improbable scenario for this appliance: As the appliance is especially designed for the purpose to consume energy during off-peaks periods when cheaper tariffs are offered the consumer expects the device to do so without managing it by himself.

3.9.6.2 Applying flexibility on appliance power demand

Id and title: 2-1 Power line triggered operation
Description: Signals via e.g. power line may be used to communicate about the availability of surplus power on the grid. This can be detected by the electric heating unit and transferred into action. Action may be an immediate start of charging as far as the device is in a special “ready for operation” mode. Alternatively other means like frequency sensing might be used as the frequency is changing with total load on the grid and high availability of energy will increase the load and thus the frequency.
Strategy for appliance control: To avoid an overload by too many devices starting at the same time, the algorithm used to define the start time shall have a random factor.

Change in power demand curve of single appliance:

No change.

Change in day curve (of power demand of all appliances):

As the device is designed for the use of cheaper tariffs the acceptance of the consumers for a sudden start of charging (which might not even be noticed) is assumed to be very high. Therefore a shift of 90% of the operations by several hours might be a possible scenario (here: 2 hours). As it is assumed that the charging of the device might start at any time, the operation probability will therefore increase short term, followed by a drop of the probability (Figure 3.9-2).

Consumer benefits and drawbacks:

Enhanced use of renewable energy and CHP.

Demand management benefits and drawbacks:

Usage depends on the acceptance of the consumer.

Impact on appliance design and service provided: (additional costs, limitations, additional energy consumption):

Additional costs for consumer: 10 – 50 €
Additional energy consumption: 0 – 4 W.

Consumer acceptance questions:

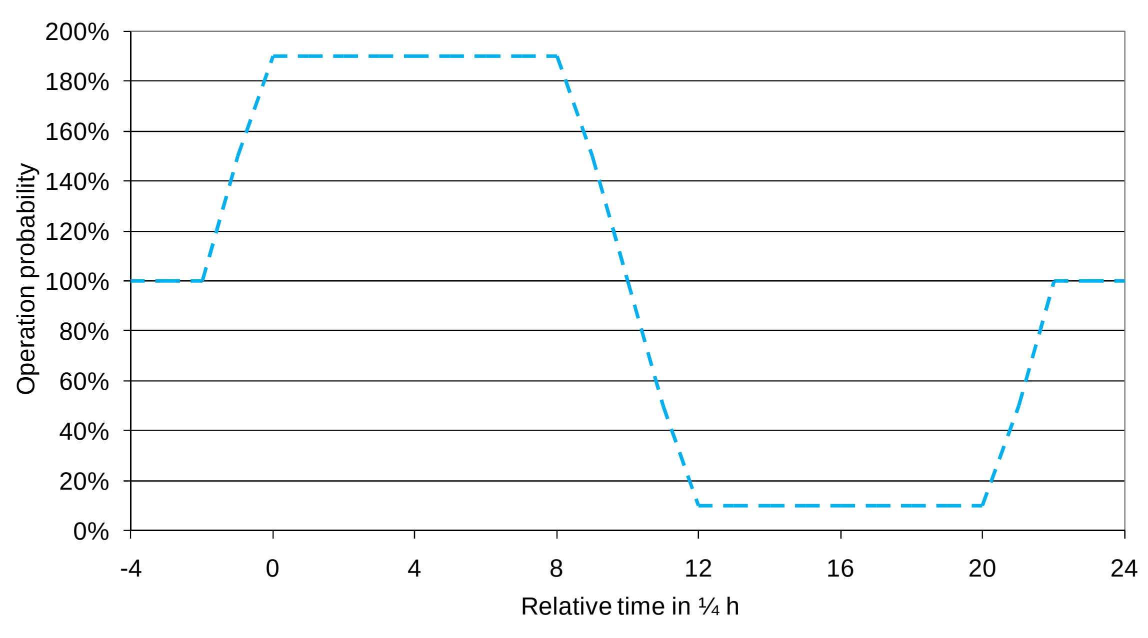
Willingness to accept this solution if additional costs are balanced by savings via energy bill.

Calculation (additional costs: 30 €):
15532 kWh/a at 0,10 €/kWh = 1553 €/a energy costs
Amortisation in 5 years: 6 €/a saving
Reduction of energy costs by ~0,4% needed.

Strategies for success:

Define business model where energy utilities sponsor the implementation of these “Power line triggered operation” modules.

Figure 3.9-2 *Example of a change in operation probability for synergy scenario 2-1*



Source: *University of Bonn*

Id and title:

2-2 Internal energy manager agent

Description:

Triggered by an external signal about shortage of energy the electric heating unit might change its operation:

- interrupt the charging phase for a certain time
- shift the start of the charging phase
- immediate start of the charging phase

Strategy for appliance control:

The external signal should include information on the shortage of energy and how long it may last. Storage heaters in an appropriate state will then react by their own intelligence to find the appropriate answer.

Change in power demand curve of single appliance:

Various. May shift charging time between seconds, minutes and up to hours.

Change in day curve (of power demand of all appliances):

As explained earlier (see 2-1) it is estimated that 90% of the devices may be used in the described mode and allow to shift the operation by several hours. The duration of the shift depends on the residual heat in the storage core, the temperature desired in the room and the time a certain temperature should be reached. Assuming a shift of 2 hours the operation probability will be changed as shown in Figure 3.9-3.

Consumer benefits and drawbacks:

Enhanced use of renewable energy and CHP.

Demand management benefits and drawbacks:

Influence on power demand by short term action. Effect will depend on the time of the day, the season and the penetration of energy management agents in storage heating systems.

Impact on appliance design and service provided: (additional costs, limitations, additional energy consumption):

Internal energy manager agent needs to be included in electronic unit of the device.
A harmonised signal of power shortage is needed.
Additional costs for consumer (signal recognition plus energy agent): 10 - 100 €.
Additional energy consumption: 0 – 4 W.

Consumer acceptance questions:

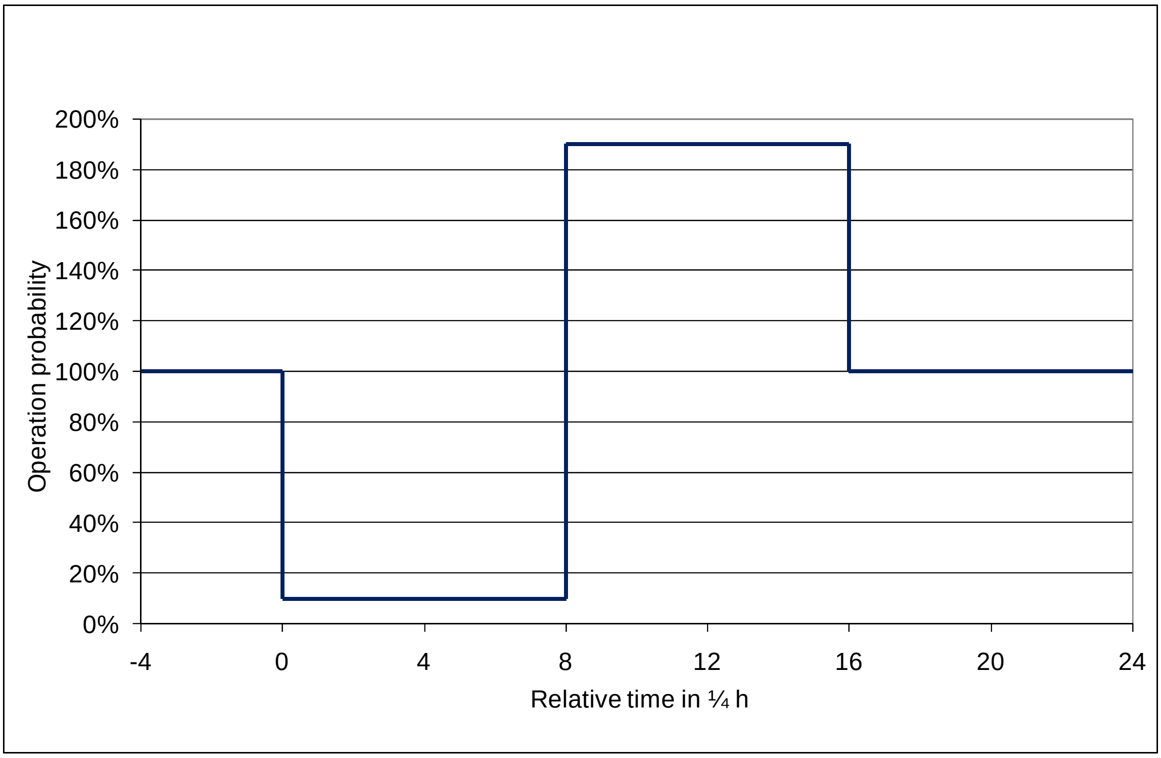
Willingness to accept this solution if additional costs are balanced by savings via energy bill.

Calculation (additional costs: 55 €):
15532 kWh/a at 0,10 €/kWh = 1553 €/a energy costs
Amortisation in 5 years: 11 €/a saving
Reduction of energy costs by ~0,7% needed.

Strategies for success:

Define harmonised signal for shortage of power (CENELEC).
Define business model where energy utilities sponsor the implementation of these “Internal energy management agent” modules.

Figure 3.9-3 *Example of a change in operation probability for synergy scenario 2-2*



Source: *University of Bonn*

3.9.6.3 Managing the power on the grid

Id and title:

3-1 Energy demand manager

Description:

The energy demand manager tries to harmonise the available power on the grid coming from conventional and renewable resources with the demand. Therefore the energy demand manager decides about the start (or stop) of the storage heating units within a predefined time interval. The energy demand manager is informed about the warmth demand of the house (temperature in the house, the range of possible fluctuations of the temperature chosen by the consumer), the outside temperature, the amount of residual heat within the storage core and thus the expected energy demand.

