



Preparatory study on Smart Appliances

Task 3 Users

Rheinische Friedrich-Wilhelms-Universität Bonn: Jasmin Geppert & Prof. Rainer Stamminger
VITO: Sven Claessens, Helena Gerard, Ana Virag & Koen Vanthournout
Armines: Marcel Perret-Gentil & Philippe Rivière
Viegand Maagøe A/S: Jan Viegand
Wuppertal Institut: Thomas Götz
Project management: Sarah Bogaert

Study accomplished under the authority of the European Commission DG Energy
under framework contract ENER.C3.2012-418-lot 1
2014/TEM/R/

Task 3 report
Version: 3 May 2016



VITO NV

Boeretang 200 - 2400 MOL - BELGIE
Tel. + 32 14 33 55 11 - Fax + 32 14 33 55 99
vito@vito.be - www.vito.be

BTW BE-0244.195.916 RPR (Turnhout)
Bank 375-1117354-90 ING
BE34 3751 1173 5490 - BBRUBEBB

The information and views set out in this study are those of the author(s) and do not necessarily reflect the opinion of the European Commission. The Commission does not guarantee the accuracy of the data included in this study. Neither the Commission nor any person acting on the Commission's behalf may be held responsible for the use which may be made of the information contained therein. This report has been prepared by the authors to the best of their ability and knowledge. The authors do not assume liability for any damage, material or immaterial, that may arise from the use of the report or the information contained therein.

All rights, amongst which the copyright, on the materials described in this document rest with the Flemish Institute for Technological Research NV ("VITO"), Boeretang 200, BE-2400 Mol, Register of Legal Entities VAT BE 0244.195.916.

TABLE OF CONTENTS

1	TASK 3 - USERS	1
1.1	<i>End-user perspective</i>	1
1.1.1	Drivers and barriers for the uptake of smart appliances	1
1.1.1.1	Drivers to buy/ use smart appliances	3
1.1.1.2	Barriers to buy/ to use smart appliances	4
1.1.1.3	Additional costs and expected financial gains	6
1.1.1.4	Possibilities to raise consumer acceptance	6
1.2	<i>End-use parameters and user requirements of appliances</i>	8
1.2.1	Periodical appliances	8
1.2.1.1	Usage Behaviour	8
1.2.1.2	User behaviour concerning periodical appliances	10
1.2.1.3	Lifespan	19
1.2.1.4	Possibilities for consumers to engage in smart periodical appliances	19
1.2.1.5	Comfort constraints and consumer objections	20
1.2.2	Continuous appliances	21
1.2.2.1	Usage Behaviour	21
1.2.2.2	User behaviour concerning continuous appliances	22
1.2.2.3	Lifespan	35
1.2.2.4	Possibilities for consumers to engage in smart continuous appliances	35
1.2.2.5	Comfort constraints and consumer objections	37
1.2.3	Behavioural appliances	37
1.2.3.1	Usage Behaviour	37
1.2.3.2	User behaviour concerning behavioural appliances	40
1.2.3.3	Lifespan	43
1.2.3.4	Possibilities for consumers to engage in smart behavioural appliances	43
1.2.3.5	Comfort constraints and consumer objections	44
1.2.4	HVAC	44
1.2.4.1	User behaviour concerning HVAC appliances	44
1.2.4.2	Comfort constraints	44
	OCCUPATION SCHEDULES	48
1.2.5	Battery operated rechargeable appliances	54
1.2.5.1	Usage Behaviour	54
1.2.5.2	User behaviour concerning charging	55
1.2.5.3	Comfort constraints	55
1.2.5.4	Occupation Schedules	55
1.2.5.5	Lifespan	56
1.2.6	Residential energy storage system	59
1.2.6.1	Usage behaviour	59
1.2.6.2	User behaviour concerning charging	60
1.2.6.3	Comfort constraints	60
1.2.6.4	Occupation Schedules	61
1.2.6.5	Lifespan	61
1.2.6.6	Energy consumption and shifting potential per appliance per day / per season (refer to task 1 for more information) for 27 EU member states.	62
1.2.7	Lighting	63
1.2.7.1	Usage Behaviour	63
1.2.7.2	Comfort constraints	64

1.2.7.3	Lifespan	65
1.2.8	Conclusions	66
1.3	<i>Data protection, data security and consumer rights</i>	69
1.4	<i>Recommendations on refined product scope</i>	72
1.5	<i>Demand side flexibility use cases – system perspective</i>	74
1.5.1	Definition of use cases	75
1.5.2	EU target model and scenarios	77
1.5.3	Demand/Load, installed capacity and fuel prices	78
1.5.3.1	Demand or Load	78
1.5.3.2	Installed capacity per Member State	78
1.5.3.3	Fuel prices	79

LIST OF FIGURES

Figure 1: General pattern of a power demand curve of an average dishwasher operating in a normal cleaning programme (source: Stamminger et al., 2009)	10
Figure 2: Frequency of operation of dishwashers during the day (Source: EUP LOT 14)	11
Figure 3: Probability of start time of the dishwasher operation for the ten European countries investigated (source: Stamminger et al., 2009)	11
Figure 4: General pattern of a daily load curve of a current dishwasher (source: modified according to Stamminger et al., 2009)	12
Figure 5: Average energy consumption for 10 European countries in 2011 (Source: Schmitz and Stamminger, 2014).....	13
Figure 6: Typical pattern of a power demand curve of an average washing machine operating in a normal cotton programme (source: Stamminger et al., 2009).....	13
Figure 7: Frequency of operation of washing machines during the day (Source: EUP LOT 14).....	14
Figure 8: Probability of start time of the washing machine operation for the ten European countries investigated (source: Stamminger et al., 2009)	15
Figure 9: General pattern of a daily load curve of a current washing machine (source: modified according to Stamminger et al., 2009).....	15
Figure 10: Typical pattern of a power demand curve of an average conventional tumble dryer operating in a normal cotton programme (source: Stamminger et al., 2009)	16
Figure 11: Typical pattern of a power demand curve of an average heat pump tumble dryer operating in a normal cotton programme (source: own illustration).....	17
Figure 12: General pattern of a daily load curve of a current conventional tumble dryer for winter and summer season (source: modified according to Stamminger et al., 2009)	18
Figure 13: General pattern of a daily load curve of a current heat pump tumble dryer for winter and summer season (source: own illustration).....	18
Figure 14: Typical pattern of a power demand curve of a refrigerator (Source: Stamminger et al., 2009)	23
Figure 15: Frequency of door openings during the day (source: Thomas, 2007)	24
Figure 16: General pattern of a daily load curve of an average refrigerator (source: Stamminger et al., 2009).....	25
Figure 17: Typical pattern of a power demand curve of a freezer during storage of new goods to be frozen (source: Stamminger et al., 2009).....	26
Figure 18: General pattern of a daily load curve of an average freezer (Source: Stamminger et al., 2009)	27
Figure 19 Daily consumption patterns of compressors in commercial refrigeration appliances, expressed in [kW/m ²], and given in dependence on the climatic zone and season in the year.	30
Figure 20: Hot water consumption per household per day for EU-25 (source: own illustration based on EUP LOT 2).....	31
Figure 21: Daily hot water consumption by season and weekday (source: BfK, 1993; taken from Stamminger et al., 2009).....	32
Figure 22: Profile of daily hot water consumption in Switzerland (source: BfK, 1993; taken from Stamminger et al., 2009).....	32
Figure 23: Profile of daily hot water consumption in UK (own illustration deduced from Defra, 2008)	33
Figure 24: General pattern of a power demand curve of NSWH (source: own illustration)	34
Figure 25: Estimated distribution of electricity consumption of NSWH over 24 hours of a day (source: own illustration deduced from ATG, 2016).....	34
Figure 26: Typical pattern of a daily load curve of a 1.5 kW CSWH (source: own illustration)	35

Figure 27: Daily power demand curve of an electric hob (source: Sidler, 1999⁶³)..... 41

Figure 28: Daily power demand curve of an electric oven (source: Sidler, 1999⁶³) 41

Figure 29: Typical pattern of a power demand curve of an electric hob (Source: Stamminger et al., 2009)..... 42

Figure 30: Typical pattern of a power demand curve of an electric oven (Source: Stamminger et al., 2009)..... 42

Figure 31: General pattern of a daily load curve of an electric oven in an average European household (source: Stamminger et al., 2009) 43

Figure 32: Average cooling demand EU28 (A/C stock and Cooling-degree-days)..... 47

Figure 33: EU28 Climate division for HVAC profiles case studies..... 48

Figure 34 : Time plugged in 56

Figure 35: Source: Consumer Electronics Association (CEA), 2014 CE Product Life Cycle. Base: U.S. Adults (n=1,013) 57

Figure 36: Battery storage requirements versus latitude. (<http://euanmearns.com/how-much-battery-storage-does-a-solar-pv-system-need/>)..... 62

LIST OF TABLES

Table 1: Rated power of heating devices (source: Stamminger et al., 2009)	9
Table 2: Average life span of periodical appliances (Source: ^a VHK, 2014; ^b EUP LOT 14; ^c Lefèvre, 2009)	19
Table 3: Rated power of devices (source: Stamminger, 2009 ⁸)	22
Table 4 Area of supermarkets expressed in converted m ² per EU-28 member state (source: calculation disclosed by correspondence by Danfoss).....	28
Table 5 (source: private correspondence with Danfoss)	29
Table 6 Share of smart enabled commercial refrigeration appliances in the total share of commercial refrigeration appliances (source: correspondence with Danfoss).....	29
Table 7: Average life span of continuous appliances (Source: ^a VHK and Armines, 2015; ^b CECED, 2006; ^b EUP LOT 2)	35
Table 8: Rated power of devices in stock (source: ^a Schätzke, 1997; ^b HEA; ^c EUP LOT 17, ^d Stamminger et al., 2009)	38
Table 9: Average life span of behavioural appliances (Source: ^a EUP LOT 23; ^b EUP LOT 22)	43
Table 10: Heating season for EU27 (Bio Intelligence Service, 2012) (values are weighted by dwelling stock).....	45
Table 11: Cooling season for EU27 (VHK, 2014 ²³)	46
Table 12: (Bio Intelligent Service, 2012 ⁶⁷) *Source: (Eco-design Boilers, 2007)	50
Table 13: Mobile subscriptions in Europe.....	57
Table 14: Cycle life as a function of depth of discharge (source: http://batteryuniversity.com/learn/article/how_to_prolong_lithium_based_batteries)	61
Table 15: Estimated recoverable capacity when storing Li-ion for one year at various temperatures	61
Table 16: Recommendation for scope and length of data retention (Smart Grids Task Force, 2011)	71
Table 17: Categorisation of appliances according to their load shifting potentials (categorisation in terms of energy or number of products/ applicability of demand shift).....	73
Table 18 Installed RES capacity and peak load per EU-28 Member State per year (Source: ENTSO-E database for 2014 for all Member States except Malta, PRIMES scenario outcomes for 2020 and 2030, and for Malta for 2014, and for peak load in Malta Enemalta)	79
Table 19: Fuel prices for 2014, 2020 and 2030 used in the model.....	80

LIST OF ACRONYMS

AC	Air Conditioning
ADSL	Asymmetric Digital Subscriber Line
BAT	Best Available Technology
BRP	Balancing Responsible Parties
CFL	compact fluorescent light
CHP	Combined Heat and Power
CSWH	hot water buffers; continuous water heaters
DHW	Domestic Hot Water
DOCSIS	Data Over Cable Service Interface Specification
DR	Demand response
DSF	Demand side flexibility
DSO	Distribution System Operators
ETSI	European Telecommunications Standards Institute
EV	Electric vehicle
GLS	general lighting service 'incandescent'
GSM	Global System for Mobile Communications
GW	gigawatt
HEG	Home Energy Gateway
HID	high intensity discharge lamp
HVAC	Heating, Ventilation and Air Conditioning
K	Temperature expressed in Kelvin
LED	light emitting diode
LFL	linear fluorescent lamp
LTE	3GPP Long Term Evolution (4G)
M2M	Machine to Machine
NRVU	Non-Residential Ventilation Units
NSWH	Night storage water heaters
PLC	power line communication
PV	Photovoltaic
RES	Renewable Energy Sources
RVU	Residential Ventilation Units
SAREF	Smart Appliances REference ontology
SOC	State Of Charge
TSO	Transmission System Operators
TWh	TeraWatt hour
UMTS	Universal Mobile Telecommunications System
UPS	Uninterruptible power supply
VDSL	Very-high-bitrate Digital Subscriber Line
VRF	variable refrigerant flow

1 TASK 3 - USERS

Task 3 is about describing and quantifying the current situation for the users which will be impacted by making appliances Demand Side Flexibility (DSF) enabled.

The first part of this Task report handles the perspective of the end-user of smart appliances. An overview of the main drivers and barriers in taking up smart appliances is given along with possibilities to overcome the barriers and raise consumer's acceptance. Furthermore, an in-depth analysis is provided of the user behaviour in view of the smart appliances defined in Task 1. A separate section addresses data protection, data security and consumer rights.

The use of DSF can serve multiple objectives from an energy system perspective which is covered in the second part of this Task report. It can be used to optimize the day-ahead scheduling of electricity production and consumption. Second, it allows in real-time to match supply and demand in case of deviations in scheduling. These use cases are explained in detail and the role of smart appliances as provider of flexibility is discussed. In Task 5, for these use cases a model will be developed allowing the environmental product assessment and definition of the base cases.

Note that the core focus of this Task report is on the impact of the use of smart appliances on the end consumer and the resulting flexibility generated to feed into the use cases, making abstraction of any specific energy market structure.

1.1 END-USER PERSPECTIVE

1.1.1 DRIVERS AND BARRIERS FOR THE UPTAKE OF SMART APPLIANCES

Shifting loads in private households by using smart appliances may require behavioural changes and some adaptations of consumer's everyday routines. Consequently, the potential of smart appliances depends on the consumer acceptance and the use of smart appliances, which are among the most crucial key factors to make this new technology being successful.

The degree to which consumers tend to implement smart appliances will depend on technical, behavioural and economic drivers and barriers and their interaction. In the following, this report gives a general overview of the current state of consumer acceptance in view of smart appliances. It points out major barriers and provides strategies to overcome these objections, to raise the consumer acceptance and for a successful market penetration of smart technologies. Economic drivers/ barriers linked to business models are discussed more in detail in section 2.2.4 in Task 2 of this report.

The S3C project¹, which aimed at research of "best practice end-user engagement strategies and tools", took both, a theoretical and an empirical approach to gain information on drivers and barriers for implementing smart appliances. From a theoretical point of view, the S3C project analysed the process of behavioural changes, which is required for the implementation of smart appliances. As

¹ S3C project: D1.1 FINAL WP 1: "Framing – Development of the theoretical framework". Deliverable 1.1: "Report on state-of-the-art and theoretical framework for end-user behaviour and market roles".

most energy –related processes (e.g. operating dishwasher or washing machine, cooking etc.) are rather habitual processes, the project concluded that consumers first have to be activated to become engaged in load shifting and using smart appliances. At the beginning of this process, the behaviour is no longer habitual, existing routines have to be reconsidered and the behaviour is changed towards a higher consciousness ('disruptive phase'). The next phase targets at an active participation of consumers. They should explicitly reflect their old and new practices ('activation phase'). In the third phase ('continuation phase'), new practices and routines are already adapted and the new behaviour becomes more and more habitual. However, new practices have to be supported and reinforced. According to the findings of the S3C project¹, drivers and barriers play a decisive role in the 'activation' and 'continuation phase'. The drivers and barriers identified in the framework of this project are discussed in the respective subsections.

Current available information from empirical studies implies that consumer acceptance in view of smart appliances and related to this, smart home technologies, is relatively high. Except for one study², preliminary findings indicate that consumers are willing to shift loads to off-peak hours by rescheduling certain household activities^{3,4,5,6,7,8,9}. However, it is important to note that the results of these studies are mainly based on questionnaires or interviews and not on consumer experiences. Thus, they reflect the expected and not the real consumer behaviour and acceptance. This means that the figures should be treated with caution.

One of the first pilot projects implementing a smart energy grid, the PowerMatching City II project¹⁰ situated in the Netherlands, encompassed a sample of 40 households to demonstrate the energy system of the future. The connected households were equipped with smart appliances and smart meters, some of them have additional solar panels or micro CHP to generate energy or heat. In this project, two different energy services were created and allocated randomly to the households, one focussing on cost savings ('smart cost savings') and one focussing on sustainability ('more sustainable together'). Experiences gained showed that participants preferred the 'smart cost savings' energy service as cost savings (expressed in euros) were more tangible for consumers as sustainability gains. This was also reflected in the fact that the active engagement (e.g. manually setting start times of household appliances) of participants allocated to this energy service was much more pronounced. As far as they had confidence in the system, participants had a bias towards automatically controlled devices because of more convenience and higher cost savings. Comprehensibility of the system and its function was identified as the main factor influencing the confidence of the participants. While using the energy monitor to control the devices at the beginning of the project, participants became familiar with the right times to turn on appliances and got on without the energy monitor over time.

² Fraunhofer-Institut für Solare Energiesysteme ISE (2011): Nachhaltiger Energiekonsum von Haushalten durch intelligente Zähler-, Kommunikations- und Tarifsysteme.

³ Mert, Tritthart (2008): Get Smart! Consumer acceptance and restrictions of Smart Domestic Appliances in Sustainable Energy Systems. IFZ – Inter-university Research Centre for Technology, Work and Culture, Graz, Austria.

⁴ Kobus, Klaassen, Mugge, Schoormans (2015): A real-life assessment on the effect of smart appliances for shifting households' electricity demand. *Applied Energy*. 2015; 147:335-43.

⁵ Saele, Grande (2011): Demand Response From Household Customers: Experiences From a Pilot Study in Norway. *IEEE Transactions on Smart Grid*. 2011; 2:102-9.

⁶ Mert, Watts, Tritthart (2009): Smart domestic appliances in sustainable energy systems—Consumer acceptance and restrictions. *ECEEE 2009 Summer Study 2009*. p. 1751–61.

⁷ Thiemann, Passenberg, Suer (2007): Preis, Verbrauch und Umwelt versus Komfort – der mündige Energieverbraucher.

⁸ Stamminger, Anstett (2013): The Effect of Variable Electricity Tariffs in the Household on Usage of Household Appliances. *Scientific Research, online Journal*. 2013; 4:353-65.

⁹ Cardinaels, Borremans (2014): Linear Intelligent Networks - Demand Response for Families.

¹⁰ PowerMatching City II project (2015): http://www.powermatchingcity.nl/data/docs/PowerMatching%20City_brochure_final_UK_29-04-2015_lowres.pdf

Consumer studies carried out within the framework of the “Energy Intelligent Europe” project „Smart Domestic Appliances in Sustainable Energy Systems (Smart-A)”¹¹, which was conducted in five European countries (Austria, Germany, United Kingdom, Slovenia and Italy) revealed that about 90 % of the respondents would accept different options of smart appliances. However, the acceptance is dependent on the respective device and smart operation mode and could not be generalized for all appliances. In terms of willingness, the highest load shifting potential was found for washing machines and dishwashers, whereas the willingness to shift cooking or entertainment applications or the operation of appliances ensuring comfort is vanishingly low^{4,5,6,7,8,12}. For more detailed information, refer to subtasks 1.2.1-1.2.7.

1.1.1.1 Drivers to buy/ use smart appliances

There are a couple of studies investigating motivations for consumers to engage in smart appliances. In general, the drivers can be divided into economic and ecological drivers as well as product-related drivers.

Economic and ecological drivers

In a study by Paetz et al.¹², a total number of four test-residents lived in a fully equipped smart home laboratory to assess smart home technologies (feedback systems, automated energy management system, dynamic pricing) in everyday life. The study revealed that dynamic pricing and related to this, monetary savings, are the main drivers for shifting loads. Because of the complexity and variability of the dynamic prices, the study participants preferred an automated energy management system. Reasonable pay-back periods for investments were identified as crucial preconditions for consumer’s acceptance of smart home technologies.

In the same smart home laboratory, focus group interviews were conducted with 29 participants to get an insight into consumer perceptions in view of smart appliances, smart metering, variable tariffs and home automation^{13,14}. The results show again the importance of monetary savings.

A questionnaire-based survey and focus group interviews in several European countries as part of the Smart-A project^{3,6} produced similar results. Also here monetary savings were the most important requirement for buying and using smart appliances. The second point is the reduction of the environmental burden.

Product related drivers

Besides economic and ecological benefits, also some product related drivers could be identified in former studies. The maturity of smart technologies, maintenance or enhancement of comfort (e.g. making housework less time consuming), good usability and higher security were found in the Smart-A consumer studies to play a decisive role for consumers to accept smart appliances. Expert interviews conducted within the framework of the Smart-A project additionally identified monitoring features (e.g. diagnosis of correct function of appliances) or “all power off”-switches as potential benefits.

¹¹ Mert et al. (2008): Consumer acceptance of smart appliances. D 5.5 of WP 5 report from Smart-A project. Available online: http://www.smart-a.org/WP5_5_Consumer_acceptance_18_12_08.pdf

¹² Paetz, Becker, Fichtner, Schmeck (2011): Shifting Electricity Demand with Smart Home Technologies – an Experimental Study on User Acceptance. 30th USAEE North American Conference 2011.

¹³ Paetz, Dütschke, Fichtner (2012): Smart Homes as a Means to Sustainable Energy Consumption: A Study of Consumer Perceptions. *Journal of Consumer Policy*. 2012; 35:23-41.

¹⁴ Paetz, Duetschke, Fichtner, Wieschtel (2011): Tomorrow's households: How do consumers react to a smart-home environment? In: Bertoldi P, editor. *Energy Efficiency in Domestic Appliances and Lighting*. Copenhagen, Denmark 2011. p. 657-69.

In the S3C report¹, five major categories of drivers were identified besides economic and ecological benefits: increase in comfort, increase in control (e.g. advances control of appliances via smart phone or tablet, further possibilities to participate in energy market), knowledge and information (e.g. feedback on energy use or energy consumption relevant parameters, more frequent billing), improved security (e.g. improved reliability of energy supply) and social process (e.g. social role, community feeling or fun).

In other studies^{15,16}, new services (e.g. monitoring of or support for elderly people) were named as a further motivators to buy and use smart appliances.

According to Mert et al.¹¹, the majority of consumers would only buy a smart appliance if they need to replace their old one anyhow.

Even though financial incentives (for instance through a dynamic pricing scheme) seems to play an important role as a driver, it can be concluded that they are not sufficient to establishing a structural change in consumer behaviour¹⁷.

1.1.1.2 Barriers to buy/ to use smart appliances

Although results of customer research have shown that consumers have a positive attitude towards smart appliances and would be willing to adopt them, there are many objections which have to be solved before a market penetration is possible (Mert et al., 2008¹¹). In the following, two main categories of barriers are distinguished: barriers in view of economic aspects and regulatory framework and product/service-related barriers.

Barriers in view of economic aspects and regulatory framework

The rollout of smart meters and informing about smart functions are definitely main barriers to uptake smart appliances (cf. Task 2, subtask 2.1.2 for more information on rollout of smart meters). A Forsa study¹⁸ showed that even 91 % do not know the term “smart meter”.

In 2010, more than 9,000 individuals in 17 countries across the globe were surveyed by Accenture¹⁹ to get consumers attitudes and opinions toward electricity management programs. According to this survey, the three major barriers, which discourage consumers from adopting smart appliances, are costs, mistrust in providers and concerns about data privacy.

In view of the costs, consumers are in general willing to accept higher initial prices for smart appliances, but some of them fear hidden costs (e.g. costs for installation or repairs) as well as unreasonable and excessive pay back periods (Mert et al., 2008¹¹).

This mistrust in energy providers represents the next major barrier in adopting smart appliances. On average, only 29 % of the consumers trust in utilities or energy providers. Nearly the same

¹⁵ Balta-Ozkan, Davidso, Bicket, Whitmarsh (2013): Social barriers to the adoption of smart homes. *Energy Policy*. 63:363-74.

¹⁶ Balta-Ozkan, Amerighi, Boteler (2014): Comparison of consumer perceptions towards smart homes in the UK, Germany and Italy: reflections for policy and future research. *Technology Analysis & Strategic Management*. 2014; 26:1176-95.

¹⁷ Boork M, Thomtén M, Brolin M, Uyterlinde M, Straver K, Kraan C, Kleine-Hegermann K, Laes E, Valkering P, Maggiore S. Key success factors and barriers to end-user engagement in smart grid projects. Paper presented at the 2014 BEHAVE conference, London. Available from: <http://behaveconference.com/wp-content/uploads/2014/08/F_Magdalena_Boork_Technical_Research_Institute_of_Sweden.pdf>

¹⁸ Forsa (2010): *Erfolgsfaktoren von Smart Metering aus Verbrauchersicht*, Berlin.

¹⁹ Guthridge (2010): *Understanding Consumer Preferences in Energy Efficiency - Accenture end-consumer observatory on electricity management*, Amsterdam.

percentage has no trust and about half of the consumers are undecided. Environmental associations, academics/ schools/ scientific associations as well as consumer associations in contrast have the highest trust level. (Guthridge, 2010¹⁶)

Consumers have the impression that economic goals of electricity providers are hidden behind a “green washing” attitude (Mert et al., 2008¹¹). Because of that, they prefer independent institutions like governmental institutions at national and European level and consumer organisations to inform them.

Changes in electricity prices and programs by energy utilities reduce the level of trust in them. From the users view, there is also a lot of scepticism about the motivation of energy suppliers to promote smart appliances. As the knowledge of consumers about renewable energies and the energy system in principle is limited, consumers often fear that economic goals are hidden behind the aforementioned “green washing” attitude and energy suppliers use the ecological benefit as a sales argument. Combined with growing doubts about control, data privacy and data protection, consumers trust in energy providers is further minimised. (Mert et al., 2008¹¹)

Product/ service-related barriers

A further objection of consumers is an expected loss of control¹. Consumers have certain mistrust in high tech solutions. In most cases, they lack knowledge about energy grids and the underlying concept of smart appliances, and consequently have concerns in view of technical failures and system reliability. On the one hand, many consumers are afraid of dependency on technology and on the other hand they do not like the idea of energy providers having control over their devices. This could be deeply rooted in the fact that consumers are accustomed of available electricity all the time and they can operate their appliances whenever they want. Consumers do not want to be restricted on electricity usage because for them, this means a loss of comfort. Another point is that consumers fear a certain stress to change their behaviour and daily routines. In the case of automatic regulation, consumer favour solutions that tie to existing platforms like smartphones and tablets²⁰ and they want to maintain control over their devices. Thus, it appears consumers prefer to have the possibility to override the smart operation mode any time they want (for example with an option to operate their appliances manually). (Mert et al., 2008¹¹; Paetz et al., 2012¹³)

The safety of smart appliances is also questioned by some consumers and plays a big role for their adoption as well. Users might be afraid of break-downs for example in case of fire or flooding. Doubts about leaving the appliances switched on during absence exist in the consumers mind. Among others, this is why manuals of traditional electrical appliances often warn consumers not to operate the devices unattended and sometimes even recommend unplugging it from mains after usage. To make things worse, insurances usually do not cover damages in absence. So consumers worry that they have to cover the costs of possible damages by themselves. (Mert et al., 2008¹¹)

In other studies^{3,13,14,15,16}, concerns expressed include a lacking interoperability, a too complicated handling (especially important for elderly and people with disabilities), error-proneness of appliances because of additional technical components and shorter life times of appliances due to short interruptions during operation. It has to be mentioned at this point that upgradeability and the length of manufacturer’s support might also be decisive factors in view of product life time (even though not named in the aforementioned studies). Additionally, the reparability of the product might be affected as more complex technology such as electronics becomes part of the product design.

According to the S3C report¹, social processes (e.g. free-rider effects or job losses) and lack of information and knowledge (e.g. perceived health risks) may be named as an additional barriers.

²⁰ Panasonic, IFA 2015

Besides that, there are some appliance-specific concerns (e.g. concerns about food safety in the case of refrigerators and freezers or about damages of textiles in the case of washing machines and tumble dryers), which are described more in detail in subtasks 3.2.1-3.2.7.

Results from an online survey by Geppert and Stamminger²¹ indicate that the probability of having concerns in view of smart appliances might be related to the degree of automation and technical complexity. Whereas only about 1/3 of participants stated to have concerns in view of a dishwasher, whose start is triggered by an external signal (e.g. via power line), half of all respondents expressed concerns in view of a remote control (e.g. interruptions or altered consumption pattern in the case of refrigerators, freezers, air condition, heating pumps or electric water heaters).

1.1.1.3 Additional costs and expected financial gains

Studies by Mert et al.¹¹ as well as Geppert and Stamminger²¹ revealed that almost all consumers are in general willing to pay a slightly higher price (up to 50 €) for smart appliances than for conventional ones when buying an appliance. An absolute statement about additional costs accepted by consumers is not possible as these costs much depend on the absolute price of the appliance, the expected payback time, the expected gain in comfort, potential additional costs (e.g. installation and upgrading) and potential future savings.

According to Mert et al. (2008)¹¹, the majority of consumers would certainly not approve a payback time of 5 years and some of them might not accept even 3 years.

The online study by Geppert and Stamminger²¹ has shown that almost 80 % of participants would buy a smart appliance under the precondition of getting incentives from their utilities (e.g. cheaper energy tariff). A reduced purchase price for the appliances would only convince about 16 %. When asked about their expected reduction in energy price, most participants stated a percentage in the range of 1 to 30 (mostly 11 to 20 percent). By trend, the expected reductions are higher in the case of remote control (e.g. interruptions of appliances, altered consumption patterns) than in the case of external signals, which trigger a delay in start time (e.g. frequency control).

A point-of-indifference analysis by Paetz et al.¹³ determined savings of 80 € per year as the point at which changes in behavioural patterns start to be worthwhile for consumers.

1.1.1.4 Possibilities to raise consumer acceptance

As described before, consumer acceptance is a key factor for smart appliances being successful. The future market penetration of smart appliances depends to a great extent on the likelihood to overcome existing consumer objections. Following aspects could help to overcome concerns and raise consumer acceptance.

As financial aspects were identified as the main driver for the use of smart appliances, attractive and transparent energy tariffs of the utilities are inevitable. Studies have shown that a reduction between 11 and 20 % in energy price is expected by the consumers as an incentive for operating appliances in a smart mode. It can be assumed that Time of Use tariffs are more suitable to motivate consumers to use appliances during off-peaks than cheaper flat tariffs. As short payback times are also essential for consumer acceptance, rebates on the purchase price of smart appliances could be another option to increase the attractiveness. However, discounts should be given in addition to attractive energy tariffs because otherwise only a minority of consumers will be convinced. In general, consumers

²¹ Geppert and Stamminger (2015): Online study on consumer acceptance and perceptions of smart appliance. Not published yet.

should be adequately informed about all costs resulting from smart appliances (including installation, infrastructure, repairs, ...). Hidden costs should be completely avoided to build trust in a long term.

Major concerns are related to safety aspects and the technology. Consumers are afraid of fire or flooding or any failures if appliances are operated during absence. Potential measures to overcome these objections include additional safety mechanisms in view of appliances (improved protection against fire or flooding), the possibility to remotely monitor different operation parameters (e.g. temperatures) and an alert via smartphone or email in the case of failures. But also the insurance can play a decisive role to overcome the safety barrier by covering damages occurring during unattended operation (for instance manufacturers offering own insurances for aqua-stop etc.). (Mert et al., 2008¹¹)

As consumers also fear error-proneness of appliances and a shorter life span due to interrupted operation and more technical components, realistic life time and fatigue tests should provide information for consumers. Extended warranties could be a further possibility to overcome this concern.

Another aspect to increase the consumer acceptance is that providers need to build trust and credibility before they see a broad adoption of smart appliances. So first they have to improve their customer relationships. In order to create trusted advisor relationship, providers need to be more transparent in their activities. In addition to that they need to match consumer's requirements for a good data protection and should also delete consumer's data after some time. As many consumers remarked that they are afraid to lose control over their devices, consumers should have the possibility to override the smart operation mode any time they want (for example with an option to operate their appliances manually) and should have access to their own data. Further it will be necessary for energy providers to build relationships with governments, regulators and associations, which are able to push the energy-efficiency agenda forward (Guthridge, 2010¹⁹). Alternatively, a regulated or government body could undertake the management of the smart appliances and the interaction with end consumers.

