Preparatory study on Smart Appliances

Task 4 Technologies – Technical Analyses of Existing Products

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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
DHW	Domestic Hot Water
DOCSIS	Data Over Cable Service Interface Specification
DR	Demand response
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
LED	Light emitting diode
LFL	Linear fluorescent lamp
LTE	3GPP Long Term Evolution (4G)
M2M	Machine to Machine
NRVU	Non-Residential Ventilation Units
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

TASK 4: TECHNOLOGIES – TECHNICAL ANALYSIS OF EXISTING PRODUCTS

The objective of Task 4 is to perform a technical analysis of products that are currently placed on the European market and have the potential to be placed in future as part of a smart grid system. This approach is to some extent different from the "traditional" Ecodesign product analysis since smart, demand response-ready appliances (with Demand Side Flexibility, DSF) are only available in very limited scale and are still far from been taken up by the market to their full potential. Appliances marketed as “smart appliances” are typically networked appliances, which can connect to mobile devices (smart phones, tablets etc.) for achieving notifications and/or being managed by these devices. In reality, there are no smart appliances on the market living up to the full scope definition in this study. This fact naturally limits the extent of an analysis of “existing products” and it has also limited the data input from the manufacturers. The study team therefore had to base the analysis on products similar in technical capabilities and on estimations.

There is furthermore an important assumption to make regarding how many appliances already are network connected and are equipped with circuitry, chipsets, software etc. necessary for the DSF functionality and thereby in the most advantageous case only need software update for being DSF ready. For these cases, the impact regarding needed changes, energy consumption of the appliance itself, costs etc. may be very limited. Opposite, there will be larger impacts for appliances currently without network connection and other needed components. This is further detailed in Section 1.1. The analysis has to determine relevant technical parameters that have an influence on the environmental life cycle performance of the products and of the production costs and selling price. This may include energy and material related product specifications. The Task 4 report provides the main input data for the later assessment of design options (Task 6) and scenarios (Task 7). It means that this report does not estimate any impact on the rest of the energy system (production, transmission and distribution), neither does it make any projections or scenarios.

Note that the focus of the Task 4 report will not so much be the products themselves (for which assessments have been carried out in the respective vertical regulations) but that it will specifically address the implications that go along with the connectivity and DSF functionality.

Against this background, the study team will focus exclusively on the impact on energy consumption in the use phase of the appliances, because this is the most relevant phase for smart appliances. We will just include brief descriptions of the production, distribution and end-of-life phase. The analyses of energy consumption is only at the end user level, i.e. of the appliances and related products and systems in the use situation in homes and offices etc. and as mentioned above the energy impact at the power supply system is targeted in the Task 6 and 7 reports.

Finally, we focus on the additional components necessary to achieve the smart appliance functionality i.e. the Demand Side Flexibility. Some of the components may also provide other functionality than the demand response and some may be integrated in the product’s design.

The team based the work on the selected product group examples (see Section 1.4.3), which are also the focus in other task reports, mainly examples from the categories “high flexibility potential with few comfort and/or performance impacts” (dishwashers, washing machines, washer dryers, radiators, boilers, heat pumps, circulators, residential air conditioners and battery storage systems).

We briefly mention lighting and smart meters. Building automation systems, energy managers etc. are not in scope of the analysis (see Task 1 report).

1.1. TECHNOLOGIES FOR SMART APPLIANCES

Smart appliances will - in the context of this study - be Demand Response (DR) enabled devices for achieving Demand Side Flexibility, which can be controlled by signals from an aggregator or alike typically through an energy manager, which can be a physical device in the home, office etc. or a virtual energy manager in the cloud.

The appliances will be traditional household appliances, HVAC units etc., which have been modified and redesigned for DSF by adding the necessary components and functionalities included for maintaining quality, safety, user comforts, privacy etc.

Smart appliances will typically contain the following additional components and design modifications compared to a non-networked and non-smart appliance:

- Network connection (fixed and/or wireless connection) corresponding to the network protocol and network interface technology used.
- Other control systems needed to be built in to process and react on the DSF signals.
- Other components needed for the demand response ability e.g. energy storage (electricity, heat, cold), safety circuits, measurement circuits, sensors etc.
- Required modifications in the existing control system programming to take into account needed changes related to the DSF mechanism relevant for the appliance for altering the electricity consumption pattern. E.g. modulate the heating, pre-heat building components or energy storage, delay start of the next program step, set part of an appliance in an off-state etc.
- Additional power supply to handle the voltage and power requirements by the electronics in a waiting for signal mode in order to comply with the eco-design networked standby requirements (i.e. Commission Regulation (EC) No 1275/2008) and/or other regulative requirements.

There is only a limited amount of network connectivity within the appliance groups selected for study in this report. Some of them are called “smart” in the meaning of having the capability to be controlled over a network. These appliances will typically not need a further network connection, but can use the existing one. Typically there would be a need for other modifications to be DSF enabled.

1.2. PRODUCTION PHASE

In the majority of the cases, the appliances will only need very limited additions of electronic circuitry and other components. This is partly because in many cases the DR enabled appliances will already be network connected for communication with a smart phone or other devices. Partly because major changes of the product and addition of hardware would be too expensive compared to the economic benefits of the DR enabling.

Therefore, the impact of the add-ons to the products to provide connectivity and DSF functionality on resources and energy used for the production phase is assumed to be marginal and not further assessed.

1.3. DISTRIBUTION PHASE

The impact on the distribution phase is assumed to be marginal of the same reasons described under the production phase and the impact will not be further assessed.

1.4. USE PHASE (PRODUCT)

1.4.1. REGULATIONS ON ENERGY CONSUMPTION

DSF will typically have an impact on the energy consumption in two ways:

- Additional consumption in control electronics, both due to the added electronics and due to the longer on time for the electronics, which typically will be always connected to the network in order to react on control signals
- Additional consumption due to increased losses in energy storage systems in broad term e.g. pre-heating or pre-cooling of building elements, storage water tanks and battery storage.

Regarding the additional consumption in control electronics, there are EU regulation, which set consumption limits in some cases.

The most relevant is the amended standby regulation (Commission Regulation (EU) No 1275/2008), which includes limits for power consumption in network standby and power management to networked standby. For the relevant appliances (household appliances, IT equipment with exceptions, consumer equipment and toys, leisure and sports equipment), the limits in network standby for non-HiNA appliances without HiNA functionality are:

- From 1 January 2015: 6.00 W
- From 1 January 2017: 3.00 W
- From 1 January 2019: 2.00 W (subject to review)

The power management requirement in effect from 1 January 2015 requires the product to automatically switch into networked standby, when it is not providing a main function.