Strategy for appliance control:

Knowing the demand for the next few hours the energy demand manager tries to use as much renewable energy and CHP as possible and optimises the overall costs.

Change in power demand curve of single appliance:

No change.

Change in day curve (of power demand of all appliances):

Following the estimation made in 2-1 and 2-2 it is assumed that at maximum 90% of the operations – at full implementation of the described feature – might be shifted according to any of the probability curves as shown for the synergy scenarios 2-1 or 2-2 in Figure 3.9-4 managed by the energy demand manager.

Consumer benefits and drawbacks:

Enhanced use of renewable energy and CHP. Cost benefits must be transferred to the consumer.

Demand management benefits and drawbacks:

Influence on power demand by medium term action.

Impact on appliance design and service provided: (additional costs, limitations, additional energy consumption):

Bidirectional communication needed. Additional switch needed to signal ‘remote operation accepted’.
A harmonised communication protocol is needed.
Additional costs for consumer (communication module via power line): 30 – 130 €.
Additional energy consumption: 0 - 4 W.

Consumer acceptance questions:

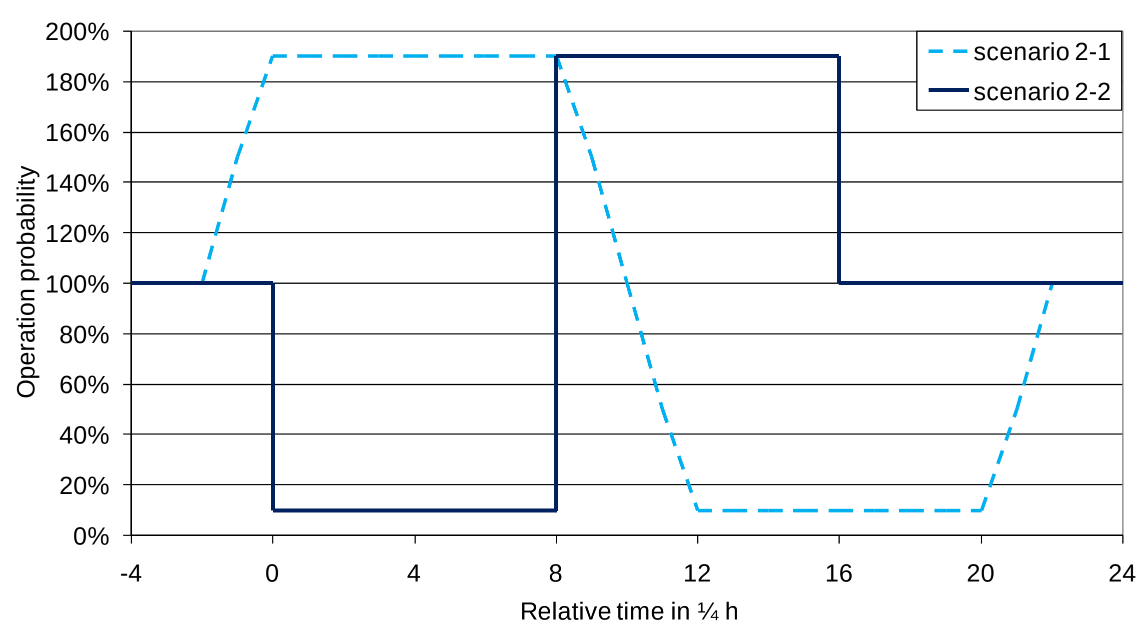
Willingness to accept this solution if additional costs are balanced by savings via energy bill.

Calculation (additional costs: 80 €):
15532 kWh/a at 0,10 €/kWh = 1553 €/a energy costs
Amortisation in 5 years: 16 €/a saving
Reduction of energy costs by 1% needed.

Strategies for success:

Define harmonised communication protocol (CENELEC).
Define business model where savings balance the additional costs for the appliance.

Figure 3.9-4 *Change in operation probability for synergy scenarios 3-1 (any of 2-1, 2-2)*



Source: *University of Bonn*

3.9.6.4 Using energy storage capacity and other technologies

Id and title: 4-1 Use of solar energy (PV)
Description: If there is a Photovoltaic-system already installed in the house of the consumer the surplus of electricity produced by the system might be used for charging the storage cores of electric heating units within the house up to a certain amount. Only in regions where no refund is paid for the supply with surplus current of PV-systems or where night time tariffs are higher than the refund.
Strategy for appliance control: No.
Change in power demand curve of single appliance: Charging power might be reduced by up to 20 - 40%.
Change in day curve (of power demand of all appliances): No change.
Consumer benefits and drawbacks: Enhanced use of renewable energy and CHP – even more when the operation is additionally linked to the availability of other renewable (or CHP) energy sources. Cost benefits.
Demand management benefits and drawbacks: Reduced power demand of charging process in general.

Impact on appliance design and service provided: (additional costs, limitations, additional energy consumption):

Installation of a connection between electric heating and solar system needed.
Additional costs for consumer: 180 € – 220 €
Additional power consumption: 0 W

Consumer acceptance questions:

Willingness to accept this solution if additional costs are balanced by savings via energy bill.
Calculation with additional costs of 200 € and an off-peak period price of 0,10 €/kWh [ST 07] assumed:
15532 kWh/a at 0,10 €/kWh = 1553 €/a energy costs
Amortisation in 5 years: 40 €/a saving
Reduced energy consumption (70% of 15532 kWh):
10872 kWh/a at 0,10 €/kWh = 1087 €/a energy costs
No reduction of energy price needed.

Strategies for success:

Define business model where savings balance the additional costs for the installation.

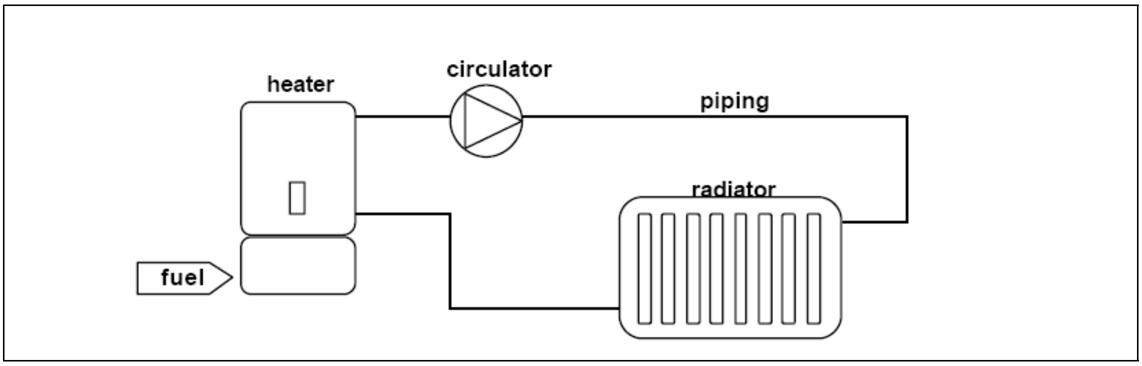
3.10 Heating circulation pump

The report focuses on central heating circulators found in household central heating systems. This product is either built into a boiler or a stand-alone component and is one of the largest electricity users of all domestic appliances. Other types of circulators or pumps e.g. for industrial use are not part of the analysis.

3.10.1 Technical description with regard to the use of energy

A heating circulation pump (or circulator) is used to re-circulate water or another heat-transfer-medium within a closed circuit e.g. a heating system in a house. Such a standard central heating system consists of a heater (boiler), the circulator, piping and heat-emitters (radiators) as shown in a simplified representation in Figure 3.10-1.

Figure 3.10-1 Typical installation of a circulator in a central heating system



Source: [SA 01]

The water is heated up usually in a boiler and then pumped by the circulator through the pipes to all radiators within the house for heating up different rooms. Then the cooled down water flows back to the boiler where it is being heated again. The pump is running as long as warmth is needed in the house. A total of about 6000 working hours are assumed for one heating period [STW 07].

The circulators on the European market can be classified into three different types: high efficiency pumps, controlled and uncontrolled pumps. The older types of the uncontrolled models are the least energy efficient ones: the water is pumped with full power through the pipes no matter whether the pressure changes or not. Even if the valves of the thermostats within the radiators are throttling the flow of the water, the electricity consumption of the circulator is not decreasing.