As many consumers have doubts concerning the ecological benefit of smart appliances, it should be assessed and verified by independent institutions as for example environmental associations, academics/ schools/ scientific and consumer associations, which enjoy a high level of trust.

Additionally, consumers expressed concerns about lacking interoperability of appliances and systems. They want to have the possibility to choose appliances from different brands and to change their energy supplier without any problems or adaptations. Uniform standards on a European basis could help to overcome these objections.

Upgrades which can be simply plugged into existing devices, may also raise consumers' acceptance. However, the risk that smart appliances can update their software after installation and could increase their energy consumption (e.g. different default standby mode, higher wash temperature, brighter screen, etc.) exists in principle. As such, the "out-of-the-box" setting would become less and less relevant.

If the smart appliance has a display, it should be a simple yet visually appealing display. The display should have an accessible and ergonomic design as suggested by studies (e.g. Consumer Focus, Smart meter in-home display design, 2012; DIN Consumer Council, Study on usability and ergonomics of smart meters, 2011). Especially in view of elderly and disabled people, special features should be foreseen. This relates to a simple handling (e.g. plug-and-play) as well as text-to-speech or other audio functions (at least the possibility to connect one should be given). (ANEC/ BEUC)

Moreover, additional functionalities and gains in comfort may raise consumer acceptance regarding smart appliances, especially if expected financial gains are low. Such functionalities may include the possibility to:

- start, control or monitor appliances remotely, e.g. via smartphone,
- switch off power of all appliances at once,
- monitor and support elderly people in their living environment,
- get informed (e.g. via smartphone) about necessary repairs or failures of appliances at an early stage,
- enable remote diagnostics and maintenance for mechanics,
- enable home energy analysis
- enable automatic adaption
- etc.

A promotion of such functionalities at the point of sale may help to increase the attractiveness of smart appliances.

1.2 END-USE PARAMETERS AND USER REQUIREMENTS OF APPLIANCES

The following subtasks 3.2.1 - 3.2.7 inform about product-specific end-use parameters and user requirements by focusing on daily and seasonal use pattern, comfort constraints, expected flexibility and typical scenarios of application.

1.2.1 PERIODICAL APPLIANCES

1.2.1.1 Usage Behaviour

Periodical appliances are appliances that periodically execute a user initiated cycle. The user is actively involved in loading and unloading the machines, whereas there is no interaction with the user while running. In this category there are the following appliances destined for private use:

- Dishwashers
- Washing machines
- Tumble dryers
 - Electric vented
 - Electric condenser
 - Heat pump dryer
- Washer-dryers

In view of periodical appliances, energy is mainly needed for heating processes. In the case of washing machines, dishwashers and washer-dryers, water is heated up for cleaning purposes. In view of tumble dryers and washer-dryers, hot air is produced, which is required for drying wet laundry. The temperatures vary according to the respective programmes. The rated power of the heating devices is shown in Table 1.

Table 1: Rated power of heating devices (source: Stamminger et al., 2009³⁴)

Appliance	Rated power of heating device
Dishwashers	1,800-2,500 W
Washing machines	1,800-2,500 W
Conventional tumble dryers	2,000-2,500 W
Heat pump tumble dryers	800-1,000 W
Washer-dryers	2,000-2,500 W

Additional energy is needed to operate circulation pumps, motors, fans and displays/ user interfaces. During spin-drying, motors of washing machines and washer-dryers reach power peaks of up to 950 W, whereas their typical operational power input is about 100 W. The rated power input of water circulation pumps is about 15-30 W. (JRC, 2015²²)

Periodical appliances have a relatively high volume of installed base in EU-28 (some of them still growing).

For dishwasher, penetration rates vary extremely between different countries with ownership rates of 40-50 % in EU-15 (2012) and 10-15 % in new member states. For EU-28, this results in 46 %. According to estimations, ownership rates in EU-28 will increase during the next decades reaching 60-70 % in 2030. (VHK, 2014²³)

The average ownership rate of washing machines (EU-27) is about 90 % with only marginal differences between countries (Bertoldi et al., 2012)³⁶.

According to estimations in 2010, the stock of tumble dryers in Europe was about 54 million appliances (Bush, Damino, Josephy, 2013²⁴) corresponding to an average ownership rate of about 32 %. In 2015, estimations indicate an amount of about 63 million appliances in stock (VHK, 2014²⁵) and a corresponding penetration rate of 29 %. Penetration rates are much higher in Western than in Eastern European countries (Lefèvre, 2009²⁶).

Washer-dryers are a small category of wet appliances. Because they are relatively new on the market, their ownership rate is only about 4 % in Europe, but still increasing (Euromonitor 2014, cited by JRC, 2015²²).

For more information on stock data, please refer to Task 2.

Given the comparatively high power consumption and the large installed base volumes, the potential of periodical appliances for load shifting is assessed to be high. Therefore, appliances of this category are described more in detail in this chapter.

²² JRC (2015): Ecodesign and Energy label revision: Household Washing machines and washer-dryers. Draft. Available online: http://susproc.jrc.ec.europa.eu/Washing_machines_and_washer_dryers/docs/Prepstudy_WASH_20150601_FINAL_v2.pdf

²³ VHK (2014): "Omnibus" Review Study on Cold Appliances, Washing Machines, Dishwashers, Washer-Driers, Lighting, Set-top Boxes and Pumps. Final report

²⁴ Bush et al. (2013): Heat Pump Tumble Driers: New EU Energy Label and Ecodesign requirements in Europe, MEPS in Switzerland, Initiatives in North America. Available online: http://www.topten.eu/uploads/File/EEDAL_heat_pump_driers_2013.pdf

²⁵ VHK (2014): ECODSIGN IMPACT ACCOUNTING Part 1 – Status Nov. 2013

²⁶ Lefèvre, 2009: Ecodesign of Laundry Dryers, Preparatory studies for Ecodesign requirements of Energy-using-Products (EuP) – Lot 16

1.2.1.2 User behaviour concerning periodical appliances

DAILY AND ANNUAL USE PATTERN

Dishwashers

According to an online survey in 10 European Countries (EUP LOT 14²⁷), the average number of dishwashing cycles per week is 4.06, corresponding to 211 cycles per year. The same average number was reported for German households by Bichler et al. (2014)²⁸.

The European Commission estimated the total electricity consumption of dishwashers in Europe to be around 25.3 TWh in 2010 (Bertoldi et al., 2012)³⁶. Dishwashers with a capacity of 13 settings currently available on the European market consume between 194 and 290 kWh/year (<http://www.topten.eu>). Stamminger et al. (2009)³⁴ reported on an average consumption of 241 kWh/year corresponding to 1.19 kWh/cycle.

Assuming a normal cleaning programme and an energy consumption of 1.19 kWh per cycle, the power demand curve of a current average dishwasher follows the pattern shown in Figure 1.

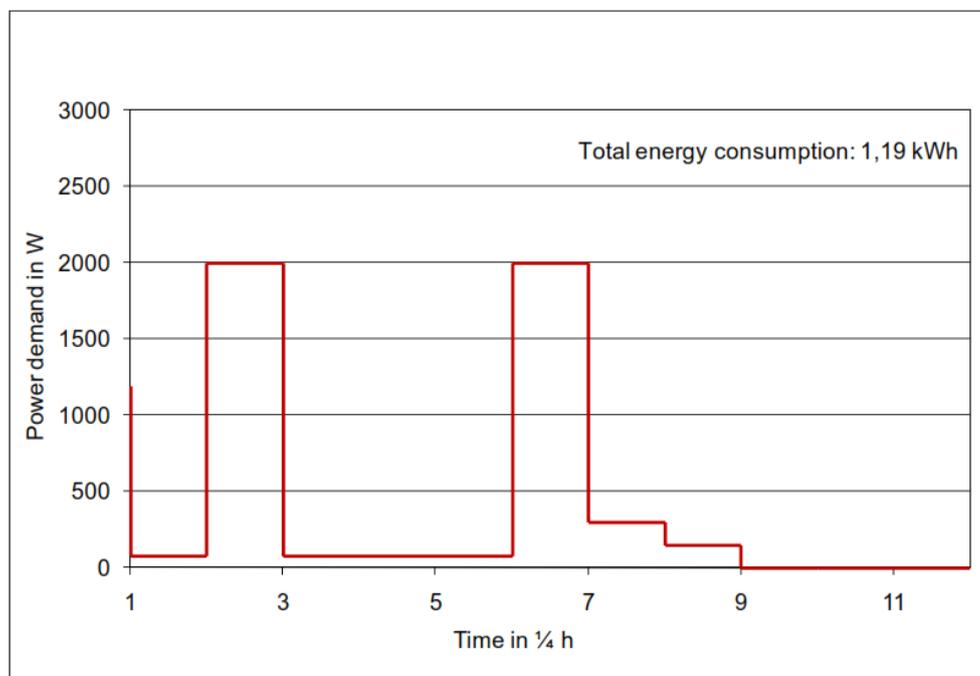


Figure 1: General pattern of a power demand curve of an average dishwasher operating in a normal cleaning programme (source: Stamminger et al., 2009³⁴)

Due to the Energy Label and other political measures, the total energy consumption of dishwashers in Europe is expected to further decrease within the next years. Assuming lower cleaning and rinsing temperatures, the power demand curve of an average dishwasher in 2025 may change towards a lower power demand in the cleaning and rinsing phase and increased cycle times.

²⁷ Preparatory Studies for Eco-design Requirements of EuP's, LOT 14: Domestic Washing Machines and Dishwashers, Task 3: Consumer Behaviour and Local Infrastructure.

²⁸ Bichler S. (2014): Verbraucherakzeptanz von Energieeinsparpotentialen an automatischen Geschirrspülmaschinen. Shaker Verlag, Aachen.

It is assumed that use patterns of dishwashers vary on a daily, but not on a seasonal basis. According to results of an online survey in ten European countries in 2007 (n=2500), dishwashers are preferably switched on in the afternoon/ evening period after dinner (Figure 2). At present, there is no reason per se to expect that the daily use pattern of dishwashers will change in the near and medium-term future.

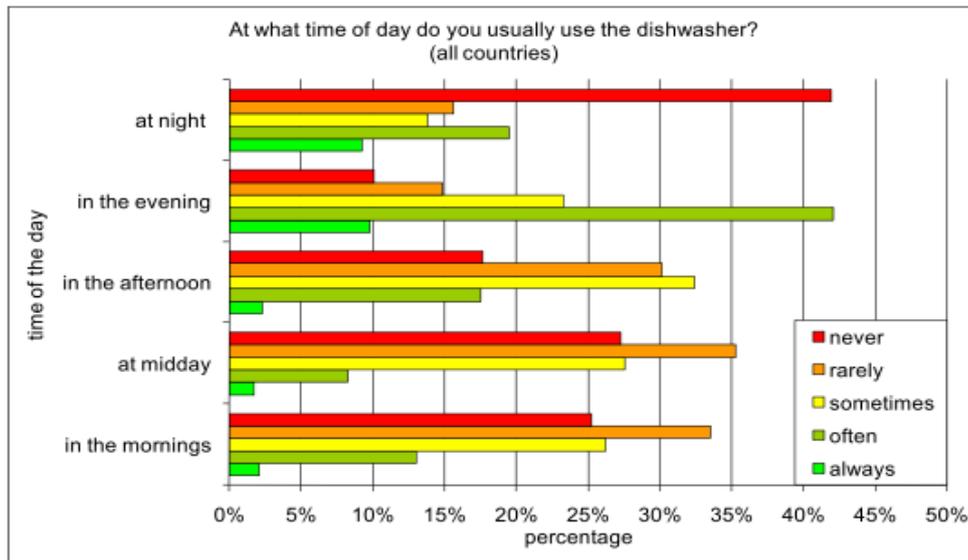


Figure 2: Frequency of operation of dishwashers during the day (Source: EUP LOT 14²⁷)

Within the framework of the Smart-A project (Stamminger et al., 2009)³⁴, this information was used to deduce the probability of start time of dishwasher operation for the ten European countries investigated (cf. Figure 3).

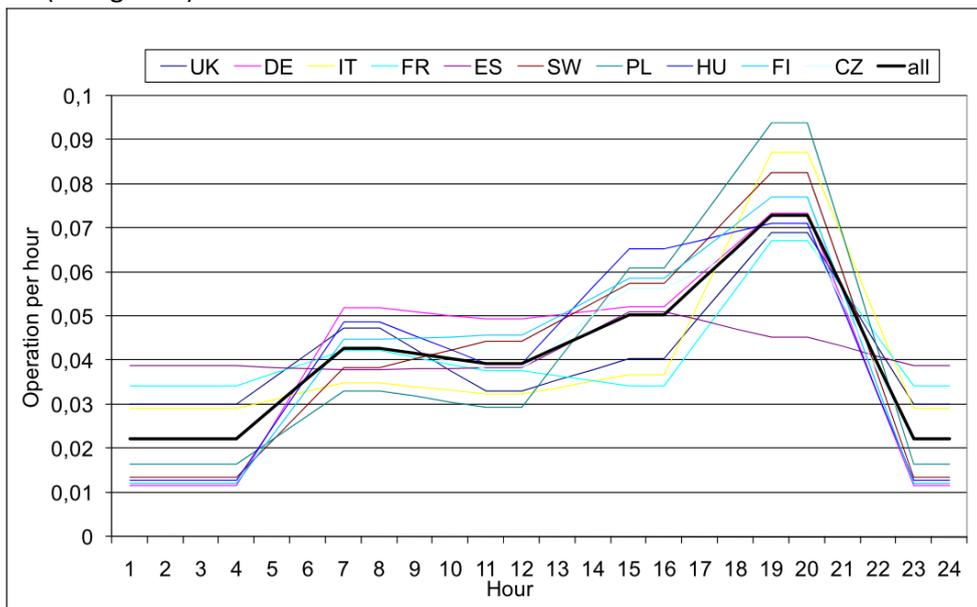


Figure 3: Probability of start time of the dishwasher operation for the ten European countries investigated (source: Stamminger et al., 2009³⁴)

In view of dishwashers, just one major scheduling period can be identified in the late afternoon/ evening (about 5 PM-8 PM). For Spain, this peak is not as pronounced as for other countries. The probability curve is rather flat, showing that dishwashers in Spain are operated all over the day with roughly the same probability.

If the general pattern of a power demand curve of a current average dishwasher (cf. Figure 1) is aggregated with the average probability of start time (cf. Figure 3) and an appliance-specific usage factor, which takes into account the average number of cycles per year, the general pattern of a daily load curve depicted in Figure 4 can be derived. It has to be noted that this daily load curve is based on data representing the user behaviour of only ten European countries, which are named in Figure 3. As the countries investigated cover a major part of the population of EU-28 and the user behaviour appears to be similar in these countries, it seems to be reasonable to assume that the consumer behaviour and this general pattern of a daily load curve is also valid for all EU-28 countries. If the total energy consumption of dishwashers will further decrease as expected for the next years, the power demand curve will change, which will have an impact on the daily load curve.

Figure 4: General pattern of a daily load curve of a current dishwasher (source: modified according to Stamminger et al., 2009³⁴)

Washing machines

In Europe, a trend towards decreasing household sizes and increasing capacity of washing machines from an average capacity of 4.8 kg in 1997 to 6.0 kg in 2008 can be observed (VHK, 2014²³). In 2011, an average number of 3.8 cycles per household and week was determined by Schmitz and Stamminger (2014)²⁹, corresponding to 198 cycles per year. The International Association for Soaps, Detergents and Maintenance Products (A.I.S.E) reported an average wash frequency of 3.2 per household and week (166 cycles per year) across Europe in 2011 (A.I.S.E., 2013³⁰).

In view of the energy consumption per household per year, large differences between the countries could be registered, which can be explained by different washing temperatures and frequencies (Figure 5).

²⁹ Schmitz and Stamminger (2014): Usage behaviour and related energy consumption of European consumers for washing and drying. *Energy Efficiency*, 7, 937-954.

³⁰ A.I.S.E. (2013). The case for the "A.I.S.E. low temperature washing" Initiative.

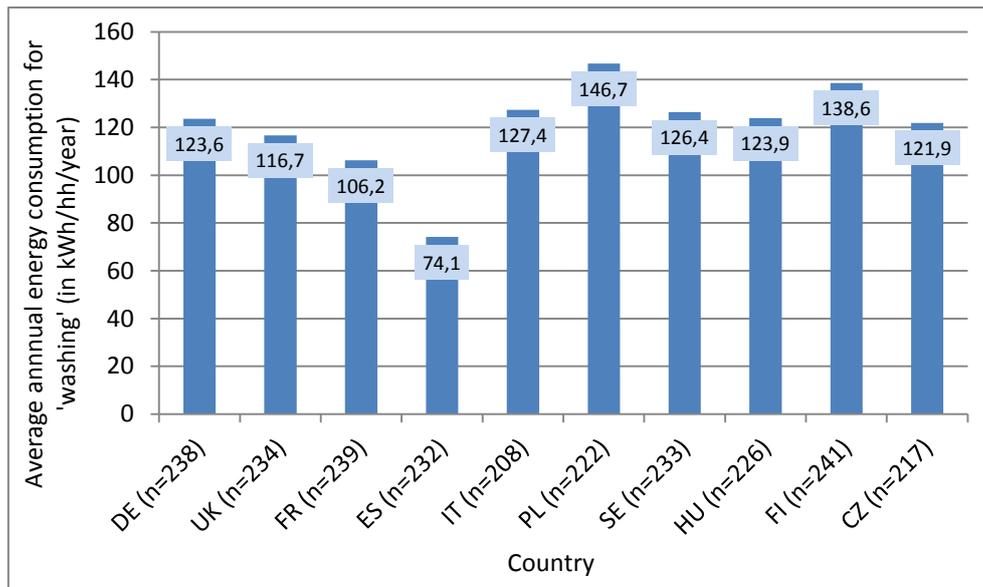


Figure 5: Average energy consumption for 10 European countries in 2011 (Source: Schmitz and Stamminger, 2014²⁹)

Assuming a normal cotton programme and an energy consumption of 0.89 kWh per cycle, the power demand curve of a current average washing machine follows the pattern shown in Figure 6.

As the power demand is dependent on the washing temperature and also the amount of water needed for the washing process, this pattern may change according to the programme chosen and the capacity of the machine.

Due to the Energy Label and other political measures, the total energy consumption of washing machines in Europe is expected to further decrease within the next years. Assuming lower washing temperatures, the power demand curve of an average washing machine in 2025 may change towards a lower power demand in the heating phase and increased cycle times.

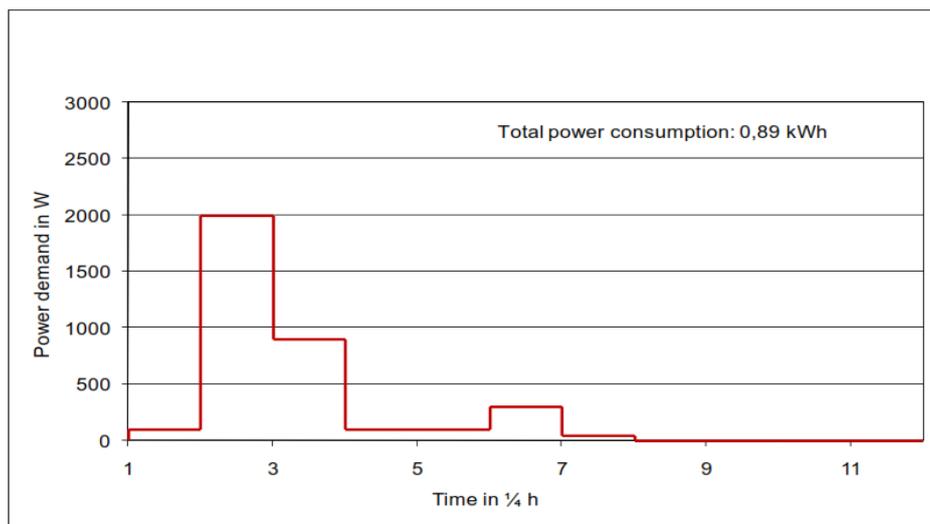


Figure 6: Typical pattern of a power demand curve of an average washing machine operating in a normal cotton programme (source: Stamminger et al., 2009³⁴)

It is assumed that use patterns of washing machines vary on a daily, but not on a seasonal basis. In 2007, about 2500 consumers from ten European countries were asked about the time of the day they usually use their washing machines (EUP LOT 14²⁷). When looking at the results showing the frequency of operation of washing machines during the day (Figure 7), two preferred time slots can be identified, one in the morning and the second in the afternoon/ evening.

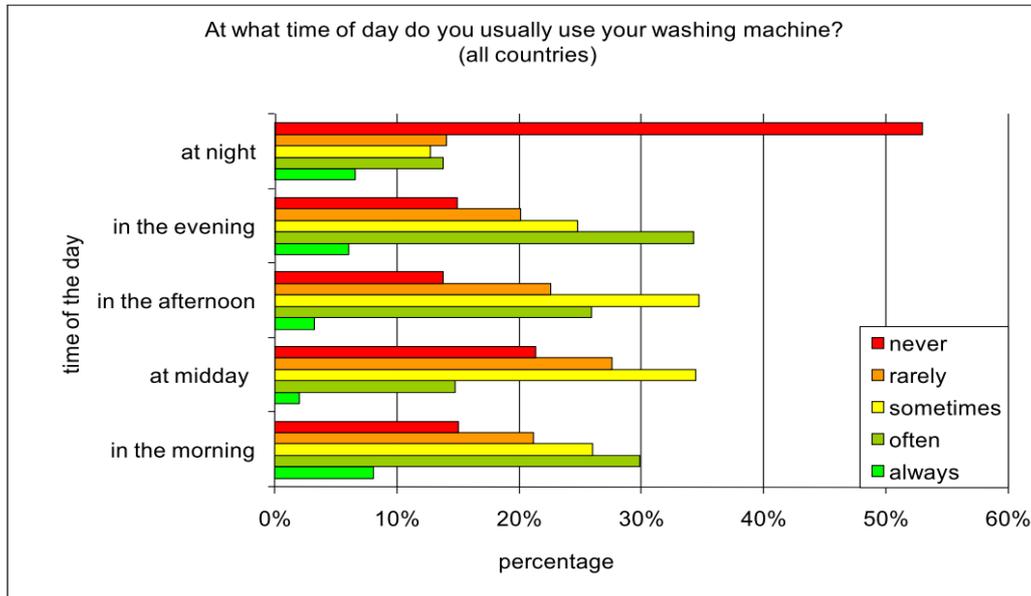


Figure 7: Frequency of operation of washing machines during the day (Source: EUP LOT 14²⁷)

Within the framework of the Smart-A project (Stamminger et al., 2009³⁴), this information was used to deduce the probability of start time of the washing machine operation for the ten European countries investigated (Figure 8). Two major time periods can be identified for the initiation of the washing machine operation, one in the morning between 7 AM and 9 AM and one in the late afternoon/ evening period (about 4 PM-8 PM). The daily use pattern is similar for all countries investigated with the exception of Spain, where the morning peak is more pronounced, as well as Sweden and Finland, where machines are predominately operated in the afternoon/ evening hours. At present, there is no reason per se to expect that the daily use pattern of washing machines will change in the near and mid-term future.

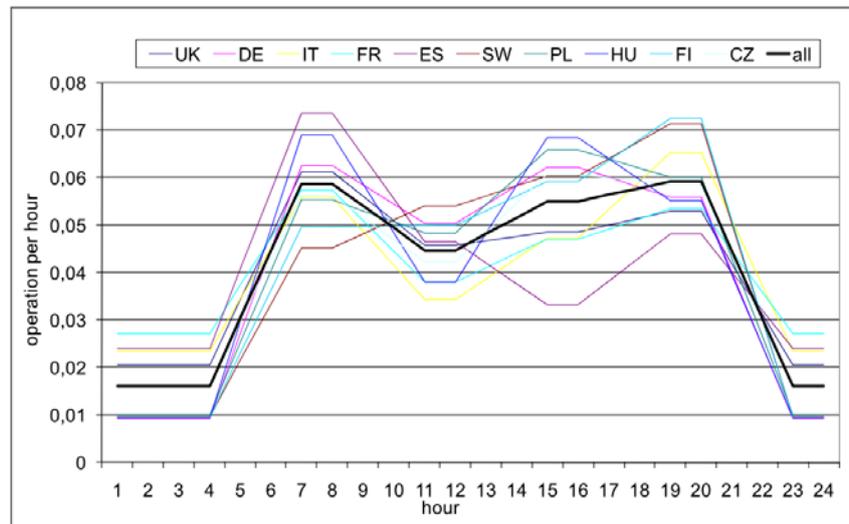


Figure 8: Probability of start time of the washing machine operation for the ten European countries investigated (source: Stamminger et al., 2009³⁴)

If the general pattern of a power demand curve of a current average washing machine (cf. Figure 6) is aggregated with the average probability of start time (cf. Figure 8) and an appliance-specific usage factor, which takes into account the average number of cycles per year, a general pattern of a daily load curve can be derived (Figure 9). It has to be noted that this daily load curve is based on data representing the user behaviour of only ten European countries, which are named in Figure 8. As the countries investigated cover a major part of the population of EU-28 and the user behaviour appears to be similar in these countries, it seems to be reasonable to assume that the consumer behaviour and this general pattern of a daily load curve is also valid for all EU-28 countries. If the total energy consumption of washing machines will further decrease as expected for the next years, the power demand curve will change, which will have an impact on the daily load curve as well.

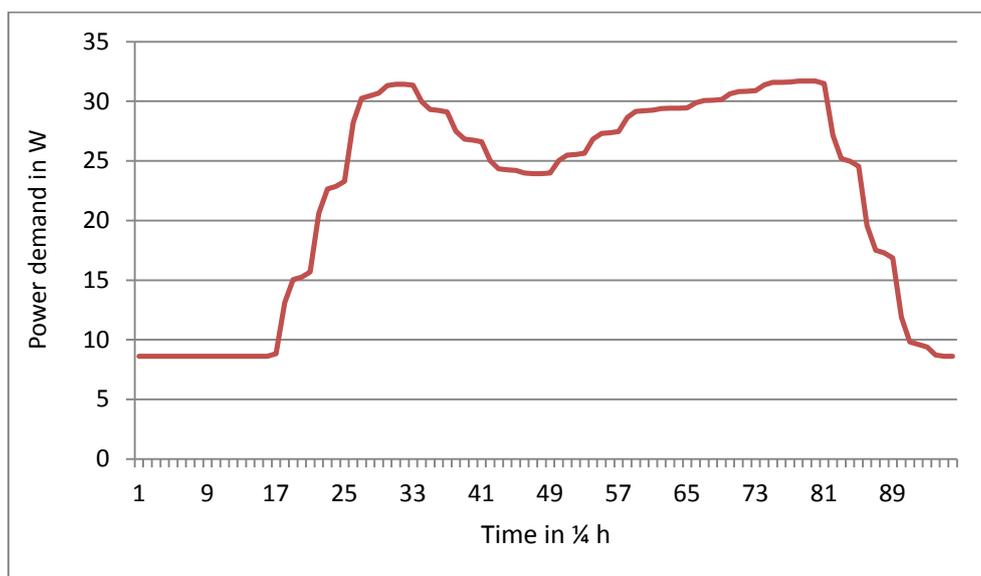


Figure 9: General pattern of a daily load curve of a current washing machine (source: modified according to Stamminger et al., 2009³⁴)

Tumble dryers

The usage of tumble dryers is highly dependent on the season. According to a survey conducted within the framework of the EUP LOT 16 study (Lefèvre, 2009²⁶), 50 % of consumers owning a tumble dryer use it always or often during the winter season. For the summer period, less than a quarter of the consumers (24 %) gave this statement. In the same study, an average frequency of 3.6 cycles per household and week (1.1 cycles/ person/ week) was calculated for the winter and 2.3 cycles per household and week (0.7 cycles/ person/ week) for the summer season. Assuming a duration of 26 weeks per season, this corresponds to an average of 153 cycles per household per year.

A study conducted in ten European countries by Schmitz and Stamminger (2014)²⁹ indicates that a share of about 16 % of all drying cycles of all households are done using a tumble dryer in winter. During summer, this share is about 9 %.

Based on data published by the European Commission (2003)³¹, Stamminger et al. (2009)³⁴ calculated an average electricity consumption of 2.46 kWh/ cycle (251 kWh per household per year). For this calculation, an annual average of 102 drying cycles per household owing a tumble dryer was assumed.

Considering a normal cotton programme and an energy consumption of 2.46 kWh per cycle, the power demand curve of a current average conventional tumble dryer (without heat pump technology) follows the pattern shown in Figure 10.

As the power demand is dependent on the process temperature and also on the amount and type of load, this pattern may vary between machines and according to the programme chosen.

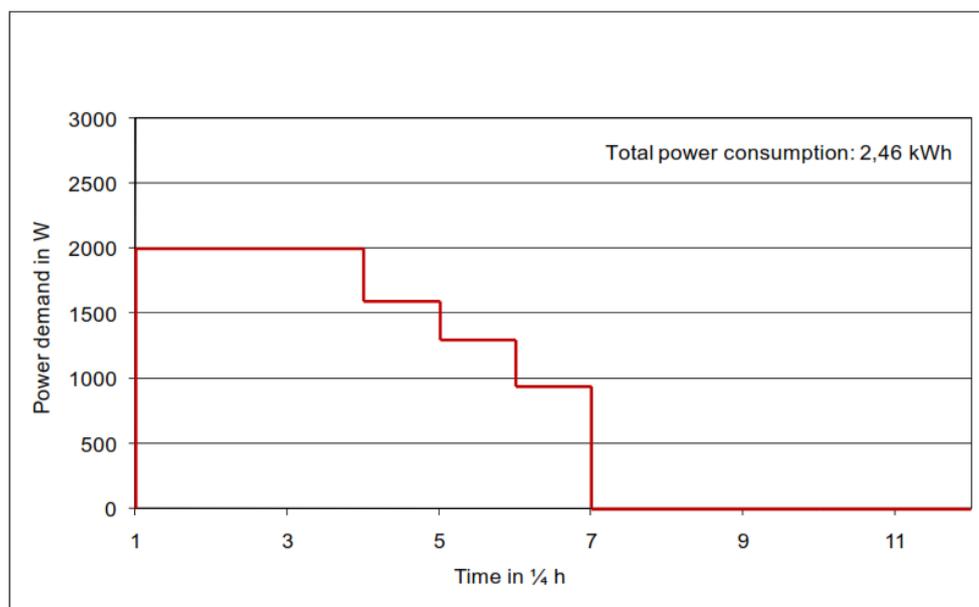


Figure 10: Typical pattern of a power demand curve of an average conventional tumble dryer operating in a normal cotton programme (source: Stamminger et al., 2009³⁴)

Due to the Energy Label, other political measures and the increasing availability of more efficient technologies (heat pump dryer), the total energy consumption of tumble dryers in Europe is expected to further decrease within the next years. This may result in a lower power demand during the whole cycle. At present, energy efficient tumble driers (class A and better) already account for

³¹ European Commission (2005): Green Paper on Energy Efficiency or Doing More with Less. COM (2005) 265 final.

42 % of total sales in EU (Michel et al., 2015³²). Figure 11 shows the power demand curve of a current average heat pump dryer.