In addition to this horizontal requirement, there may be additional product specific requirements. E.g. for lighting there is a requirement for lamp control gear on 1.0 W reduced to 0.5 W in September 2016.

1.4.2. NETWORK CONNECTIONS APPLICABLE TO ALL SMART APPLIANCES

There are many kind of network technologies, both wired and wireless, which can be used for the smart appliances and more are coming to the market and the existing technologies are further developed to typcically higher speed and less power consumption. The trend is towards wireless technologies.

Examples of network technologies include:

- Bluetooth Classic and Bluetooth 4.0
- Wi-Fi
- ZigBee
- Z-Wave
- Ethernet, 10-1000 Mbps

Based on several sources, main network interfaces used currently excluding Wi-Fi would have a power consumption at dc level (see power supply losses below) of less than 0.5 W. A recent source, the EDNA report[1], states average power consumption of four Ethernet interface products to be 0.59 W (dc), where 2 of the products consume 0.43 W. These data confirm a BAT level of 0.5 W.

Regarding Wi-Fi, there are networked interfaces of less than 0.05 W, but also of several watts. The EDNA report states an average of three products to be 0.36 W, where the product with lowest consumption consumes 0.14 W.

There is ongoing work for developing a specification for low power Wi-Fi (IEEE 802.11ah) for sub 1 GHz frequency bands. Wi-Fi cards for several frequency bands (currently 2.4 GHz (most typical) and 5 GHz bands) typically have higher consumption levels, but mobile phones are examples of products with several radios (Wi-Fi 2.4 and 5 GHz, LTE, 2G, 3G, Bluetooth and NFC) and with low consumption levels.

The EDNA report reports ZigBee average consumption to be 0.13 W, where the product with lowest consumption consumes 0.09 W.

All in all and with the major developments of network interfaces for mobile devices, non-chargeable battery devices for Internet of Things and networked connected smart appliances, the expectation is that power consumption (dc) for network interfaces would be no below 0.6 W.

Price examples from Alibaba.com include:

- Wi-Fi module: 10$ (8.7€) (≥ 10 pieces)
- Zigbee wireless module: 3-4$ (2.6-3.5€) (≥ 10 pieces)

For product series with much larger numbers, the prices would naturally be much lower.

Power supply losses are typically larger at lower load points. If the active consumption of the product is more than 20 W, the load point would be at 10 % load or less, which may increase the losses. However, there are still much focus on reduction of power supply losses and also technologies on the market to obtain a more flat efficiency curve.

An alternative would be to have a dedicated auxiliary power supply for delivering low power for networked standby and standby/off designed for high efficiency at these power levels. An example of this is that an auxiliary power supply delivering 12 V, 3 A with 85 % efficiency and a price of 2-3$ (equivalent to 1.6-2.3€)[2].

Regulative activities include:

- A proposal on revised EPS regulation with the inclusion of a 10 % load point information requirement
- Code of Conduct on Energy Efficiency of External Power Supplies Version 5 setting requirements on 10 % load (e.g. 72 % efficiency at 10 W nominal power, 76 % at 20 W and 78 % at 30 W)

If the efficiency is 80-90 %, the loss would be maximum 0.2 - 0.4 W at 2 W consumption.

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[1] "Energy Efficiency of the Internet of Things. Technology and Energy Assessment Report. Prepared for IEA 4[E] EDNA". April 2016.

[2] http://waweis.en.alibaba.com/productgrouplist-801270815/Fashional_Laptop_Adapters.html

1.4.3. APPLIANCE EXAMPLES

In this section, we assses the selected product group examples, which are also the focus in other task reports.

Each product group is assessed through these steps:

- Description of the appliance type
- Network connection: Description of the network connection regarding type of network and network interface technology (related to the type of network).
- Additional components: Possible additional components needed such as storage (electricity, heat, cold), safety circuits (eg. washing machine lock during more extended periods), modulating circuits, measurement circuits, sensors etc.
- Appliance modifications: Other hardware or software changes needed
- Demand response mechanism: Description of the kind of DSF expected to be relevant for the appliance and how the electricity consumption pattern will be altered. E.g. modulate the heating, delay the start of the next program step etc.
- Cost impact: Additional cost, indicated quantitatively or qualitatively
- Energy impact: The relevant energy impact will be indicated in the form of power draw for the
- various components or totally

There are necessarily considerable uncertainties related to these assessments. Not only how the total impact will be, but also how much of this impact is due to being the DSF functionality in the definition of this study. E.g. how many additional energy consuming components and/or how much will the existing component increase their consumption in order to be DSF enabled or be active in periods, where the product else would be switched off. And would an appliance be network connected only to be demand response enabled or would it in any case be network connected e.g. for being able to send notifications to the users' smart phone.

The uncertainty also relates to the fact that there are very few demand response enabled products on the market and also only few networked products, which are not IT or consumer electronics.
The study team has tried to estimate how much of the energy and cost impact is related to demand response enabling and provided the assumptions in the text.

→ Periodical appliances (dishwashers, washing machines, tumble dryers, washer-dryers)

Description

<u>Description of dishwashers</u>
A dishwashing programme is formed by several steps. The number of steps as well as their duration and temperatures are dependent on the respective programme. The basic steps are: pre-rinsing, cleaning, intermediate rinsing and drying. At the beginning of the dishwashing process, water is led into the tube until reaching a predefined quantity or level. The water is maintained throughout the individual steps of the cleaning process.

Depending on the programme selected by the consumer, the water is heated by a resistant heating system (rated power between 1,800 and 2,500 W) to a certain temperature (mainly 50/55°C, 60/65°C or 70/75°C). The cleaning process is continued for a defined period of time (programme-dependent).

The cleaning step is followed by one or more intermediate rinsing steps applying cold water. In a final rinsing step, the water and the load items are heated up again to a predefined temperature normally exceeding the temperature in the cleaning phase. The heat is used in the drying process to evaporate the water film from the surface of the dishes. At the end of the programme, the water is pumped to the water outlet by using a drainage pump.

Electrical energy is mainly needed for heating up the water (and indirectly the load items and the interior of the machine) to the desired temperature. About 25 to 50 % of the total water consumed in the dishwashing process is heated up. The remaining 50 to 75 % of the water is used as cold water in the pre-wash and the intermediate rinsing phase.