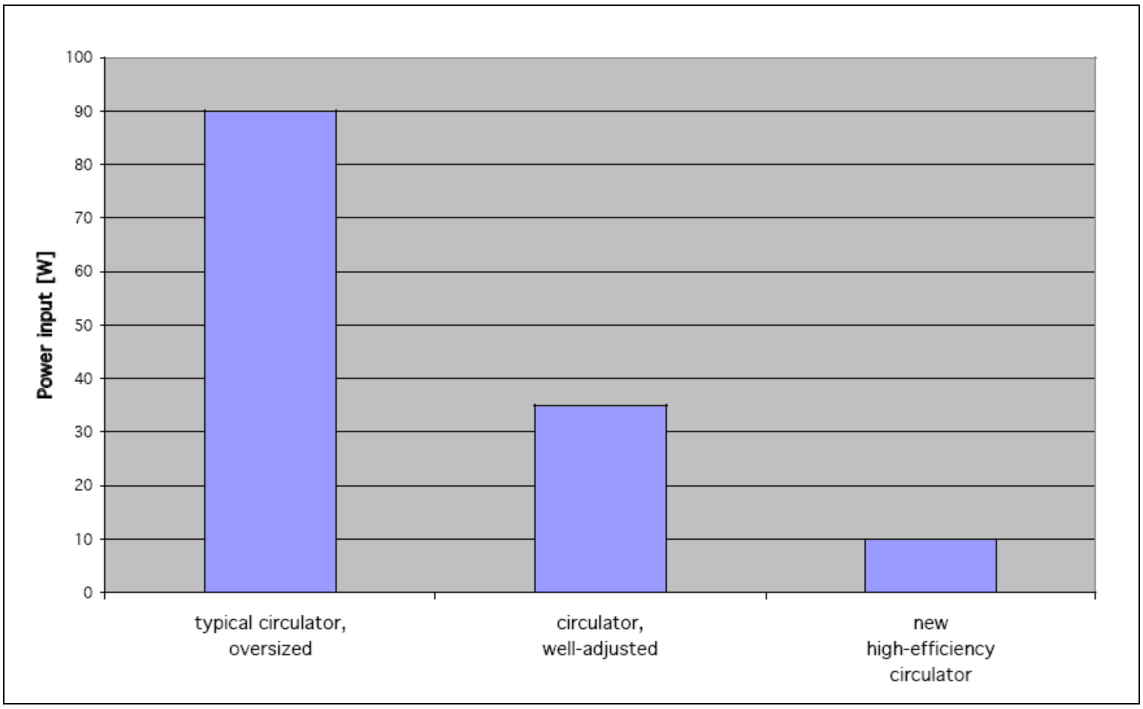
The controlled pumps are regulating the pressure within the heating system automatically: with a decreasing need for warmth in the house the energy consumption of the circulator sinks as well. Therefore the circulator operates about three-quarters of the heating period in partial load with only the half amount of the maximum possible flow rate of the water. The most efficient pumps of this controlled type consumed in a test cycle over one year about 150 kWh in an average single family house which is about 20 – 30% of the consumption of an older type [STW 07].

An energy saving can also be achieved by replacing old pumps with high efficiency circulation pumps [KE 03]. These pumps are electronically commutated and due to their efficient technology a reduction in circulator annual electricity use by 60% and more is achievable [BA 07].

The hydraulic performance of circulators is expressed in “flow” (in m^3/h) at a certain head (pressure delivered, in m) and depends on pump design and motor controls which is related to a certain amount of electricity consumption and makes it reasonable to classify them by this consumption.

As reported in the recent ECEEE summer study [BA 07] a typical circulator in European heating systems has a power input of 80 to 100 W which the study stated as far oversized. Installers are often choosing bigger pumps for not receiving any complaints from their customers. Additionally the hydraulic balance is often uneven which is compensated by the installation of a bigger pump. The study resumes that with a correct hydraulic balance in a well adjusted heating system a conventional technology circulator of e.g. 35 W would be sufficient or even of 10 W when a high efficient pump would be chosen (Figure 3.10-2).

Figure 3.10-2 Comparison of the input power of different circulators



Source: [BA 07]

3.10.2 Penetration in Europe

According to the SAVE II study on energy efficiency of circulators for central heating systems [SA 01] the circulator market in Europe is dominated by just two producers with over 90% of the overall production: Grundfos Group and Wilo-Salmson AG. Grundfos produces about 8,5 and Wilo about 5 million circulators per year. The study published an estimated stock of about 87,4 million units and sales of 8 – 8,6 million units of circulators (P < 250 W) for heating systems in the EU-15 in 1995 (Table 3.7-1).

Table 3.10-1 Estimated stock and sales circulator pumps EU-15 in 1995 demand side analysis (VHK 2000)

Country	Circulator pump stock			Circulator pump market			Circulator repair	Total market
	Small (<250 W)	Large (>250 W)1)	Total stock circulators	Boilers in new built homes	Boilers in renovations2)	Boiler replacement		
	(*1.000)	(*1.000)	(*1.000)	(*1.000)	(*1.000)	(*1.000)	(*1.000)	(*1.000)
AU	2.022	7	2.029	47	9	102	51	209
BE	3.100	5	3.105	32	6	155	78	272
DK	1.009	13	1.022	16	3	51	26	96
DE	22.173	93	22.266	352	70	1.115	557	2.096
FI	1.116	11	1.127	28	6	56	28	118
FR	15.099	48	15.147	233	47	758	379	1.419
IE	856	0	857	30	6	43	21	101
IT	11.439	56	11.495	138	28	576	288	1.030
NL	5.219	8	5.227	80	16	262	131	489
PT	332	0	332	9	2	17	8	36
ES	3.277	5	3.282	80	16	164	82	342
SV	2.314	20	2.334	12	2	117	58	189
UK	18.678	27	18.705	150	30	937	468	1.586
LU	109	0	109	3	1	5	3	11
EL	320	0	320	8	2	16	8	34
Total	87.063	293	87.357	1.218	244	4.374	2.186	8.028

1) Estimated: 1 large circulator per 100 households.

2) Estimated: 20% of newly built dwellings.

Source: [SA 01]

Van Holsteijn en Kemna (VHK) estimated in their EuP-study [VHK2 05] a stock of 103 million units for the EU-25 with an average product life of 13 years which renders a replacement market of 7,9 million pumps. Combining this figure with the an assumed amount of new sales of 1,8 million units VHK calculate a total of 9,7 million circulators in 2005.The stock model of the SAVE II study [SA 01] shows a total increase in the pump energy consumption of 9% from 1995 to 2005 giving a total of 95 million circulators in 2005 for the EU-15. VHK assessed some additional 25,7 million households in the New Member States, of which 6,75 million were assumed to have individual central and 9,35 million some form of collective heating (Table 3.10-2). Due to their assumption of one individual circulator per 10 households with collective heating VHK added 7,7 million units to the stock which makes a total of 103 million. Since all wet heating systems require a circulator, they enjoy a 100% penetration of the current boiler market.

Table 3.10-2 Estimate of sales of central heating boilers in EU-25 countries

Central and Eastern Europe	dwellings (mio)	central heating (%)	dwelling with CH (mio)	dwellings with block/district heating (mio)	dwellings with individual central heating systems	sales if product life is 20 yrs ('000 units)
remarks:	(1)	(1)	calculation	(2)	calculation	(3)
Czech Republic	3.7	79,8	2.98	1.49	1.49	74
Estonia	0.6	67,9	0.42	0.25	0.17	9
Hungary	4.1	47,6	1.93	1.62	0.31	15
Latvia	0.9	64,9	0.61	0.38	0.23	12
Lithuania	1.4	71,8	0.97	0.54	0.43	22
Poland	11.9	72,9	8.71	4.78	3.93	197
Slovakia	1.7	n.a.				
Slovenia	0.7	65,4	0.47	0.28	0.18	9
Total / average	25.7	64%	16.09	9.35	6.75	337

1) Data of dwellings and of % central heating are from UNECE (Human Settlements Program (www.unece.org/env/hs/bulletin/seltab_e02.htm)

2) 40% of all dwellings assumed to be block/district heating (no data found covering all countries)

3) minimal life time of 20 years for cast iron, coal fired boilers is assumed

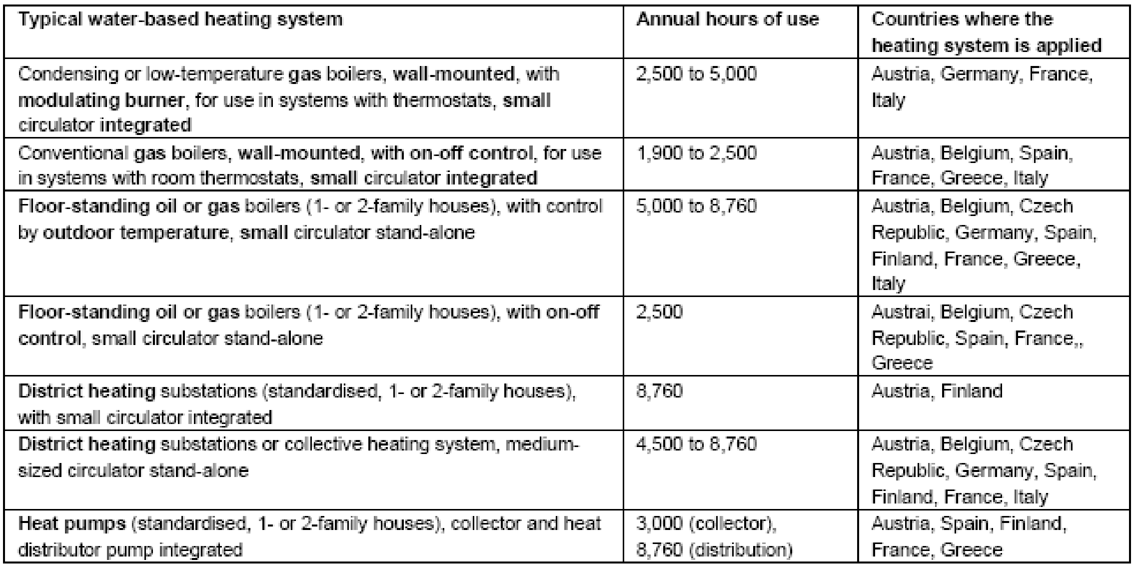
Source: [VHK2 05]

3.10.3 Consumption of energy in Europe

In a study about the electricity consumption and efficiency trends in the EU [EEF 06] a share of 4% of the overall electricity consumption among residential end-use equipment in the EU-15 in 2004 was published for central heating circulation pumps. That means a total amount of 30 TWh was consumed by circulators, which is more than the double amount consumed by laundry dryers or dishwashers.