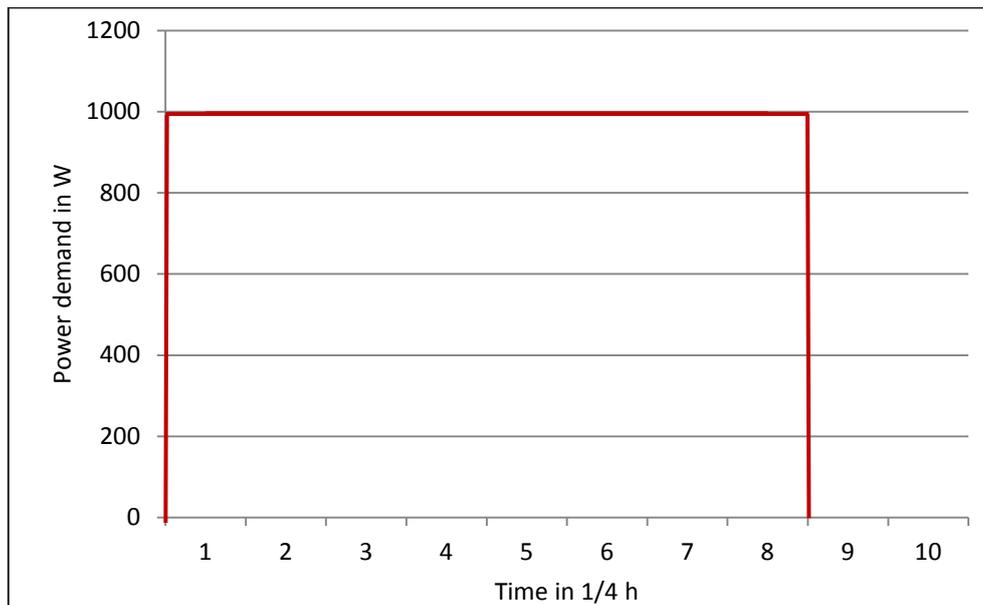


Figure 11: Typical pattern of a power demand curve of an average heat pump tumble dryer operating in a normal cotton programme (source: own illustration)

Use patterns of tumble dryers vary both, on a daily and on a seasonal basis. According to Stamminger et al. (2009)³⁴, the probability of the start time of the tumble dryer operation can be derived from the respective information about washing machines (Figure 8) by simply adding two hours to the time the washing cycle is started. Normally, the washing and drying process are done consecutively. The offset of two hours is seen as an average time span between the start of these two devices. Against the background of increasing cycle times of washing machines, this offset is expected to become larger in the near and mid-term future.

If the general pattern of a power demand curve of a current average conventional tumble dryer (cf. Figure 10) is aggregated with the average probability of start time (cf. Figure 8) and an appliance-specific usage factor, which takes into account the average number of cycles per season, a general pattern of a daily load curve can be derived (Figure 12). For heat pump tumble dryers, the general pattern of a daily load curve is shown in Figure 13. It has to be noted that this daily load curve is based on data representing the user behaviour of only ten European countries, which are named in Figure 8. As the countries investigated cover a major part of the population of EU-28 and the user behaviour appears to be similar in these countries, it seems to be reasonable to assume that the consumer behaviour and this general pattern of a daily load curve is also valid for all EU-28 countries. If the total energy consumption of tumble dryers will further decrease as expected for the next years, the power demand curve will change, which will have an impact on the daily load curve as well.

³² Michel, Attali and Bush (2015): Energy efficiency of White Goods in Europe: monitoring the market with sales data. Changes and trends regarding energy efficiency, energy consumption, size and price in the markets of refrigerators, washing machines and tumble driers in the EU, France and Portugal, 2004 to 2014. Available online: http://www.topten.eu/uploads/File/WhiteGoods_in_Europe_June15.pdf.

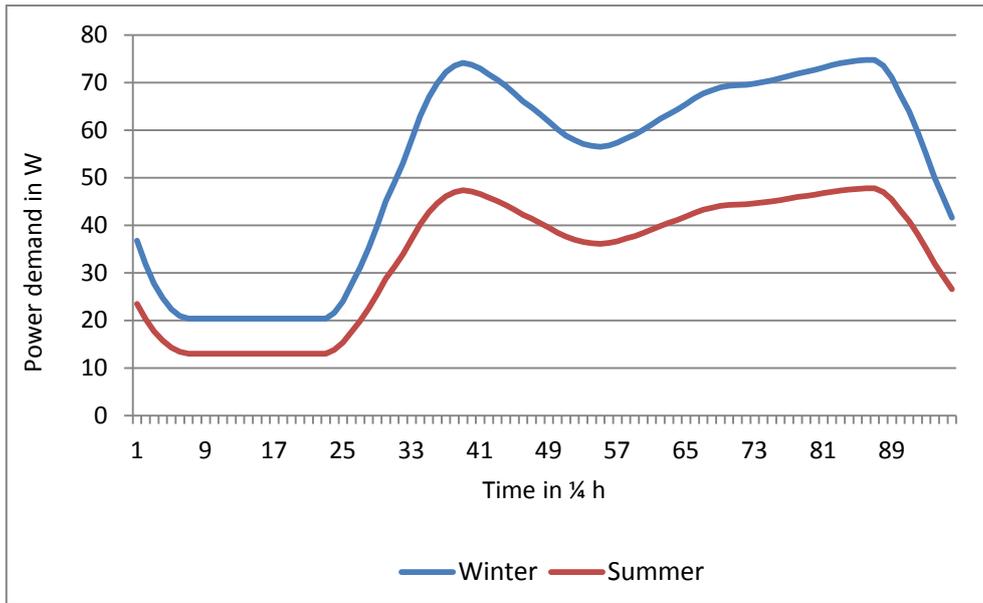


Figure 12: General pattern of a daily load curve of a current conventional tumble dryer for winter and summer season (source: modified according to Stamminger et al., 2009³⁴)

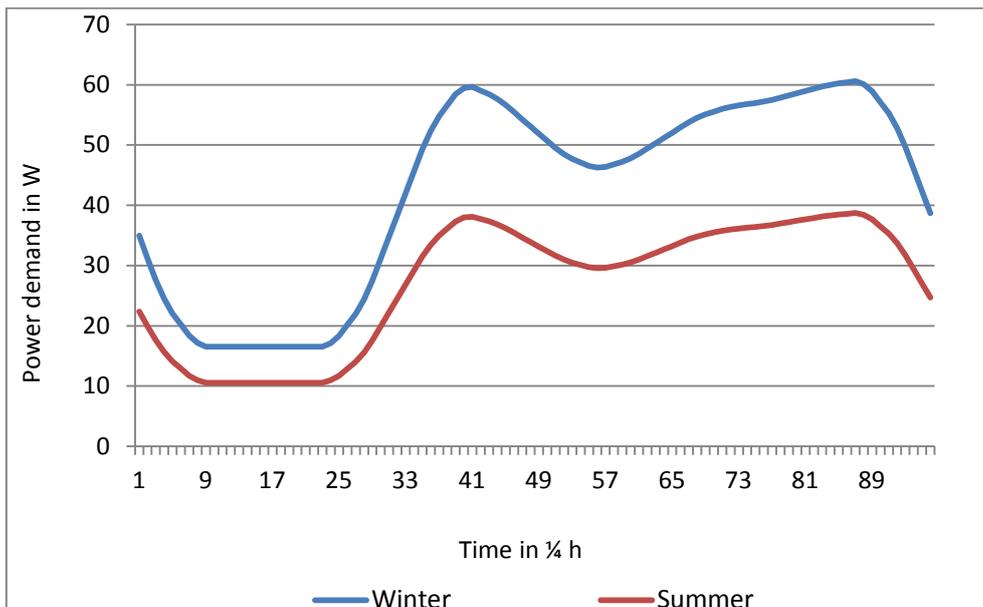


Figure 13: General pattern of a daily load curve of a current heat pump tumble dryer for winter and summer season (source: own illustration)

Washer-dryers

According to a study by Schmitz and Stamminger (2014)²⁹ conducted in ten European countries, the average number of washing cycles per week and household is 4.3. This corresponds to an annual number of 224 cycles. The aforementioned study also revealed that washer-dryers are mainly used for washing purposes. The integrated drying function is only used in 29 % of all wash cycles. This means an average frequency of 1.3 times a week. Even though the majority of appliances in this study were equipped with a ‘wash and dry in a row’ function (no consumer interaction is needed between the washing and the drying cycle as far as the load capacities for washing and drying are respected), this function is only chosen for 24 % of all wash cycles (corresponding to 1.1 cycles per

week). This might be explained by the fact that the capacity for drying is often smaller than for washing, which means that either consumer interaction would be needed to remove wet clothes partly before drying or alternatively the washing capacity cannot be used to the full extent. Another reason is the fact that not all fabrics and items are suitable for tumble drying and therefore have to be removed after the washing process.

The energy consumption of washer-dryers currently available on the market varies between 3.7 kWh and more than 6 kWh (<http://www.topten.eu>) for a washing and drying cycle. This wide range can be explained by the fact that only the efficient appliances are equipped with a heat pump, while the inefficient ones are lacking this technology.

It is assumed that use patterns of washer-dryers vary both, on a daily and on a seasonal basis. The study by Schmitz and Stamminger (2014)²⁹ has shown that in summer, owners of washer-dryers predominately prefer to dry their laundry outside. About 60 % of participants in this study stated to use the drying function of the washer-dryer rarely or never during the summer season. For the winter season, only about half of the households gave this statement. Even though no data are available, it might be assumed that the probability of start time of the washer-dryer operation is equivalent to the probability pattern of washing machines (cf. Figure 8).

1.2.1.3 Lifespan

The average life span of periodical appliances may vary depending on the manufacturer, the model, the equipment, the use conditions and the maintenance. However, calculations and estimations from GfK and experts from industry suggest an average life span of 10 to 15 years for appliances of this category. Information that is more detailed is given in Table 2.

Table 2: Average life span of periodical appliances (Source: ^a VHK, 2014²³; ^b EUP LOT 14²⁷; ^c Lefèvre, 2009²⁶)

Type of appliance	Average life span
Dishwashers:	13 years ^a
Washing machines:	14 years ^b
Tumble dryers:	13 years ^c
Washer-dryers:	n.a.

1.2.1.4 Possibilities for consumers to engage in smart periodical appliances

In view of periodical appliances, two different possibilities to shift energy or modulate power could be identified.

1. Remote activation: the user selected program is remotely activated before the user deadline is reached.
2. Altered electricity consumption pattern: while the appliance is activated, the consumption patterns changed through pausing the operation, changing the temperatures, etc.

In the first case, the machines are remotely started, e.g., when a surplus of (renewable) energy is available on the grid. For this case, user's involvement is limited to the activation of the respective mode and the definition of a desired deadline. As the operation of a single appliance is only shifted in time, the sequence of the programme and with this, the power demand curve of a cycle, remain unchanged. In the case of washing machines or washer-dryers, the drum should be reversed after the end of the cycle until switching the machine off to avoid the laundry going mouldy or sticking

together (additional energy is needed for this function, in average 10 W³³). Appliances in this category offer a high energy shifting capacity. Studies indicate that around 30 % of the configurations of washing machines and tumble dryers can be operated with remote activation. For dishwashers this is 56 %. The average length of the time window for remote activation varies from 3 to 8 h (Mert et al. 2008¹¹).

In the second case, machines may change their operation if they are triggered by an external signal, e.g., showing a shortage of energy available on the grid. Possible changes include short-term interruptions, changes in temperatures or spinning speed or shifts of single programme phases (e.g. heating or spinning phases). This may change the power demand curve of a single appliance and the overall duration of a cycle. For periodical appliances, short-term interruptions might be critical if they occur during the heating phase. Depending on their duration and the actual process temperature, heat energy may be lost to the surroundings and additional energy is needed to recover the process temperature. Investigations by Stamminger et al. (2009)³⁴ recommend interruptions not exceeding a time of 10 minutes in order to avoid significant losses in heat energy. A further aspect, which has to be taken into account in view of short-term interruptions, is the performance. If the operation of washing machines or tumble dryers is interrupted, for instance, the laundry may go mouldy or stick together or fading of colours may occur. In order to avoid such textile damages, the drum should be moved in regular intervals during interruptions longer than 5 minutes.

The complexity of technical adjustments and redesign needed is higher for the second than for the first option.

Flexibility is typically situated in the afternoon and especially in the evening. The evening flexibility peak is most pronounced for the dishwashers. There is more flexibility in the weekends than in during weekdays. As described before, there are almost no seasonal effects for dishwashers and washing machines. However, tumble dryers are predominately used in winter season.

1.2.1.5 Comfort constraints and consumer objections

Several studies (e.g. Kobus et al., 2015⁴, Saele and Grande, 2011⁵, Mert et al., 2009⁶, Paetz et al., 2011¹², D'hulst et al., 2015⁵⁰, Vanthournout et al., 2015⁵²) have shown that the willingness of consumers to shift loads to off-peak hours is rather high for washing machines and for dishwashers. Pilot studies, however, revealed significant inter-personal differences.

In view of washing machines, concerns expressed include safety aspects (e.g. fear of flooding or fire if appliances are operated unattended or during the night). Additionally, consumers are afraid of noise during operation at night. Although the willingness to postpone wash cycles is generally high (77 % of consumers asked in the framework of the Smart-A Study would accept shifts of at least 3 hours), the fear of textile damages (e.g. getting mouldy) is becoming a critical factor for shifting operation (Mert et al., 2008¹¹). Also short term power interruptions may cause textile damages like colour fading or getting mouldy and should therefore not exceed 5 minutes without tumbling (Stamminger et al., 2009³⁴).

For dishwashers, consumers' acceptance of shifting loads or short term interruptions is markedly high. According to findings of the Smart-A project (Mert et al., 2008¹¹), the majority of consumers would be willing to shift their operation at least for 3 hours. Since many consumers already use their dishwasher during night or absence from home, only a few of them are afraid of unattended operation, flooding, fire or noise.

In view of tumble dryers, consumer's acceptance of load shifts demand might be lower than for other periodical appliances. Normally, their operation immediately follows the washing process. If the start is postponed, consumers are afraid of textile damages and wrinkles. In the case of washer-dryers, the level of acceptance is assumed to be higher than for separate tumble dryers as no additional

³³ Based on measurements of University of Bonn, not published

consumer interaction is required if the load capacity of the washing and drying function is respected. (Mert et al., 2008¹¹)

In a pilot study in the framework of the LINEAR project focussing on the flexibility potential of washing machines, dishwashers and tumble dryers and other wet appliances, significant shares of the flexible electricity consumption were shifted to lower price periods, whereas the dishwasher outperformed the other wet appliances in flexibility. User fatigue couldn't be observed during the project. The participants of this pilot study reported on a small impact in view of the comfort, which is not further specified. (Vanthournout et al., 2015⁵²)

1.2.2 CONTINUOUS APPLIANCES

1.2.2.1 Usage Behaviour

Continuous appliances are appliances that provide a capacity to store thermal energy in a form ready to be delivered to the user without any further transformation. These appliances require no interaction with the user after initial set up, although user actions can impact the appliance's operation. In this category we need to distinct between the following appliances destined for private use:

- Refrigerators
- Freezers
- Electric storage water heaters

Moreover, commercial refrigeration appliances fall in the category of continuous appliances.

Residential refrigerators and freezers are mostly based on a closed vapour-compression system. Besides a compressor, they consist of three main components, an evaporator, a condenser and an expansion valve. A fluid refrigerant circulates inside a closed piping system. By absorbing the heat inside the refrigerator or freezer and cooling down the air, the refrigerant evaporates to a gas and flows to the compressor, where it is compressed. The compression causes the temperature and the pressure of the refrigerant to rise. After that, the refrigerant passes the condenser, where it releases heat (equivalent to the heat absorbed inside the refrigerator/ freezer and the thermal equivalent of compressor's work) to the surroundings and becomes liquid. The expansion valve is used to expand the refrigerant and control its flow back to the evaporator. In this process, electrical energy is mainly needed to operate the compressor. Additional energy may be required for the internal light, fans, displays and automatic defrosters.

In the case of electric storage water heaters (hot water buffers), cold water is heated up by one or two direct immersion heating elements, which are located near the bottom and in the upper part of an insulated storage tank. The tank is connected to a cold water supply and has an outgoing insulated pipe for hot water, which normally supplies different taps. Wattage and voltage of electric storage water heaters vary depending on their storage capacity and the temperature range. Whereas the usual residential voltage current (230 V, 16 A) is sufficient for devices with a small storage capacity up to 30 litres, water heaters with larger tanks are frequently connected to high voltage current (~ 400 V). Besides the energy needed for heating up the water, electric storage water heaters may consume stand-by energy to maintain the desired water temperature (about 1.8-2.6 kWh per day; Stamminger et al., 2009³⁴). However, water heaters and hot water storage tanks are now subject to Ecodesign requirements (COMMISSION REGULATION (EU) No 814/2013 of 2 August 2013), which

³⁴ Stamminger (2009): Synergy potential of smart domestic appliances in renewable energy systems. Shaker Verlag, Aachen.

regulate a decrease of standing losses. Consequently, the stand-by energy consumption to maintain a desired water temperature will reduce within the next years.

The rated power of the aforementioned appliances is shown in Table 3.

Table 3: Rated power of devices (source: Stamminger, 2009¹⁸)

Appliance	Rated power of devices
Refrigerators/ freezers	50-300 W
Electric storage water heaters	2000-6000 W

For residential refrigerating appliances, the market penetration is extremely high reaching 1.4 appliances per EU households in 2015. This corresponds to a total of 303 million appliances in stock. (VHK and Armines, 2015³⁵) During the last years, refrigerator-freezer-combinations account for the highest share of refrigerating appliances (60 % in EU-15, about 80 % in New member States; Bertoldi et al., 2012³⁶)

According to estimates by JRC, the installed stock of electric storage water heaters in EU-27 in 2007 was 90 million units. Electric storage water heaters with a capacity of more than 30 litres represent 27 % of the installed base of primary water heaters. (Bertoldi and Anatasiu, 2009³⁷)

For more information on stock data, refer to Task 2.

Given the high power consumption of electric water heaters and the large installed base volumes of refrigerating appliances, the potential of this category for smart applications is assessed to be high. Therefore, these appliances are described more in detail in this chapter.

1.2.2.2 User behaviour concerning continuous appliances

DAILY AND ANNUAL USE PATTERN

Refrigerators

In view of refrigerators energy consumption, only limited data are available. According to VHK (2014²⁵), an average annual energy consumption of 270 kWh per refrigeration appliance in stock in 2015 was calculated. This corresponds to a total energy consumption of about 82 TWh/a (303 million appliances in stock in 2015²⁵). During the last years, energy efficiency improvements have overcompensated the trend towards an increase in size³⁸ and it can be assumed that refrigeration appliances will become even more efficient in the future. According to latest data from Topten.eu (2015)³⁹, the average declared energy consumption for refrigerators sold in 2014 was 231 kWh. Besides technical factors, the user behaviour and environmental factors determine the energy consumption of refrigerators (Geppert and Stamminger, 2013⁴⁰). These factors include:

³⁵ VHK and Armines (2015): Ecodesign & Labelling Review Household Refrigeration. Preparatory/review study Commission Regulation (EC) No. 643/2009 and Commission (Delegated) Regulation (EU) 1060/2010. Interim report

³⁶ Bertoldi, Hirl, Labanca (2012): Energy Efficiency Status Report 2012, Electricity Consumption and Efficiency Trends in the EU-27.

³⁷ Bertoldi, Atanasiiu (2009). Electricity Consumption and Efficiency Trends in European Union – Status Report 2009, European Commission DG Joint Research Centre

³⁸ Herzog (2015): THE MDA (Major domestic appliances) EU ENERGY LABEL REACHING ITS LIMIT? A DISCUSSION. Available online: http://iet.jrc.ec.europa.eu/energyefficiency/sites/energyefficiency/files/events/EEDAL15/S7_Policies7/eedal15_submission_49.pdf

³⁹ Topten.eu (2015): Energy efficiency of white goods in Europe: monitoring the market with sales data. Available online: http://www.topten.eu/uploads/File/WhiteGoods_in_Europe_June15.pdf (latest 10-03-2015)

⁴⁰ Geppert and Stamminger (2013): Analysis of effecting factors on domestic refrigerators' energy consumption in use Energy Conversion and Management, Volume 76, December 2013, Pages 794-800.

- Ambient temperature and humidity
- Exposure to external heat sources (direct sunlight, ovens, dishwashers, washing machines)
- Capacity
- Temperature setting
- Insertion of warm load
- Frequency and duration of door openings
- Installation (freestanding or built-in)

Previous studies have shown that the user behaviour (e.g. temperature settings, insertion of load) as well as environmental factors like ambient conditions vary largely in European countries, making it difficult to predict the energy consumption of refrigerators in real life (EUP LOT 13⁴¹), Geppert and Stamminger, 2010⁴²).

Depending on their capacity, the actual power demand of refrigerators is between 50 and 300 W, whereas Stamminger et al. (2009)³⁴ calculated an average of 138.2 W. Although the efficiency of compressors is still increasing, it can be assumed that this average power demand remains constant over the next years due to a trend towards higher capacities (average net volume in 2015²⁵: 278 l; growth rate 1.2 % per year²³). Under normal conditions, the compressor is working intermittently with a total operation time of about 1/3. However, this operation time may increase up to 100 % under extreme conditions (extremely high ambient temperatures, large amount of hot load). Figure 14 shows a typical pattern of a power demand curve of a refrigerator.

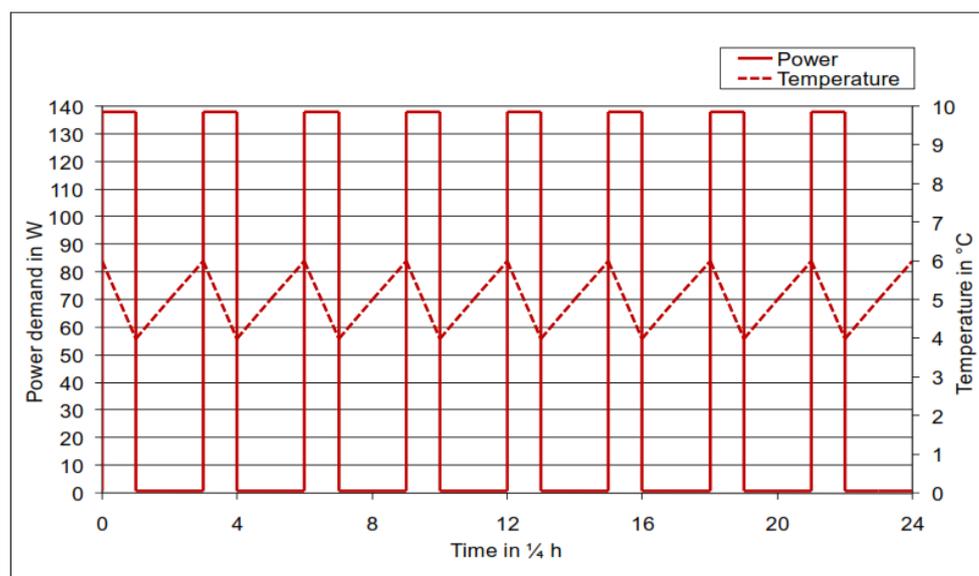


Figure 14: Typical pattern of a power demand curve of a refrigerator (Source: Stamminger et al., 2009³⁴)

It is assumed that use patterns of refrigerators mainly vary on a daily basis. Seasonal variations due to differences in ambient temperatures are only weak and may be neglected as refrigerators are normally located inside closed rooms where the temperature is nearly constant all over the year. In

⁴¹ Preparatory Studies for Eco-design Requirements of EuPs. LOT 13: Domestic Refrigerators & Freezers. Final Report

⁴² Geppert and Stamminger (2010): Do Consumers Act in a Sustainable Way Using Their Refrigerator? The Influence of Consumer Real Life Behaviour on the Energy Consumption of Cooling Appliances International Journal of Consumer Studies, 34(2), 219-27

view of daily variations, results of a study in different European households by Thomas (2007)⁴³ suggest an increased use in the afternoon/ evening period (Figure 15). It seems reasonable to assume that this usage pattern will not change within the next decade.

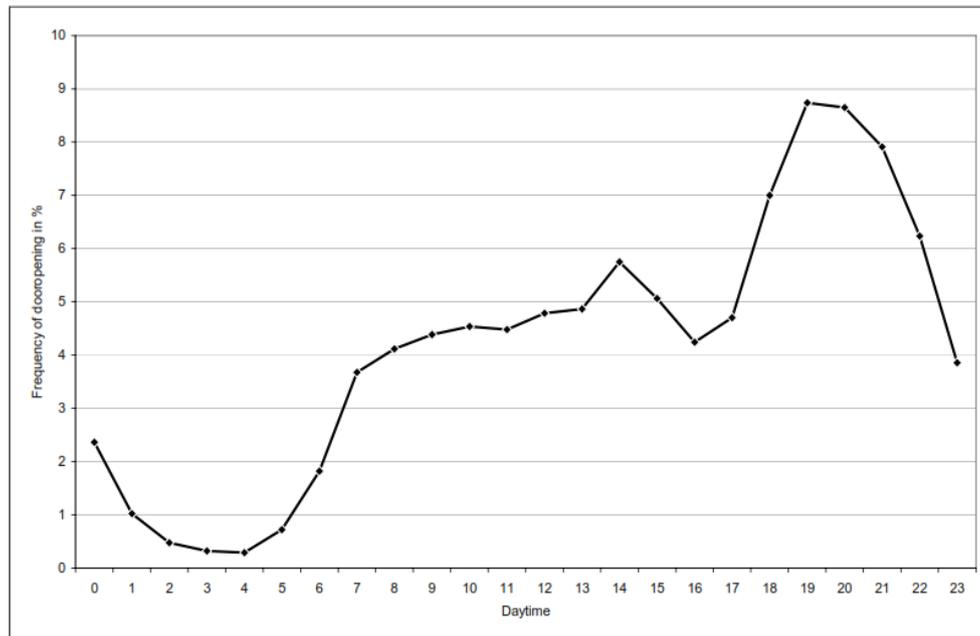


Figure 15: Frequency of door openings during the day (source: Thomas, 2007⁴³)

If the typical pattern of a power demand curve of a refrigerator (shown in Figure 14) as well as the daily usage pattern (cf. Figure 15) are taken into account and it is assumed that 25 % of the total energy consumption is caused by this usage (e.g. door opening, placing of warm food), a typical daily load curve of an average refrigerator in Europe will follow the pattern shown in Figure 16. (Stamminger et al., 2009³⁴)

⁴³ Thomas S. (2007): Erhebung des Verbraucherverhaltens bei der Lagerung verderblicher Lebensmittel in Europa. Shaker Verlag, Aachen.

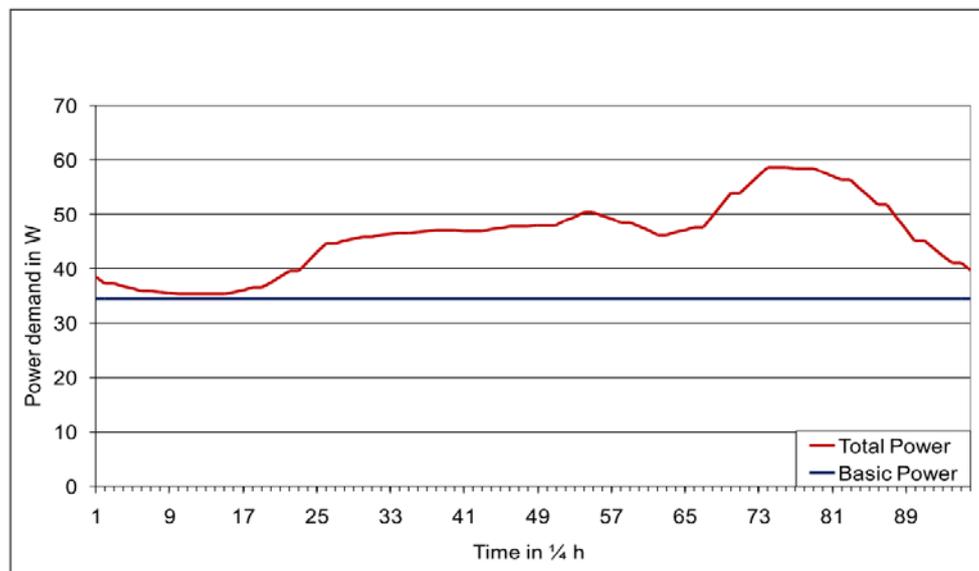


Figure 16: General pattern of a daily load curve of an average refrigerator (source: Stamminger et al., 2009³⁴)

Freezers

In view of freezers energy consumption, only limited data are available. In most cases, no distinction is made between refrigerators and freezers. In the preparatory study in 2005, a total energy consumption of 40 TWh/ year for freezers (54,292 million appliances in 2005) was calculated (EUP LOT 13⁴¹). This is corresponding to an annual consumption of about 737 kWh per appliance. In the meantime, freezers have become substantially more efficient.

As described for refrigerators, user behaviour and environmental factors determine the energy consumption of freezers (Geppert and Stamminger, 2013⁴²Error! Bookmark not defined.). These factors include:

- Ambient temperature and humidity
- Exposure to external heat sources (direct sunlight, ovens, dishwashers, washing machines)
- Chest vs. upright freezers
- Capacity
- Insertion of frozen load
- Insertion of load to freeze
- Frequency and duration of door openings
- Installation (freestanding or built-in)
- Activation of “super frost” function

Previous studies have shown that the user behaviour (e.g. temperature settings, insertion of load) as well as environmental factors like ambient conditions vary largely in European countries, making it difficult to predict energy consumption of freezers in use (EUP LOT 13⁴¹, Geppert and Stamminger, 2010⁴²Error! Bookmark not defined.).

Depending on their capacity, the actual power demand of freezers is between 50 and 200 W, whereas Stamminger et al. (2009)³⁴ calculated an average of 105.5 W. Under normal conditions, the compressor is working intermittently with a total operation time of about 1/3. However, this operation time may increase up to 100 % under extreme conditions (extremely high ambient temperatures, large amount of unfrozen load). The typical pattern of a power demand curve of a freezer without any consumer interaction is similar to that of refrigerators shown in Figure 14.

It is assumed that use patterns of freezers vary on a daily and on a seasonal basis. Ambient temperatures are often higher during the summer (EUP LOT 13⁴¹), resulting in an increased operation

time of compressors. The most common temperature setting is $-18\text{ }^{\circ}\text{C}$ and this setting remains unchanged in the majority of households (EUP LOT 13⁴¹). On a daily basis, consumer's interaction with freezers is normally very limited. According to estimations by Stamminger et al. (2009)³⁴, consumers open their freezers about one to two times per day to take out frozen food (mostly in the afternoon/ evening period) and one to three times per week to place unfrozen food. Opening the freezer's door once and taking out frozen food doesn't have a significant impact on the energy consumption. However, the operation time of the compressor and consequently the energy consumption will increase if new goods have to be cooled down and frozen. To avoid excessive rises in temperature and defrosting of frozen food after storing new goods, consumers can activate a "super frost" function in preparation. This function forces the freezer to cool down to a lower than the normal temperature. Nevertheless, the temperature inside the freezer will increase as soon as unfrozen food is placed, and the compressor operates non-stop until the heat is removed. After switching off the "super-frost" function, the temperature raises back to the initial one, accompanied by a pause in compressor's operation. These changes in power demand curve are illustrated in Figure 17.