Besides the heating energy, additional energy is needed to operate circulation and drainage pumps, as well as displays and user interfaces. The rated power input of water circulation pumps is about 15-30 W. (JRC, 2015[3])

After the end of the programme, a small amount of energy may be needed to keep some safety functions alive (e.g. water protection sensor systems or remote control systems). (Stamminger et al., 2009[4]).

Description of washing machines

A washing programme is formed by several steps. The number of steps as well as their duration and temperatures are dependent on the respective programme. The basic steps are: main wash, several rinsing cycles and spinning cycle. A pre-wash step is optional. Depending on the programme chosen, the water is heated to a certain temperature (mainly 20, 30, 40, 60 and 95 °C) by using a resistant heating system (power rating between 1,800 and 2,500 W).

The heating process may be shortly interrupted for equalizing the temperature of water and load. The water is recirculated throughout the main wash cycle. The cleaning process is continued for a defined period of time (programme-dependent). The cleaning step is followed by several rinsing steps. The motor-driven drum is rotating in a reversing way at a certain speed during both, the main wash and the rinsing phases. After the main wash phase and between the rinsing phases, the drum rotates at a higher speed in order to remove water and soapsuds from the laundry. The highest rotation speed (programme-dependent) is reached in the final spinning phase. This is to extract as much water as possible from the load. At the end of the programme, the water is pumped to the water outlet by using a drainage pump.

Electrical energy is mainly needed for heating up the water (and indirectly the load items and the interior of the machine) to the desired temperature. About ¼ to ⅓ of the total water consumed in the washing process is heated up. The remaining water is used as cold water in the rinsing phase. Besides the heating energy, additional energy is needed to operate circulation and drainage pumps, the drum motor as well as displays/ user interfaces. During spin-drying, motors of washing machines 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, 2015[5])

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[3] 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

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

[5] 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

After the end of the programme, a small amount of energy may be needed to keep some safety functions alive (e.g. water protection sensor systems or remote control systems). (Stamminger et al., 2009[6]).

Description of tumble dryers

During the drying process, hot air is circulated through the drum while the drum is rotated driven by a motor. The hot air causes the moisture from the laundry to evaporate and thus dries the laundry. The hot air can either be generated by an electrical heating system (rated power between 2,000 and 2,500 W) or by a gas-fired heater (low acceptance in Europe).

After taking up the moisture from the laundry, the resulting humid air can be either vented via an air duct to the outside of the house (vented dryer) or the water vapour may be condensed by cooling the air using a heat exchanger (condenser dryer). In the latter case, the condensing water is collected inside a tank or drained via a pipe. Alternatively, it is possible to regain the energy contained in the humid air by using a heat pump (heat pump dryer). While passing the heat pump, the water vapour condenses and the thermal energy is extracted and reused afterwards to heat up dry air going into the drum. In this way, energy savings of about 40 to 50% of the total energy consumption are possible. Heat pump dryers become more and more important in the European market.

The drying process can either be controlled by a sensor which detects the remaining moisture of the load finishes the drying process if a specific humidity is reached or by a timer function.

Electrical energy is mainly needed for heating up the air (and indirectly the load items and the interior of the machine) to a programme-specific temperature. Besides the heating energy, additional energy is needed to operate the drum motor, fans, the heat pump (in the case of heat pump dryers) as well as displays and user interfaces.

Description of washer-dryers

Washer-dryers are a combination of a washing machine and a tumble dryer in the same cabinet. The washing and the drying process are performed consecutively as described before.

Electrical energy is mainly needed to heat water and the load items during the washing process and to generate hot air for drying. Besides the heating energy, additional energy is necessary to operate the drum motor, pumps, fans and displays/ user interfaces. After the end of the programme, a small amount of energy maybe needed to keep some safety functions alive (e.g. water protection sensor systems or remote control systems).

Network connection

Models equipped with Wi-Fi (or other network connectivity), other type of gateway connection or frequency sensing are already available from a few manufactures in the European market, but the market penetration so far is believed to be marginal. Functionality includes notification of the progress of washing etc. and start of machines remotely.

To make a an appliance connected, there is, as fas as can be concluded for the moment, a need for a connectivity module (antenna, wireless electronics and interface), which connects to the existing device electronics[5].

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

Additional components

Machines already being network connected and with sufficient computational power may have all the components needed for the DSF functionality. If not, there would be a need for computational power, printed circuit board and wires[7].

Appliance modifications

Enabling periodical appliances for DSF functionality requires new control software.

The software establishes the communication with the energy manager and receives the controls signals from the supply side. It controls the machine regarding start and stop and altered electricity consumption pattern, see next section.

Demand response mechanism

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

1. Remote or signal activation: The user selected programme is remotely activated before the user deadline is reached. E.g. the user fills the washing machine with clothes in the evening and select 07:00 in the morning the day after as the deadline for having the clothes washed.

2. Altered electricity consumption pattern: While the appliance is activated, the consumption patterns changed through pausing the operation, changing the temperatures, changing heating power, changing spinning speed (in the case of washing machines and washer dryers) etc.

In the first case, the machines are remotely started, e.g., when a surplus of (renewable) energy is available on the grid. 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 second case, machines may change their operation after it has been started via the remote signal, e.g. if there is a shortage of energy available on the grid. Periodical appliances may react to the signal by the control software to reduce the power load and still finish the work witin a pre-defined deadline. Possible operation cycle changes include short-term interruptions, changes in temperatures or shifts of single programme phases (e.g. cleaning or final rinsing phase and spinning). This may change the power demand curve of a single appliance and the overall duration of a cycle.

Cost impact

If the machine already is network connected and has a sufficient control circuitry, the main cost will be for the software development, testing and documentation. This again depends on the amounts of products in the series of machines. If the machine is not network connected, there is a need for a wireless connectivity module.
CECED has provided the following information on costs[5] *(non exhaustive bill of materials):*

- *Wireless electronics (consumer electronics examples)*
  - *Asus Google Nexus Player & Gamepad TV500I-0009 SI38244-SBd (Wi-Fi; Bluetooth; FM Radio – Flip Chip, solder): 8.10$*
  - *Apple I Pad Air 2 (802.11 ac dual-antenna MIMO + BT 4.0 – Based on Broadcom BCM 4345 Chip): 4.50$*
- *Computational power*
  E.g.: Raspberry Pi Zero: 5€

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[7] See also: CECED contribution to Ecodesign prep study on SA. Cost impact of connectivity". 15/01/2016.