The summer study of the ECEEE [BA 07] published that the electricity consumption of circulators for heating purposes in households in the EU-27 amounted to about 50 TWh per year caused by over 100 million pumps mostly with a power input below 250 W. That means that about 2% of the total electricity consumption in the EU is consumed by circulators in single or double family homes and flats. In more than 140 interviews investigating the distribution of typical water-based heating systems in various European countries the study concluded the heating market structure as very diverse over Europe (Table 3.10-3).

Table 3.10-3 Typical water-based heating systems with important market shares in the examined EU Member States

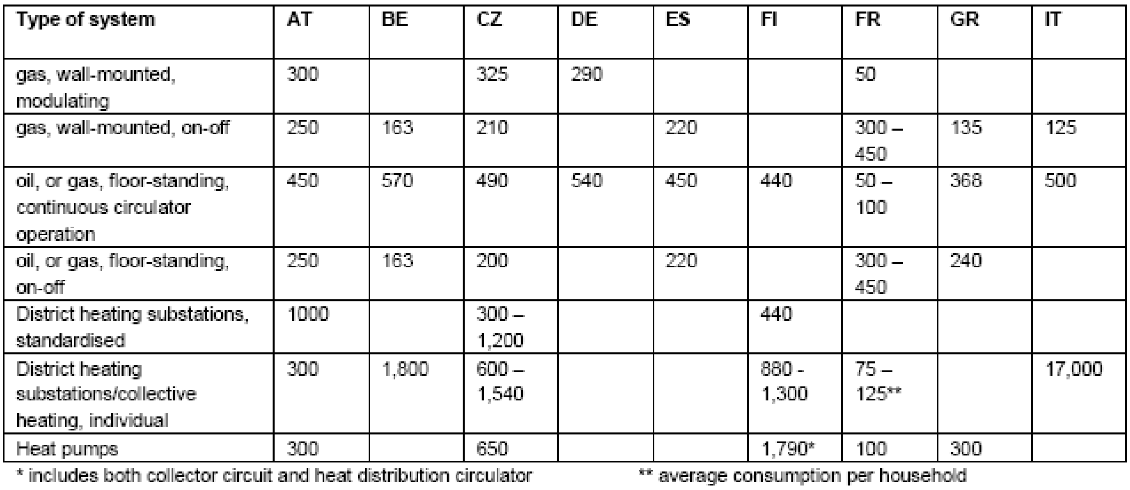


Typical water-based heating system	Annual hours of use	Countries where the heating system is applied
Condensing or low-temperature **gas boilers**, **wall-mounted**, with **modulating burner**, for use in systems with thermostats, **small circulator integrated**	2,500 to 5,000	Austria, Germany, France, Italy
Conventional **gas boilers**, **wall-mounted**, **with on-off control**, for use in systems with room thermostats, **small circulator integrated**	1,900 to 2,500	Austria, Belgium, Spain, France, Greece, Italy
Floor-standing oil or gas boilers (1- or 2-family houses), with control by **outdoor temperature**, **small** circulator stand-alone	5,000 to 8,760	Austria, Belgium, Czech Republic, Germany, Spain, Finland, France, Greece, Italy
Floor-standing oil or gas boilers (1- or 2-family houses), with **on-off control**, small circulator stand-alone	2,500	Austrai, Belgium, Czech Republic, Spain, France,, Greece
District heating substations (standardised, 1- or 2-family houses), with small circulator integrated	8,760	Austria, Finland
District heating substations or collective heating system, medium-sized circulator stand-alone	4,500 to 8,760	Austria, Belgium, Czech Republic, Germany, Spain, Finland, France, Italy
Heat pumps (standardised, 1- or 2-family houses), collector and heat distributor pump integrated	3,000 (collector), 8,760 (distribution)	Austria, Spain, Finland, France, Greece

Source: [BA 07]

The same European wide market study [BA 07] published the average energy consumption in the different countries per year (Table 3.10-4).

Table 3.10-4 Typical water-based heating systems: annual circulator energy consumption (kWh/year)



Type of system	AT	BE	CZ	DE	ES	FI	FR	GR	IT
gas, wall-mounted, modulating	300		325	290			50		
gas, wall-mounted, on-off	250	163	210		220		300 – 450	135	125
oil, or gas, floor-standing, continuous circulator operation	450	570	490	540	450	440	50 – 100	368	500
oil, or gas, floor-standing, on-off	250	163	200		220		300 – 450	240	
District heating substations, standardised	1000		300 – 1,200			440			
District heating substations/collective heating, individual	300	1,800	600 – 1,540			880 - 1,300	75 – 125**		17,000
Heat pumps	300		650			1,790*	100	300	

* includes both collector circuit and heat distribution circulator ** average consumption per household

Source: [BA 07]

For Germany a recent study [STW 07] published slightly different figures for the power demand of a circulator than those shown in Table 3.10-4: the power demand of a circulator in a three-person household in a single family house varies depending on the specific efficiency and the age of the pump from 520 to 800 kWh (for an old pump) and from 60 to 150 kWh (for a new one) with an estimated amount of 6000 working hours per heating period in a year.

Taking the electricity consumption of 50 TWh/a [BA 07] as well as the amount of 105 million circulators (103 million calculated by VHK for 2005 [VHK2 05] plus 2 million due to sales and replacements within 2 years) into account leads to an average power consumption per circulator of about 476 kWh/a.

Due to an initiative of the European pump industry, represented by Europump[1], a general classification like the existing EU Energy label with levels from A to G was devised by Europump in 2005 for the energy efficiency of circulators [EP 05]. In Germany an amendment to the mandatory energy saving legislation [ENEV 07] was recently passed in which the installation of new pumps or replacement of old ones by controlled or high efficiency pumps was regulated.

3.10.4 Effects on energy consumption due to consumer usage

Heating circulation pumps are appliances which are operating usually automatically and on the demand for warmth in the home of the consumer. Therefore the consumption of energy in the period of use is determined by following factors:

- Type of pump (electric motor and motor controller type, etc.)
- Duration of the heating period
- Hydraulic adjustment of the heating system

As reported in the ECEEE summer study [BA 07] private households often do not even know that there is a circulator in their heating system which causes 5 – 10% of their total electricity bill.

The average amount of working hours for circulators in Europe depends on the need for warmth in the households which then in turn depends on the heating days in the different countries. Due to different climate zones in Europe the real demand for room heating varies a lot among the countries. For the calculation of operating hours the heating degree days [WRI 03] respectively heating days of each country are used. When the average temperature of the day is under the “heating limit temperature” of 15°C this day is called “heating day”. Heating degree days are summations of negative differences between the mean daily temperature and the room (base) temperature of 18°C. With data of average temperatures per month for each country published by Eurometeo [EM 07] the average temperature of the heating period was determined (Table 3.10-6). As heating period these months are chosen which reached average temperatures ≤ 15°C. The way for calculating the average temperature in the heating period is shown exemplarily for the UK in Table 3.10-5: all month with an outside temperature ≤ 15°C are used for calculating the average temperature of 8,6°C.

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[1] Europump: European association of pump manufactures

Table 3.10-5 Heating days and average temperature of the heating period (e.g. UK)

Month	**°C**
January	4
February	4
March	6
April	8
May	12
June	15
July	17
August	17
September	14
October	11
November	7
December	5
Average temp. (heating period)	**8,6**

The number of heating days Z [d] is calculated by the following formula:

$$Z\,[d] = G/(ti - tz)$$

where:

G [Kd] = number of heating degree days
ti = 18°C (base temperature)
tz = average outside temperature during the heating period

Source: [EUP13 07]

With the heating degree days' data published by World Resources Institute in 2003 [WRI 03] the heating days are determined as shown in Table 3.10-6.

Table 3.10-6 Heating days in various European countries

Countries	**Heating degree days**	**Heating days**	**Average outside temp. (heating period)**
	G [Kd]	**Z [d]**	**tz [°C]**
Czech Republic	3569	270	4,8
Finnland	5212	345	2,9
France	2478	253	8,2
Germany	3252	264	5,7
Hungary	3057	233	4,9
Italy	1838	167	7,0
Poland	3719	277	4,6
Spain	1431	154	8,7
Sweden	4375	319	4,3
United Kingdom	2810	299	8,6

Source: [EUP13 07]