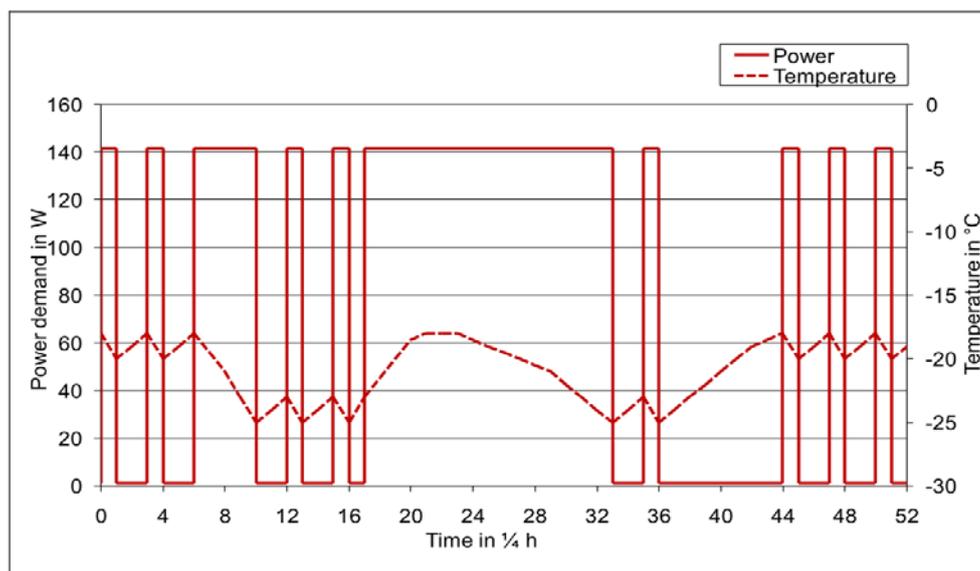


Figure 17: Typical pattern of a power demand curve of a freezer during storage of new goods to be frozen (source: Stamminger et al., 2009³⁴)

If the consumer behaviour is taken into account and it is assumed that 10 % of the total energy consumption is caused by this consumer behaviour (e.g. placing unfrozen food), a typical daily load curve of an average freezer in Europe will follow the pattern shown in Figure 18. (Stamminger et al., 2009³⁴)

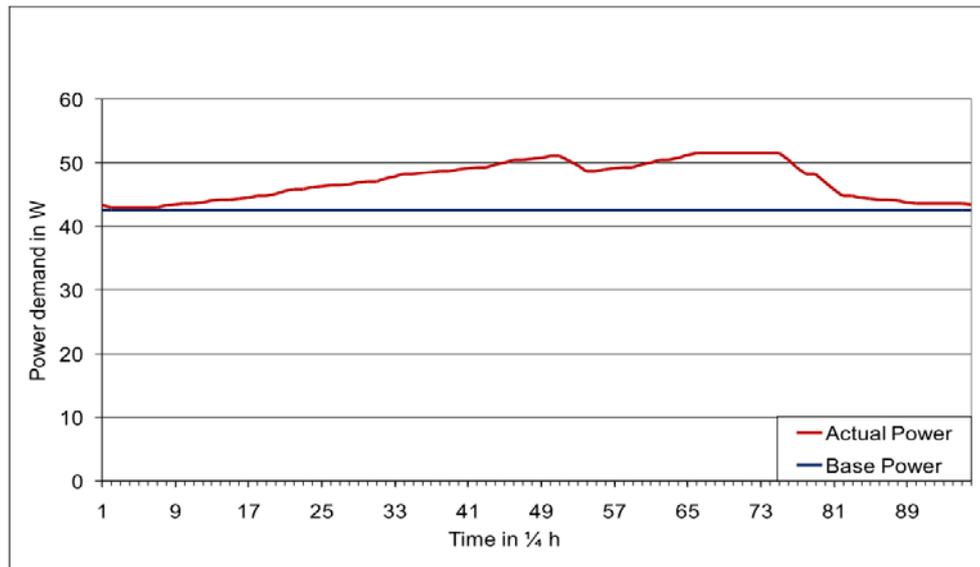


Figure 18: General pattern of a daily load curve of an average freezer (Source: Stamminger et al., 2009³⁴)

Commercial refrigeration appliances

In close cooperation with industry, specifics of the consumption from commercial refrigeration, and its flexibility potential were estimated. Firstly, general daily patterns for consumption of commercial refrigeration appliances are developed. Secondly, the timeframe for maximum average load shifting time for these processes is given in the paper.

In (Funder-Kristensen et al., 2015), a methodology to calculate aggregated total consumption of a group of different types of supermarkets is developed. In the cited paper, two relevant flexible processes are identified related to commercial refrigeration: cooling process by compressors, and defrosting process. Flexibility in commercial refrigeration related to the compressor process can be best described as load shedding or load shifting, whereas the flexibility from the defrosting process can be utilized as load shifting.

The method relies on the number and area of different types of supermarkets in the considered area. In (Funder-Kristensen et al., 2015), a simple way to convert all the supermarket types into a single generic supermarket class is utilized. For the purposes of this study, the same method is applied. The converted area of all the supermarket types into this generic class per EU-28 member state is presented in Table 4. The numbers for 2014 and 2020 are obtained from industry, and they are based on Planet Retail data.

For 2030 data in Table 4, a compound annual growth rate of 2% in the period from 2020 to 2030 for the retail market is assumed. Moreover, it is assumed that basic flexibility per m^2 will increase. This is not covered by increase in yearly average consumption per m^2 , but in the increased number of supermarket area [m^2].

Table 4 Area of supermarkets expressed in converted m² per EU-28 member state (source: calculation disclosed by correspondence by Danfoss).

Converted area [m ²]	2014	2020	2030
Austria	2.622.887	2.795.862	3.408.140
Belgium	2.759.579	2.991.654	3.646.810
Bulgaria	506.870	693.879	845.835
Cyprus	90.513	150.011	182.863
Czech Republic	1.782.830	1.888.133	2.301.623
Germany	22.149.284	24.004.219	29.261.009
Denmark	1.607.371	1.625.977	1.982.057
Estonia	538.496	701.350	854.942
Spain	7.838.926	9.302.877	11.340.155
Finland	2.013.210	2.418.153	2.947.715
France	22.066.766	23.334.136	28.444.182
United Kingdom	11.342.746	12.405.664	15.122.435
Greece	1.409.347	1.568.836	1.912.403
Croatia	873.687	1.123.874	1.369.996
Hungary	3.317.630	3.415.686	4.163.702
Ireland	981.409	1.022.173	1.246.023
Italy	7.085.567	7.451.524	9.083.366
Lithuania	573.585	637.757	777.422
Luxembourg	174.537	196.275	239.258
Latvia	241.197	282.752	344.674
Malta	30.171	50.004	60.954
Netherlands	3.395.744	3.806.681	4.640.323
Poland	3.720.754	4.548.618	5.544.740
Portugal	1.672.448	2.139.876	2.608.497
Romania	911.194	1.188.816	1.449.160
Sweden	3.539.269	3.817.954	4.654.064
Slovenia	485.984	542.125	660.847
Slovakia	757.481	909.795	1.109.035

The consumption of the commercial refrigeration is determined separately for the two identified flexible processes. The consumption of the defrost process is treated as a constant not depending on the time of the year and the climatic zone. The estimated consumption of the defrosting process is 13 [kW/m²], and it can be shifted for maximally 90 minutes, see (Funder-Kristensen et al., 2015).

The yearly consumption of the compressor is correlated with the outside temperature, and follows seasonal and daily patterns. The variations in consumption by commercial refrigeration due to the climate differences between EU-28 member states are taken into account by division of EU-28 into three climatic zones. These zones are defined as follows.

Climatic zones:

- A: Denmark, Sweden, Finland, Estonia, Latvia, Lithuania, the Netherlands, United Kingdom, and Ireland
- B: Germany, Belgium, Luxembourg, Poland, Czech Republic, Austria, Slovakia, Slovenia, Croatia, Hungary, Bulgaria and Romania
- C: Portugal, France, Greece, Italy, Spain, Cyprus, and Malta.

The consumption for each of the climatic zones is based on the calculations for a particular city from

the zone. For zone A, this is Copenhagen, for zone B, Berlin, and for zone C, Madrid. Detailed calculations are conducted as presented for different cities in (Mikhailov et Matthiesen, 2013), where “Pack Calculation II” tool is developed and valorised.

Table 5 (source: private correspondence with Danfoss)

Climatic zone	yearly average [kW/m ²]	Daily variation [% of daily average]	Seasonal variation [% of yearly average]
A	40	40	40
B	43	50	45
C	46	55	50

The consumption is different depending on the climatic zone, and is defined as presented in Table 5.

The yearly consumption of the compressor follows a sinus curve with the highest amplitude in summer and lowest amplitude in winter. The yearly average is used to shift the sinus curve so that the correct consumption is obtained. The consumption also follows a sinus curve each day (each 24 hours). This sinus curve is centered around the daily average with a daily amplitude. The peak of the daily sinus curve corresponds to the hottest time of the day, which is at 2-3 pm according to the climate report for the ... The coldest part of the day then corresponds to the time before the dawn in the middle of night before sunset, around 4-5am.

As for the yearly consumptions oscillations, end of January is the coldest (30 January), end of July hottest (30 July), so the consumption of commercial refrigeration is also the coldest on at the end of January, and hottest at the end of July. Similar assumption is also used in (Mikhailov et Matthiesen, 2013). The developed profiles can be validated against the profiles presented in (Fredslund, 2013).

It is assumed that this consumption can be shifted for 15 minutes on average, (Funder-Kristensen et al., 2015).

Lastly, not all the commercial refrigeration appliances will be able or willing to participate in the demand response schemes. Therefore, an estimation of share of smart enabled commercial refrigeration appliances in the total share of commercial refrigeration appliances is presented in Table 6. As there are currently only pilots starting around provision of such flexibility, for 2014 and 2014, it is assumed there are no smart enabled commercial refrigeration appliances in EU-28 area. In the coming years, according to the educated guess from industry, the share of flexible commercial refrigeration actually providing flexibility is expected to increase to 50% and surpass the share of smart enabled residential refrigeration.

Table 6 Share of smart enabled commercial refrigeration appliances in the total share of commercial refrigeration appliances (source: correspondence with Danfoss).

Year	2014	2020	2030	
Smart enabled appliances [%]		0	10	50

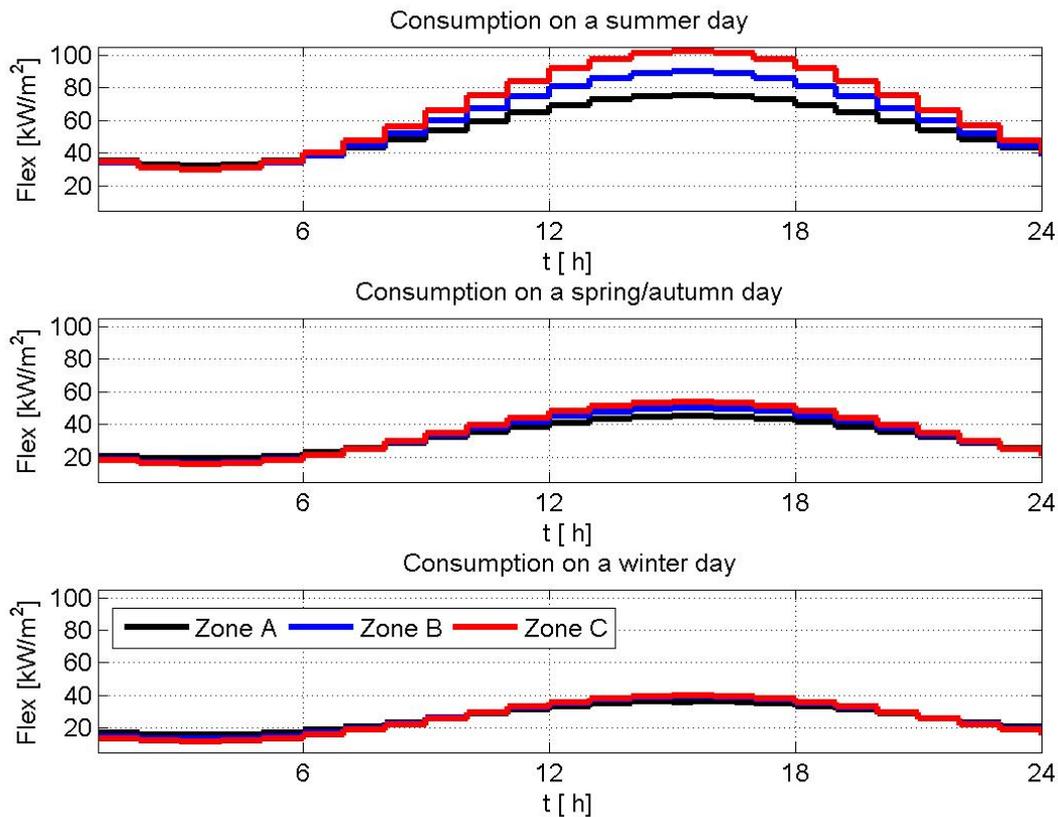


Figure 19 Daily consumption patterns of compressors in commercial refrigeration appliances, expressed in $[\text{kW}/\text{m}^2]$, and given in dependence on the climatic zone and season in the year.

Electric water heaters

According to Bertoldi et al. (2012)³⁷, electric water heaters consumed 8.7 % of total residential electricity consumption in 2007, corresponding to 73.0 TWh/ year. Taking into account the installed stock of in total 73 million devices⁴⁴ (about 20 million of night storage water heaters⁴⁴), an average annual consumption of about 1000 kWh per appliance can be calculated.

As described for refrigerators and freezers, the energy consumption of electric water heaters is also significantly affected by user's behaviour and environmental factors:

- Number of people per household
- Frequency, duration and timing of showers or baths per person
- Number and usage of appliances connected to hot water supply (e.g. dishwashers, washing machines)
- Manual dishwashing habits
- Use of hot water for cooking
- Presence at or absence from home
- Temperature of hot water
- Temperature of incoming cold water

⁴⁴ VHK, 2007 + industry estimations from Ariston Thermo Group (personal communication). Includes electrical storage and heat pump water heaters

In 2007, the preparatory study on water heaters (EUP LOT 2⁴⁵) calculated an average hot water consumption of 24 litres per person per day for EU-25, corresponding to an average of 59 litres per household per day. However, there are considerable differences between different member states as shown in Figure 19.

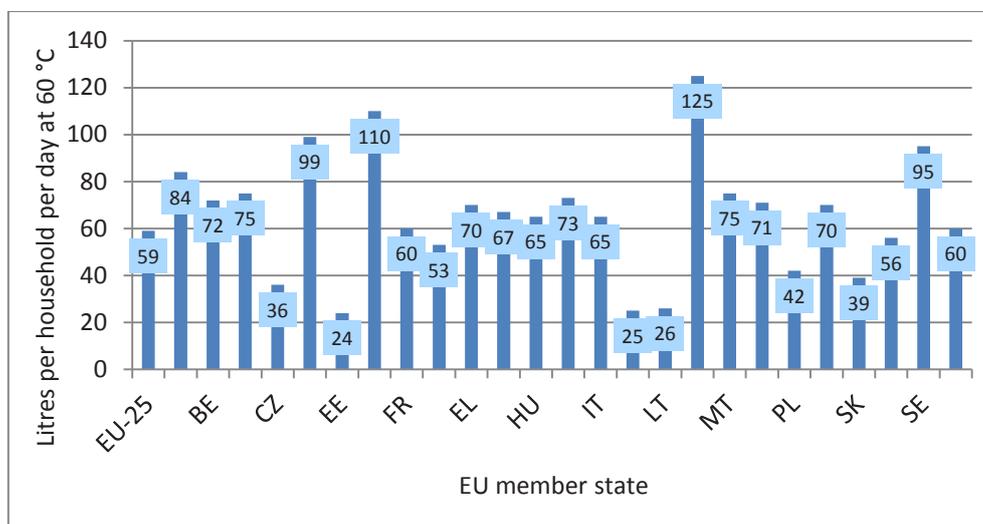


Figure 20: Hot water consumption per household per day for EU-25 (source: own illustration based on EUP LOT 2⁴⁵)

Due to changes in consumer behaviour and variations in temperature of the incoming (cold) water, seasonal variations in use pattern of electric water heaters can be assumed. In-home measurements of water temperature and water consumption in 20 multi-family houses in Switzerland in 1993 have shown that the hot water temperature remained unchanged at about 60 °C all year. This study also suggests that the daily hot water consumption varies on a seasonal basis and that it is dependent on weekdays/ weekend (Figure 20). Defra (2008)⁴⁶ reported on similar seasonal effects observed in UK with highest volumetric hot water consumption in winter and lowest consumption in summer. The same study also analysed the annual pattern of incoming cold water temperatures. Regarding to this, considerable differences (about 10 K between the coldest and warmest temperature) have been found with highest temperatures occurring in summer. European data on seasonal variations of both, volumetric hot water consumption and cold water inlet temperatures, are lacking so far.

⁴⁵ Preparatory Study on Eco-design of Water Heaters. Final report.

⁴⁶ Defra, 2008: Measurement of Domestic Hot Water Consumption in Dwellings. URL: https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/48188/3147-measure-domestic-hot-water-consump.pdf.

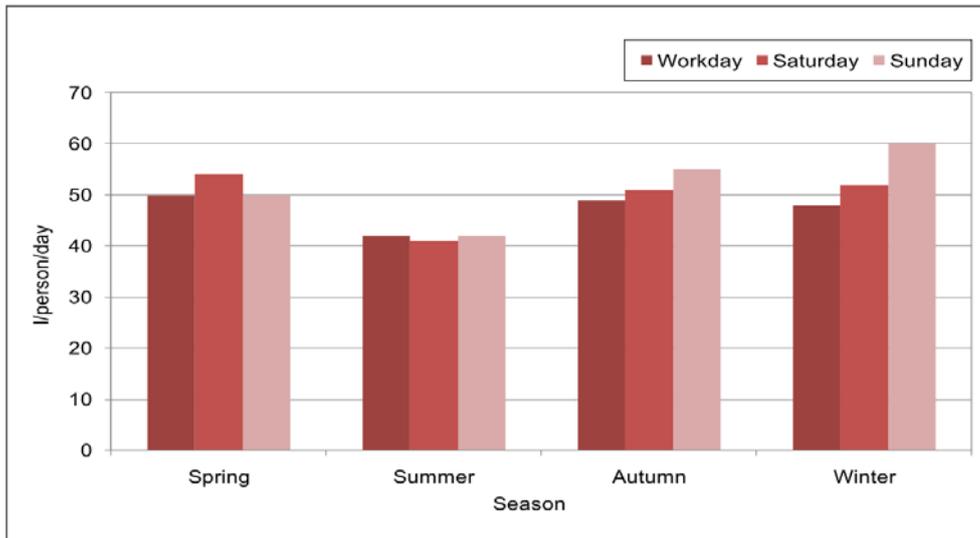


Figure 21: Daily hot water consumption by season and weekday (source: BfK, 1993; taken from Stamminger et al., 2009³⁴)

Besides seasonal variations, use pattern of electric water heaters also varies on a daily basis.

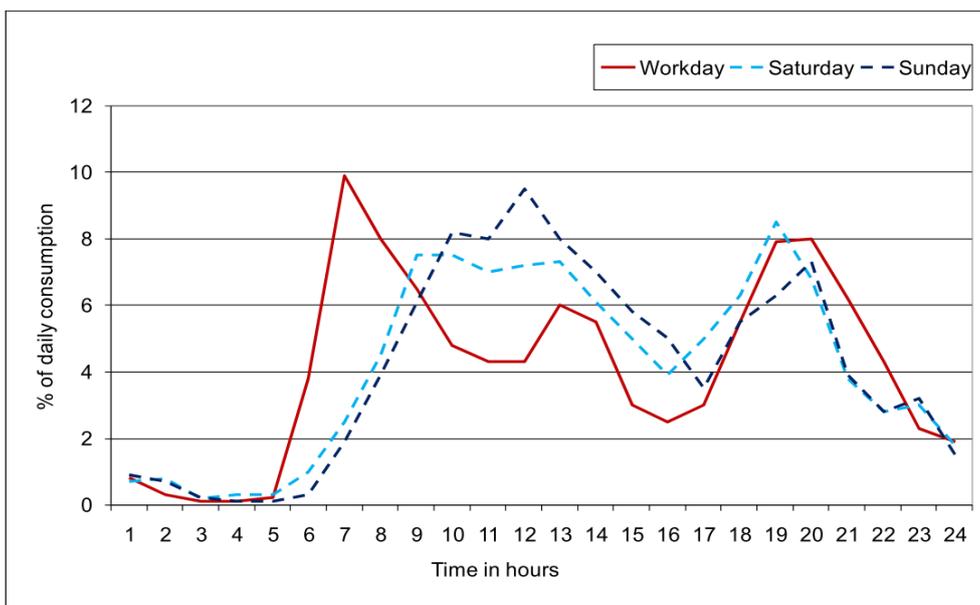


Figure 22: Profile of daily hot water consumption in Switzerland (source: BfK, 1993⁴⁷; taken from Stamminger et al., 2009³⁴)

On working days, two peaks can be observed, one in the morning between 6 a.m. and 9 a.m. and one in the evening period between 7 p.m. and 10 p.m. (Figure 21). Whereas the morning peak is postponed by about 4 hours (between 10 a.m. and 2 p.m.) during the weekend, the evening peak almost remains unchanged. More recently, Defra (2008)⁴⁶ published similar information on hot water consumption pattern in UK, from which the following daily profile has been deduced (Figure 22). For

⁴⁷ Bundesamt für Konjunkturfragen, 1993: Blatter, Borel, Hediger, Simmler: Materialien zu RAVEL. Warmwasserbedarfszahlen und Verbrauchscharakteristik. Bern.

this reason, it seems to be reasonable to assume that the daily profile shown in Figure 21 is still valid today and similar for all European countries.

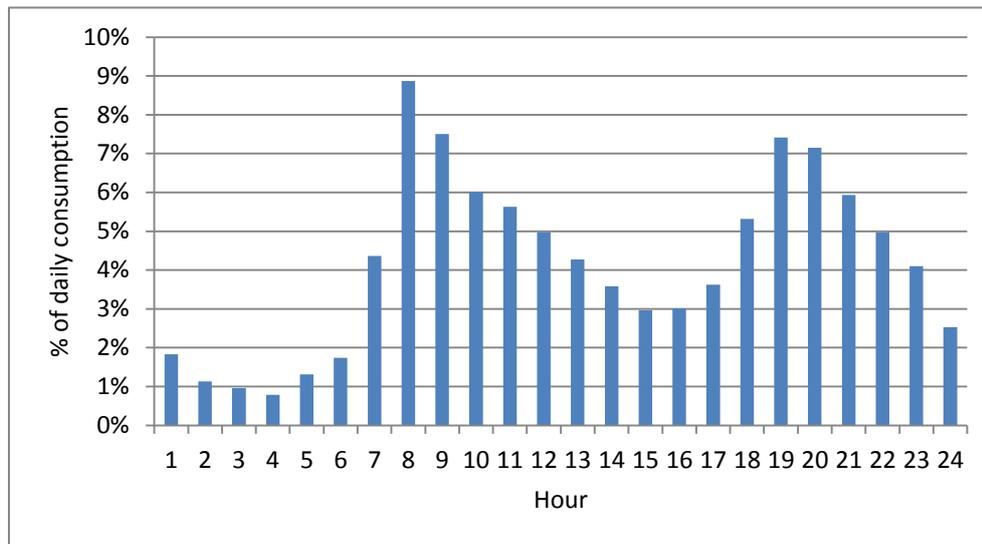


Figure 23: Profile of daily hot water consumption in UK (own illustration deduced from Defra, 2008⁴⁶)

In view of power demand curves of storage water heaters, it has to be distinguished between two main types: storage heaters, which heat during the night only (NSWH) and maintain the water temperature during the day and continuous water heaters, which reheat the stock of water to the predefined temperature after each tapping event (hot water buffers; CSWH). In general, the storage capacity of NSWH is higher (usually between 100 and 300 l, average 200 l) compared to CSWH (average 80 l). Regarding NSWH, power varies between 1500 and 3000 W dependent on capacity with an average power of 2500 W. In the case of CSWH, the power is lower (average 1500 W). (ATG, 2016⁴⁸)

Information about the distribution of these two types of storage water heaters is scarce. According to estimations by a manufacturer, water heaters heating during the night are the prevailing type in France and Germany (about 20 million appliances in stock in 2015⁴⁸), whereas continuous storage water heaters (about 53 million appliances in stock in 2015⁴⁸) are predominately used in Spain, Italy, Hungary, Czech Republic and Poland. In UK, both types are common. Data on the distribution in other European Countries are currently not available. (Stamminger et al., 2009³⁴)

General pattern of power demand curve for NSWH is exemplarily shown in Figure 23, whereas a storage capacity of 200 l, a temperature difference of 45 K, a rated power of 2.5 kW and an efficiency of 80 % (representative for the actual stock⁴⁸) was assumed. Actual power demand curves may differ from the pattern given here. In general, the power demand curve needs to fit the respective total energy consumption, which is dependent, amongst others, on the amount of water to be heated, the temperature of the incoming cold water and the target temperature. At present, NSWH usually start loading around 10-11 pm and stop heating when respective target temperature is reached (ATG, 2016⁴⁸). An estimated distribution of energy consumption of NSWH over 24 hours of a day is given in Figure 24.

⁴⁸ ATG, 2016: Artiston Thermo Group, personal communication.

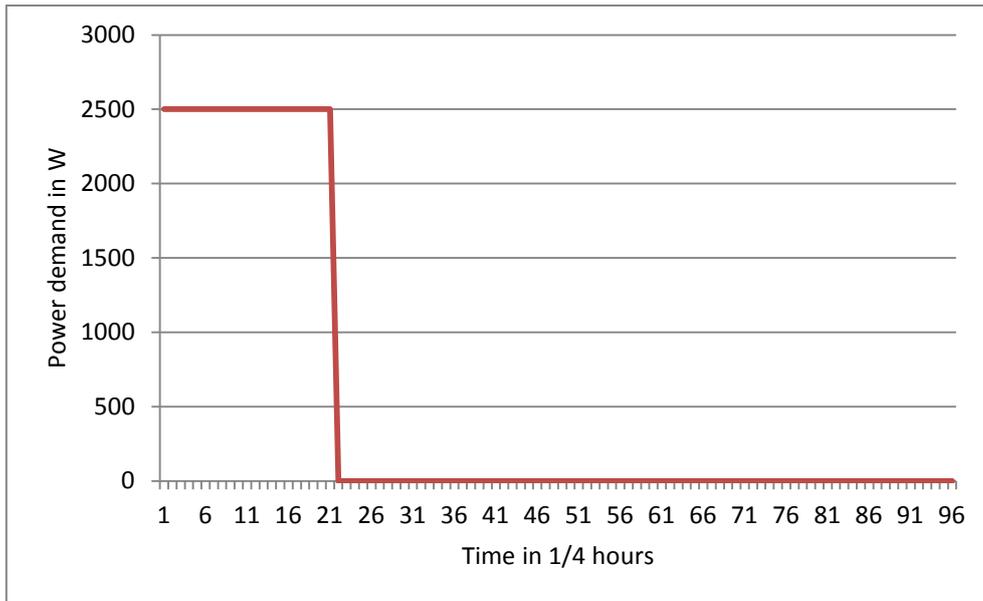


Figure 24: General pattern of a power demand curve of NSW (source: own illustration)

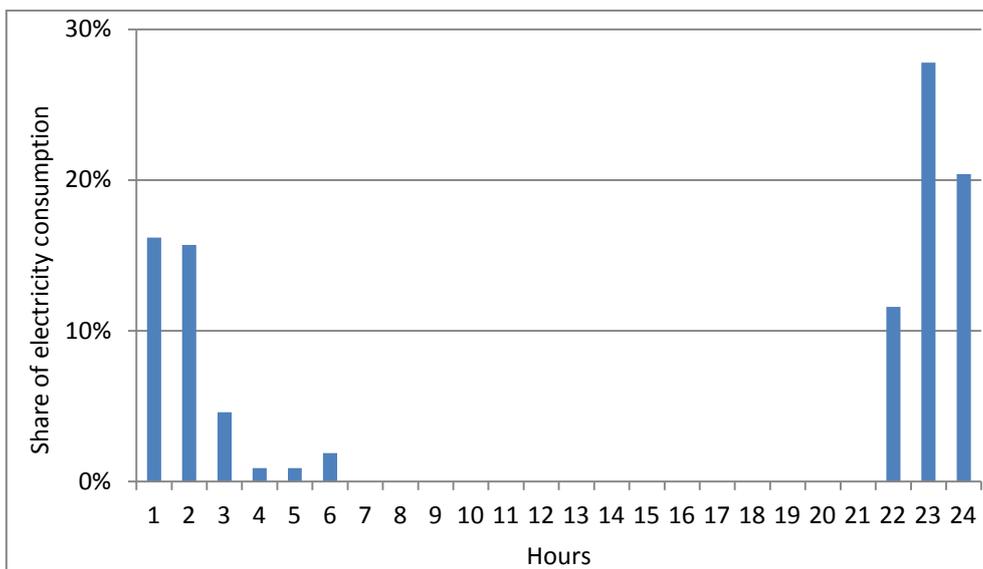


Figure 25: Estimated distribution of electricity consumption of NSW over 24 hours of a day (source: own illustration deduced from ATG, 2016⁴⁸)

Load curve of CSWH directly corresponds to the daily tapping pattern (Figure 22). If the profile of daily hot water consumption (cf. Figure 8) is combined with the general pattern of a power demand curve of a 1.5 kW CSWH heating up 59 l ($\Delta T = 45 \text{ K}$), a typical pattern of a daily load curve () can be derived. It has to be noted that this daily load curve is just an example. As the pattern is dependent on the total amount of water to be heated, the temperature difference and the rated power, it is only valid under the conditions specified before. Due to huge variations in conditions between different countries and even between households in the same country, it is impossible to give a general pattern of a daily load curve of storage water heaters.

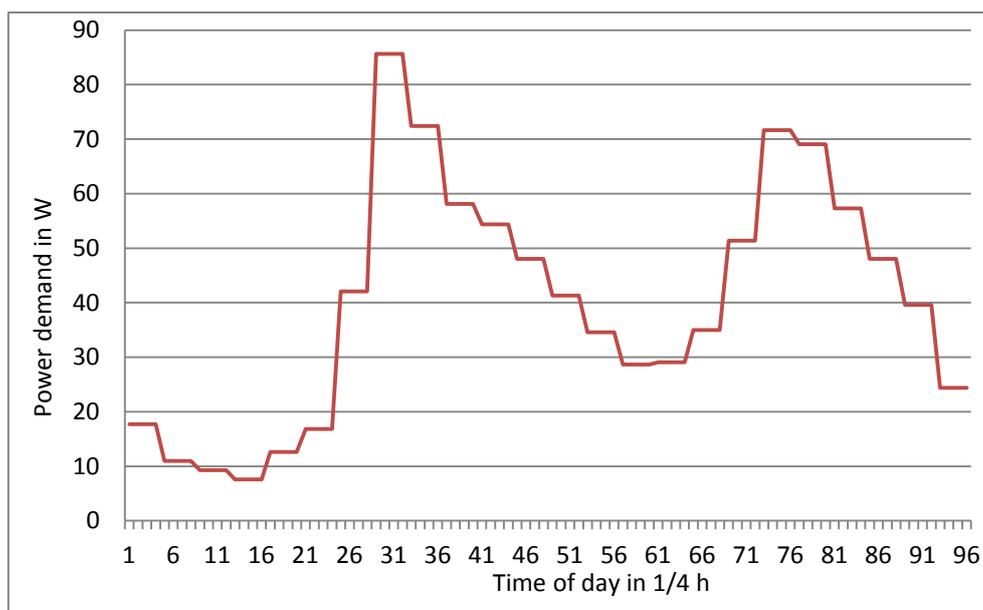


Figure 26: Typical pattern of a daily load curve of a 1.5 kW CSWH (source: own illustration)

1.2.2.3 Lifespan

The average life span of continuous appliances may vary depending on the manufacturer, the model, the equipment, the use conditions and the maintenance. Average data are given in Table 2.

Table 7: Average life span of continuous appliances (Source: ^a VHK and Armines, 2015³⁵; ^b CECED, 2006⁴⁹; ^c EUP LOT 2⁴⁵)

Type of appliance	Average life span
Refrigerators:	12-13 years (+ 3-4 years secondary use) ^a
Freezers:	17 years ^b
Storage water heaters:	15 years ^c

1.2.2.4 Possibilities for consumers to engage in smart continuous appliances

In view of continuous residential appliances, two different possibilities to shift energy or modulate power could be identified.

1. Power line triggered operation (e.g. frequency control): changes in frequency are detected by appliances and transferred into action (activation or delay of cooling or heating).
2. Altered electricity consumption pattern: changes in the operational parameters of the appliance (motor speed, temperature settings, etc.) allow modification of the consumption pattern.

In the first case, the appliances are activated when a surplus of energy/ renewable energy is available on the grid, communicated e.g. via power line frequency or other control signals. In the following, the procedure is explained taking the example of frequency control.

⁴⁹ CECED, 2006: Energy Efficiency, A shortcut to Kyoto Targets. The Vision of European Home Appliance Manufacturers.

Both, surplus and shortage of energy have an impact on the total load on the grid and thus the frequency. These changes in frequency can be detected by appliances of this category and transferred into a respective action.