Moreover, additional costs are due for the following components:

- *On board or external antenna*
- *Printed Circuit Board*
- *Wires*

In addition, CECED informs that costs for the bill of material would need to be multiplied by an "industrialisation factor" that would reflect manpower (production), adaptation of the appliance/platform functionalities and higher safety and quality requirements. Furthermore, the organisation states that there are other costs related to product adaptation to connectivity, which is certification process for materials related to connectivity and licensing costs related to the use of connectivity technology such as Wi-Fi.

Based on information from industry experts and the above information, the study team has estimated the following cost levels:

- A networked appliance only needing software modifications, testing, documentation etc.: 5-10€
- A non-networked appliance also needing a network connectivity module etc.: 15-20€

These are costs at the manufacturing level including testing and documentation, but without mark up for the distribution and retail level. Note that a pre-condition for these estimates is that modifications concern larger product series thus represent a situation after redesign and optimisation in the context of a future smart grid market.

Energy impact

For the additional energy consumption of the network connection, see the previous section on network connections. If the starting point is a networked appliance, the energy consumption of network connection should not be allocated the DSF.

In the case of remote activation, the machine may consume additional standby energy for safety functions (such as door lock) and a higher activity level for the electronics, while waiting for a start signal. For washing machines, the study team has been informed about power levels of about 5-10 W (e.g. the door lock consumed 5 W), however, the source also informed that new products are under development with much lower power consumption.

Regarding altered electricity consumption pattern, the energy consumption may be influenced in different ways. 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)[4] recommend interruptions not exceeding a time of 10 minutes (5 minutes in rinsing phase of dishwashers) in order to avoid significant losses in heat energy. If the temperature of single programme steps or the whole process is lowered, the total energy consumption may be reduced corresponding to the temperature reduction. If single programme phases are postponed, the total operation time (e.g. operation time of the circulation pump) is prolonged, which entails a slight increase in total power consumption.

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, which causes additional energy consumption.

Regarding tumble dryers, some kind of drum rotation or pre-drying is recommended for the time waiting for the start of the process to avoid the wet laundry of getting mouldy and wrinkled.

→ Radiators

Description

The operating principle of electric radiators consists in heating indoor air using an electric resistance through convection and sometimes both convection and radiation. Cooler indoor air will enter through the lower part of the convector and heated air will exit by the upper part. Some convectors are equipped with radiating surfaces (mainly conceived using aluminum) that are able to transfer 40 % of the total heat in form of irradiative power. The only controlled variable that modulates electric radiators is the indoor temperature, using an electronic thermostat (PI or PID). Most common installed electric radiators have a total installed power between 750 W and 2000 W and their operating mode is only on/off, controlled by an established set point. (Da Silva 2011)[8], (Bézian et al. 1997)[9].

Network connection

Network connection to external devices can be via cable or Wi-Fi (Da Silva 2011). Wireless signal may include Wi-Fi, Bluetooth, Zigbee, Z-Wave etc.

Additional components

No extra components needed for demand response enabling for electric radiators, if it already has an electronic thermostat that can switch off/on the appliance given an external signal.

Appliance modifications

Only software adaptability must be done, in order to allow an external signal from a grid operator to control the equipment. Software changes may refer to adapting the appliance to respond to different external signals (room temperature, energy pricing, external orders from the grid).

If the radiator does not have a communicating electronic thermostat, there is also a need to change the hardware.

Demand response mechanism

Different studies have taken place in France regarding the different signals and curtailment programs used to control electric radiators. The external signals are: On/off signal, mode-eco signal (lowering the set point e.g. 2°C under the regular set point), pre-heating (heating off peak periods prior to curtailment). For each kind of curtailment method an important factor is the ratio of the curtailed energy and the energy consumption after the curtailment. It is important to point that the results (occupants comfort, the ratio of energy saved and after-consumption) of the previously presented curtailment mechanisms are highly dependent on the building's thermal properties. Compared to the electric thermal storage heaters (see next section), the radiators store heat in the building components.

Cost impact

One source[10] reports that the total installation cost of a DR mechanism per home i.e. including the central energy manager and the connections to the radiators is approximately between 35€ and 85€

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[8] David Da Silva. Analyse de la flexibilité des usages électriques résidentiels : applications aux usages thermiques. ElectriC power. Ecole Nationale Supérieure des Mines de Paris, 2011. French. NNT : 2011ENMP0070

[9] Bézian, Jean-Jacques ; Barles, Pierre ; Claude François & Inard Christian. 1997. Les émetteurs de chaleur. Presses de l'école des Mines.

[10] Réseau de transport électricite (2015): Valorisation socio économique des réseaux électriques intélligents. (French)

(including extra material, technical intervention and internet or telecom installations). However, this intervention does not allow feedback from the demand side, it operates only in "slave mode" which means that the range could be an underestimation. On the other hand, not all the costs can be attributed only to the smart functionalities of the appliance.

For the purpose of this study, the study team has estimated the costs for the individual radiator at[11]:

- A networked radiator only needing software modifications, testing, documentation etc.: 5-10€
- A non-networked appliance also needing a network connectivity module etc.: 10-15€

Energy impact

Energy impact will be in the form of energy consumption of the network connection, if the demand response will be done over a network system that requires extra communicating technology.

In addition, if there is a need to pre-heat to a higher temperature than normal, there would be an additional heat loss from the building.

→ Electric thermal storage heaters

Description

These systems are capable to store heat in the radiators, when energy prices are low (actually off-peak hours during the night) due to the fact that they have a core made of refractive bricks, granite, aluminum or ceramic material. These systems are normally controlled with a variable speed ventilator that modulates the quantity of air that will pass through the radiator. The controlled variable that modulates electric thermal storage heaters is indoor temperature, using an electronic thermostat (PI or PID) and another thermostat that indicates when the "heat" charging takes place. Most common installed electric radiators have a total installed power between 500 W and 2000 W and their operating mode is only on/off, controlled by an established set point. (Da Silva, 2011).

Network connection

These equipments can be either controlled by their internal control or an external control. Communicating to external devices can be via cable or wireless connection such as Wi-Fi.

Additional components

No extra components needed to optimize the curtailment of electric thermal storage heaters, if the appliance already has an electronic thermostat that can switch off/on the appliance given an external signal.

Appliance modifications

Only software adaptability must be done, in order to allow an external signal from a grid operator to control the equipment. Software changes may refer to adapting the appliance to respond to different external signals (room temperature, energy pricing, external orders from the grid).

If the radiator does not have a communicating electronic thermostat, there is also a need to change the hardware.

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[11] These are costs at the manufacturing level including testing and documentation, but without mark up for the distribution and retail level. Note that a pre-condition for these estimates is that modifications concern larger product series thus represent a situation after redesign and optimisation in the context of a future smart grid market.