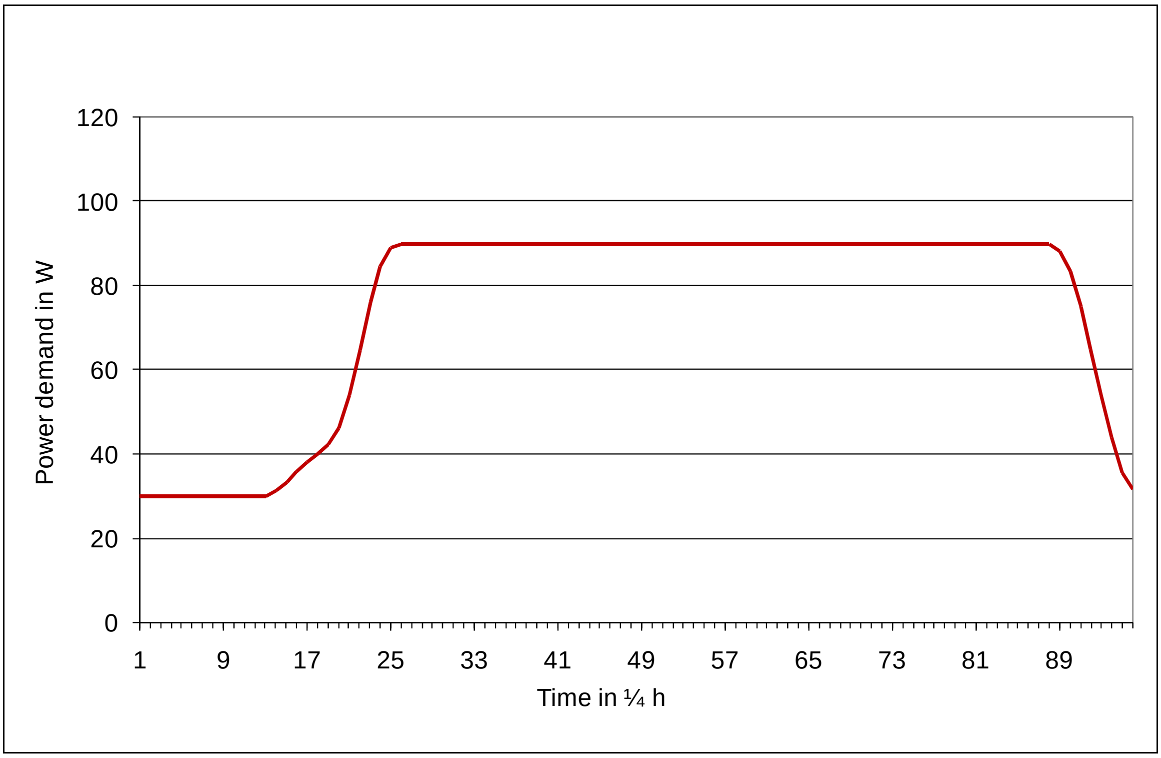
The average of the heating days of Table 3.10-6 amounts to a total of about 258 days to be taken as operating days per year for average European circulators.

3.10.5 Power demand and load curves

The average power consumption per circulator of about 476 kWh/a combined with the amount of 258 operating days per year leads to an average power consumption per circulator of about 1,8 kWh per day in Europe.

Assuming that the power consumption of a circulator is usually high during the day and low at night the daily power demand curve of average circulators in the EU might follow a general pattern as shown in Figure 3.10-3 (power input of 90 W assumed [BA 07]).

Figure 3.10-3 General pattern of a daily load curve of a circulator in an average European household in ¼ hour steps



Source: University of Bonn

3.10.6 Synergistic potentials

Within this chapter it is tried to explore possible synergies when heating circulation pumps are somehow linked to sustainable energy sources, like solar or wind energy or heat from CHP processes. For each of these synergistic potentials it is described where the synergy comes from, what are possible constraints and what needs to be fulfilled to gain the potential. It is also estimated how many appliances might be affected and how these synergies might affect the power demand curve or the probability of operation of heating circulation pumps, including a possible recovery phase. As most of these synergies are not yet realised, they are somewhat hypothetical, but based on best engineering practise. If costs are given, they describe the expected additional prize the consumer has to pay for this feature. If ranges are given, the higher value normally corresponds to an implementation of this feature in a first introduction phase, while the lower value estimates how costs may develop at a large scale use. Results of the consumer survey will be added in a supplementary document to this report.

In the following synergy scenarios the complexity of technical adjustments on the device considered increases from level 1 (3.10.6.1) to level 4 (3.10.6.4) steadily. Whereas in level 1 the consumer still has the full control whether to use the described option or not, in level 2 some of that control was handed over to the machine which then reacts to incoming signals. In level 3 the full control is in the hands of an external manager (e.g. electric utility) who decides about when and how often the machine is being switched on or off after it was set in a ready mode by the consumer. Therefore signals are being transmitted in a bidirectional way. In level 4 additional options for storing energy or using other technologies are taken into account.

3.10.6.1 Shifting operation in time

Id and title: 1-1 Consumer shifts operation in time
Description: The consumer receives a signal about the availability of renewable energy or energy from CHP plants. Depending on the signal, he shifts the operation of a circulator to run at a time, where in relation to the expected load too much electricity is generated. The information about the availability may be communicated via radio (e.g. weather forecast), internet or remote control signals coming from the electricity provider. The consumer has to make his own decision whether to use this information or not. Available timer or “start time delay” options may be used.
Strategy for appliance control: This synergy option requires the active engagement of the consumer by transferring the information of shortage or surplus of renewable energy into the operation of the appliance. The broadcasting of the information may be randomized or varied in time locally to avoid that too many consumers are acting on the same signal at the same time.
Change in power demand curve of single appliance: No change.
Change in day curve (of power demand of all appliances): Circulators with an LED display to inform the householder about the actual power input, water flow or operation mode are already available on the market [STW 07]. This shows that there is a demand for a higher degree of transparency about the circulator operation among the consumers. Therefore the consumer-acceptance for using such a kind of information might be similar to the acceptance for using start time delay functions in other domestic appliances. But due to the fact that the awareness of any energy saving potential in this device is estimated to be quite low and that usually not the final customer but installation constructors are choosing the pump, the potential for using this option is assumed to be very low (2%) as well. As the consumer usually has a precise feeling for temperature changes in a room, a delay of the operation by up to 15 minutes is estimated as the most likely scenario, which will result in a reduction of the operation probability, followed by a recovery period (Figure 3.10-4). But the range for shifting the operation time might vary a lot depending on the preferences of the consumer and therefore even include a shift up to several hours.
Consumer benefits and drawbacks: Enhanced use of renewable energy and CHP. But probably only accepted by convinced environmentalists.

Demand management benefits and drawbacks:

Consumer behaviour is unpredictable. Experience may allow forecasting consumer behaviour. Consumer acceptance may depend on the time of the day, season and the inside temperature of the house.

Impact on appliance design and service provided: (additional costs, limitations, additional energy consumption):

Most of the heating systems today are already equipped with some kind of time setting system. As this regulates the operation of the pump and so there is no need for an extra time system for it, the consumer will not have to bear any additional costs by using this option. Also no additional energy consumption.

Additional costs for consumer: 0 €
Additional energy consumption: 0 W.

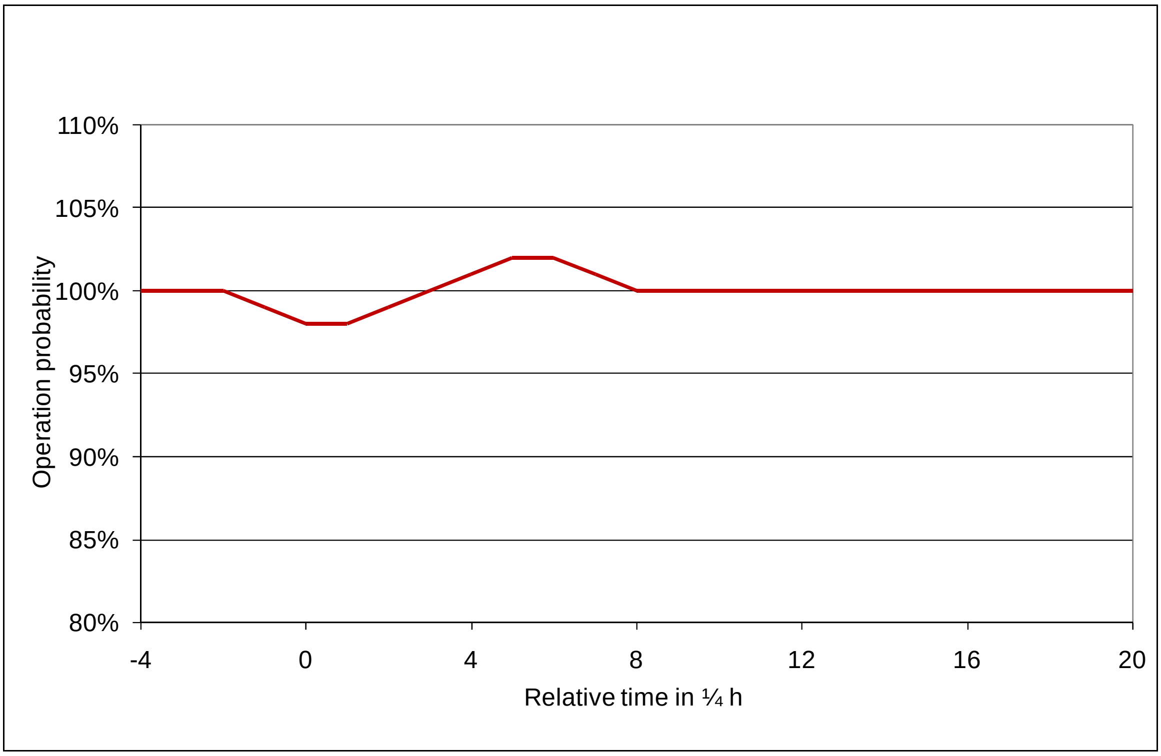
Consumer acceptance questions:

Willingness to accept without direct benefit.

Strategies for success:

Increase environmental awareness and practise

Figure 3.10-4 Example of a change in operation probability for synergy scenario 1-1



Source: University of Bonn

3.10.6.2 Applying flexibility on appliance power demand

Id and title:

2-1 Power line triggered operation

Description:

Signals via e.g. power line may be used to communicate about the shortage of energy on the grid. This can be detected by the washing machine and transferred into action. Action may be an immediate interruption in the operation as far as the device is in a special “ready for operation” mode. Alternatively other means like frequency sensing might be used as the frequency is changing with total load on the grid and low availability of energy will decrease the load and thus the frequency.