If power shortage is for example indicated during the operation of a refrigerator's compressor, the compressor will stop its operation even if the temperature, at which the thermostat normally switches off, is not reached. On the other hand, if there is a surplus of energy available on the grid, the compressor will start to operate even if the maximum temperature, at which the thermostat normally switches on, is not reached yet. In this way, the upper and lower temperature limits will not be exceeded. The hysteresis rather gets smaller and as a consequence, the food quality will not be compromised. For freezers, the same scenario is applicable. In the case of storage water heaters, a surplus of energy may prepone the start of the heating process and a power shortage may interrupt it for a short period of time. In the case of frequency control, appliances operate fully automatic so that no consumer interaction is required. In response to the load on the grid, frequency control may change the on-off cycle of refrigerators and freezers and may prepone or delay start of electric storage heaters or interrupt their operation by seconds or minutes.

In the second case, the appliances are remotely controlled and may change their operation. For refrigerators and freezers, possible changes include pre- or postponed start of the compressor, changes in temperature hysteresis or motor speed/ power level. In view of water heaters, the following changes are possible: delay in start or interruption of heating phase, preponing operations for storing energy in anticipation of future use in the coming hours, reducing or increasing water temperature desired. In order to enable remote control of appliances, a bidirectional communication is needed. This may change the power demand curve of a single appliance (e.g. shift in operation by seconds or minutes or changes in motor power) and the overall duration of a cycle.

The complexity of technical adjustments and redesign needed is higher for the second than for the first option.

For appliances in this category, flexibility depends on the thermal storage capacity. Flexibility is mainly situated in the afternoon (refrigerators and freezers) and in the early morning (electric water heaters). The flexibility of hot water buffers remains to a great extent stable during the day (D'hulst et al., 2015⁵⁰). Whereas for refrigerators and freezers, seasonal effects are only weak, water heater loads are seasonal with highest potential occurring in winter.

In view of commercial refrigeration appliances, flexibility is limited for appliances containing perishable goods (e.g. supermarket cabinets), as a predefined maximum temperature always has to be maintained for reasons of food safety. However, flexibility may be provided by changing cooling power or turning off the light (e.g. at night). As far as beverage coolers, which do not contain any perishable goods, are concerned, the flexibility goes far beyond what is possible for supermarket cabinets. A growing number of beverage coolers are equipped with electronic control components (so called "energy management devices") steering energy consuming components/ functions of the appliance. Besides changing speed or power of compressors or fans or turning off the light, working temperatures may be increased during off-peak hours (e.g. during night or during the weekend). (JRC, 2014⁵¹)

In general, it has to be mentioned that DSF should promote and not compromise food safety, thermal performance and energy efficiency of refrigerating appliances.

⁵⁰ D'hulst, Labeeuw, Beusen, Claessens, Deconinck, Vanthournout (2015): Demand response flexibility and flexibility potential of residential smart appliances: Experiences from large pilot test in Belgium. Applied Energy 155: 79-90.

⁵¹ JRC (2014): JRC Technical Reports - Ecodesign for Commercial Refrigeration. Preparatory study update Final report.

1.2.2.5 Comfort constraints and consumer objections

In order to prevent microbial growth and quality losses of food, the temperature inside the compartment of refrigerators has to be kept constant within narrow ranges. As a result, delays in start time, short term interruptions and changes in temperature hysteresis are only feasible to a limited extent. Whereas it is possible to store energy by cooling to lower than normal storage temperatures in the case of freezers, this possibility is limited in the case of refrigerators because of the risk of freezing sensitive food and losing food quality.

Although the acceptance for smart operation of refrigerators and freezers is generally high (96-98 % of consumers asked in the framework of the Smart-A Study would accept shifts), the fear of food spoilage or deterioration is becoming a critical factor (Mert et al., 2008¹¹). Additionally, consumers raised doubts concerning a safe operation of the technology. To provide failure –resistant technologies and the possibility to monitor easily the storage temperatures might help to overcome these concerns (Mert et al., 2008¹¹).

In view of electric storage water heaters, it is essential for a high consumer acceptance to always ensure a sufficient amount of hot water. Consequently, shifts in operation are limited, especially for water heaters with small storage capacities. In terms of devices with large storage capacities, operation shifts are possible without comfort or user impact. Operation of water heaters may also be adapted to shortages of power on the grid by reducing the desired water temperature (at present about 60 °C). However, this scenario might be critical from a hygienic point of view as the growth of microorganisms such as *Legionella* can only be reliably prevented at higher water temperatures of about 60 °C. In the framework of the LINEAR project, user acceptance with smart domestic hot water buffers was examined (Vanthournout et al., 2015⁵²; Linear⁵³). In order to avoid losses in comfort, some measures were used in the aforementioned study. So, a minimum state of charge was defined determining that the state of charge may not be less than 30 %. If it comes below this value, the buffer is automatically recharged until reaching a value higher than 30 %. These measures proved effective during the study as none of the participants complained about comfort losses. Due to the fact that no further consumer interaction is required once the comfort settings are done, consumer's acceptance for smart operation of domestic hot water buffers was high. Also in the study by Mert et al., 2008¹¹, participants predominately stated to accept smart operation of water heaters as long as there is no loss of comfort.

1.2.3 BEHAVIOURAL APPLIANCES

1.2.3.1 Usage Behaviour

Behavioural appliances are appliances where the operation is linked to its functionality and whose operations require the active involvement of consumers. In this category there are the following appliances destined for private use:

- Electrical hobs
- Electric ovens
- Range hoods
- Vacuum cleaners
- Instantaneous water heaters

⁵² Vanthournout, Dupont, Foubert, Stuckens, Claessens (2015): An automated residential demand response pilot experiment, based on day-ahead dynamic pricing. *Applied Energy* 155: 195-203.

⁵³ Linear (local intelligent networks and energy active regions): www.linear-smartgrid.be

Regarding **electric hobs**, three main types may be distinguished: sealed hobs using solid plates made of cast iron, ceramic hobs heated with a halogen heating element and induction hobs. In the case of sealed hobs, heat is transferred via thermal conduction. In view of ceramic hobs, a halogen heating element is producing the heat, which is transferred to the cooking ware by radiation and conduction. Induction hobs create heat energy inside the cookware itself by inducing turbulent electric flow in its bottom. In all three cases, electrical energy is mainly needed for heating processes. Additional energy may be required for displays.

In the case of **electric ovens**, a variety of heating methods can be used including top and bottom heat, fan heat, grill and combinations of them. The heat is mainly transferred via radiation and, to a minor degree, by convection. Normally, temperatures can be set between 50 and 300 °C. Besides the energy needed for heating processes, electric ovens may consume stand-by energy (e.g. display, clock, and programme). Additional to single ovens, combinations of hobs and ovens (called cookers) are available and very common in the European market. (Stamminger et al., 2009³⁴)

In view of electric **range hoods**, a variety of types and sizes are available on the market, including wall-chimney-hoods, island hoods, under-cabinet hoods or downdraft hoods. Their main function is to remove airborne grease, combustion products, smoke, fumes and odours coming from cooking processes. Range hoods can either be vented or ductless. Vented hood exhaust the air to the outside of the house by using a fan. On its way to the outside, the air passes one or more grease filters. Ductless hoods use several filters (e.g. activated charcoal) to clean the air and recirculate it back to the kitchen. Energy is mainly consumed by the fan. Additional energy may be required for lighting, displays and for stand-by losses.

Vacuum cleaners are appliances that suck up dust and particles from the floor and other surfaces by creating a partial vacuum. The main components are a fan, which is driven by a motor, different filters and nozzles. There are many different designs and technologies available on the market, e.g. canister, drum, upright, hand-held, robotic, cyclonic, bag less, bagged, wet-and-dry vacuum cleaners. Energy is mainly needed to operate the motor/ to create the partial vacuum.

In view of **instantaneous water heaters**, water is instantly heated up by passing the device. Heater rods of bare wire are often preferred for these devices. Due to their high wattage, instantaneous water heaters need to be connected to high voltage current (~ 400 V). In contrast to electric storage heaters, hot water is not stored and consequently no stand-by energy is required to maintain water at a desired temperature.

The rated power of the aforementioned appliances is shown in Table 5.

Table 8: Rated power of devices in stock (source: ^aSchätzke⁵⁴, 1997; ^bHEA⁵⁵; ^cEUP LOT 17⁵⁶, ^dStamminger et al., 2009³⁴)

Appliance	Rated power of devices
Electric hobs	100-2,000 W (per plate) ^a
Electric ovens	Up to 3,500 W
Electric cookers	8,000-13,000 W ^b
Range hoods	120-1,000 W ^b
Vacuum cleaners	1,000-2,700 W ^c
Instantaneous water heaters	2,400-27,000 W ^d

⁵⁴ Kutsch, Piorkowsky, Schätzke (1997): Einführung in die Haushaltswissenschaft. Haushaltsökonomie, Haushaltssociologie, Haushaltstechnik. Stuttgart 1997

⁵⁵ HEA (2015): Fachwissen Elektroherde. Available online: <http://www.hea.de/service/fachwissen/elektroherde/>

⁵⁶ Work on Preparatory Studies for Eco-Design Requirements of EuPs (II). Lot 17 Vacuum Cleaners. Final report

Since September 2014, vacuum cleaners are subject to Ecodesign requirements, which regulate a progressive decrease of rated input power (European Commission, 2013⁵⁷). Consequently, the average rated power will reduce within the next years.

According to the EUP LOT 23⁵⁸ report, 145.7 million electric hobs (solid plates, radiant and induction hobs, mixed hobs, electric cooker tops) were in stock in 2007, corresponding to a penetration rate of 71 % (assumption: 205 million households). The overall trend shows that the share of electric hobs (especially induction hobs) will increase during the next years with slightly decreasing shares of gas fuelled hobs. However, there are variations between the member states with some favouring electric (e.g. Germany and Sweden) and some gas fuelled hobs (e.g. Italy).

The penetration rate (EU-15) for electric fuelled ovens in 1998 was 61 % (Kasanen, 2000⁵⁹). Sales figures from 2006 (96 % of all build-in units were electric ovens) admittedly show a trend towards an increasing share of electric ovens (EUP LOT 22⁶⁰). There are differences across the member states with some preferring electric ovens (e.g. Scandinavian countries) and some preferring gas fuelled appliances (e.g. Spain and Ireland).

In view of range hoods, the EUP LOT 10⁶¹ report on ventilation indicates about 36 million hoods in stock in 2005 and about 39 million in 2010. Consequently, the penetration rate is about 19 % but is estimated to increase within the next years.

According to the EUP LOT 17 report⁵⁶, the European market for vacuum cleaners is already oversaturated meaning that on average, every household has such an appliance and some households even have more than one.

According to estimates by JRC, the installed stock of instantaneous water heaters in EU-27 in 2007 was 29 million units. Instantaneous water heaters (> 12 kW) represent a share of 6.6 % of the installed base of primary water heaters. In view of secondary installations, instantaneous water heaters have a share of 7 %. (Bertoldi and Anatasiu, 2009³⁷)

For more information on stock data please refer to Task 2.

As all behavioural appliances require an active involvement of consumers during operation and cooking and cleaning activities are time-bound in the majority of households, the acceptance of consumers for shifts in operation are presumably low. In view of instantaneous water heaters, smart operation would lower consumer's comfort significantly and is therefore considered as improbable. Concerning hobs and ovens, however, the potential of short term interruptions can be assessed as rather high as far as the cooking or baking results are not compromised. In contrast, short term interruptions are improbable for range hoods and vacuum cleaners as their power demand remains also constant during operation and interruptions in power supply would interrupt their operation. A reduction of their power would decrease their performance (lower air change rate, a loss of suction

⁵⁷ European Commission (2013): COMMISSION REGULATION (EU) No 666/2013 of 8 July 2013 implementing Directive 2009/125/EC of the European Parliament and of the Council with regard to ecodesign requirements for vacuum cleaners

⁵⁸ Preparatory Studies for Eco-design Requirements of EuPs (III) Lot 23 Domestic and commercial hobs and grills, included when incorporated in cookers. Final report

⁵⁹ Kasanen, P. (2000): Save II study, efficient domestic ovens, Final report, TTS Institute

⁶⁰ Preparatory Studies for Eco-design Requirements of EuPs (III) Lot 22 Domestic and commercial ovens (electric, gas, microwave), including when incorporated in cookers. Final report

⁶¹ Preparatory study on the environmental performance of residential room conditioning appliances (airco and ventilation). Study on residential ventilation - Final report

power or a reduction of heating power, respectively), and will presumably not be accepted by consumers.

Because of the reasons mentioned before, the focus is on electric hobs, ovens and cookers in the remainder of this chapter.

1.2.3.2 User behaviour concerning behavioural appliances

DAILY AND ANNUAL USE PATTERN

Electric hobs and ovens

Data on energy consumption of electric hobs, cookers and ovens are limited and often only available for one of the aforementioned appliances. Bertoldi et al. (2012)³⁷ reported on a total consumption of 63.1 TWh for electric hobs and ovens together (40.1 TWh for hobs, 23.0 TWh for ovens). Considering stock data as shown above, an average energy consumption of about 206 kWh per appliance and year can be calculated for hobs (including mixed hobs and cooker tops). According to the SAVE II final report on efficient domestic ovens (Kasanen, 2000⁵⁹), the average energy consumption per electric oven per year in Europe is 138 kWh with large variations between different member states.

Besides technical factors, the user behaviour and environmental factors determine the energy consumption of hobs. These factors include:

- Choice of cooking utensils (pots and pans)
- Use of lids
- Type of hob (solid plate, radiant, induction)
- Temperature setting
- Duration of the cooking or baking process
- Use of synergistic effects
- Frequency of cooking or baking
- Frequency and duration of door openings (ovens)
- Heating mode of the oven (top or bottom heat, convection, grill, combinations)
- Use of pyrolytic function (ovens)

In a study by Sidler (1999)⁶², the operation time for different hobs varied between 26 and 58 minutes per day. Data by Sidler (2009)⁶³ suggest seasonal effects of cooking showing that more energy is consumed in winter than in the summer period.

In view of electric ovens, Kasanen (2000)⁵⁹ reported on an average use frequency of 110 times per year, whereas the frequency is higher in Scandinavian countries and France and much lower in Italy and the Netherlands. The average operation time is 55 minutes per cycle (EUP LOT 22⁶⁰).

Sidler (1999)⁶² has published daily power demand curves of hobs and ovens, which are given in Figure 2624 and Figure 2725, respectively.

⁶² Sidler et al. (1999): An experimental investigation of cooking, refrigeration and drying in 100 households. Programme SAVE, Project ECUEL.

⁶³ Sidler, O (2009): ENERTECH. "Notes techniques: Connaissance et maîtrise des usages spécifiques de l'électricité dans le secteur résidentiel"

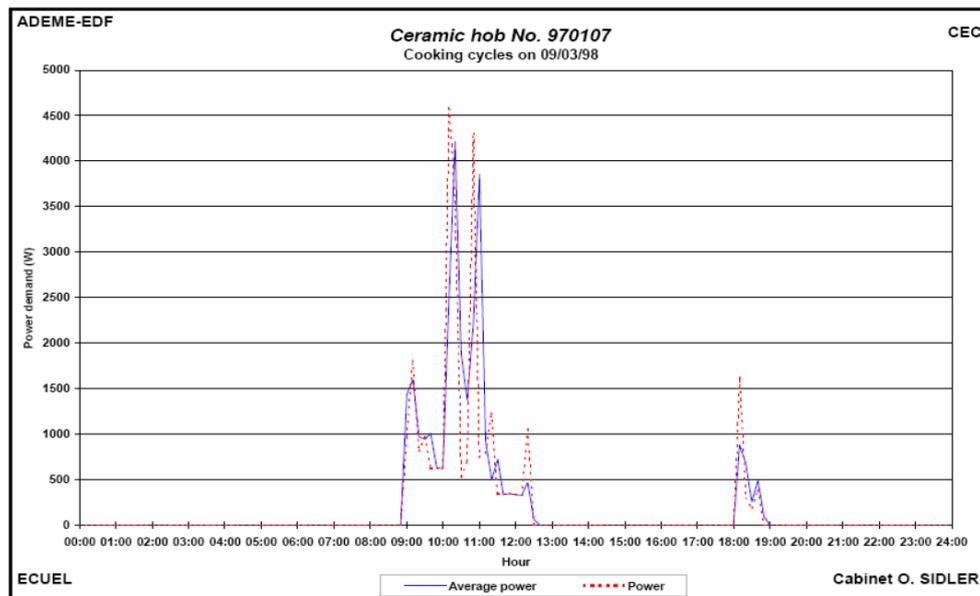


Figure 27: Daily power demand curve of an electric hob (source: Sidler, 1999⁶²)

In view of daily variations of electric hobs, the results suggest an increased use late in the morning (between 9 a.m. and 11 a.m.) and in the evening period (between 6 p.m. and 7 p.m.). For electric ovens, only one main use period was found in the morning (between 8.30 a.m. and 11 a.m.)

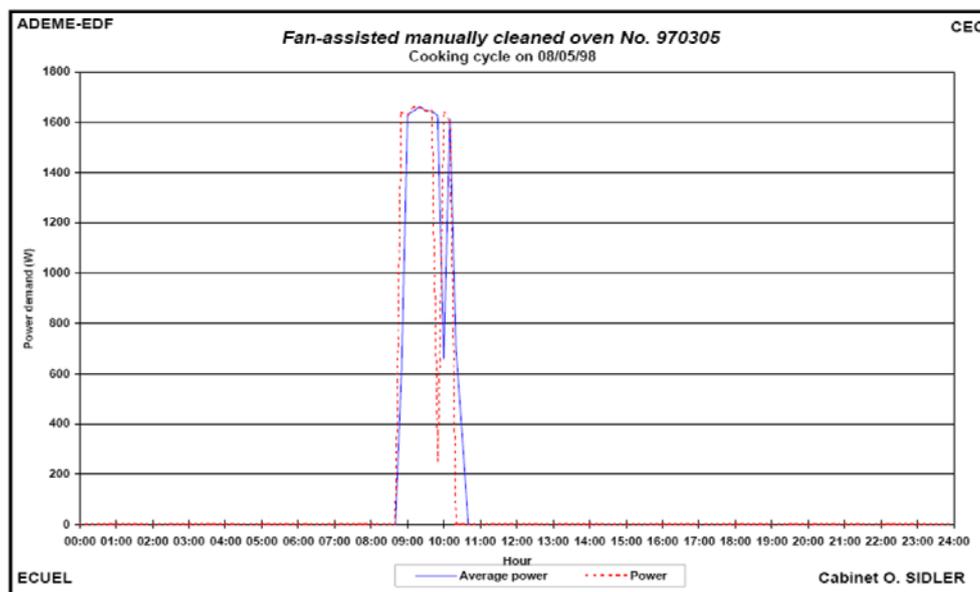


Figure 28: Daily power demand curve of an electric oven (source: Sidler, 1999⁶²)

Depending on the type of hob, the size of the plate and the temperature chosen, the actual power demand of hobs will vary between about 100 and 2,000 W. During operation of a hob, a typical pattern of power demand can be identified, independent on the actual power. This typical pattern is given in Figure 2826. In the starting phase, the hob normally uses its full power to heat itself up. After that, the heating element of the hob is working intermittently, whereas the phases in power on mode are much shorter than the first (heating up) phase.

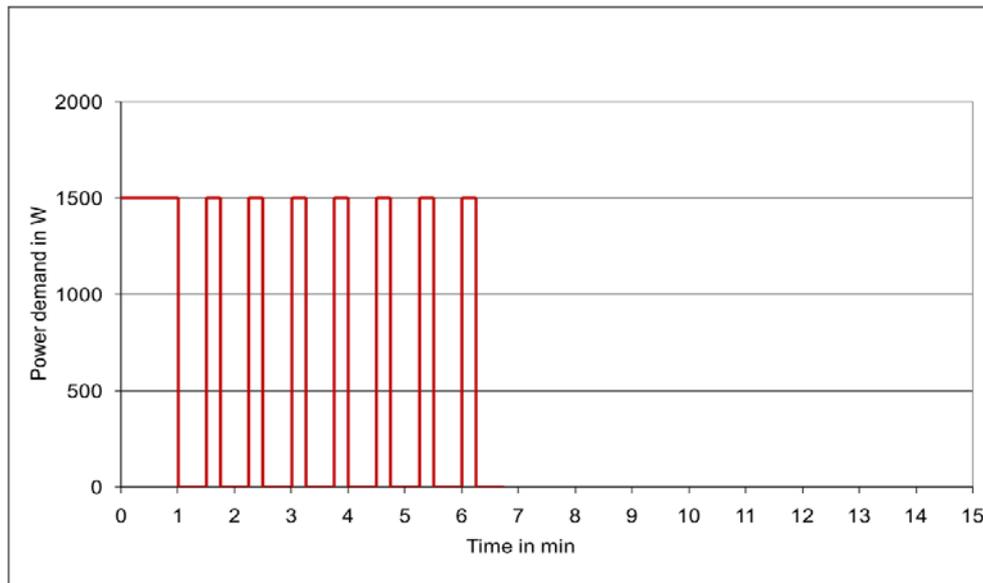


Figure 29: Typical pattern of a power demand curve of an electric hob (Source: Stamminger et al., 2009³⁴)

A typical power demand curve of an electric oven (Figure 2927) looks similar to that of a hob. However, the heating up phase is much longer than for hobs. Electric ovens are also working intermittently, whereas the total operation time of the heating element depends on the heating method as well as on the temperature setting.

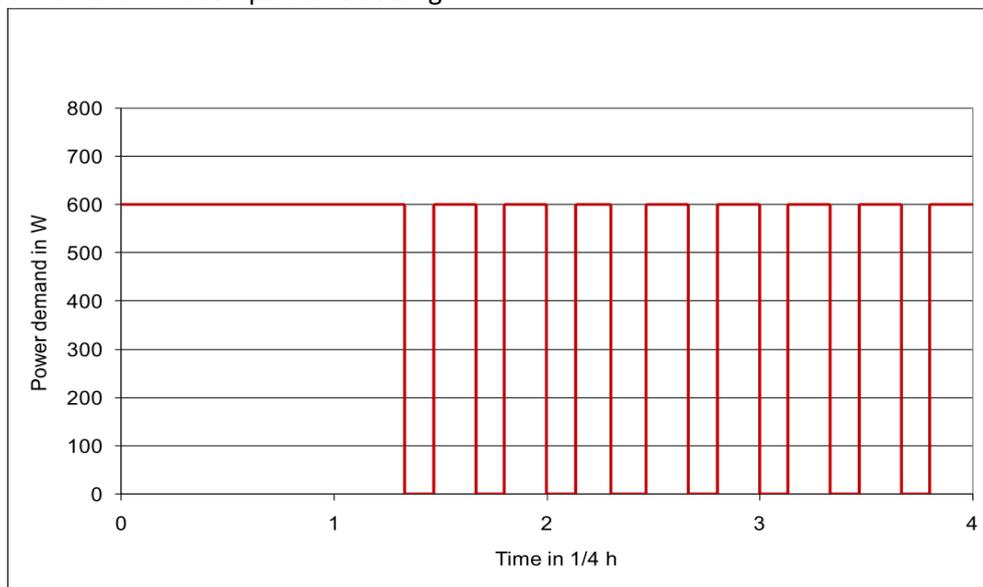


Figure 30: Typical pattern of a power demand curve of an electric oven (Source: Stamminger et al., 2009³⁴)

If the daily cooking behaviour is taken into account, a typical daily load curve of an electric oven in an average European household will follow the pattern shown in Figure 3028. (Stamminger et al., 2009³⁴)

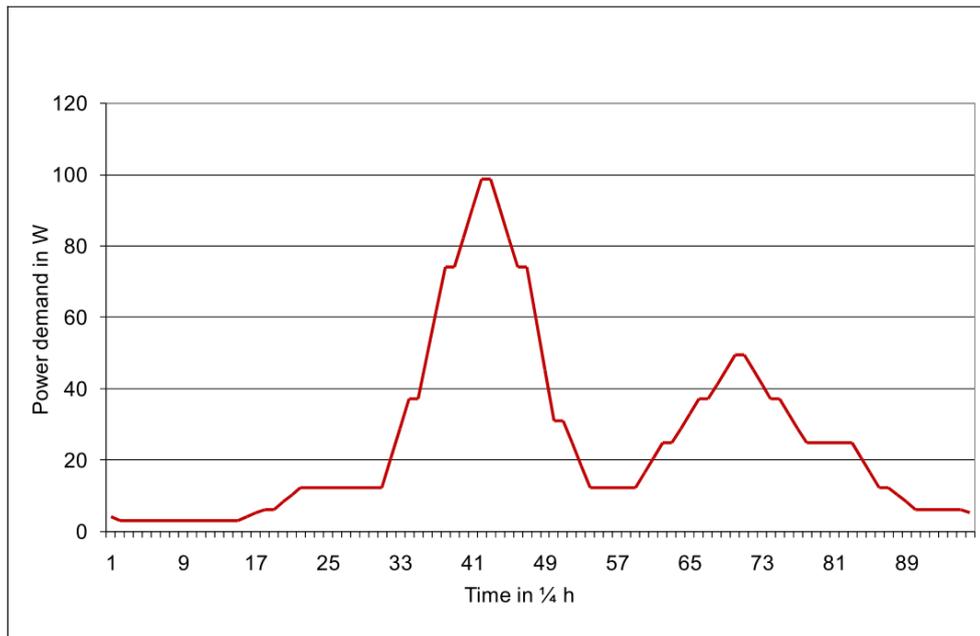


Figure 31: General pattern of a daily load curve of an electric oven in an average European household (source: Stamminger et al., 2009³⁴)

1.2.3.3 Lifespan

The average life span of behavioural appliances may vary depending on the manufacturer, the model, the equipment, the use conditions and the maintenance. Average data are given in Table 6.

Table 9: Average life span of behavioural appliances (Source: ^a EUP LOT 23⁵⁸; ^b EUP LOT 22⁶⁰)

Type of appliance	Average life span
Electric hobs (except induction):	19 years ^a
Electric hobs (induction):	15 years ^a
Electric ovens:	19 years ^b

1.2.3.4 Possibilities for consumers to engage in smart behavioural appliances

In view of hobs and ovens, one possibility to shift energy or modulate power could be identified.

1. Altered electricity consumption pattern: pause between heating cycles, interrupt the heating phase, etc.

In this case, appliances may change its operation if they are triggered by an external signal showing a shortage of energy available on the grid. Possible changes include prolongation of intervals between two heating phases, interruption of a heating phase or changes in heating power. The external signal should include information on the shortage of energy and how long it will last and the appliance will answer with an appropriate action. Power demand curve of a single appliance can be changed in different ways, e.g. shift in operation or reduction of power by seconds or minutes. As such changes must not compromise the performance of the cooking process, it has to be ensured that they are limited in time (up to a few seconds) and don't take place during the first heating phase. (Stamminger et al., 2009³⁴)

Flexibility is typically situated especially in the late morning and, to less extent, in the evening. As described before, there are week seasonal effects of cooking resulting in maximum energy consumption during winter and minimum consumption during the summer period.

1.2.3.5 Comfort constraints and consumer objections

As described above, the operation of behavioural appliances requires an active involvement of the consumer and thus is time-bound in narrow ranges. For this reason, the acceptance of consumers for shifts in operation is presumable low. However, short term interruptions for a few seconds or postponed heating phases will hardly be recognised by the users so that these scenarios will rather be accepted. In order to prevent losses in the performance of the cooking process, interruptions or shifts in heating phases have to be strictly limited in time. Data on the maximum tolerable duration of interruptions are lacking so far. If the cooking process is compromised in any way, consumers will not accept the aforementioned changes in operation. (Stamminger et al., 2009³⁴)

1.2.4 HVAC

The following section contemplates to incorporate HVAC equipment through DSF technology to the basic balancing mechanisms/ancillary services of the electrical grid. In order to do so, the main grid-stabilizing mechanisms used in most European deregulated markets will be taken into account: e.g. frequency containment, automatic frequency restoration, manual frequency restoration.

Concerning HVAC technologies (heating, ventilation and air conditioning), use patterns must match the timing of the balancing grid mechanisms (instantaneous, short term, long term, ...) so that the incorporation of a DSF technology may allow the grid operator to adjust their operations without interrupting a defined cycle or jeopardizing occupants' comfort.

1.2.4.1 User behaviour concerning HVAC appliances

HVAC appliances are installed to ensure thermal comfort and air quality to buildings' occupants. The main constraint regarding energy shifting HVAC appliances are the consequences on thermal comfort, humidity, CO₂ and other pollutants that these actions may cause. The points to be covered in this section are: comfort constraints, seasonal periods, occupation schedules, lifespan of HVAC appliances.

1.2.4.2 Comfort constraints

- Heating: During the winter, the inside temperature for occupation periods (which could be specified by end-users) should not fall below 18 °C (19 °C for tertiary buildings). As well as the variation of temperature should not be higher than 2°C/h according to the standard EN 15251.
- Cooling: During summer, the inside temperature for occupation periods (which could be specified by end-users), shall not exceed 27°C according to EN 15251. As well as the variation of temperature should not be higher than 2°C/h according to EN 15251 standard.
- Air treatment: Ventilation assures air quality for building occupants; the standard EN 15251 gives guidance regarding standard air flow rates by person and admissible pollutant concentration in buildings.

SEASONAL PERIODS

Europe can be divided into three main climate types: oceanic, continental and Mediterranean. These different climates will modulate the potential for demand side flexibility by HVAC appliances within the continent. The used base is heating-degree-days/hours and cooling-degree-days, which take into account the amount of time that the heating/cooling is on and how far is the external temperature from the inside temperature set point. The seasonal periods are the heating period and the cooling period.

Heating season

Table 10: Heating season for EU27 (Bio Intelligence Service, 2012⁶⁴) (values are weighted by dwelling stock)

EU Country	Heating Season (months)	Heating-degree-days
Finland	10,8	323
Sweden	10,2	306
Estonia	8,8	265
Latvia	8,6	257
Lithuania	8,3	250
Poland	7,7	231
Austria	7,6	229
Czech Republic	7,6	229
Denmark	7,5	226
Slovakia	7,5	224
Croatia	6,7	208
Germany	7,2	215
Luxembourg	7	214
Romania	7	211
United Kingdom	6,9	210
Slovenia	6,7	208
Hungary	6,7	202
Ireland	6,7	202
Netherlands	6,7	201
Belgium	6,7	200
Bulgaria	6,4	193
France	6,1	184
Italy	5,4	163
Spain	5,3	158

⁶⁴ BIO Intelligence Service (2012) Preparatory Studies for Ecodesign Requirements of EuPs (III), ENER Lot 20 – Local Room Heating Products - Task 3: Consumer behavior and local infrastructure. Prepared for the European Commission, DG ENER.

Greece	5	151
Portugal	4,5	135
Cyprus	3,8	114
Malta	3,5	105
EU28 mean	6,9	209

Regarding the cooling season, the following Table 8 shows the different potentials within the European Union (EU27).

Cooling season

Table 11: Cooling season for EU27 (VHK, 201423)

Member State	Cooling-degree-days	Total (population correction)	Population Share
Ireland	5	0,035	0,70%
Denmark	57	0,684	1,20%
Netherlands	75	2,7	3,60%
Estonia	78	0,234	0,30%
Sweden	81	1,701	2,10%
Belgium	84	1,764	2,10%
United Kingdom	94	12,408	13,20%
Finland	97	1,164	1,20%
Latvia	102	0,408	0,40%
Luxembourg	103	0,103	0,10%
Lithuania	105	0,63	0,60%
Czech Republic	116	2,204	1,90%
France	138	18,354	13,30%
Germany	168	30,912	18,40%
Slovenia	187	0,561	0,30%
Austria	213	3,408	1,60%
Poland	216	14,904	6,90%
Slovakia	260	3,38	1,30%
Bulgaria	275	3,85	1,40%
Croatia	277	1,939	0,70%
Hungary	282	5,64	2,00%
Portugal	324	5,832	1,80%
Romania	379	12,886	3,40%
Italy	420	52,08	12,40%
Spain	652	45,64	7,00%
Malta	714	0,714	0,10%
Greece	893	16,967	1,90%
Cyprus	972	0,972	0,10%
EU 28 Mean	263	n/a	100%

Table 7 and Table 8 summarize the total seasonal demand for HVAC appliances (EU 27) using the base indicator of heating-degree-days and cooling-degree-days. The number of heating-degree-days is on average ten times more important than the cooling-degree-days and it has a more homogenous behavior within the member states. On the contrary, for the cooling season the total potential (weighted by population of each member state) has an uneven distribution, being the cooling demand for Mediterranean and continental climates (Spain, Italy, Greece, Romania, France, Germany, Slovakia) much more important than oceanic and northern countries (see Figure 31).