Demand response mechanisms

The thermal storage of these radiators allows them to have certain flexibility when it comes to require electricity to charge the core. Normally, they are conceived to charge, when energy prices are low.

Cost impact

One source[12] reports that the total installation cost of a DR mechanism per home i.e. including the central energy manager and the connections to the radiators is approximately between 35€ and 85€ (including extra material, technical intervention and internet or telecom installations). However, this intervention does not allow feedback from the demand side, it operates only in "slave mode" which means that the range could be an underestimation. On the other hand, not all the costs can be attributed only to the smart functionalities of the appliance.

For the purpose of this study, the study team has estimated the costs for the individual radiator at[13]:

- A networked radiator only needing software modifications, testing, documentation etc.: 5-10€
- A non-networked appliance also needing a network connectivity module etc.: 10-15€

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Energy impact

Energy impact will be in the form of energy consumption of the network connection, if the demand response will be done over a neetwork system that requires extra communicating technology. In addition, there will be a heat loss from the thermal storage.

→ Electric Boilers

Description

A boiler is a vessel or a closed reservoir where water or another fluid heats using an energy source, where the fluid is circulated in the building, where it gives off the heat to heat the room. Energy sources can be electricity resistances, gas or fuel; however in this study only electric boilers are considered. Electric boilers are similar to hot water electric storages for which the electric element is larger in order to be able to supply the heating needs of a dwelling. Normally, the main controlled variable is the boiler's exiting water temperature, adjusting it to modulate the charge of the boiler.

Network connection

Connecting to the network will be done via a smart thermostat that will communicate the exiting water temperature, therefore controlling the boiler. If there is a smart thermostat, the network connection usually takes places over Wi-Fi (or other wireless technologies) or an Ethernet connection.

Additional components

A storage tank can be installed to allow energy curtailment. The boiler will run in off-peak periods and the stored water can be distributed in the dwelling. If the boiler already has an electronic thermostat that allows communication and external control, no extra pieces or hardware is required.

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[12] Réseau de transport électricite (2015): Valorisation socio économique des réseaux électriques intélligents. (French)

[13] These are costs at the manufacturing level including testing and documentation, but without mark up for the distribution and retail level. Note that a pre-condition for these estimates is that modifications concern larger product series thus represent a situation after redesign and optimisation in the context of a future smart grid market.

Another way to enable communication is with an adaptor between the boiler and the energy manager / network, capable of sending and receiving signals.

Appliance modifications

Software modifications must be done in order to allow an external signal from a grid operator to control the equipment.

If the boiler does not have a communicating electronic thermostat, there is also a need to change the hardware.

Demand response mechanism

Start and stop of the boiler can done with flexibility depending of the heat capacity of the building and on the size of a possible storage tank.

Cost impact

One source[14] reports that the total installation cost of a DR mechanism per home i.e. including the central energy manager and the connections to the boiler and the radiators is approximately between 35€ and 85€ (including extra material, technical intervention and internet or telecom installations). However, this intervention does not allow feedback from the demand side, it operates only in "slave mode" which means that the range could be an underestimation. On the other hand, not all the costs can be attributed only to the smart functionalities of the boilers and radiators.

For the purpose of this study, the study team has estimated the costs for the individual boiler at[15]:

- A networked boiler only needing software modifications, testing, documentation etc.: 5-10€
- A non-networked boiler also needing a network connectivity module etc.: 10-15€

Energy impact

Energy impact will be in the form of energy consumption of the communicating device, if the demand response will be done over a wireless system that requires extra communicating technology.

In addition, when the water in the storage tank is pre-heated there are additional thermal losses to be considered.

→ Heat pumps

Description

A heat pump is an electrical device that extracts heat from one place and transfers it to another, by circulating a refrigerant through a cycle of evaporation and condensation. The most common type of heat pump is the air-source heat pump, which transfers heat from the outside air and the dwelling . If you heat with electricity, a heat pump can reduce the amount of electricity you use for heating by as much as 30% to 40%.

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[14] Réseau de transport électricite (2015): Valorisation socio économique des réseaux électriques intélligents. (French)

[15] These are costs at the manufacturing level including testing and documentation, but without mark up for the distribution and retail level. Note that a pre-condition for these estimates is that modifications concern larger product series thus represent a situation after redesign and optimisation in the context of a future smart grid market.

Other type of heat pumps include geothermal pumps and water-air heat pumps. Controlled variables of a heat pump system are: indoor temperature (set point) and speed of the compressor (modulating load).

Network connection

These equipments can be either controlled by their internal control or an external control. Communicating to external devices (i.e. smart grids) can be via cable or wireless connection such as Wi-Fi.

Additional components

No extra components needed to optimize the curtailment of heat pumps. Some heat pumps are used as well to supply hot water, and therefore there is a storage tank, which might be and extra part enabling more flexibility to the system as a whole (heating + domestic hot water).

Appliance modifications

Most heat pumps already have a thermostat that allows communication and external control so, no extra pieces or hardware is required. Only software adaptability must be done, in order to allow an external signal from a grid operator to control the equipment. According to some experts (heat pump manufacturer), several studies must be done to develop part load control via intelligent thermostats and improve heat pumps performance (nowadays, the main control is a communicative thermostat that sends on/off signals). Another way to enable communication is with an adaptor between the heat pump and the energy manager / network, capable of sending and receiving signals.

Demand response mechanism

The mechanism is very similar to the other heating technologies such as boilers. I.e. start and stop of the heat pump can done with flexibility depending of the heat capacity of the building and on the size of a possible storage tank.

In addition, the intelligent thermostat in order to avoid performance degradation, needs to be capable of not only sending on/off signals, but to work on part load (reducing the speed of the compressor by 20% i.e). This connectivity could be done through the smart thermostat or via an adaptor between the appliance and the external party.

Cost impact

One source[16] reports that) the total installation cost of a DR mechanism per home i.e. including the central energy manager and the connections to the radiators is approximately between 35€ and 85€ (including extra material, technical intervention and internet or telecom installations). However, this intervention does not allow feedback from the demand side, it operates only in “slave mode” which means that the range could be an underestimation. On the other hand, not all the costs can be attributed only to the smart functionalities of the appliance.

According to one manufacturer, enabling demand response to a heating device using a vapor-compression cycle would raise the retail price approximately 100€ to 200€ (software adaptability and development, installation costs, intervention etc.).