Strategy for appliance control:

The operation of the circulator will be interrupted as the machine is working. To avoid an overload by too many machines recovering at the same time, the algorithm used to define the start time shall have a random factor.

Change in power demand curve of single appliance:

No change.

Change in day curve (of power demand of all appliances):

Short breaks (5 – 10 min) might not even be noticed by the consumers and therefore the acceptance for this option could be assumed to be quite high. But as the awareness of circulators as energy using products in the household is assessed to be at a very low level and due to the assumption that the technical supplies required might mostly be implemented only in higher standard or new types, a shift of about 5% of the operations by seconds and minutes up to ¼ hour might be a possible scenario. As far as the pump is working an interruption of the operation will cause a decrease in the operation probability short term, followed by a recovery of the probability (Figure 3.10-5).

Consumer benefits and drawbacks:

Enhanced use of renewable energy and CHP.

Demand management benefits and drawbacks:

Usage depends on the acceptance of the consumer.

Impact on appliance design and service provided: (additional costs, limitations, additional energy consumption):

Additional costs for consumer (frequency sensing or other means): 10 – 50 €
Additional energy consumption: 0 W.

Consumer acceptance questions:

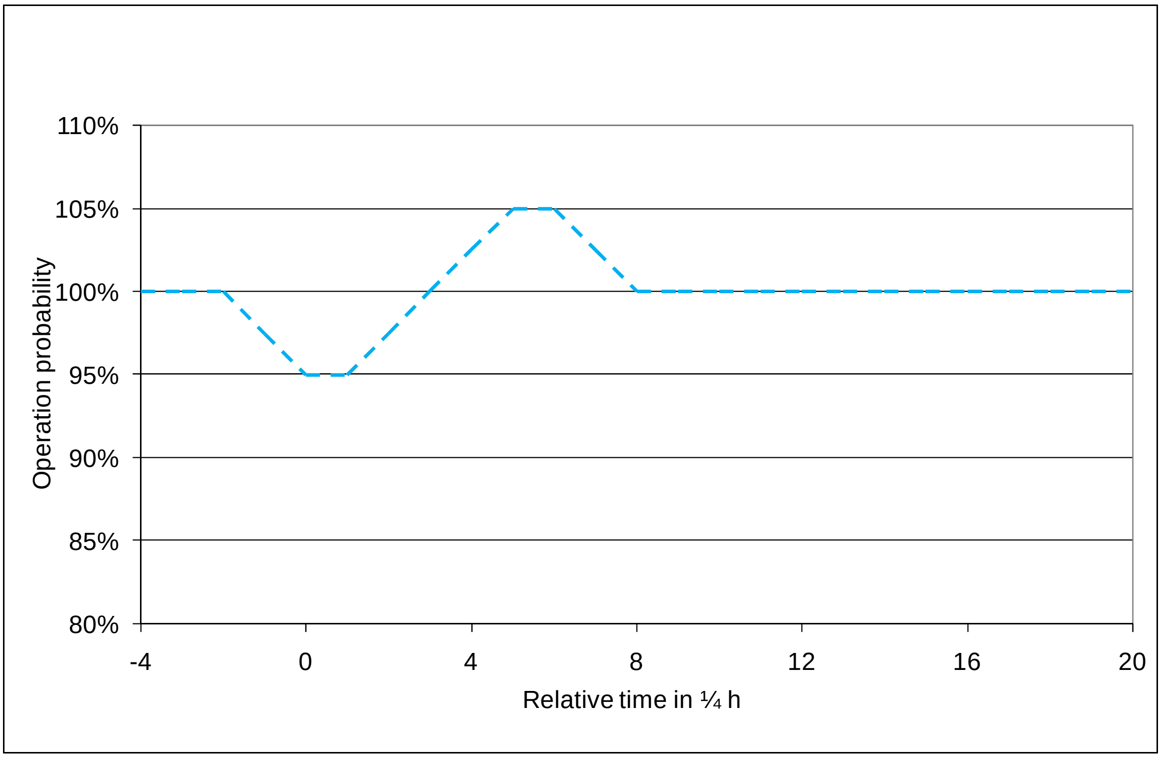
Willingness to accept this solution if additional costs are balanced by savings via energy bill.

Calculation (additional costs: 30 €):
476 kWh/a at 0,20 €/kWh = 95 €/a energy costs
Amortisation in 5 years: 6 €/a saving
Reduction of energy costs by ~6% needed.

Strategies for success:

Define business model where energy utilities sponsor the implementation of these “Power line triggered operation” modules.

Figure 3.10-5 Example of a change in operation probability for synergy scenario 2-1



Source: University of Bonn

Id and title: 2-2 Internal energy manager agent
Description: In modern heating systems often some kind of energy management is already installed (like reducing power demand during the night). This could be optimised by taking external signals about shortage of energy into account which results in a change of the circulator operation: - delay the start - interrupt the operation up to a certain time - reduce the power demand by choosing a slower operation mode (selection of a lower pump speed at times of energy shortage and a higher speed when a huge amount of energy is available)
Strategy for appliance control: The external signal should include information on the shortage of energy and how long it may last. Pumps in an appropriate state will then react by their own intelligence to find the appropriate answer.
Change in power demand curve of single appliance: Various. Possible are short breaks in the operation for a few minutes or up to an hour (depending on the temperature range for the inside temperature chosen by the consumer and the outside temperature).
Change in day curve (of power demand of all appliances): As explained earlier (see 2-1) it is estimated that 5% of the devices may be used in the described mode and allow to shift the operation by seconds, minutes and up to an hour. Assuming a shift of 1 hour the operation probability will be changed as shown in Figure 3.10-6.
Consumer benefits and drawbacks: Enhanced use of renewable energy and CHP. Too long breaks will cause a loss of comfort for the consumer.

Demand management benefits and drawbacks:

Influence on power demand by short term action. Effect will depend on the time of the day, the season and the penetration of energy management agents in circulators.

Impact on appliance design and service provided: (additional costs, limitations, additional energy consumption):

Internal energy manager agent needs to be included in electronic unit of the device.
A harmonised signal of power shortage is needed.
Additional costs for consumer (signal recognition plus energy agent): 10 - 100 €.
(As controlled and high efficiency pumps are already available on the market these types are taken as basis for the estimation of the additional costs).
Additional energy consumption: 0 W.

Consumer acceptance questions:

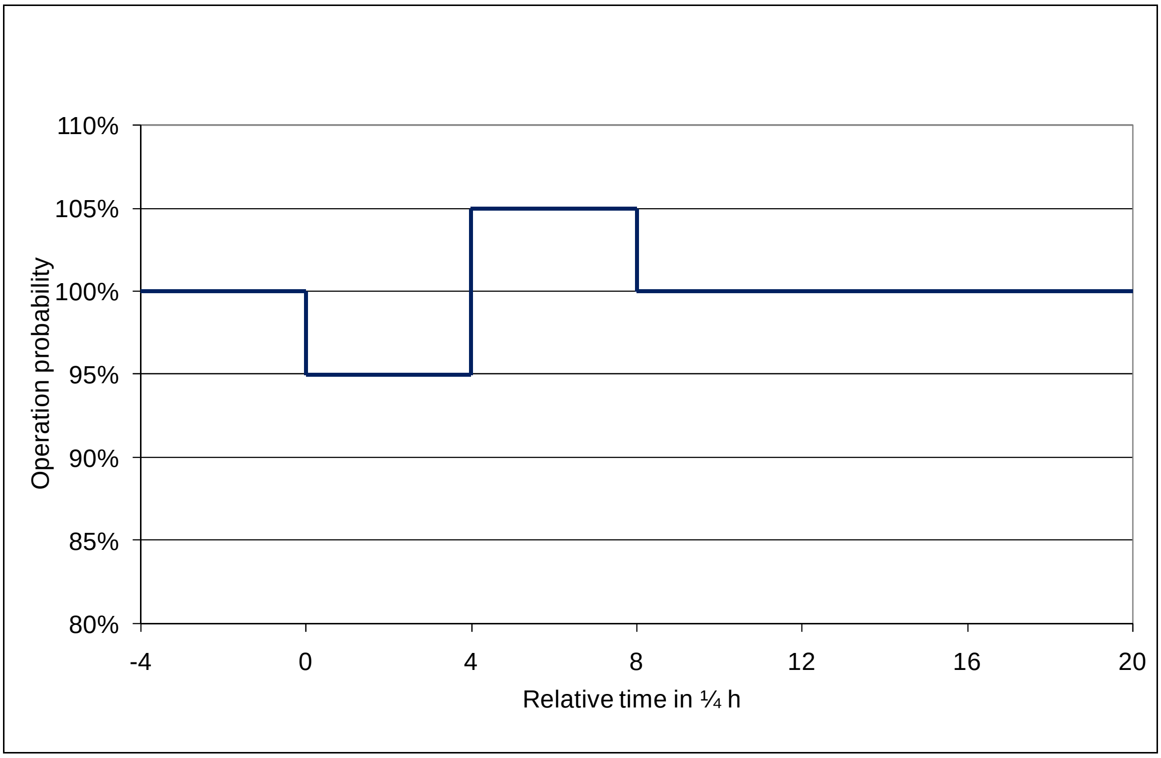
Willingness to accept this solution if additional costs are balanced by savings via energy bill.