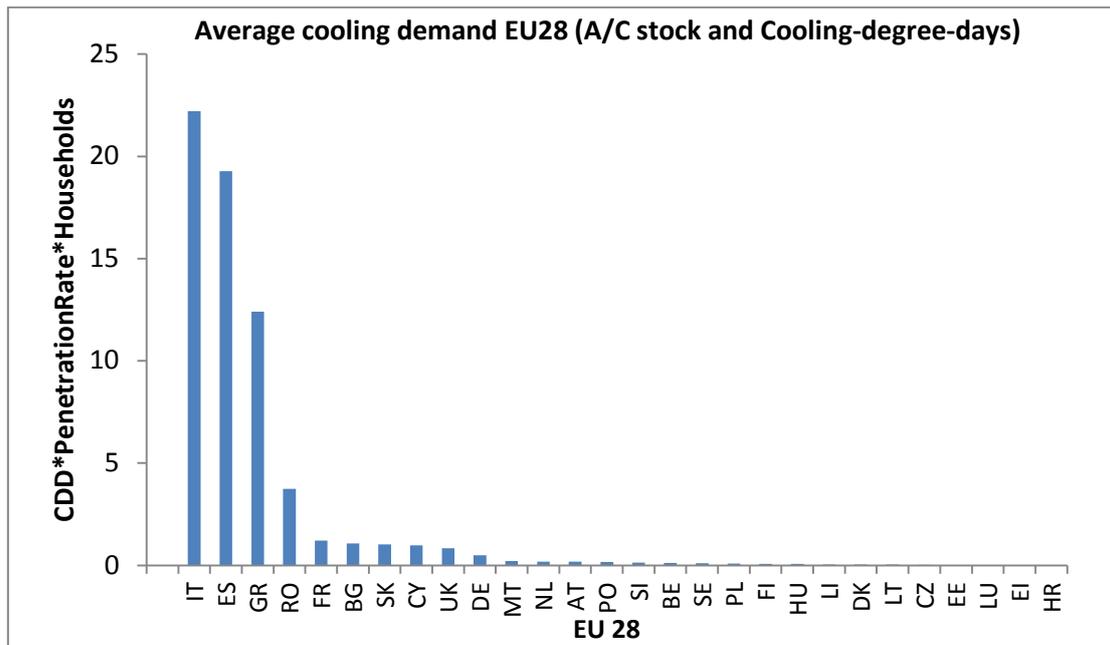


Figure 32: Average cooling demand EU28 (A/C stock and Cooling-degree-days)

Nevertheless, given that Europe has 3 different time zones, user behavior among the continent is not homogeneous and therefore, the heating/cooling demand is shifted in time. A different approach is therefore proposed: Europe is divided in representative climates, respecting the different countries' time zones. The following map of Europe (Figure 32) shows the climatic division that has been made in order to simulate the heating and cooling demand for Europe.



Figure 33: EU28 Climate division for HVAC profiles case studies

Climatic zones:

- Portugal (GMT 0)
- United Kingdom, Ireland (GMT 0)
- France (GMT +1)
- Germany (GMT +1)
- Italy, Slovenia, Croatia (GMT +1)
- Belgium, Netherlands and Luxembourg (GMT +1)
- Denmark, Sweden (GMT +1)
- Poland, Czech Republic, Austria, Slovakia and Hungary (GMT +1)
- Greece (GMT +2)
- Bulgaria and Romania (GMT +2)

OCCUPATION SCHEDULES

Many different occupation schedules are possible, for the residential sector as for the tertiary sector. User behavior in the residential sector is influenced by the dwelling's occupants (age, type of work, profession, unemployed, ...). The following data was used in order to build the different occupation schedules for the residential and the tertiary sector:

Residential occupation periods

- A French study (INSEE, 2015) resulting from different inquiries regarding 10,000 representative French dwellings. The following information was collected: Number of people per dwelling, occupation schedules, profession, and age of the inhabitants. This data will be used to simulate every European country; under the hypothesis that people's schedule and behavior is the same among EU28.

Tertiary occupation periods

- For the tertiary sector the occupation schedules are much more homogeneous, among the different service sectors: Office buildings, hotels, retail stores, hospitals, supermarkets, sport facilities, retirement homes and schools. The occupation schedules for each building are given below, as well as for different occupation areas within the building:
 - Hotel:
 - Kitchen : 7h-9h , 10h-14h and 18h-23h from Monday to Sunday
 - Restaurant and Lobby: 8h-22h from Monday to Sunday
 - Rooms: 18h-9h from Monday to Sunday
 - Supermarket:
 - Main sales' area: 9h-21h from Monday to Sunday
 - Offices: 9h-20h from Monday to Saturday
 - Office Building:
 - Offices: 7h-20h from Monday to Friday
 - Conference rooms: 7h-20h from Monday to Saturday
 - School: Idem as for office buildings
 - Retirement Home:
 - Common areas: 9h-20h from Monday to Sunday
 - Nursing rooms: 7h-20h from Monday to Sunday
 - Cafeteria: 8h-9h,13h-14h and 19h-20h from Monday to Sunday
 - Rooms: 0h-24h from Monday to Sunday
 - Hospital:
 - Offices: 7h-20h from Monday to Sunday
 - Restaurant and Laboratories: 7h-20h from Monday to Sunday
 - Operating rooms: 7h-20h from Monday to Sunday
 - Rooms: 0h-24h from Monday to Sunday
 - Sport Facilities: 9h-21h from Monday to Sunday
 - Retail stores:
 - Main shopping area: 9h-21h from Monday to Saturday
 - Cinema: 13h-2h from Monday to Sunday

LIFESPAN OF HVAC APPLIANCES

The lifespan of HVAC products may vary according to the equipment, but a good estimation is around from 10 to 15 years for boilers, air conditioners and heat pumps. More detailed information is given in Table 9:

Table 12: (Bio Intelligent Service, 2012Error! Bookmark not defined.) *Source: (Eco-design Boilers, 2007)

Main Category	Type of heating appliance	Average lifespan
Fixed heaters	Convector panel heaters	12
	Radiators	20
	Fan heaters	12
	Ceramic heaters	12
	Radiant heaters	12
	Storage heaters (static)	20
	Storage heaters (dynamic)	20
	Under-floor heating	40
Portable electric heaters	Convector panel heaters	12
	Radiators	12
	Fan heaters	12
	Radiant heaters	12
	Ceramic heaters	12
Boilers	Gas Fired	12*
	Oil Fired	12*

Energy consumption and shifting potential per appliance per day / per season (refer to task 1 for more information) for 28 EU member states.

Heating:

- Peak power: up to about 95 GW (2010)
- Energy consumption: about 280 TWh/a
- Potential energy to be shifted: about 30 TWh/a, about 100 GWh/day in the coldest winter months (heating off for one hour)

Cooling:

- Peak power: 160 GW
- Energy consumption: 80 TWh (2010)
- Potential energy to be shifted: 65 GWh/day (this corresponds a the mean demand over the summer for an off-period of one hour)

Air treatment:

- Energy consumption: 59 TWh (2010) or
- Peak power: 10 GWh
- Potential energy to be shifted: 10 GWh/day (air treatment off for one hour)

CASE STUDIES (POSSIBILITIES FOR CONSUMERS TO ENGAGE IN SMART APPLIANCES)

Residential sector

- Heating and cooling needs: Thermal simulations at a national scale for each country of EU28, using the platform Smart-E (Armines, 2015). This platform focuses on the thermal and electrical energy consumption in residential dwellings and service buildings. It has a library of algorithms that has been designed to simulate real or hypothetical cities using a techno-explicit bottom up approach fed with public databases and specific users' data.
- Weather data: Dry bulb temperatures and radiation data were obtained for each of the following cities: Paris, Madrid, Lisbon, London, Frankfurt, Brussels, Prague, Bucharest, Athens, Rome, Stockholm and Helsinki. Each of these cities represents a country (or several countries of the climatic zone) (www.noaa.org and "Blanc et al, HelioClim Project")
- Building diversity: Orientation, size of the building, glazed surfaces, year of construction, insulation were taken from the study (INSEE, 2015) for a representative sample of 10000 buildings in France. For the other EU countries the building distribution was considered the same.
- Insulation values: Insulation ratio values were obtained from (VHK, 2007) for each country of Europe.
- Penetration of electric heating: After obtaining a demand curve for each climatic zone, this curve is weighted according to the number of square meters and the penetration of electric heating technologies (radiators, electric boilers, radiators...) in each country. Data comes from the following studies: "Policy development for improving RES-H/C penetration in European Member States (RES-H Policy), 2009", www.episcope.eu, www.tabula.org.
- Penetration of air conditioning in Europe: Data for each country in Europe was obtained from "Ecodesign Lot 10: Room air conditioning and fan units".

Tertiary sector

- Heating and cooling needs were obtained from 8 different service sector buildings, using the software Climhybu (CSTB, 2010). Then these curves are weighted with the heated and cooled surface per country.
- Characteristic tertiary buildings for the following service sector were considered: Hospitals, Hotels, Schools, Retirement Homes, Offices (three types of sizes), Retail shops, supermarkets and sport facilities.
- Weather data: Dry bulb temperature and radiation data for the year 2014 were obtained from www.noaa.org for temperatures and Blanc et al., 2011 for radiation to the climatic zones described above.

- Distribution of the tertiary sector building (by square meters) was obtained from the following source: www.buildingsdata.eu
- Penetration of the heating technologies: Entranze Project 2013 and www.episcope.eu
- Penetration of air conditioning: Source distribution by sector: Preparatory study, Lot 6 Air conditioning (task 2) and (Werner, 2010).

POSSIBILITY OF ADAPTATION TO GRID CONTROL MECHANISMS:

HVAC systems can be shut down and turned on without any built-in machine constraints (unlike Washing machines for example), as well as their capacity can be adjusted (change the speed of the compressor - which would more efficient than turning the units off-, the temperature set point or the fan speed). Therefore, there is an important potential for all “grid balancing mechanisms” in order to shift the energy consumed by HVAC in different times of the day.

Australian case for example: the Demand-Response project began in 2005 due to the fact of the increasing energy demand caused by the growing penetration rate of AC (air conditioning is a peak coincident load in Australia). It is projected that the proportion of Australian households that would be equipped with an AC unit will increase from 56% in 2010 to 70% in 2020. In order to avoid peak demands, the regulation AS4755 mandates to incorporate Demand Response mechanisms to AC units, so a third party actuator can modulate the load. Encouragements include a low price of the DR platform (10AUS\$, around 1% of the retail cost for a residential unit), and Payments of \$250 are offered to customers who buy an AS/NZS 4755 compliant air conditioner and have it activated on installation, and to customers who have their existing air conditioner connected to the Energex communications system (Wilkenfeld, 2011⁶⁵).

END CONSUMER COST:

PURCHASE COST:

Surplus purchase cost of the appliance due to the DSF functionality. According to one stakeholder, enabling demand side flexibility in HVAC appliances would increase the retail price. This price would vary if a centralized control unit enables to operate several DSF HVAC appliances. Price estimation for one household having three air conditioners can be seen in the figure below:

Item	Number	Unit price	Initial
CEM & installation	1	2,000€	2,000€
Adaptor	3	100€	300€
Set up	1	100€	100€
Total			2,400€

⁶⁵ Wilkenfeld (2011): Smart appliances for smart grids: flexibility in the face of uncertainty 2011

Another scenario, is whether the customer completely relies on an aggregator to control directly the HVAC appliance (the air conditioner for instance). This would only add up the set up and the adaptor price, increasing only around 150€.

For tertiary buildings (commercial), prices are considerably higher. Considering a VRV (variable refrigerant flow unit air conditioning unit), enabling demand side flexibility according to one stakeholder is as follows (all prices in Euros):

Item	Number	Unit price	Initial	Running (per year)
Controller (I/F& S/W)	1	8000	8000	0
Mobile router	1	500	500	120
Install & setup	1	10500	10500	0
Total			19000	120

In addition, these prices include the following investments from the industry side:

- Development costs
 - Hardware and software modifications
 - Certification (radio frequency regulation if Wifi is used, safety regulations)
 - License and membership fees (Wifi alliance, Bluetooth...)
- Compatibility test costs
 - Adaptability to different smart-phones (smart-phones will be mainly used as an operation terminal)
 - Annual update and bug fixes of the application software
- Operating costs
 - The communication between the household and the grid/aggregator requires an IP address resolution

EXPERIENCE WITH DSF MECHANISMS IN HVAC EQUIPMENTS

- Daikin has implemented DSF control in many countries over the world, allowing them to control remotely HVAC equipment. More precisely, they have participated in **Open ADR** trial by Japanese government, university and companies, in order to carry out cooperative operation with smart cities and aggregators in wide areas. Mainly speaking, the control consisted in a “Power Measurement Unit” which sends only information about the difference of total demand and target current. HVAC equipment (air conditioners, heat pumps) power down automatically depending on established difference and pre-settled priority.
- The EcoGrid project carried out by Sintef Energy Research and other partners in Bornholm (Denmark), evaluated the potential of demand side flexibility appliances (mainly heat pumps and electric heating) based on a real-time market approach. This demand response program

lets distributed energy resources and flexible electricity demand, receive and respond to variable electricity prices. Different control systems and interfaces were used along the project: Ecohome (present in 60% of the studied homes, remote control of the heating system), Greenwave Reality (electric radiators and heat pump control), Siemens Synco Living (consists of a central unit/control panel that is connected to the internet, the control of the electric heating and/or domestic hot water boiler is done via contactors installed in the fuse box of the participants and thermometer probe in the boiler). The final conclusions of this project are not yet available, but preliminary results regarding the tests and adjustments done in 2013/2014 winter show that: For the IBM Greenwave reality solutions a maximum of 90 minutes of heating off-time is now guaranteed, with no single off time period longer than 60 minutes and with a few hours in between off periods. In addition some recommendations and preliminary conclusions for further analyses and deployment of demand side flexibility mechanisms are: Low data quality -the system must receive reliable temperature readings to ensure that heating is regulated in accordance with the comfort preferences of the customer-, internet connection must be stable, the nature of the individual heat pumps' own optimization system limits regulation possibilities, comfort setting of the households gives little room for "down or up" regulation for consumption. (<http://www.eu-ecogrid.net/>)

1.2.5 BATTERY OPERATED RECHARGEABLE APPLIANCES

1.2.5.1 Usage Behaviour

This category comprises the following segments:

- Multimedia :
 - Smartphones
 - Tablets
 - Laptops
 - (Video) cameras
 - Personal navigation
 - etc.
- Household appliances
 - Electric toothbrushes
 - Fans
 - Vacuum cleaners
 - Clocks
 - Shaving products
 - etc.
- Power tools
 - Drill machines
 - Screwdriver
 - Garden trimmers, mowers & edgers
 - etc.

Given the low power consumption in the charging process, only appliances with large installed base volumes and frequent charging patterns will have enough potential for load shifting.

Household appliances have smaller installed base volumes than smartphones and tablets and it is presumed that they have a lower and less predictable charging frequency. On top of that many have such low consumption that the charging energy is too small to be relevant, even in large numbers.

For power tools, the charging power is higher compared to multimedia devices, but the charging frequency is usually lower and these appliances have a 'charging when going to be used' pattern, making it hard to provide flexibility. Also the amount of 'active' appliances is much lower.

Personal navigation devices and digital cameras have smaller installed base volumes than smartphones and tablets and it is presumed that they have a lower and less predictable charging frequency.

Smartphones and tablets have low charging power consumption, but have a very large volume (and still growing) installed base.

Laptops have also a smaller installed base than smartphones and almost similar to tablets but a higher charging power consumption.

Therefore only laptops, smartphones and tablets appliances will be taken into account in the remainder of this chapter.

1.2.5.2 User behaviour concerning charging

It is clear that if the devices are smartly charged, it is essential for a good user acceptance, to always guarantee sufficient State of Charge (SOC).

1.2.5.3 Comfort constraints

From studies by the J.D. Power and Associates 2012⁶⁶ it is shown that satisfaction with battery performance is becoming a critical factor in overall satisfaction as well as brand loyalty. It is clear that if the devices are smartly charged, it is essential for a good user acceptance, to always guarantee sufficient State of Charge (SoC). This puts a constraint on the smart charging to be able to predict very accurately and reliably the next usage of the multimedia device in order to guarantee the expected comfort on next usage.⁶⁷

1.2.5.4 Occupation Schedules

A 4-week study⁶⁸ with more than 4000 attendees, which assessed their smartphone charging habits, was performed by Ferreira et al.. From this, an insight on charging behaviour could be retrieved. It has been observed that many charging instances happen overnight, with connection to power supply

⁶⁶ J.D. Power and Associates Reports. Denzil Ferreira, Anind K. Dey, Vassilis Kostakos. Understanding Human-Smartphone Concerns: A Study of Battery Life. Has Become a Significant Drain on Customer Satisfaction and Loyalty. March 2012. Pervasive Computing. June 2011.

⁶⁷ Sasu Tarkoma, Matti Siekkinen, Eemil Lagerspetz, Yu Xiao, Aalto University, Finland. Smartphone Energy Consumption - Modeling and Optimization. August 2014.

⁶⁸ Denzil Ferreira, Anind K. Dey, Vassilis Kostakos. Understanding Human-Smartphone Concerns: A Study of Battery Life. Pervasive Computing. June 2011.

units typically for periods > 14 hours (See Figure 3330). They also noticed that the majority of charging events during the day are for short periods (< 3 h).

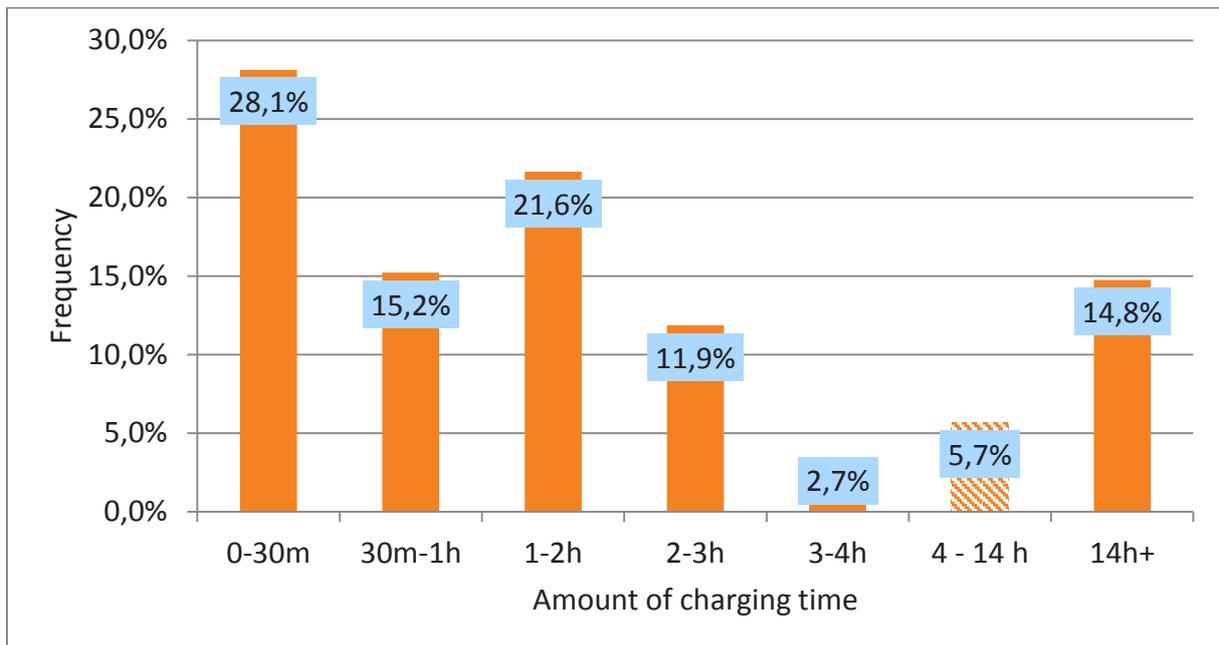


Figure 34 : Time plugged in

When looking at the time slots, it is seen that 2 major scheduling periods can be identified for the initiation of the charging, one between 6 PM and 8 PM and another between 1AM and 2 AM.

1.2.5.5 Lifespan

The lifespan of approximately 5 years for smartphones and tablets is rather short compared to other consumer electronics (Figure 3431).

2014 Expected Life Cycle

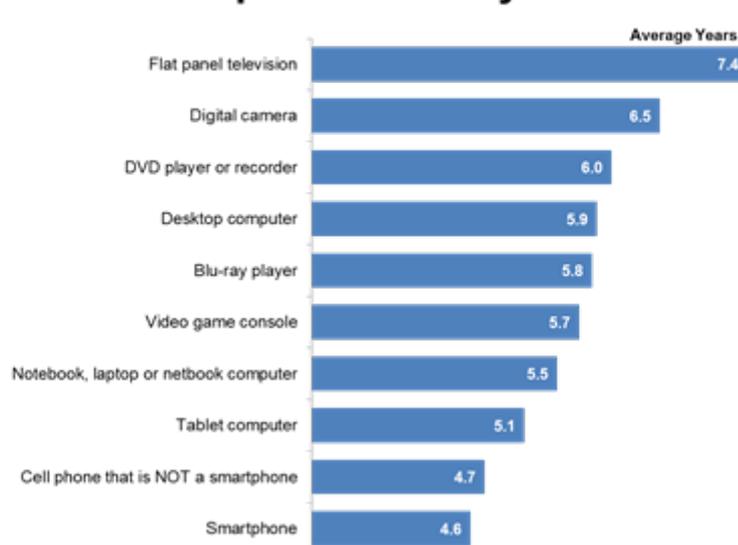


Figure 35: Source: Consumer Electronics Association (CEA), 2014 CE Product Life Cycle. Base: U.S. Adults (n=1,013)

Energy consumption and shifting potential per appliance per day/ per season for 28 EU member states.

As stated in Task 1, the potential per appliance and day is very low. The main benefit needs to come from the large volume of appliances:

For smartphones only, the sales figures (IDC⁶⁹ and Gartner⁷⁰) worldwide have gone from 300 million in 2010 to more than 650 million in 2012 and grew to above 1 billion in 2014. The situation is similar for tablets worldwide, with sales growing from 200 million in 2013 to an expected 260 million in 2016 (Gartner, January 2015)⁷¹. Estimates of laptop sales vary between 200 and 180 million.

For Europe (EU28), the sales of all mobile phones (smartphones and regular mobile phones) range from 227 million in 2009 to 213 million in 2013.

Table 13: Mobile subscriptions in Europe

	2014	2020
Mobile subscriptions (million)	1,135	1,280
Smartphone subscriptions (million)	475	815

The figures for Europe*⁷² on the installed base show almost half a billion of smartphone subscriptions in 2014 and an expectation of more than 800 million subscriptions by 2020.

⁶⁹ IDC Press Release : Worldwide Smartphone Growth Expected to Slow to 10.4% in 2015, Down From 27.5% Growth in 2014, According to IDC, August 2015, <http://www.idc.com/getdoc.jsp?containerId=prUS25860315>

⁷⁰ Gartner Press Release : Gartner Says Smartphone Sales Surpassed One Billion Units in 2014, March 2015, <http://www.gartner.com/newsroom/id/2996817>

⁷¹ Gartner, Press Release : Gartner Says Tablet Sales Continue to Be Slow in 2015, January 2015, <http://www.gartner.com/newsroom/id/2954317>

⁷² Ericsson, Europe Ericsson Mobility Report Appendix, November 2014

When looking at the total energy consumption of these appliances of

- Smartphone: 3 to 5 kWh/year
- Tablet: 12 kWh/year
- Laptop: between 150 and 300 kWh/year.

it can be concluded that a flexibility capacity would derive from the large number of appliances, rather than from the individual power consumption.

A first calculation of the authors is based on the assumption that in 14.8% of the charging session appliances are plugged in long enough to provide flexibility (as stated in Figure 3330). Taking into account the values for smartphones this could lead to $14.8\% * 4 \text{ kWh (average)} * 475 \text{ million} = 281 \text{ GWh per year}$ or 0.77 GWh/day and for tablets $14.8\% * 15\text{kWh} * 200 \text{ million} = 444 \text{ GWh}$ shifting potential per year or 1.2 GWh/day , but here the assumption is made that the 14.8% of sessions also corresponds to the same amount of charging power. It's however clear that for correct calculations, there is still a general lack of available and reliable studies on this. For laptops the calculations were not done, since no info is found on the charging (duration) patterns for these devices. These charging patterns will probably be different to that of the smartphones by the nature of the usage pattern and the fact that laptops are often connected to mains power supply while being used.

Important note:

It has to be taken into account that the energy (demand) shifting potential is a balance between flexibility and energy saving.

From a flexibility point of view, the longer the charger is connected, the more shifting potential is (theoretically) available. However from an energy saving point it is important to disconnect the charger ASAP after the battery is fully charged since it also consumes (little, but present) power when devices are connected.

Given the evolution and regulation on the requirements for standby, off mode electric power consumption of electrical and electronic household and office equipment⁷³, the issue will become less important.

* From the report it is not clear which countries are included, but since also Russia is mentioned it will be broader than EU28.

⁷³ COMMISSION REGULATION (EU) No 801/2013. Amending Regulation (EC) No 1275/2008 with regard to ecodesign requirements for standby, off mode electric power consumption of electrical and electronic household and office equipment, and amending Regulation (EC) No 642/2009 with regard to ecodesign requirements for televisions. 22 August 2013.

1.2.6 RESIDENTIAL ENERGY STORAGE SYSTEM

1.2.6.1 Usage behaviour

Differentiation

Grid-connected battery-based electric energy storage systems are a recent development for dwellings. Two different set-ups exist:

- back-up power
- electric energy storage

The first one is similar to uninterrupted power supply systems that are used in industry, data centers and hospitals. For households they can be an alternative for noisy generators and can take over the power supply in a household immediately if necessary. In countries with a questionable electricity grid or where fear exists that a power outage can happen, there are several companies who sell such 'home battery backup systems'. These batteries have to always be fully charged until a power outage happens, so they cannot be used as a smart appliance in the context of this study.

The second set-up is the fast growing market: storing cheaper (renewable) electric energy to avoid buying expensive electricity at a later period. The stored electricity is often generated by a PV installation. For this new product category, there is no unique and universal definition so far. Therefore, the following terms are used (amongst others):

- storage battery for home use
- residential energy storage system
- solar-energy storage unit
- solar battery
- home battery

In off-grid dwellings batteries are already common practice, often powering a DC-grid. This is however out of scope of this document.

Basic use of a home battery

A home battery is usually used together with a PV installation. It avoids that more expensive electricity has to be bought back in the evening whereas own solar electricity flows into the distribution grid in the daytime. Storage is a way to increase the self-consumption of solar energy and therefore a residential energy storage system is a DSF capable smart appliance, relieving the distribution grid. The proof of attractiveness and the premises to be so are described in^{74,75}. In Germany 25,000 home batteries have been installed up to 2015⁷⁶. Some home battery sellers state explicitly that their storage systems can also be connected to small wind turbines and cogeneration units. Although buying electricity at the night tariff and to use it in the daytime would sound like another possibility, the spread between these tariffs is mostly small.

⁷⁴ Grietus Mulder, Daan Six, Bert Claessens, Thijs Broes, Noshin Omar, Joeri Van Mierlo. The dimensioning of PV-battery systems depending on the incentive and selling price conditions. Applied Energy. April 2013.

⁷⁵ Michael Fuhs, Shamsiah Ali-Oettinger. Storage has landed. PV Magazine. November 2012.

⁷⁶ „Die Sonne speichern“, Presse, 8 January 2015. [Online]. Web address: <http://die-sonne-speichern.de/pressemeldungen/>. [Latest: 4 May 2015].

Distinction between different implementations

1. Residential energy storage systems combined with a separate PV installation. The installation consists of a battery storage system and additional convertors to connect the storage system to the house grid.
2. Fully integrated residential energy storage systems with PV (e.g. SMA Sunny Island). In these systems the battery storage is part of the PV installation and a single integrated controller takes care of the balancing between PV, grid and storage
3. Setup 2 combined with smart control of appliances, e.g. via controlled power plugs.
4. Standalone residential energy storage systems. The purpose here is, e.g., to use the electricity price differences (business case -> difference in prices) – communication tariffs or to provide, e.g., ancillary services with volume as a control signal.
5. Electric Vehicle (EV) To Home. In this setup, electric vehicles will be used as a (mobile) Battery Storage Systems, to store and extract electric energy. The setup is currently in use in Japan, but not yet popular in the EU.

1.2.6.2 User behaviour concerning charging

The main goal for setup 1, 2 and 3 is maximisation of self-consumption, in order to minimise the economic disadvantage due to feed in tariffs that are lower than the buying price.

Setup 4 focusses more on the difference in pricing in time. This can be due to Day/Night, Peak/Off peak pricing or in the future, variable pricing blocks during the day. Or to receive reservation and activation fees for other services.

Setup 5 (EV's) is out of scope of the study.

The systems taken into account for this chapter are focussed on residential usage and range between 2 to 10 kWh.

The biggest market for Battery Storage Systems in Europe is Germany with an installed base of 25,000 installed systems today⁷⁶. For other European countries figures are very low and some only have some projects with experiment setups. No exact figures were found for these countries.

1.2.6.3 Comfort constraints

The modern residential energy storage systems operate fully automated. The systems can make use of advanced algorithms taking into account price variations, solar predictions based on regional weather information, self-learning techniques to predict expected consumption, etc. These algorithms need minimal or no user interaction. The capacity needed is dependent on consumption patterns and installed appliances (E.g. heat pump or not) and installed PV capacity.

An additional advantage, but certainly not the main goal, is that the residential energy storage system can provide in backup power when the grid is not available. The household can go in Island Mode, but first needs to disconnect physically from the grid. This might require extra hardware such as a grid feeding monitoring.

1.2.6.4 Occupation Schedules

The usage and dimensioning is dependent on the targeted DSF business case. More details on the different business cases are described in T2.3.

1.2.6.5 Lifespan

Most system manufacturers estimate the lifespan at 15 to 20 years. For modern Li-Ion batteries this is feasible if they operate within their designated operations conditions (Temperature, Charging and Depth of discharge limits). For Lead-Acid the maximum discharge depth is around 50 % while for Li-Ion this can vary between 50 and 100 % of nominal capacity, depending on the type. For some battery types, 100% is not possible, but we can state that the majority has a higher Depth of Discharge level than Lead-Acid⁷⁷.

The capacity of the batteries degrade over time dependent on type of battery, the number of cycles, depth of discharge and temperature as shown below (see Table 11 and Table 12).

Table 14: Cycle life as a function of depth of discharge (source: http://batteryuniversity.com/learn/article/how_to_prolong_lithium_based_batteries)

Depth of discharge	Discharge cycles	
100% DoD	300 – 500	A partial discharge reduces stress and prolongs battery life. Elevated temperature and high currents also affect cycle life.
50% DoD	1,200 – 1,500	
25% DoD	2,000 – 2,500	
10% DoD	3,750 – 4,700	

Table 15: Estimated recoverable capacity when storing Li-ion for one year at various temperatures

Temperature	40% charge	100% charge	
0°C	98%	94%	Elevated temperature hastens permanent capacity loss. Not all Li-ion systems behave the same.
25°C	96%	80%	
40°C	85%	65%	
60°C	75%	60% (after 3 months)	

For more technical details on the lifespan and constraints of batteries refer to Task 4.