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[16] Réseau de transport électricite (2015): Valorisation socio économique des réseaux électriques intélligents. (French)

The 100-200€ range should be considered as the high end of the range of additional costs. These costs are assessed to include research & developement costs and costs associated with the first appliances being produced in small series in a short term perspective. The material costs in the 100-200€ range are estimated to apply to brand materials before complete redesign and optimization in the longer term. As an illustration, there are different types of adaptors in the market (connectivity via WLAN, Wireless, KNX Bus) that have the same function of establishing a communication pathway between the appliance and the third party control. Most air conditioners and heat pumps already have an integrated port capable of receiving signals (from the remote control for example), which in this case the only additional price should be the adaptor. Prices for the cheapest available adaptors and electronic thermostat are listed in the table below.

Table 2. Prices for additional components to enable demand side flexibility

Component	Function	Produced by / reference	Model	Unit retail price
Adaptor	RS485 Modbus	RealTime / Alibaba	RTD-RA	10 €
Electronic Thermostat	Receive external signals	Kampa / Alibaba	BC109	2 €

Energy impact

Energy impact will be in the form of energy consumption of the communicating device, if the demand response will be done over a wireless system that requires extra communicating technology.

In addition, if there is a storage tank and/or a need to pre-heat to a higher temperature than normal, there would be an additional heat loss.

→ Circulators

Description

Boiler circulating takes suction from a header that is connected to several downcomers from the bottom of the boiler drum and discharge through additional tube circuits. Boiler circulating pumps must develop only enough head to overcome the friction of the tube circuits. The controlled variable corresponds to the water temperature, that will indicate to stop or run the circulator pump. New, efficient models will include variable speed pumps in order to modulate the consumption according to the demanded heat.

Network connection

In new boilers, where the circulating pumps are controlled by the boiler's integrated system, the connection to the network follows the same logic as for radiators, boilers, heat pumps, which is via the electronic thermostat. This thermostat will regulate the boiler circulator according to the heat demand. The connection to the network will be via the electronic thermostat over the ethernet or wireless technologies (Wi-Fi, Zigbee, Bluetooth etc.). For already installed boilers whose circulators pumps are independent from the measured temperature, their control relies on the on/off of the pump. These pumps normally run all heating season.

Additional components

No additional components are needed to enable demand response to circulator pumps. The pumps will be turned on and off depending on the boiler's command.

Appliance modifications

To enable demand response in circulator pumps, they need to be connected to the boiler's control system, whch in all of the cases is done over an electronic thermostat. This thermostat, depending on the heating demand, will send a signal to the circulator pumps (on/off signal, or a variable speed drive pump).

Demand response mechanism

The mechanism is very similar to the other heating technologies such as boilers. I.e. start and stop or modulating the speed of the circulator can done with flexibility depending of the heat capacity of the building.

Cost impact

There is no available information regarding the costs of enabling demand response in circulators, but the cost impact is assumed to be similar to the other heating system components[17]:

- A networked circulator only needing software modifications, testing, documentation etc.: 5-10€
- A non-networked circulator also needing a network connectivity module etc.: 10-15€

Energy impact

Energy impact will be in the form of energy consumption of the communicating device, if the demand response will be done over a wireless system that requires extra communicating technology. Additional, there will be larger heat losses of the building if more heat is stored in the building components.

→ Residential air conditioners (< 12 kW)

The air conditioners consist of a thermodynamic refrigerating system to transfer heat from two different sources (indoor air and outdoor air). It is based on the same principle of a heat pump, with the condenser and evaporator having different roles to transfer heat in either direction. Air conditioners are used as a source of ventilation and dehumidification during summer periods. Mainly residential units are either split systems or centralized units. Controlled variables are indoor temperature via a thermostat and sometimes compressor speed.

Network connection

Most air conditioners have a control unit capable of receiving external signal from a centralized controller or a remote control. Connectivity can be easily incorporated, via Ethernet or wireless technologies (Wi-Fi, Zigbee, Bluetooth).

Additional components

No extra components needed to optimize the curtailment of air conditioners if a communicating thermostat already exists. Another way should be an adaptor between the air conditioner and the energy manager / network, capable of sending and receiving signals.

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[17] These are costs at the manufacturing level including testing and documentation, but without mark up for the distribution and retail level. Note that a pre-condition for these estimates is that modifications concern larger product series thus represent a situation after redesign and optimisation in the context of a future smart grid market.

Appliance modifications
Most air conditioners already have a thermostat that allows communication and external control, no extra pieces or hardware is required if the thermostat can comunicate. In this case, only software adaptability must be done, in order to allow an external signal from a grid operator to control the equipment. Another possibility is to enable communication is with an adaptor between the air conditioner and the energy manager / network, capable of sending and receiving signals (via WLAN, Zigbee, KNXBus, Wifi).

Demand response mechanism
Two different mechanisms are described in Air conditioning Australian AS 4755, on/off of the air conditioners and modulating the charge of the air conditioner (25%, 50%, and 75%). However, this intervention does not allow feed back from the demand side, it operates only in “slave mode”.

Cost impact
Two sources are studied: AS 4755 states that two different cost scenarios are possible. If the air conditioner already has an enabled DR interface, only 185$ are need to enable the DR program (contact the client, visit customer site and connect the air conditioner to the grid). In the air conditioner does not comply with a DR interface, the whole installation cost rises up to 300$. However, these costs include much more than the technology changes in the air conditioners and cannot be used for the purpose of the current study.

According to another manufacturer, enabling demand-response would rise the retail price of the air conditioner by 100€ to 200€ (software adaptability and development, installation costs, intervention etc.).

The 100-200€ range should be considered as the high end of the range of additional costs. These costs are assessed to include research & developement costs and costs associated with the first appliances being produced in small series in a short term perspective. The material costs in the 100-200€ range are estimated to apply to brand materials before complete redesign and optimization in the longer term. As an illustration, there are different types of adaptors in the market (connectivity via WLAN, Wireless, KNX Bus) that have the same function of establishing a communication pathway between the appliance and the third party control. Most air conditioners and heat pumps already have an integrated port capable of receiving signals (from the remote control for example), which in this case the only additional price should be the adaptor. Prices for the cheapest available adaptor and electronic thermostat are listed below:

Table 3. Prices for additional components to enable demand side flexibility

Component	Function	Produced by / reference	Model	Unit retail price
Adaptor	RS485 Modbus	RealTime / Alibaba	RTD-RA	10 €
Electronic Thermostat	Receive external signals	Kampa / Alibaba	BC109	2 €

Energy impact
Energy impact will be in the form of energy consumption of the communicating device, if the demand response will be done over a wireless system that requires extra communicating technology.