Calculation (additional costs: 55 €):
476 kWh/a at 0,20 €/kWh = 95 €/a energy costs
Amortisation in 5 years: 11 €/a saving
Reduction of energy costs by ~12% needed.

Strategies for success:

Define harmonised signal for shortage of power (CENELEC).
Define business model where energy utilities sponsor the implementation of these “Internal energy management agent” modules.

Figure 3.10-6 Example of a change in operation probability for synergy scenario 2-2

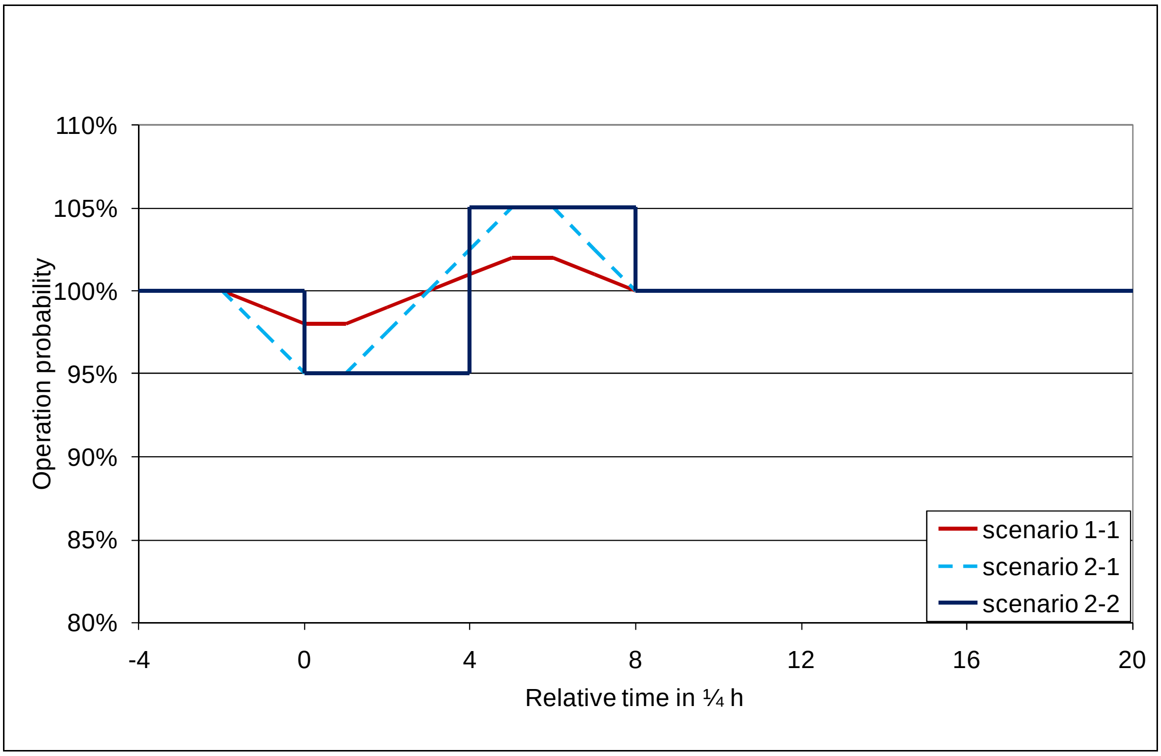


Source: University of Bonn

3.10.6.3 Managing the power on the grid

Id and title: 3-1 Energy demand manager
Description: The energy demand manager tries to harmonise the available power on the grid coming from conventional and renewable resources with the demand. Therefore the energy demand manager decides about the start (or stop) of the pump within a predefined time interval. The energy demand manager is informed about the warmth demand of the house (temperature in the house, the range of possible fluctuations of the temperature chosen by the consumer), the outside temperature and thus the expected energy demand.
Strategy for appliance control: Knowing the demand for the next few hours the energy demand manager tries to use as much renewable energy and CHP as possible and optimises the overall costs.
Change in power demand curve of single appliance: No change.
Change in day curve (of power demand of all appliances): May allow shifting perhaps 5% of the operations at any time by seconds, minutes and up to an hour (estimation see 2-1) according to the probability curves as shown for the synergy scenarios 1-1, 2-1 and 2-2 (Figure 3.10-7). As the consumer is not involved in the operation of the device any more, the probability curve of scenario 1-1 (delayed start) stands for a second option of scenario 2-2.
Consumer benefits and drawbacks: Enhanced use of renewable energy and CHP. Cost benefits must be transferred to the consumer.
Demand management benefits and drawbacks: Influence on power demand by medium term action. Influence only on those pumps which are running.
Impact on appliance design and service provided: (additional costs, limitations, additional energy consumption): Bidirectional communication needed. Additional switch needed to signal ‘remote operation accepted’. A harmonised communication protocol is needed. Additional costs for consumer (communication module via power line): 30 – 130 €. (As controlled and high efficiency pumps are already available on the market these types are taken as basis for the estimation of the additional costs). Additional energy consumption: 0 W.
Consumer acceptance questions: Willingness to accept this solution if additional costs are balanced by savings via energy bill. Calculation (additional costs: 80 €): 476 kWh/a at 0,20 €/kWh = 95 €/a energy costs Amortisation in 5 years: 16 €/a saving Reduction of energy costs by ~17% needed.
Strategies for success: Define harmonised communication protocol (CENELEC). Define business model where savings balance the additional costs for the appliance.

Figure 3.10-7 Change in operation probability for synergy scenarios 3-1 (any of 1-1, 2-1, 2-2)



Source: University of Bonn

3.10.6.4 Using energy storage capacity and other technologies

Any additional scenarios regarding the issues of this section did not seem to be very realistic for heating circulation pumps at present.

3.11 Domestic appliances: summary of results

The following Table 3.11-1 summarises all figures which are calculated or estimated for the ten appliances in the analysis within chapter 3. In the first part some data of the devices are given followed by estimated figures for a potential use of the options described in scenario 1-1 to 3-1: for the estimated acceptance of a delay in the operation time of the appliance and for the estimated range of additional costs for the consumer as well as the likely additional power demand. These are the figures used in the evaluations of economic efficiency in each synergy scenario which are summed up in the following part of the table. The figures are calculated as follows: from the average of the additional investment costs for the consumer the amortisation costs per year of this measure over a period of 5 years is calculated (linear). This figure is then compared to the total energy costs per year for the use of this appliance which describes the amount of which either the energy costs per year should be reduced (indicated by "-" in Table 3.11-1) or the energy price could be raised (indicated by "+" in Table 3.11-1). Some headwords for each of the level 4 scenarios are finalising the table.

The results of the economic efficiency calculations for an implementation of the option in focus range from no reduction of the electricity costs to a reduction of up to 53% of the assumed electricity costs needed for an amortisation of the additional investment costs within a period of 5 years. Apart from some options which are so expensive that it would not be possible for them to pay off within this time at all, most of the options investigated are lying within this range for all appliances. Therefore their economical relevance strongly depends on a reduction of electricity costs. A few of the options would be economically beneficial for the consumer even without any incentive due to the relative low additional costs and the huge amount of electricity to be saved by an implementation of the option. Some of the options of level 4 are showing a good potential for synergies but are yet too expensive.

Table 3.11-1 Results of the appliance analysis

	Appliances									
	WM	TD	DW	OS	RF	FR	AC	WH	EH	CP
Energy consumption per day (cycle) [kWh]:	0,89	2,46	1,19	0,61	0,79	1,1	1,7	2,7	59	1,8
Energy consumption per hh/a [kWh]:	150	251	241	420	403,5	414	900	A 1900 B 950 C 1900	15532	476
Penetration [%]:	95	34,4	42	77	106	52	8	23	8	70
Water consumption per hh/a [m^3]:	11,22	-------	4,06	-------	-------	-------	-------	-------	-------	-------
Energy costs per year [€] at 0,20 €/kWh (0,10 €/kWh for EH):	30	50	50	84	80	83	180	A 380 B 190 C 380	1553	95