⁷⁷ Jeff Dahn and Grant M. Ehrlich. Lithium-Ion Batteries. Linden’s handbook of batteries. 2011.

1.2.6.6 Energy consumption and shifting potential per appliance per day / per season (refer to task 1 for more information) for 27 EU member states.

SHIFTING POTENTIAL

For the purpose of this report, a distinction is made between the overall shifting capacities independent of a business case and the “battery with PV” business case, since that is currently the most used and we have more detailed information on this.

The overall shifting capacity is dependent on the operating range of the installations. Parameters like maximal depth of discharge, maximal charge and discharge currents determine how much of the total capacity can be actually used for flexibility. The parameters differ for the used battery technologies (Lead-acid, Li-Ion, etc.).

For the battery with PV installations, the shifting potential will vary strongly in the different seasons as well as with geographical location (Figure 3532). Below it is estimated what this would mean on a European level.

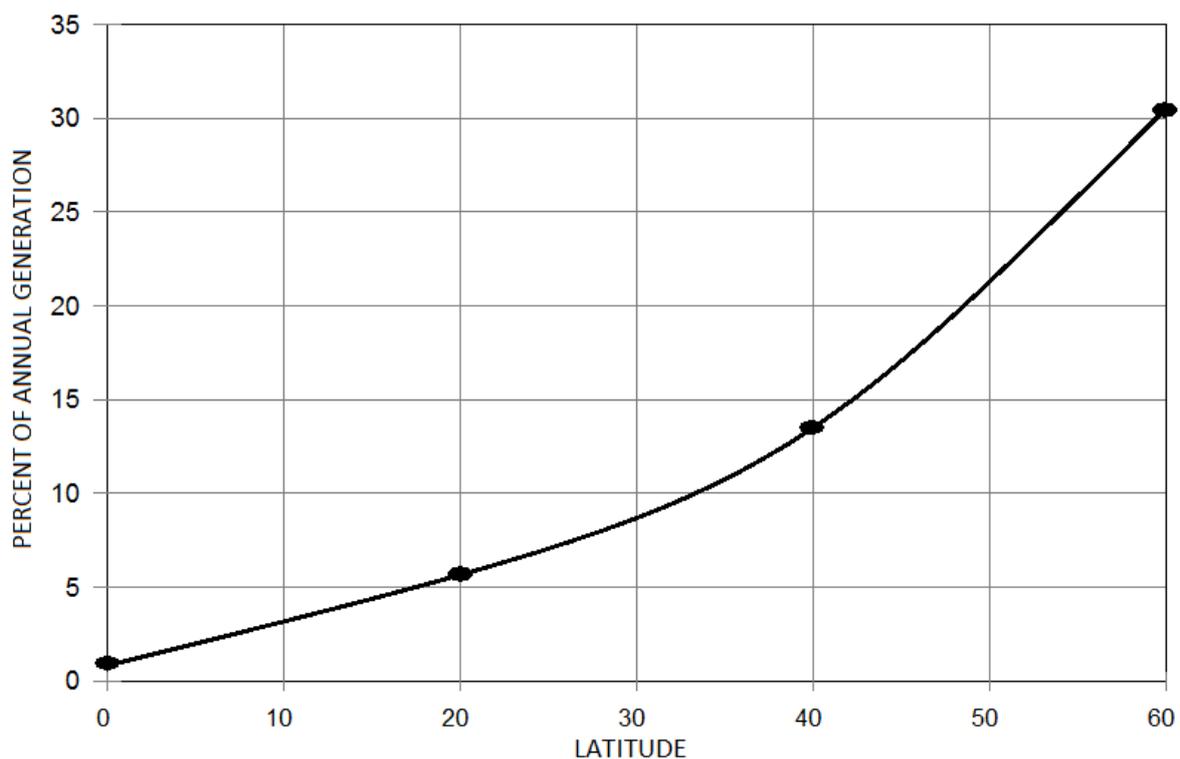


Figure 36: Battery storage requirements versus latitude. (<http://euanmearns.com/how-much-battery-storage-does-a-solar-pv-system-need/>)

By the end of 2013, in total 81 GW of PV was installed and in 2014 an additional 10 GW was installed⁷⁷. IEA-RETD⁷⁶ indicates that 20% of the installed PV capacity is situated in the residential sector, which results in a total of 18 GW of installed residential PV capacity in Europe.

The average capacity of residential installations is 4 kW⁷⁸, so translated to the number of installations 4.5 million existing installations can be assumed.

For each installation a self-consumption share without storage of 40% is estimated, when storage is integrated this is expected to be 70% with an average storage of 4 kWh (based on a conservative estimate which is a bit higher than the smallest installations (~2 kWh) but below the average (6 kWh) of the range of the residential installations (2 to 10 kWh).

- The average production of an installation would be 4 kW * 1,000 full load hours /year = 4,000 kWh.
- 40% self-consumption equals to 1,600kWh/year⁷⁵.
- The assumed 30% extra gained from the storage for later consumption, accounts for 1200 kWh.
- For the average consumption of a household, figures from Germany were used⁵²: 3,500 kWh/year. All together this applies that a household would need to retrieve 3,500 kWh – 1,600 kWh (PV) – 1,200 kWh (storage) = 700 kWh from the grid and 1,200 kWh (30%) of the PV production is sent back to the grid (feed-in).
- The total shifting potential can now be calculated twofold :
 - Shifting for self-consumption: 1,200 kWh * 4.5 million installations = 5.4 TWh
 - Additional shifting by using the remaining full load cycles. Since the objective is to store and extract from the residential energy storage on daily basis, 365 full load cycles per year can be assumed. The used 1,200 kWh used for self-consumption accounts for 300 full load cycles of 4 kWh, leaving additional storage capacity for 65 days resulting in 260 kWh/year. Based on the 4.5 million installations this provides a shifting potential of around 1.17 TWh.

All together this results in a shifting potential of about 5.5 TWh, which is 0.18% of the total electricity consumption (3,101.3 TWh) in EU28 in 2013⁷⁹.

1.2.7 LIGHTING

1.2.7.1 Usage Behaviour

This category comprises lighting in residential and commercial indoor areas and public street lighting by use of the following types of light sources:

- LFL: Linear fluorescent lamp
- CFL: Compact fluorescent light
- Tungsten
- GLS: General lighting service ('incandescent')
- HID: High intensity discharge lamp
- LED: Light emitting diode

⁷⁸ Australian Energy Market Operator (AEMO). Ltd Rooftop PV Information Paper - National Electricity Forecasting. 2012

⁷⁹ Net electricity generation, 1990–2013. Eurostat online.

The general usage is that the light is switched on when it is needed and switched off again after use. In offices and other commercial indoor areas, there is a high degree of automatic systems, either on/off or variable according to the incoming daylight.

There are the following possibilities to modulate capacities:

- For advanced LED light bulbs: There are already LED light bulbs on the market, which can be controlled by a smart phone over Wi-Fi – in some cases combined with a special hub for the bulbs. This can be further developed into a DSF enabled system controlled by signals from the power supply system. For LED systems there will be no technical problems in dimming and switching off the light.
- For CFLs: It is also possible to build in DSF enabling, but in a less extent dimming compared to LEDs.
- Generally, for all light bulbs (LED, CFL, Tungsten, GLS) it is technical possible to mount an extra DSF module for switching on and off the bulbs.
- For luminaires and lighting systems in commercial areas (mainly LFL): There are already advanced systems on the market, which can be controlled by local conditions in the lighted area through presence sensors and solar radiation sensors combined with the time of day. This can be further developed into a system controlled by signals from the power supply system.
- Public street lighting: Street lighting systems are already highly controlled from outside and it is possible to combine this with a DSF module.
- Many light technologies can be dimmed (tungsten, halogen, fluorescent, LED etc.) resulting in reduction in power load and energy consumption. Lighting including street lighting is naturally mostly switched on in periods with no solar radiation apart from indoor areas with no or few windows such as basements, commercial centres etc. meaning that the energy consumption is higher in evenings and during nights, though also depending on time of year and geographical location within EU. For offices and some other commercial area, the energy consumption is reduced during weekends. The energy consumption is higher during these periods, which would be a basis for the flexibility potential.

1.2.7.2 Comfort constraints

The negative comfort impact by DSF enabled lighting is naturally a serious constraint. Light is used when there is a need for light and only too little awareness or not correctly adjusted control systems will result in a potential for reducing light intensity or switching off without comfort impacts.

The comfort impacts will be large especially in the homes and commercial areas, which may include safety issues. Only very short periods of dimmed or switched off time would be accepted; we assume 5 minutes per day.

For public street lighting the comfort impact may be more limited, at least for shorter periods of time. On average, we assume half an hour per day.

1.2.7.3 Lifespan

Lifespan is measured in hours of light. The life varies from about 1000 hours for tungsten lighting sources up to around 50000 hours for LED lighting.

Energy consumption and shifting potential per appliance per day/ per season for 28 EU member states.

The estimated stock year 2013 based on the Ecodesign Preparatory Study on Light Sources (ENER Lot 8/9/19⁸⁰):

- LFL: Linear fluorescent lamp: 2209 million units
- CFL: Compact fluorescent light: 4406 million units
- Tungsten: 2569 million units
- GLS: General lighting service ('incandescent'): 561 million units
- HID: High intensity discharge lamp: 84 million units
- LED: Light emitting diode: 144 million units

Separately, the estimated number of street lighting luminaires in EU-25 is about 60 million (2004 figures)⁸¹.

Total calculated energy consumption year 2013 calculated on the basis of (Kemna, 2014):

- LFL: Linear fluorescent lamps: 126 TWh/year
- CFL: Compact fluorescent light: 33 TWh/year
- Tungsten: 57 TWh/year
- GLS: General lighting service ('incandescent'): 13 TWh/year
- HID: High intensity discharge lamp: 48 TWh/year
- LED: Light emitting diode: 1 TWh/year
- Total: 279 TWh/year

Total energy consumption (2020) of street lighting is 35 TWh/year (VITO, 2007).

Data on shifting or capacity modulating potential per appliance in a smart grid perspective are scarce. Instead, we have assessed the potential from available data on stock, lumen output, operating hours, and efficiency⁸² combined with more details on street lighting.

Based on average data on lumen/unit and lumen/watt, the average wattage for each unit is:

- LFL: Linear fluorescent lamps: 29 watt
- CFL: Compact fluorescent light: 11 watt
- Tungsten: 50 watt
- GLS: General lighting service ('incandescent'): 51 watt
- HID: High intensity discharge lamp: 144 watt
- LED: Light emitting diode: 5 watt

⁸⁰ VITO. Preparatory Study on Light Sources for Ecodesign and/or Energy Labelling Requirements ('Lot 8/9/19'). Draft Interim Report, Task 2 (revision 1)

⁸¹ VITO. Preparatory Studies for Eco-design Requirements of EuPs. Final Report. Lot 9: Public street lighting. 2007.

⁸² René Kemna (VHK). ECODESIGN IMPACT ACCOUNTING Part 1 – Status Nov. 2013. May 2014.

- Tungsten stock: 36 watt

The technical potential for load shifting for each light bulb is of the same size assuming switching off. Modulating i.e. dimming potential is much less but naturally depends on the dimming level.

Based on data on the total amount of lumen for EU27 and the lighting efficiency, we have calculated the total power draw for each type of lighting technology assuming full simultaneous power draw:

- LFL: Linear fluorescent lamps: 56 GW
- CFL: Compact fluorescent light: 36 GW
- Tungsten: 49 GW
- GLS: General lighting service ('incandescent'): 8 GW
- HID: High intensity discharge lamp: 7 GW
- LED: Light emitting diode: 29 GW
- Total: 185 GW

This figure needs to be reduced with a simultaneity factor i.e. taking into account that all lighting devices are not switched on all the time. As a rough estimate, we assume a 30 % simultaneity factor and a 50 % comfort factor i.e. only 50 % would be possible to switch off without losing unacceptable comfort losses. The total shifting potential is therefore about 28 GW.

Of this total shifting potential, street lighting is estimated at about 5 GW (based on VITO, 2007) and residential and commercial indoor lighting is 23 GW.

If assumed maximum 5 minutes and 30 minutes of acceptable off time per day for residential and commercial indoor lighting and street lighting, respectively, then the switching potential would be about 4 GWh/day.

Functionalities supporting energy efficiency

For lighting in homes and commercial areas, information feedback on the level of consumption; when the consumption takes places in relation to the needs and efficiency and possibilities of impacting the consumption by behaviour changes and change of bulbs and lighting systems may provide substantial energy savings.

Street lighting is typically highly controlled and professional procured, and only few savings would be possible to achieve with more information feedback.

1.2.8 CONCLUSIONS

Periodical appliances

Periodical appliances are characterised by relatively long average lifespans (about 13 to 14 years) and relatively high power consumption. The numbers of installed base are high for washing machines reaching almost 200 million appliances. For dishwashers, tumble dryers and washer-dryers, these numbers are markedly lower with lowest ownership rates occurring in Eastern European countries. By trend, the penetration rates of these appliances are increasing in all the Member States. Periodical appliances offer a high flexibility, whereas the dishwasher outperforms the other

periodical appliances in flexibility. Delay in start time as well as short term interruptions of operation or modulations in power consumption pattern (e.g. postponing single phases) are assumed to be accepted by consumers if the performance is not compromised. User's concerns mainly focus on safety aspects (e.g. flooding or fire during unattended operation). These concerns could be addressed by improving safety features and by offering relevant insurances.

Continuous appliances

Cooling appliances like refrigerators and freezers are characterised by high numbers of installed base in all the Member States and relatively low power consumption. Load shifting would be possible (e.g. changes of compressor on and off cycles, short term interruptions of compressor's operation) but strictly limited in time for reasons of food safety and quality (seconds to a few minutes). Flexibility could also be provided by modulating power consumption (e.g. changes in motor speed). As cooling appliances operate fully automatic, there is no impact on user's comfort. If food safety and quality is not compromised and the system is working reliably, consumers will rather accept smart operation.

Electric storage water heaters are available in relatively large numbers in the Member States with numbers of installed base ranging in about 90 million units. In comparison to other residential appliances, they are characterised by extremely high power consumption. However, electric storage water heaters represent a heterogeneous category with comprising appliances with different storage capacities and modes of operation. Whereas water heaters heating during the night are the prevailing type in France and Germany, continuous storage water heaters are predominately used in Spain, Italy, Hungary, Czech Republic and Poland. In UK, both types are common. Data on the distribution in other European Countries are currently not available. Load shifting potential of electric storage water heaters highly depends on their storage capacity. As far as consumer's comfort is not compromised, delay in start of operation or interruptions would be possible. The same applies for modulation of power consumption (e.g. changes in temperature settings or power).

The average lifespan of continuous appliances is within the range 13-17 years.

Behavioural appliances

Despite large numbers of installed base in all Member States and a high level of rated power, the flexibility of all behavioural appliances is low. This can be explained by the fact that their operation requires an active involvement of the consumer and thus is time-bound in narrow ranges. In most cases, the consumer wants the service being available directly upon request and load shifts would have serious impacts on consumer's comfort. For this reason, users will presumably not accept shifts in operation. For hobs and ovens, short-term interruptions or postponed heating phases for a few seconds will rather be accepted, if the cooking process is not compromised in any way. However, there is a lack of available studies on this topic.

HVAC

HVAC appliances have a great potential to become communication-enabled or DSF enabled, given that they represent the main energy consumption in dwellings in the EU (heating accounts for 53% and cooling for 7%) (Waide et al., 2014). The main constraint regarding the communicating- or external action on HVAC systems is thermal comfort. The main disadvantage would be the possibility to jeopardize occupant's thermal acceptance (normally inside temperature) when demand-response acts on their HVAC appliances (on/off on peak hours, reducing the inverter current, load of the heat

pump) during some time. These appliances are present among the whole EU28, with a penetration ratio for heating around 90% (EcoheatCool,2005) and for cooling around 15% (Ecodesign Lot 10, 2008). Heating presents a more homogeneous stock, due to Europe's temperate climate, being the opposite for air conditioners, where the stock is heterogeneous within the Member States. It is negligible in 20 of the Member States (less than 6%), and more important in Mediterranean and Eastern Europe (Italy, Spain, Greece, Romania, Slovakia, Southern France, Portugal). According to (BIOIS, 2011) heating is used approximately 7 months in EU28 (with demand largely varying between countries) and air conditioning 4 months for the countries/regions mentioned before (June to September). Taking into account that the heating market in Europe is saturated, existing heating technologies will decrease in sales, except for those that are more energy efficient and will be replaced (or be installed in new constructions) such as heat pumps i.e. (see also Task 1, Annex 1). As for air conditioners, for a penetration rate of 15% (more saturated markets on Member States mentioned above), future trends (Rivière, 2007) estimate a sales growth, mainly on split reversible A/C systems.

Battery operated rechargeable appliances

Due to the relatively low power consumption, Battery Operated Rechargeable Appliances need to be available in large numbers to be able to provide sufficient flexibility.

In this category we selected smartphones, tablets and laptops as possible candidates. These appliances today are largely available in all the Member States. Numbers of installed base range in hundreds of millions, all together.

Furthermore they already have sufficient control logic and communications features available, so that the implementation will be mainly limited to software. A quick calculation shows that sufficient flexibility (hundreds of GWh per year) can be gained without any change in user behaviour. But it is also clear that for correct calculations, there is still a general lack of available and reliable studies on this subject.

If the flexibility would need to be increased, the devices should be connected to their charging stations (wired or wireless) for longer periods, limiting the mobility that usually is the key feature of these appliances. On top of that, it has to be taken into account that the energy (demand) shifting potential is a balance between flexibility and energy saving, where longer connection leads to more shifting potential, but also to more energy consumption due to power losses (little, but present) when devices are connected. The lifespan of the devices is rather short, 4-5 years.

Residential energy storage system

From their nature, Residential Energy Storage Systems are ideal appliances for providing flexibility in the electric grid. Today we mainly see implementations of these systems in combination with PV installations. In this case maximum self-consumption of the PV generated energy is the goal. These systems can operate fully automatic and have no impact on the users comfort. Apart from this business case, the storage systems can also be used for different other business cases like dynamic pricing, peak shaving from and to the grid and aggregator services.

Although it's not their prime target, they can also provide additional comfort in cases of power downs. If we look at the current installations, we see that these systems are still very small in

numbers and only common in Germany (25.000). The individual flexibility however is large. The lifespan of installations is expected to be between 15 and 20 years, but is strongly dependent on its usage (Temperature, Charging and Depth of discharge limits) and the quality of the battery. A quick calculation on the PV case shows a shifting potential of about 5.5 TWh per year.

Lighting

Due to energy labelling and ecodesign measures, there is a high focus on energy efficient lighting, both regarding efficient lighting devices and regarding efficient control (presence sensors, automatic dimming according to actual needs, etc.). When lighting is an energy service, which needs to be produced simultaneous as the needs occur, all lighting load shifting would have serious user impacts including safety issues.

Therefore, even though the technical potential is large, the flexibility is low, especially for homes and commercial areas, and the real potential will mainly exist for short periods of emergency load shifting.

1.3 DATA PROTECTION, DATA SECURITY AND CONSUMER RIGHTS

For some (but not all) DSF applications, high-resolution data on energy consumption are required. However, frequent measurement of power consumption may have serious implications on data privacy and the security of consumers as various information on the consumer can be deduced from these data (Siddiqui et al., 2012⁸³, Molina-Markham et al., 2010⁸⁴). This information include the number of people living in a household or present at home at a certain point of time, type and brand of appliances available in a household, use patterns of devices, use mode, daily routines (e.g. sleeping, eating, showering, watching TV, etc.). In principle it can be said that the higher the frequency of readings, the more precise information can be deduced (Karwe and Strüker, 2014⁸⁵). Related to data privacy, potential questions and concerns raised by consumers are manifold. They include, but are not limited to the following (Siddiqui et al., 2012⁸³):

- Who is collecting and storing the data?
- For how long will the data be stored?
- Frequency of data readings
- Encryption of data
- How will the data be safeguarded?
- Who else has access to the data?
- Will the data be used for other purposes besides electricity delivering and billing?

⁸³ Siddiqui, Zeadally, Alcaraz, Galvao (2012): Smart Grid Privacy: Issues and Solutions. Computer Communications and Networks (ICCCN), 2012.

⁸⁴ Molina-Markham, Shenoy, Fu, Cecchet, Irwin (2010): Private Memoirs of a Smart Meter. BuildSys '10 Proceedings of the 2nd ACM Workshop on Embedded Sensing Systems for Energy-Efficiency in Building, pp. 61-66.

⁸⁵ Karwe and Strüker (2014): A Survey on Privacy in Residential Demand Side Management Applications. In: Cuellar (Ed.): Smart Grid Security. Second International Workshop, SmartGridSec 2014, Munich, Germany, February 26, 2014. Revised Selected Papers. Springer

- Can the data be used for or against a consumer?
- Liability in case of data abuse
- Access to control the appliances

Unless it is ensured that data protection and privacy of individuals are respected, consumers will not accept any DR programmes.

As conditions differ widely in different member states (e.g. penetration rate of smart meters, responsible entities for installation of smart meters, involvement of Data Protection Authorities, data paths, etc.), it is hard to define specific rules and recommendations in view of data processing and data protection. Nevertheless, the Task Force Smart Grid Expert Group 2^{86,87} and the Article 29 Data protection working party⁸⁸ made general recommendations for data handling and safety as well as consumer protection:

“Privacy by design and default” is recommended for the design of technologies and services involved in processing private data. Privacy by Design means that privacy is embedded into design and architecture of the whole system. It should ensure data reduction and data economy as readings should take place only in intervals necessary for the respective system and service. The same applies for the transmission of readings. In general, processing and transmitting of data should be reduced to a minimum. Data should remain on the consumer’s side to the highest possible extent (for some DSF applications, it is possible to retain data locally and communicate it only in case of an imminent DR action). Entities, given the proper authorisation, should only have access to personal data necessary to fulfil their respective role.

The **retention of data** should be related to the purpose. Different retention periods may apply for different purposes (e.g. billing, taxation, billing complaints, optimisation of energy consumption). The Smart Grid Task Force made some recommendations on the scope and length of data retention, which are summarised in Table 13.

⁸⁶ Task Force Smart Grids Expert Group 2 (2011): Essential Regulatory Requirements and Recommendations for Data Handling, Data Safety, and Consumer Protection. Recommendation to the European Commission

⁸⁷ Task Force Smart Grids Expert Group 2 (2011): Regulatory recommendations for data safety, data handling and data protection report

⁸⁸ Article 29 Data Protection Working Party: Opinion 12/2011 on smart metering

Table 16: Recommendation for scope and length of data retention (Smart Grids Task Force, 2011⁸⁶)

Purpose	Scope	Length	Kept by
Network maintenance	Personal/anonymised/aggregated	strictly necessary / national law	Utility
Billing and payments	summed up usage	around 12-13 months / national law	Utility and energy market supplier
Billing complaints	detailed personal data	national law	consumer
Taxation – tax records	summed up usage	national law	utility
Taxation – tax breaks	detailed personal data		consumer
Value added services	upon consent	upon consent	any interested
Policy making	anonymised/aggregated	unlimited	public authorities

Data should be retained in an **aggregated and anonymised form** to the highest possible extent. For billing purposes, aggregation of several readings of one individual meter is conceivable, for load management the aggregation of data from several meters. It has to be ensured that the actions of individual households and patterns of single appliances cannot be recognised. Another possibility is to retain the information locally until their communication is triggered in case of imminent DR actions.

Pseudonymisation has to be named as a further security measure hampering the possibility to link consumption data and identity information. Notwithstanding the above, it has to be mentioned that none of the aforementioned security measures are impregnable.

In order to ensure privacy, **safeguards** should be available comprising the whole system (elements of the network at home, the transmission of data, the storage of the data and any processing). These safeguards should be updated on a regular basis.

Any **disclosure of private data to or processing of data** by third parties should require the knowledge and consent of the respective consumer. This should include the right to withdraw any consent given earlier.

If any **Value Added Services** apart from energy supply (e.g. optimisation of energy consumption) are offered by the energy provider or a third party, it has to be an optional service and the customer needs to explicitly opt-in to provide its data for this purpose.

In the case of **mobility** (e.g. customers changing their providers, their locations, etc.), it should be ensured that the data stay linked to the respective customer or will be deleted completely. Regarding a change of the provider, this includes a secure transmission of the data.

Additionally, it has to be mentioned that Directive 95/46/EC on the protection of individuals with regard to the processing of personal data and on the free movement of such data and national laws implementing this Directive also apply to data processing in the framework of smart appliances and smart meters. In some respect, the aforementioned Directive is outdated as it does not take adequate account of new technological developments and Internet Services as for instance Cloud computing. For this reason and in order to harmonise data protection in Europe, a new General Data Protection Regulation is planned for the near future replacing Directive 95/46/EC.

Besides privacy concerns, consumers and experts also raise security concerns in view of smart applications. On the level of individual consumers, hacker attacks may imply a loss of control of single appliances or the introduction of malicious software (e.g. for spying purposes or profiling). On a grid level, attacks and introduction of malware might have enormous consequences. They can initiate an instantaneous increase or drop in demand, both destabilising the grid and resulting in severe problems or even damages of distribution, transmission and generation facilities. (Yan et al., 2012⁸⁹)

According to Stakeholders' opinion, the risk of an attack on the infrastructure is considerably higher than the risk of an attack on an individual appliance. Even though, some measures are recommended to decrease the risk of an individual attack. For instance, a manual "connection on/ off" switch should be provided that allows the consumer setting back the appliance to a local control. Additionally, an update capability should be available in the communication interface to tackle known threats and future security needs. Moreover, it has to be ensured that settings can only be changed within proper limits. If these limits are going to be exceeded, a safety shutdown of the respective appliance is recommended.

According to the National Institute of Standards and Technology⁹⁰ (NIST), deliberate attacks are not the only threats in view of the security of smart applications. Also potential accidents, e.g. due to equipment failures, user error or natural catastrophes should be taken into account.

Besides data protection and security, protection of vulnerable costumers, who may be disadvantaged because of remuneration schemes, is of major importance. In view of DSF applications, vulnerability may be defined in terms of the access and understanding of new technologies and the possibility to make use of these technologies for energy managing and cost saving purposes (NEA, 2014⁹¹). Elements that potentially contribute towards consumer vulnerability include but are not limited to disability, age, (mental) health problems, hearing or visual impairment, low literacy, language or numeracy skills, tenure and low income. In order to avoid disadvantages of vulnerable costumers and ensure that all consumers can access the benefits resulting from DSF applications, adequate (political) measures have to be taken to provide support for vulnerable costumers and their specific problems.

1.4 RECOMMENDATIONS ON REFINED PRODUCT SCOPE

In order to refine the product scope from the perspective of consumer behaviour, all appliances are categorised according to their load shifting potential (Table 14). The categorisation has been done on the basis of the information and assessments mentioned before.

⁸⁹ Yan, Qian, Sharif, Tipper (2012): A Survey on Cyber Security for Smart Grid Communications. IEEE Communications surveys & Tutorials, 14, 4.

⁹⁰ NIST Special Publication 1108R2 (2012): NIST Framework and Roadmap for Smart Grid Interoperability Standards, Release 2.0. Available online: http://www.nist.gov/smartgrid/upload/NIST_Framework_Release_2-0_corr.pdf

⁹¹ NEA (2014): Developing an Extra Help Scheme for vulnerable smart meter customers. Available online: https://www.citizensadvice.org.uk/global/migrated_documents/corporate/smart-meter-extra-help-scheme-full-report-final1.pdf

Table 17: Categorisation of appliances according to their load shifting potentials (categorisation in terms of energy or number of products/ applicability of demand shift)

High potential	Medium potential	Low/ no potential
Washing machines	Refrigerators/ freezers	Electric water heater (instantaneous)
Dishwasher	Battery operated rechargeable appliances (smart phones and tablets)	Vacuum cleaners
Tumble dryer Washer-dryer		Range hoods Battery operated rechargeable appliances (others)
Electric water heater (storage) HVAC		Lighting Hobs
Battery storage systems		Ovens

The „high potential“-category consists of appliances, which have high numbers of installed products and/ or a high level of rated power/ high energy consumption. The consumer acceptance of load shifts or short interruptions is good for these appliances and it seems feasible to handle their comfort constraints.

Although **refrigerators and freezers** have high numbers of appliances in stock and it is assumed that smart operation (e.g. frequency control) would be accepted by consumers, these devices are categorised as “medium potential” due to their low level of rated power. The same applies for chargers of **smart phones and tablets**.

The potential of **hobs and ovens** is assessed to be low despite the large installed base in the EU and a high level of rated power. The assessment can be explained by the fact that their operation requires an active involvement of the consumer and thus is time-bound in narrow ranges. For this reason, the acceptance of consumers for shifts in operation is presumable low and only short-term interruptions for a few seconds or postponed heating phases will rather be accepted, if the cooking process is not compromised in any way.

Instantaneous electric water heaters are categorised as a low/ no potential appliance. To reach a high level of consumer acceptance, it is essential to always ensure a sufficient amount of hot water. This is only possible in the case of storage water heaters. In view of instantaneous water heaters, short-term interruptions in power supply would cause losses in comfort, which will not be accepted by consumers.

In view of **vacuum cleaners** and **range hoods**, shifts in operation and short-term interruptions are also improbable. Their power demand remains constant during operation and interruptions in power supply would consequently interrupt their operation. A further reduction of their power would decrease their performance (lower air change rate or a loss of suction power, respectively), and will presumably not be accepted by consumers.

Battery operated rechargeable appliances others than smart phones and tablets are categorised as low/ no potential appliances. This is due to the fact that they either have a smaller installed base or a

lower and less predictable charging frequency (e.g. household appliances, power tools, navigation systems).

In the case of **lighting**, load shifts or short term interruptions would decrease the comfort for consumers and will presumably not be accepted.

Onset on barriers and opportunities for Ecodesign

During the last years, the share of appliances offered on the European market, which can be connected to the Internet for safety or convenience reasons, has continuously been growing. It can be expected that this trend will further grow. This might be seen as an opportunity for DSF. As far as it is possible to use the same software, there would be (almost) no extra costs for consumers to operate their existing appliances in a smart mode in order to shift loads. This would result in a very short payback time, which was identified as a key success factor.

From the consumers' point of view, data protection and consumer rights have to be seen as the major barrier. To overcome this barrier, it is essential to harmonise standards at European level and develop technical solutions for appliances, communication and billing systems that ensure the highest security standards when dealing with personal data.

1.5 DEMAND SIDE FLEXIBILITY USE CASES – SYSTEM PERSPECTIVE

The use of DSF in the energy system can serve multiple objectives. First, it can be used to optimize the day-ahead scheduling of electricity production and consumption. Second, it allows in real-time to match supply and demand in case of deviations in scheduling. These use cases are explained in detail below and the role of smart appliances as provider of flexibility is discussed.

In Task 5, for these use cases a model will be developed allowing the environmental product assessment and definition of the base cases. Section 1.5.2 gives an overview of the European market context and in section 1.5.3 the main data assumptions used in the model are listed.

Note that the modelling of the use cases makes abstraction of any specific energy market structure. For there is varying support for DR in the deregulated EU Member States' energy markets. In some countries no DR mechanisms are available, in others DR is already extensively used in the large industry. The way the energy market is organized will determine the extent and distribution of the return from the DR business cases. The following factors vary significantly between Member States, making an overall assessment of the impact of DR on all market players case-specific (non-exhaustive list of factors):

- The ownership of the smart meter is not identical for all EU Member States (e.g. owner can be the DSO or the retailer).
- The access to ancillary services of the TSO for DSF sources varies and depends on the ancillary service products of the respective TSO's.
- Various versions of variable tariffs are available throughout Europe and not all countries support variable tariffs.

- The role, obligations and rights of DR aggregators is not yet clear in many Member States.
- The rights and methods of the DSO to interact with DSF for the purpose of safeguarding the distribution grids from this extra source of variability is not yet clear in many Member States.
- In only few Member States, mechanisms exist to alter the perimeter of the BRPs with the effect of residential DSF.

1.5.1 DEFINITION OF USE CASES

Two distinct use cases can be defined, based on two important time blocks in the market: day-ahead versus real-time.