In addition, if there is a need to pre-cool to a lower temperature than normal, there would be an additional cool losses from the building.

→ Ventilation

Description

Ventilation includes energy using products whose main function is to renew the air of occupied buildings. In the residential sector, local and central extraction fans and local and central heat recovery ventilation units are used. Two different types of ventilation are used: simple mechanical ventilation, and double flow ventilation, being the main difference between these two the possibility to recover heat from the extracted air. Two types of controlled are used: hygrometric control and auto-regulated. The controlled variables are: internal air humidity.

Network connection, additional components and appliance modification

Given that most of the mechanical ventilation units do only have an on/off switch, the connectivity to the network must be done via a hardware installation. New circuits that can receive signal from the aggregator/utility and can turn on/off the ventilation, must be installed.

Demand response mechanisms

Mechanical ventilation units do not consume too much energy, compared to other HVAC equipments. The interest in enabling demand response on ventilation is to reduce the thermal gains (or losses) that would raise the heating/cooling needs.

Cost impact

There is no available information regarding cost impact, but it is assumed to be in the same size as the heating system components described in the previous sections

Energy impact

Energy impact will be in the form of energy consumption of the communicating device, if the demand response will be done over a wireless system that requires extra communicating technology.

→ Residential energy storage system

Description

The battery storage systems in scope of the study, are residential energy storage systems, which stores electric energy in batteries. Products on the market are currently mainly used to store excess electricity for house PV systems (photovoltaics). Many storage systems can also get their energy from small wind turbines, cogeneration units or directly from the grid. This new market did not find already a clear appliance identifier. The following terms are used, amongst others:

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

A separated market exists for storage units that are uniquely dedicated to back-up power. These are out of the scope, as determined in Task 3 report.

Residential energy storage systems consist of a diverse family of devices. Since it is a new category of appliances on the market, they are not well known currently for their possibilities. A difference with most appliances is that they cannot be installed everywhere in Europe without a national approval: all electricity sources, have to be approved for each European country according to the rules of the local electricity grid operators.

Storage batteries for home use increase drastically the self-consumption of generated electricity by PV systems and other local sources. This can be interpreted as a demand side response, although strictly speaking demand response concerns the end-user, what storage is not, except its own consumption due to conversion and standby losses. The current systems can have more features than other types of smart appliances. Storage batteries with included control systems can furthermore be seen as smart appliances, because they can alleviate the distribution grid by peak-shaving the power to the grid without curtailing the electricity source like a PV installation or small wind turbine. Another feature and focus of the current study is that several storage system providers aggregate all their storage appliances to supply ancillary grid services, recently indicated as ‘swarm power’.

Many home storage systems have implemented load management functionality to switch devices like washing machines and heat pumps in order to maximise the direct self-consumption of the residential electricity source, like a PV installation. This makes part of the energy management system that is built into the storage device.

Concerns
Several technical issues have to be noticed regarding capacity, efficiency, partial load use, standby losses and also their place in a dwelling.

The battery capacity is not necessarily the useful capacity. The latter depends on the allowed depth of discharge. A 10 kWh home battery that allows 80% discharge, results into a storage of 8 kWh effectively. It is the latter value that really counts.

The inverter, charger and battery have each an efficiency. The combined efficiency has to be taken to assess the energy loss. The manufacturers give values between 75 and 97 %. Values over 90 % seem unrealistic since batteries alone have roughly 90% efficiency (both for Li-ion and valve regulated lead-acid batteries (VRLA) according to representative test cycles in the battery laboratory of VITO. The charger and inverter efficiency have to be subtracted. Unfortunately, no public standard exists to determine the efficiency of a home battery. This lack makes the efficiency statements questionable. The chain efficiency for over 40 brands is given in an overview[18]. An average of 88±5% can be deduced.

The devices also have a stand-by consumption due to the controllers, power electronics and internet connection. The source in footnote **Error! Bookmark not defined.** gives a large spread in standby losses: from 5 to 80 W. The average is 30 ±20 W. This means that storage systems can have a high impact on a dwelling’s energy consumption. This will be treated under ‘energy impacts’.

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[18] PV Magazine. Storage Special. Available < http://www.pv-magazine.com/fileadmin/PDFs/pv-magazine_Storage_Special_Jul_2015.pdf >. [Accessed 15.10.15]

Home batteries cannot be connected to the domestic at an arbitrary place. At least in Germany they should be connected to the distribution box in the dwelling[19].

Network connection
The residential energy storage system all seem to have at least one internet connection. This is used for the owners, so that they can follow up the operation and impact of the storage device on the electricity use.

Many systems are able to implement energy management to maximise the use of solar power or other renewable power by enabling load management. The load actions can be achieved by digital outputs on the inverter, by special AC connections on the inverter, by controllable wall plugs or with help of a communication protocol technologies and protocols between the smart appliances. The energy management system has to perform conversion of protocols and mappings into neutral data models.

The home batteries seem well equipped to act as a smart, communicating appliance.

Additional components
The need for additional components depends on the level of smartness that is anticipated. All home batteries can discharge towards the grid. If the storage should also be able to absorb excess electric energy from the grid, then an AC connection to the battery is needed. From Figure 1 this appears valid for 2/3 of the available systems. The ones that have a DC connection would need a software update to allow bi-directional operation of the inverter.

Appliance modifications
Storage batteries for home use have the possibility to go further in grid services than other smart appliances are able. Below an overview of the possible services can be found, apart from demand side management[20]:
Currently deployed practices:

- peak-shaving at generation side: less PV towards grid (mandatory for the German subsidy system).
- mandatory primary frequency support during exceptional deviations (> 50.2 Hz).
- real-time primary frequency support when activated anteriori by the aggregator.
- aggregated secondary frequency down-regulation support (charging the battery).

Future possibilities:

- peak shaving at consumption side: draw less power from grid;
- reactive power correction (cosine phi correction);
- balancing between the three electric phases: possible when using three separate single phase inverters;
- real-time voltage droop control.

Delivering the currently deployed and future services requires new control software to be integrated in the existing software of the dc-dc converters and inverters. The basic software to allow current injection in the grid and to maintain the voltage and frequency in island-grids is already available.

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[19] Forum Netztechnik/ Netzbetrieb im VDE. ‚FNN-Hinweis Anschluss und Betrieb von Speichern am Niederspannungsnetz‘, Berlin, Juni 2014,

[20] F. Geth, e.a., „Multi-objective battery storage to improve PV integration in residential distribution grids,” *IEEE Trans Sust Energy ,* vol. 4, 2013.