		Appliances									
		WM	**TD**	**DW**	**OS**	**RF**	**FR**	**AC**	**WH**	**EH**	**CP**
Estimated use of this option [%]:	1-1	10	5	20	5	5	5	10	A ----- B ----- C 1	-------	2
	2-1	10	-------	10	5	100 (UK) 10	100 (UK) 5	10	A 75 B 50 C -----	90	5
	2-2	10	30	20	5	5	5	10	A 75 B 50 C -----	90	5
	3-1	10	max. 30	max. 20	5	max. 100 (UK) max. 10	100 (UK) 5	10	A 75 B 50 C -----	90	max. 5
Estimated delay of the operation: most likely / maximum	1-1	3h / 9h	3h / 9h	up to 19h	up to 30 min	up to 30 min	up to 30 min	up to 1h	A ----- B ----- C up to 30 min	-------	up to ¼h
	2-1	3h / 9h	-------	3h / 19h	sec.	sec. - min.	sec. - min.	sec. - min. or up to 1h	A up to hrs B sec. - min. C -----	2h / several hrs	up to ¼h
	2-2	sec.,min. / ¼h	sec.,min. / ¼h	sec.,min. / ¼h	sec.	sec. - min.	sec. - min.	¼h / 1h	A up to hrs B sec. - min. C -----	2h / several hrs	up to 1h
	3-1	3h / 9h	3h / 9h	3h / 19h	sec.	sec. - min.	sec. - min.	up to 1h	A up to hrs B sec. - min. C -----	2h / several hrs	up to 1h
Additional costs for consumer in synergy scenario [€]:	1-1	5 - 25	5 - 25	5 - 25	0	0	0	5 - 25	A ----- B ----- C 5 - 25	-------	0
	2-1	10 - 50	-------	10 - 50	10 - 50	2 - 5 (UK) 10 - 50	2 - 5 (UK) 10 - 50	10 - 50	A 10 - 50 B 10 - 50 C -----	10 - 50	10 - 50
	2-2	10 - 100	10 - 100	10 - 100	10 - 100	10 - 100	10 - 100	10 - 100	A 10 - 100 B 10 - 100 C -----	10 - 100	10 - 100
	3-1	30 - 130	30 - 130	30 - 130	30 - 130	30 - 130	30 - 130	30 - 130	A 30 - 130 B 30 - 130 C -----	30 - 130	30 - 130
	4-1	150 - 250	100 - 400	150 - 250	-------	40 - 50	40 - 200	8 - 12 80 - 120	A 80 - 120 B 80 - 120 C -----	180 - 220	-------
	4-2	50 - 150	-------	50 - 150	-------	too exp.	40 - 200	140 - 160	-------	-------	-------
	4-3	60 - 120	-------	-------	-------	-------	too exp.	50 - 70	-------	-------	-------
	4-4	-------	-------	-------	-------	-------	-------	too exp.	-------	-------	-------
Additional power demand [W]:	all	2 (if specified)									
Average additional costs [€]:	1-1	15	15	15	0	0	0	15	A ----- B ----- C 15	-------	0
Amortisation in 5 years by savings per year of…[€]:		3	3	3	0	0	0	3	A ---- B ---- C 3	-------	0
Energy costs per year [€]:		30	50	50	84	80	83	180	A ---- B ---- C 380	-------	95
Energy cost reduction (-) / rise (+) per year…[%]:		-10	-6	-6	-------	-------	-------	-2	A ---- B ---- C -1	-------	-------

		Appliances									
		WM	**TD**	**DW**	**OS**	**RF**	**FR**	**AC**	**WH**	**EH**	**CP**
Average additional costs [€]:	2-1	30	-------	30	30	3,5 (UK) 30	3,5 (UK) 30	30	30	30	30
Amortisation in 5 years by savings per year of…[€]		6	-------	6	6	0,7 (UK) 6	0,7 (UK) 6	6	6	6	6
Energy costs per year [€]:		30	-------	50	84	80	83	180	A 380 B 190 C ----	1553	95
Energy cost reduction (-) / rise (+) per year…[%]		-20	-------	-12	-7	-1 (UK) -8	-1 (UK) -7	-3	A -2 B -3 C ----	-0,4	-6
Average additional costs [€]:	2-2	55	55	55	55	55	55	55	55	55	55
Amortisation in 5 years by savings per year of…[€]		11	11	11	11	11	11	11	11	11	11
Energy costs per year [€]:		30	50	50	84	80	61	180	A 380 B 190 C ----	1553	95
Energy cost reduction (-) / rise (+) per year…[%]		-37	-22	-22	-13	-14	-13	-6	A -3 B -5 C ----	-0,7	-12
Average additional costs [€]:	3-1	80	80	80	80	80	80	80	80	80	80
Amortisation in 5 years by savings per year of…[€]		16	16	16	16	16	16	16	A 10 B 10 C ----	16	16
Energy costs per year [€]:		30	50	50	84	80	83	180	A 380 B 190 C ----	1553	95
Energy cost reduction (-) / rise (+) per year…[%]		- 53	- 32	- 32	- 19	- 20	- 19	- 9	A -3 B -6 C ----	- 1	- 17
Average additional costs [€]:	4-1	200	250	200	-------	45	120	100	A 100 B 190 C ----	200	-------
Amortisation in 5 years by savings per year of…[€]		40	50	40	-------	9	24	20	A 20 B 20 C ----	40	-------
Energy costs / reduced energy costs per year [€]:		30	50 / 8	50 / 25	-------	80	83	180	A 380/304 B 190/170 C ----	1553 / 1087	-------
Energy cost reduction (-) / rise (+) per year…[%]		too exp.	-16	-30	-------	-11	-29	-11	A +15 B 0 C ----	+ 27	-------
Average additional costs [€]:	4-2	100	-------	100	-------	too exp.	120	150	-------	-------	-------
Amortisation in 5 years by savings per year of…[€]		20	-------	20	-------	-------	24	30	-------	-------	-------
Energy costs / reduced energy costs per year [€]:		30 / 19	-------	50 / 6	-------	80	83	180	-------	-------	-------
Energy cost reduction (-) / rise (+) per year…[%]		- 30	-------	+ 48	-------	-------	-29	- 17	-------	-------	-------
Average additional costs [€]:	4-3	90	-------	-------	-------	-------	too exp.	60	-------	-------	-------
Amortisation in 5 years by savings per year of…[€]		18	-------	-------	-------	-------	-------	12	-------	-------	-------
Energy costs / reduced energy costs per year [€]:		30 / 7	-------	-------	-------	-------	61	180	-------	-------	-------
Energy cost reduction (-) / rise (+) per year…[%]		+ 17	-------	-------	-------	-------	-------	-7	-------	-------	-------

		Appliances									
		WM	**TD**	**DW**	**OS**	**RF**	**FR**	**AC**	**WH**	**EH**	**CP**
Average additional costs [€]:	4-4	-------	-------	-------	-------	-------	-------	0	-------	-------	-------
Amortisation in 5 years by savings per year of…[€]		-------	-------	-------	-------	-------	-------	0	-------	-------	-------
Energy costs / reduced energy costs per year [€]:		-------	-------	-------	-------	-------	-------	180	-------	-------	-------
Energy cost reduction (-) / rise (+) per year…[%]		-------	-------	-------	-------	-------	-------	-------	-------	-------	-------
Short info level 4:	4-1	Energy storage	Heat by CHP, solar	Use of hot water	----	Energy storage	Energy storage	Cold storage	Heat by CHP solar	Use of solar	----
	4-2	Use of hot water	----	Heat by CHP, solar	----	Absorber	Energy storage (phase change material)	Inverter	----	----	----
	4-3	Heat by CHP, solar	----	----	----	----	Absorber	Cool outdoor air	----	----	----
	4-4	----	----	----	----	----	----	Absorber	----	----	----

Source: *University of Bonn*

4 Summary

Current policies and measures for increasing the share of renewable energies in power generation systems lead to intensified requirements on the coordination of energy demand and supply. The challenges on a load management with an increasing part of fluctuating energy generation by renewable energies – i.e. mainly by solar and wind power – will increase more and more in the future. The need for a thorough coordination of the generation and the demand side is also essential for the supply of heat if generated by renewable sources or combined heat and power systems. As about 30% of the electricity consumption in Europe is caused by the residential sector and thereof the biggest part by domestic appliances it is essential to include them into future flexible energy systems.

In this report the following ten devices

- washing machine
- tumble dryer
- dishwasher
- oven and stove
- refrigerator
- freezer
- air conditioner
- water heater
- electric heating (storage unit)
- heating circulation pump

have been analysed about their synergy potential in respect of the

- possibilities for a more efficient use of power and heat supplied by renewable energies or CHP,
- ability to adapt their operation to the requirements set by the energy supply,
- technical possibilities for a more flexible use,
- additional costs of such smart appliances as compared to conventional appliances and the
- additional energy consumption due to a smart operation.

The fluctuation of the power demand concerning an individual household mainly depends on consumer behaviour, the technical equipment used by a household and the regional circumstances like climate. The theoretical model on which this survey is based upon describes the power demand per household appliance and the average power demand per day of a bundle of household appliances, both local and regional. It also identifies the relevant parameters for the possibilities of domestic appliances to adapt their operation to the requirements set by the energy supply.

Existing studies and data have been collected and summarised for each appliance with regard to their technical functionality due to the use of water and energy, their market penetration as well as energy and water consumption in Europe, the effects on energy and water consumption due to the usage of the consumers as well as the power demand and load curves of the devices. Based on this data synergistic potentials for a smarter use of each appliance have been investigated and possible constraints were identified. In four different levels the synergy potential of each appliance when operated under smart energy conditions and connected to regenerative energy sources or CHP were investigated regarding what additional technical elements are needed to enable a smart operation and what is the amount of additional costs and energy required. The complexity of technical adjustments increases from level 1 to level 4 steadily. Level 1, 2 and 3 deal with the operation probability of the appliance with different levels of connectivity to smart energy systems. In level 4 the possibilities of the device for a more intense use of renewable energy and CHP in connection to other technologies and storage capacities were investigated. Specific opportunities and restrictions have been pointed out for each appliance.

After the detailed analysis of each single type of appliance by itself the effect of having all appliances operating during one day in one average household in Europe and in specified European regions was investigated for year 2010 and 2025. The regions which were defined as representative for the different parts of Europe and included in the analysis are:

- Region A: South Europe
- Region B: Scandinavia
- Region C: New Member States
- Region D: Germany/Austria
- Region E: United Kingdom

Depending on the region the actual load curve is different, as penetration of appliances and usage is different. Common for all is a high level of power consumption during day time, which may be seen as a natural consumer of renewable solar energy generated. Also common is a high peak in the evening. Here strategies to shift the peak into night are needed as then wind energy may be used.

Domestic appliances offer a wide range of opportunities to contribute to a load management in energy systems with an increasing part of fluctuating energy generation when being adjusted with latest technique and smart controlling options. The market penetration of such smart appliances will mainly depend on the acceptance by the consumers and therefore on the costs and benefits of smart devices in comparison to conventional ones.

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