1) Day-ahead use case

In day-ahead, the schedule of electricity production and consumption is determined. In order to match supply and demand, balance responsible parties have several possibilities. First, they can adapt their production volume by optimizing own generation units or by participating to the various European Power Exchanges that enable them to trade volumes in the short term (day-ahead). The prices on the power exchange are determined on an hourly basis and are published in a transparent way. The prices on the day-ahead market reflect the marginal cost of the last unit that is needed to produce these volumes.

DSF could directly participate in the day-ahead market platform. The Balancing Responsible Parties (BRPs) have also the possibility to modify the load in order to match supply and demand. Load reduction or load shifting can avoid costs of additional production during hours with high prices. In this case, the DSF is directly integrated in the portfolio of the BRP. Independent how DSF by the use of smart appliances is offered in day-ahead, it will support the matching of supply and demand at a lower cost. In case of high estimated production of RES during certain hours, load could be shifted or increased during these hours. In case of high estimated load, a decrease or shift in load will have a downward effect on prices.

The day-ahead scheduling of production and consumption is done at national level. However, in recent years, an evolution towards more integrated markets on European level can be observed. Several day-ahead markets within the EU are coupled today, resulting in a unified day-ahead price in case of no congestion of transmission lines.

The harmonisation of day-ahead markets is part of the larger goal of European harmonisation as discussed in 1.5.1. In 2015, a total of 20 EU power markets are coupled through the Multi-Regional Coupling⁹².

⁹² The Multi-Regional Coupling (MRC) is a cooperation between the Power Exchanges APX, Belpex, EPEX SPOT, Nord Pool Spot and OMIE, and the Transmission System Operators 50Hertz, Amprion, Creos, Elia, Energinet.dk, Fingrid, National Grid, REE, REN, RTE, Statnett, Svenska Kraftnät, TenneT TSO B.V. (Netherlands), TenneT TSO GmbH (Germany) and TransnetBW.

2) Imbalance use case

In real-time, deviations are observed between supply and demand. Different reasons can explain these deviations. Changing weather conditions are the primary source of these deviations. The realised production of renewable energy sources (wind and solar) is highly dependent on the weather. The demand or load is also affected by weather conditions such as temperature and cloud cover. In addition, non-weather related causes such as sudden outages of generation units or human errors e.g. in load forecasts can also explain why there is an imbalance between supply and demand in real-time.

The TSO is responsible for the stability of the grid and security of supply at the lowest cost in real-time or in near real-time. It will monitor in real-time the deviations of the grid and activate the necessary ancillary services in order to balance the system. Ancillary services can be provided by both, generation and load management, dependent on the type of ancillary service product. Dependent on the country, ancillary services are contracted by the TSO via yearly, monthly or weekly tenders. Today, the three categories of ancillary services are FRC⁹³, FRRa⁹⁴ and FRRm⁹⁵. The relevant ancillary services for DSF today are FCR and FRRm. FRC is used by the TSO to ensure that the grid frequency stays within a certain range within the interconnected high-voltage European system. FRRm is used by the TSO to cope with major imbalance and congestion issues.

The cost of the activation of ancillary services (FRRa and FRRm) is reflected in the imbalance price published afterwards. As each BRP is responsible for the balance of its own portfolio, their individual imbalances will be invoiced based on the imbalance prices.

Similar to the day-ahead use case, DSF can be part of the imbalance use case in different ways. First, DSF can participate directly in the market of ancillary reserves (FCR and FRRm). An example of DSF participating to the market of FRRm is the product R3DP in Belgium (see later). The response time for FRRm is on average 15 minutes, which is sufficient for DSF to participate. In general, it is more difficult for DSF to participate in the market of FCR due to the fast response time that is required (15 seconds). However, applications based on batteries could participate to this market.

Alternatively, DSF can be used by the BRPs in order to optimize the balancing of their portfolio which results in a decrease of their imbalance costs.

Today, there exists a large variety of balancing mechanisms⁹⁶. Efforts are made to harmonize these rules within Europe (see also 1.5.1), in order to improve efficiency and increase competition in the

⁹³ FRC = frequency containment reserves or currently called primary reserves. FCR are continually activated and have a fast response time (15 sec).

⁹⁴ FRRa = automated frequency restoration reserves or currently called secondary reserve. FRRa is activated on automated basis.

⁹⁵ FRRm = manual frequency restoration reserves of currently called tertiary reserves.

⁹⁶

https://www.entsoe.eu/Documents/Publications/Market%20Committee%20publications/150127_WGAS_Survey_2014.pdf

market of ancillary services. Dependent on the organisation of the market, which varies between countries, prices of ancillary services, settlement mechanisms in case of imbalance and incentives for BRPs to actively balance their portfolio differ substantially.

Note: besides the two main use cases as discussed above, DSF could serve other objectives as well, such as DSO grid congestion cases, reactive power voltage support in the transmission grid,.... However, these use cases are less mature (e.g. DSOs are today not incentivized to contract flexibility as costs for flexibility are not remunerated) and the value of flexibility from smart appliances cannot be estimated based on today's situation.

1.5.2 EU TARGET MODEL AND SCENARIOS

In 2007 the EU Member States agreed upon a clear set of targets for the integration of renewable energy. By 2020, the EU has a goal of a 20% reduction of greenhouse gas emissions, a minimum of 20% of energy savings and an increase of the share of renewable energy to at least 20% of the consumption⁹⁷. Building upon the targets defined for 2020, in October 2014 the EU determined a policy framework for 2030 for climate and energy. The 2030 framework sets a target of 40% reduction in greenhouse gas emissions, a minimum of 27% of EU consumption to be produced from renewable energy sources and a 30% improvement in the EU energy efficiency compared to the projections⁹⁸. The different EU targets with respect to the increase of renewable energy will have large effects on the grid, especially due to the intermittency of most renewable sources (wind and solar).

Besides increasing efforts in meeting the different climate and energy targets, steps are made at European level to stimulate the harmonisation of European energy markets. The European Target Model for Market Integration aims at a more integrated and efficient market with lower prices and increased stability that would benefit Transmission System Operators (TSOs), generators, investors, traders and ultimately end-consumers. The European Target Model addresses all market segments from forward markets to day-ahead, intra-day, balancing markets and cross border capacity calculation. In the short term, congestion on cross border interconnections hinders the integration of markets. Increased capacity and new interconnections should provide a long term structural solution.

In 2015, progress has been made in the first place with the development of network codes and the harmonisation of day-ahead markets⁹⁹. Less progress has currently been made on the level of balancing markets which are still mainly organised on a national level, resulting in a large variety of mechanisms across Europe¹⁰⁰. An example of initiatives to harmonize the balancing markets, in

⁹⁷ Directive 2009/28/EC; Directive 2009/29/EC; Decision 406/2009/EC; Directive 2009/31/EC

⁹⁸ <http://ec.europa.eu/energy/en/topics/energy-strategy/2030-energy-strategy>

⁹⁹ https://www.entsoe.eu/Documents/Events/2014/141013_ENTSO-E_Update-on-IEM-related%20project%20work_final.pdf

¹⁰⁰

https://www.entsoe.eu/Documents/Publications/Market%20Committee%20publications/150127_WGAS_Survey_2014.pdf

particular, imbalance settlement, is the international grid cooperation control (IGCC)¹⁰¹. The IGCC enables netting of the imbalance volumes between the participating countries, and hence reducing the need for activation of reserves.

The targets for renewable energy, in combination with the ongoing harmonisation of energy markets will determine the future market design. In the following analysis, results are presented for 2015, 2020 and 2030. In addition, the expected market design of an integrated European market, although not yet a reality, is used as a reference case for market design.

1.5.3 DEMAND/LOAD, INSTALLED CAPACITY AND FUEL PRICES

1.5.3.1 Demand or Load

The estimated demand for EU28 is based on the realised hourly load data of 2014 as published by the statistical database of ENTSO-E¹⁰². The load is corrected for import and export with countries not belonging to the EU28. In order to determine the load in 2020 and 2030, a yearly increase of 1.4% is assumed¹⁰³.

1.5.3.2 Installed capacity per Member State

The installed capacity of production units per Member State is based on the installed capacity of 2014 as published by the statistical database of ENTSO-E. For 2020 and 2030, the production mix per Member State is based on the PRIMES scenarios¹⁰⁴. The PRIMES model simulates the European energy system and markets on a country-by-country basis and across Europe for the entire energy system. The model produces projections over the period 2015 to 2050 in 5-years intervals¹⁰⁵. Utilized values for the installed wind capacity, solar capacity and peak load are summarized in

¹⁰¹ http://www.tennet.eu/nl/fileadmin/downloads/About_Tennet/Publications/Other_Publications/plugin-Market_information_IGCC_tcm43-20521.PDF

¹⁰² <https://www.entsoe.eu/data/data-portal/Pages/default.aspx>

¹⁰³ KPMG. Power Sector Development in Europe – Lenders’ Perspectives 2011 - A survey of banks on the prospects for power infrastructure financing in Europe

¹⁰⁴ <http://ec.europa.eu/transport/media/publications/doc/trends-to-2050-update-2013.pdf>.

¹⁰⁵ More information on the PRIMES model is listed on the website of E3Lab of the National Technical University of Athens - http://www.e3mlab.ntua.gr/e3mlab/index.php?option=com_content&view=category&id=35:primes&Itemid=80&layout=default&lang=en

Table 18 Installed RES capacity and peak load per EU-28 Member State per year (Source: ENTSO-E database for 2014 for all Member States except Malta, PRIMES scenario outcomes for 2020 and 2030, and for Malta for 2014, and for peak load in Malta Enemalta¹⁰⁶)

	Installed solar capacity [MW]			Installed wind capacity [MW]			Peak load [MW]		
	2014	2020	2030	2014	2020	2030	2014	2020	2030
AT	400	787	1466	1529	3114	6051	12355	13430	15433
BE	1840	2429	4813	1966	4772	7068	13110	14251	16376
BG	1060	1116	1534	850	923	1515	8638	9390	10790
CY	79	194	658	145	249	329	871	947	1088
CZ	2011	2011	2068	277	307	387	10058	10933	12564
DE	35357	49089	53584	35600	48956	69949	81031	88081	101219
DK	282	360	762	4489	5960	7420	6163	6699	7699
EE	0	0	0	354	495	1056	1786	1941	2231
ES	7667	12655	16945	25028	25213	35707	39394	42821	49208
FI	7	50	60	411	1538	2556	13945	15158	17419
FR	4630	7470	13913	10238	25687	47354	84280	91612	105276
GB	1574	5985	8853	12140	38627	50721	50997	55434	63702
GR	3052	3286	3640	2195	3433	3745	8448	9183	10553
HR	16	27	182	394	640	713	3012	3274	3762
HU	3	93	712	413	903	1236	5712	6209	7135
IE	0	0	674	2088	11200	5992	4572	4970	5711
IT	16204	19553	28206	7371	222	22598	49523	53832	61861
LT	0	0	0	221	226	251	1408	1530	1758
LU	78	226	409	78	428	290	878	954	1097
LV	1	1	1	155	86	681	1172	1274	1464
MT	8	48	211	1	3561	191	290	316	363
NL	131	788	1037	4619	9624	12359	17850	19403	22297
PL	6	51	530	2472	6515	8843	23593	25645	29470
PT	1051	2212	5613	5398	5689	8324	8295	9017	10362
RO	214	679	1860	1566	1572	4043	8738	9499	10915
SE	13	182	248	3646	4447	5107	24295	26409	30348
SI	85	130	444	8	225	453	2074	2254	2591
SK	539	787	1009	48	113	455	4523	4917	5650

1.5.3.3 Fuel prices

The fuel price for the different technologies will determine which power plant will run and at which price. The fuel costs in the model for (prices of oil, gas and coal) for 2020 and 2030 are based on an average of the price scenario's as defined in the World Energy Outlook 2013 and the price scenario's

¹⁰⁶Enemalta:http://www.transport.gov.mt/admin/uploads/media-library/files/DAirMaltaStudyVisit_The%20Energy%20Sector%20in%20Malta.pdf

presented in the Energy Technology Perspectives¹⁰⁷. Prices for 2014 are based on realised market prices¹⁰⁸. The prices are not country specific.

The CO₂-prices in the model for 2014 are based on the average price of the EUA Dec 2014 contract as quoted during 2014 (published by ICE¹⁰⁹). The prices for 2020 for CO₂ are based on the current published price (16/10/2015) of the EUA December 2020 contract (published by ICE). The price for 2030 is based on an analysis of Thomson Reuters¹¹⁰.

The prices for biomass are based on typical values for wood pellets as published on FOEX¹¹¹. For biomass, the assumption is taken that in most countries, support schemes exist. An average of 55€/MWh as support value for biomass is used¹¹². Table 16 summarizes the fuel prices used in the simulation.

Table 19: Fuel prices for 2014, 2020 and 2030 used in the model

		Year 1 (2014)	Year 2 (2020)	Year 3 (2030)
Nuclear	[EUR/MWh_prim]	6,98	6,98	6,98
Coal	[EUR/MWh_prim]	9,20	11,93	11,97
Natural gas	[EUR/MWh_prim]	18,75	31,66	32,71
Hydro	[EUR/MWh_prim]	5,06	4,84	4,84 ¹¹³
Wood pellets	[EUR/MWh_prim]	48,48	53,54	57,42
Oil	[EUR/MWh_prim]	5,96	9,07	48,00
CO2	[EUR/tCO2]	6,98	6,98	6,98

¹⁰⁷ <http://www.iea.org/etp/etpmodel/assumptions/>

¹⁰⁸ [http://knoema.com/wxgcxde/commodity-prices-forecast-2015-2019-charts-and-tables?variable=Natural%20gas%20\(US%24%2FmBtu%2C%20Europe\)](http://knoema.com/wxgcxde/commodity-prices-forecast-2015-2019-charts-and-tables?variable=Natural%20gas%20(US%24%2FmBtu%2C%20Europe))

¹⁰⁹ <https://www.theice.com/market-data>

¹¹⁰ <http://www.changepartnership.org/wp-content/uploads/2014/10/Point-Carbon-2014-11042014-MSR-Point-Carbon.pdf>

¹¹¹ <http://www.foex.fi/index.php?page=pix-rcp>

¹¹²

https://ec.europa.eu/energy/sites/ener/files/documents/ECOFYS%202014%20Subsidies%20and%20costs%20of%20EU%20energy_11_Nov.pdf

¹¹³ XXX

LIST OF REFERENCES

- A.I.S.E. (2013). The case for the “A.I.S.E. low temperature washing” Initiative.
- ATG, 2016: Artiston Thermo Group, personal communication. Article 29 Data Protection Working Party: Opinion 12/2011 on smart metering
- Australian Energy Market Operator (AEMO). Ltd Rooftop PV Information Paper - National Electricity Forecasting. 2012.
- Balta-Ozkan, Davidso, Bicket, Whitmarsh (2013): Social barriers to the adoption of smart homes. Energy Policy. 63:363-74.
- Balta-Ozkan, Amerighi, Boteler (2014): Comparison of consumer perceptions towards smart homes in the UK, Germany and Italy: reflections for policy and future research. Technology Analysis & Strategic Management. 2014; 26:1176-95.
- Bichler S. (2014): Verbraucherakzeptanz von Energieeinsparpotentialen an automatischen Geschirrspülmaschinen. Shaker Verlag, Aachen.
- Bertoldi, Atanasiu (2009). Electricity Consumption and Efficiency Trends in European Union – Status Report 2009, European Commission DG Joint Research Centre
- Bertoldi, Hirl, Labanca (2012): Energy Efficiency Status Report 2012, Electricity Consumption and Efficiency Trends in the EU-27.
- BIO Intelligence Service (2012) Preparatory Studies for Ecodesign Requirements of EuPs (III), ENER Lot 20 – Local Room Heating Products - Task 3: Consumer behavior and local infrastructure. Prepared for the European Commission, DG ENER.
- Boork M, Thomtén M, Brolin M, Uyterlinde M, Straver K, Kraan C, Kleine-Hegermann K, Laes E, Valkering P, Maggiore S. Key success factors and barriers to end-user engagement in smart grid projects. Paper presented at the 2014 BEHAVE conference, London. Available from: <http://behaveconference.com/wp-content/uploads/2014/08/F_Magdalena_Boork_Technical_Research_Institute_of_Sweden.pdf>
- Bundesamt für Konjunkturfragen, 1993: Blatter, Borel, Hediger, Simmler: Materialien zu RAVEL. Warmwasserbedarfszahlen und Verbrauchscharakteristik. Bern.
- Bush et al. (2013): Heat Pump Tumble Dryers: New EU Energy Label and Ecodesign requirements in Europe, MEPS in Switzerland, Initiatives in North America. Available online: http://www.topten.eu/uploads/File/EEDAL_heat_pump_driers_2013.pdf
- Cardinaels, Borremans (2014): Linear Intelligent Networks - Demand Response for Families.
- CECED, 2006: Energy Efficiency, A shortcut to Kyoto Targets. The Vision of European Home Appliance Manufacturers.
- COMMISSION REGULATION (EU) No 801/2013. Amending Regulation (EC) No 1275/2008 with regard to ecodesign requirements for standby, off mode electric power consumption of electrical and electronic household and office equipment, and amending Regulation (EC) No 642/2009 with regard to ecodesign requirements for televisions. 22 August 2013.

Dahn and Ehrlich: Lithium-Ion Batteries. Linden's handbook of batteries. 2011.

Defra, 2008: Measurement of Domestic Hot Water Consumption in Dwellings. URL: https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/48188/3147-measure-domestic-hot-water-consump.pdf

Denzil Ferreira, Anind K. Dey, Vassilis Kostakos. Understanding Human-Smartphone Concerns: A Study of Battery Life. Pervasive Computing. June 2011.

D'hulst, Labeeuw, Beusen, Claessens, Deconinck, Vanthournout (2015): Demand response flexibility and flexibility potential of residential smart appliances: Experiences from large pilot test in Belgium. Applied Energy 155: 79-90.

Directive 2009/28/EC; Directive 2009/29/EC; Decision 406/2009/EC; Directive 2009/31/EC

„Die Sonne speichern“, Presse, 8 January 2015. [Online]. Web address: <http://die-sonne-speichern.de/presse-meldungen/>. [Latest: 4 May 2015].

Ecodesign LOT 10, TASK 2 Final Report, 2008. URL: http://www.eup-network.de/fileadmin/user_upload/Produktgruppen/Aircon_Final_report_of_Task_2.pdf.

Ericsson, Europe Ericsson Mobility Report Appendix, November 2014

European Commission (2005): Green Paper on Energy Efficiency or Doing More with Less. COM (2005) 265 final.

European Commission (2013): COMMISSION REGULATION (EU) No 666/2013 of 8 July 2013 implementing Directive 2009/125/EC of the European Parliament and of the Council with regard to eco-design requirements for vacuum cleaners.

Eurostat online: Net electricity generation, 1990–2013.

Forsa (2010): Erfolgsfaktoren von Smart Metering aus Verbrauchersicht, Berlin.

Fraunhofer-Institut für Solare Energiesysteme ISE (2011): Nachhaltiger Energiekonsum von Haushalten durch intelligente Zähler-, Kommunikations- und Tarifsysteme.

Fredslund K.: Load profiles for Supermarket refrigeration, Part of EUDP-I ESO2 project, 2013

Funder-Kristensen T. ; Green T., Bjerg P.: Supermarket refrigeration as an important smart grid appliance, 16th European conference, technological innovations in refrigeration and in air conditioning, Milan, June 2015

Fuhs, Shamsiah Ali-Oettinger. Storage has landed. PV Magazine. November 2012.

Gartner Press Release: Gartner Says Smartphone Sales Surpassed One Billion Units in 2014, March 2015, <http://www.gartner.com/newsroom/id/2996817>

Gartner, Press Release: Gartner Says Tablet Sales Continue to Be Slow in 2015, January 2015, <http://www.gartner.com/newsroom/id/2954317>

Geppert and Stamminger (2010): Do Consumers Act in a Sustainable Way Using Their Refrigerator? The Influence of Consumer Real Life Behaviour on the Energy Consumption of Cooling Appliances International Journal of Consumer Studies, 34(2), 219-27.

Geppert and Stamminger (2013): Analysis of effecting factors on domestic refrigerators' energy consumption in use Energy Conversion and Management, Volume 76, December 2013, Pages 794-800.

Geppert and Stamminger (2015): Online study on consumer acceptance and perceptions of smart appliance. Not published yet.

Guthridge (2010): Understanding Consumer Preferences in Energy Efficiency - Accenture end-consumer observatory on electricity management, Amsterdam.

HEA (2015): Fachwissen Elektroherde. Available online: <http://www.hea.de/service/fachwissen/elektroherde/>

Herzog (2015): THE MDA (Major domestic appliances) EU ENERGY LABEL REACHING ITS LIMIT? A DISCUSSION. Available online: http://iet.jrc.ec.europa.eu/energyefficiency/sites/energyefficiency/files/events/EEDAL15/S7_Policies7/eedal15_submission_49.pdf.

<http://ec.europa.eu/energy/en/topics/energy-strategy/2030-energy-strategy>

https://ec.europa.eu/energy/sites/ener/files/documents/ECOFYS%202014%20Subsidies%20and%20costs%20of%20EU%20energy_11_Nov.pdf

<http://ec.europa.eu/transport/media/publications/doc/trends-to-2050-update-2013.pdf>

[http://knoema.com/wxgcxde/commodity-prices-forecast-2015-2019-charts-and-tables?variable=Natural%20gas%20\(US%24%2FmBtu%2C%20Europe\)](http://knoema.com/wxgcxde/commodity-prices-forecast-2015-2019-charts-and-tables?variable=Natural%20gas%20(US%24%2FmBtu%2C%20Europe))

IDC Press Release: Worldwide Smartphone Growth Expected to Slow to 10.4% in 2015, Down From 27.5% Growth in 2014, According to IDC, August 2015, <http://www.idc.com/getdoc.jsp?containerId=prUS25860315>

INSEE (2015): Recensements de la population 2012 (french)

J.D. Power and Associates Reports. Denzil Ferreira, Anind K. Dey, Vassilis Kostakos. Understanding Human-Smartphone Concerns: A Study of Battery Life. Has Become a Significant Drain on Customer Satisfaction and Loyalty. March 2012. Pervasive Computing. June 2011.

JRC (2014): JRC Technical Reports - Ecodesign for Commercial Refrigeration. Preparatory study update. Final report.

JRC (2015): Ecodesign and Energy label revision: Household Washing machines and washer-dryers. Draft. Available online: http://susproc.jrc.ec.europa.eu/Washing_machines_and_washer_dryers/docs/Prepstudy_WASH_20150601_FINAL_v2.pdf

Karwe and Strüker (2014): A Survey on Privacy in Residential Demand Side Management Applications. In: Cuellar (Ed.): Smart Grid Security. Second International Workshop, SmartGridSec 2014, Munich, Germany, February 26, 2014. Revised Selected Papers. Springer.

Kasanen, P. (2000): Save II study, efficient domestic ovens, Final report, TTS Institute.

Kobus, Klaassen, Mugge, Schoormans (2015): A real-life assessment on the effect of smart appliances for shifting households' electricity demand. Applied Energy. 2015; 147:335-43.

KPMG. Power Sector Development in Europe – Lenders’ Perspectives 2011 - A survey of banks on the prospects for power infrastructure financing in Europe

Kutsch, Piorkowsky, Schätzke (1997): Einführung in die Haushaltswissenschaft. Haushaltsökonomie, Haushaltssoziologie, Haushaltstechnik. Stuttgart 1997.

Lefèvre, 2009: Ecodesign of Laundry Dryers, Preparatory studies for Ecodesign requirements of Energy-using-Products (EuP) – Lot 16.

Linear (local intelligent networks and energy active regions): www.linear-smartgrid.be

Mert et al. (2008): Consumer acceptance of smart appliances. D 5.5 of WP 5 report from Smart-A project. Available online: http://www.smart-a.org/WP5_5_Consumer_acceptance_18_12_08.pdf

Mert, Tritthart (2008): Get Smart! Consumer acceptance and restrictions of Smart Domestic Appliances in Sustainable Energy Systems. IFZ – Inter-university Research Centre for Technology, Work and Culture, Graz, Austria.

Mert, Watts, Tritthart (2009): Smart domestic appliances in sustainable energy systems—Consumer acceptance and restrictions. ECEEE 2009 Summer Study 2009. p. 1751–61.

Michel, Attali and Bush (2015): Energy efficiency of White Goods in Europe: monitoring the market with sales data. Changes and trends regarding energy efficiency, energy consumption, size and price in the markets of refrigerators, washing machines and tumble driers in the EU, France and Portugal, 2004 to 2014. Available online: http://www.topten.eu/uploads/File/WhiteGoods_in_Europe_June15.pdf.

Mikhailov , A. and Matthiesen, H. O.: System Efficiency for Natural Refrigerants, ASHRAE Journal, August 2013

Molina-Markham, Shenoy, Fu, Cecchet, Irwin (2010): Private Memoirs of a Smart Meter. BuildSys '10 Proceedings of the 2nd ACM Workshop on Embedded Sensing Systems for Energy-Efficiency in Building, pp. 61-66.

Mulder, Six, Claessens, Broes, Omar, Van Mierlo: The dimensioning of PV-battery systems depending on the incentive and selling price conditions. Applied Energy. April 2013.

NEA (2014): Developing an Extra Help Scheme for vulnerable smart meter customers. Available online: https://www.citizensadvice.org.uk/global/migrated_documents/corporate/smart-meter-extra-help-scheme-full-report-final1.pdf

NIST Special Publication 1108R2 (2012): NIST Framework and Roadmap for Smart Grid Interoperability Standards, Release 2.0. Available online: http://www.nist.gov/smartgrid/upload/NIST_Framework_Release_2-0_corr.pdf

Paetz, Becker, Fichtner, Schmeck (2011): Shifting Electricity Demand with Smart Home Technologies – an Experimental Study on User Acceptance. 30th USAEE North American Conference 2011.

Paetz, Duetschke, Fichtner, Wieschtel (2011): Tomorrow's households: How do consumers react to a smart-home environment? In: Bertoldi P, editor. Energy Efficiency in Domestic Appliances and Lighting. Copenhagen, Denmark 2011. p. 657-69.

Paetz, Duetschke, Fichtner (2012): Smart Homes as a Means to Sustainable Energy Consumption: A Study of Consumer Perceptions. *Journal of Consumer Policy*. 2012; 35:23-41.

Panasonic, IFA 2015.

PowerMatching City II project (2015): http://www.powermatchingcity.nl/data/docs/PowerMatching%20City_brochure_final_UK_29-04-2015_lowres.pdf

Preparatory Studies for Eco-design Requirements of EuPs. LOT 13: Domestic Refrigerators & Freezers. Final Report.

Preparatory Studies for Eco-design Requirements of EuP's, LOT 14: Domestic Washing Machines and Dishwashers, Task 3: Consumer Behaviour and Local Infrastructure.

Preparatory Studies for Eco-design Requirements of EuPs (III) Lot 23 Domestic and commercial hobs and grills, included when incorporated in cookers. Final report.

Preparatory Studies for Eco-design Requirements of EuPs (III) Lot 22 Domestic and commercial ovens (electric, gas, microwave), including when incorporated in cookers. Final report.

Preparatory Study on Eco-design of Water Heaters LOT 2. Final report.

Preparatory study on the environmental performance of residential room conditioning appliances (airco and ventilation). Study on residential ventilation - Final report.

RES-H Policy (2009): Policy development for improving RES-H/C penetration in European Member States.

Saele, Grande (2011): Demand Response From Household Customers: Experiences From a Pilot Study in Norway. *IEEE Transactions on Smart Grid*. 2011; 2:102-9.

Sasu Tarkoma, Matti Siekkinen, Eemil Lagerspetz, Yu Xiao, Aalto University, Finland. Smartphone Energy Consumption - Modeling and Optimization. August 2014.

Schmitz and Stamminger (2014): Usage behaviour and related energy consumption of European consumers for washing and drying. *Energy Efficiency*, 7, 937-954.

Siddiqui, Zeadally, Alcaraz, Galvao (2012): Smart Grid Privacy: Issues and Solutions. *Computer Communications and Networks (ICCCN)*, 2012.

Sidler et al. (1999): An experimental investigation of cooking, refrigeration and drying in 100 households. Programme SAVE, Project ECUEL.

Sidler, O (2009): ENERTECH. "Notes techniques: Connaissance et maîtrise des usages spécifiques de l'électricité dans le secteur résidentiel".

Stamminger R. (2009): Synergy potential of smart domestic appliances in renewable energy systems. Shaker Verlag, Aachen.

Stamminger, Anstett (2013): The Effect of Variable Electricity Tariffs in the Household on Usage of Household Appliances. *Scientific Research*, online Journal. 2013; 4:353-65.

S3C project: D1.1 FINAL WP 1: “Framing – Development of the theoretical framework”. Deliverable 1.1: “Report on state-of-the-art and theoretical framework for end-user behaviour and market roles”.

Task Force Smart Grids Expert Group 2 (2011): Essential Regulatory Requirements and Recommendations for Data Handling, Data Safety, and Consumer Protection. Recommendation to the European Commission.

Task Force Smart Grids Expert Group 2 (2011): Regulatory recommendations for data safety, data handling and data protection report.

Thiemann, Passenberg, Suer (2007): Preis, Verbrauch und Umwelt versus Komfort – der mündige Energieverbraucher.

Thomas S. (2007): Erhebung des Verbraucherverhaltens bei der Lagerung verderblicher Lebensmittel in Europa. Shaker Verlag, Aachen.

Topten.eu (2015): Energy efficiency of white goods in Europe: monitoring the market with sales data. Available online: http://www.topten.eu/uploads/File/WhiteGoods_in_Europe_June15.pdf (latest 10-03-2015).

Vanthournout, Dupont, Foubert, Stuckens, Claessens (2015): An automated residential demand response pilot experiment, based on day-ahead dynamic pricing. Applied Energy 155: 195-203.

VHK (2007): EcoBoiler Project. Eco-design Boilers, Executive Summary | 30 Sept. 2007 | VHK for European Commission.

VHK (2014): "Omnibus" Review Study on Cold Appliances, Washing Machines, Dishwashers, Washer-Driers, Lighting, Set-top Boxes and Pumps. Final report.

VHK (2014): ECODESIGN IMPACT ACCOUNTING Part 1 – Status Nov. 2013

VHK (2015): Ecodesign & Labelling Review Household Refrigeration. Preparatory/review study Commission Regulation (EC) No. 643/2009 and Commission (Delegated) Regulation (EU) 1060/2010. Interim report.

VITO. Preparatory Studies for Eco-design Requirements of EuPs. Final Report. Lot 9: Public street lighting. 2007.

VITO. Preparatory Study on Light Sources for Ecodesign and/or Energy Labelling Requirements ('Lot 8/9/19'). Draft Interim Report, Task 2 (revision 1).

Wilkenfeld (2011): Smart appliances for smart grids: flexibility in the face of uncertainty 2011.

Work on Preparatory Studies for Eco-Design Requirements of EuPs (II). Lot 17 Vacuum Cleaners. Final report.

www.buildingsdata.eu

www.changepartnership.org/wp-content/uploads/2014/10/Point-Carbon-2014-11042014-MSR-Point-Carbon.pdf

https://www.entsoe.eu/Documents/Publications/Market%20Committee%20publications/150127_WGAS_Survey_2014.pdf

www.entsoe.eu/Documents/Events/2014/141013_ENTSO-E_Update-on-IEM-related%20project%20work_final.pdf

www.episcope.eu

www.eu-ecogrid.net/

www.e3mlab.ntua.gr/e3mlab/index.php?option=com_content&view=category&id=35:primes&Itemid=80&layout=default&lang=en

www.foex.fi/index.php?page=pix-rcp

www.iea.org/etp/etpmodel/assumptions/

www.noaa.org

www.tennet.eu/nl/fileadmin/downloads/About_Tennet/Publications/Other_Publications/plugin-Market_information_IGCC_tcm43-20521.PDF

www.theice.com/market-data

Yan, Qian, Sharif, Tipper (2012): A Survey on Cyber Security for Smart Grid Communications. IEEE Communications surveys & Tutorials, 14, 4.