However, some additional software will be required to implement the functions above which can be divided in three categories:

- Energy management software: This software is installed at the highest level within the residential energy system. The software determines the power set-point of the battery, with the purpose to e.g. maximize self-consumption, provide primary frequency reserve, etc. or a combination of these services. The energy management software can be a very basic system which only takes rudimentary PV predictions into account and only controls the PV module and the battery. However, the software can also consist of a much more elaborate system: to predict the PV generation, it can take into account local weather predictions, measured temperature etc. It can employ distributed measurements and self-learning algorithms to estimate the current consumption, the flexibility and near-term power requirements of the household. The software does not have to be limited to the PV and battery system, but can also control white goods, heat pumps and electric vehicle charging. As such, the energy management software does not have to be deployed within the PV-battery system. It can be an integral part of the PV-battery system, but it might as well be a separate system that controls not only the PV-battery system but also appliances such as white goods, heat pump etc. It is important to notice that the energy management software can also receive set-points from a third party, such as an aggregator to adjust the households power set-point.
- Grid interaction software: This software is implemented in the control of e.g. the inverter itself and thus resides at a lower level than the energy management software. Examples are real-time voltage and primary frequency droop control, where the measurements of the inverter are used to adjust the power set-point in support of the grid. Another example is the reactive power control where reactive power can be injected into the grid when the inverter notices grid voltage deviations. A third example is the redistribution of currents if the system uses 3 single-phase inverters, such that the current balance is restored. This software needs to be implemented on the inverter which connects PV and battery to the grid.
- Due to the nature of the software development process and the difference in the complexity (e.g. PV prediction, demand response management and self-learning consumption algorithms) and extensiveness (including PV modules, stationary battery, white goods, heat pumps, electric vehicles) of the developed software, it is not possible to put a price tag on the development and implementation of the software.

For these services additional precise measurement may be necessary, an improved controller strategy and probably the hardware that runs the algorithms.

Demand response mechanism

The main mechanism is the storage of the energy in batteries from where the energy can be drawn. In the case of PV systems, energy from PV can also be used to reduce the grid consumption.

All devices can act as smart appliance with a different degree of services:

- providing electricity to the grid or to the residence in case of generation shortage,
- absorbing PV or grid electricity in case of over-generation
- services such as reactive power support, primary frequency reserve, secondary frequency reserve for down-regulation, local voltage support.

Cost impact

The cost impact depends on the complexity of the implemented solution, see above. Little to no hardware modifications are required since many available systems do not need extra components and communication with aggregators is already available. Some software developments will be necessary to improve the performance of the system, possibly necessitating more accurate measurement equipment.

Energy impact

The energy impact is high since residential electric energy storage devices have a high capacity in comparison to other smart appliances. They can also be more dynamically used during the day than e.g. dish washers. Task 3 report deduces 5.5 TWh/y impact.

Notwithstanding the positive impact there is also a serious negative energy impact. This can be split into conversion losses and stand-by losses.

The conversion loss is around 10% (see the paragraph ‘concerns’ above for a more precise description of the losses). Assuming a 5 kWh storage system performing 250 cycles/y, the loss is 125 kWh/yr. In economic studies this loss has to be taken into account for the profitability of storage systems.

The stand-by loss of storage systems are on average high: 30 W, with outliers down to 5 W and up to 80 W. This means that most of the storage systems are serious consumers of electric energy. This is elucidated in Table 4 and compared with an average consumption of 3500 kWh/y. Storage is thus part of the high consumers in a house. This is quite unknown to the public and also ignored in most on the economic studies. From above calculation on conversion loss it appears that the stand-by loss is probably the highest of both.

Table 4: Impact on stand-by loss on yearly electric energy consumption

Standby loss (W)	5	30	80
Yearly consumption (kWh)	44	263	701
Contribution to average household of 3500 kWh/y (%)	1%	8%	20%

Important is to take notice that the introduction of storage devices outside Germany is hindered by the tariff structures. It has to be attractive to store PV energy locally. This will only be so if the feed-in tariff of PV energy is low and the buy-back price high. Also the cost contribution to the distribution grid operator has to be ‘smart’. If a flat-rate annual cost is paid for his services in case a PV installation is present, then this is not encouraging to optimise the self-consumption of PV energy. A net metering structure is economically excluding the introduction of electric energy storage in dwellings.

→ Lighting

Description

Lighting includes lighting in residential and commercial indoor areas and public street lighting by use of different kind of light sources such as LFL (Linear fluorescent lamp), CFL (Compact fluorescent light), HID (High intensity discharge lamp) and LED (Light emitting diode). As described in previous task reports there are several lighting comfort constraints because light is used when there is a need for light and for most cases, reduction of light intentensity will result in a comfort loss.

This section will therefore only briefly assess lighting.

There are already systems on the market for remotely controlled lighting, both for the homes and for commercial indoor areas and for public street lighting. Recently, there have been introduced new systems for home use, where the light can be controlled via a smart phone, which gives a better opportunity for also regulation lighting through demand response. There are basically two systems on the market: One with the use of a control box that the smart phone communicates through and one with direct connection from the smart phone to the light bulb through Wi-Fi and Bluetooth.

Network connection
Network connection includes wired (mainly Ethernet) and wireless connections (Wi-FI, Bluetooth, Zigbee etc.). For demand response enabling the lighting bulbs and systems need to be connected to the central energy manager for receiving remote control signals.

For non-networked lighting devices and lighting systems, there is a need to build in a network connection.

Additional components
Lighting devices and light systems need electronics to be able to communicate with the central energy manager and to switch on/off and modulate the lighting output. As mentioned above, some systems comes with a control box for controlling the light bulbs.

Appliance modifications
The appliances need none or few modifications if they are able to communicate with the central energy manager.

Demand response mechanism
The demand response mechanism will be to reduce the light intensity or to swith off the light.

Cost impact
There is a substantial cost impact on remotely managed systems and especially in the home lighting area because the systems are quite new on the market.

Examples of lighting devices (not larger systems) include:
- Philips Hue LED Lamps starter set with 3 bulbs 10 W, Wi-Fi bridge etc.: 161 EUR (Amazon.de)
- OSRAM Lightify Starter Kit with wireless gateway and 1 LED Bulb dimmable 9.5W: 76 EUR (Amazon.de)
- ELINKUME Wi-Fi LED lamp (without bridge / gateway needed): 39 EUR (Amazon.de)

Energy impact
There is an additional energy consumption for the light bulbs and the related systems, mainly due to the networked components.

For products within the scope of Commission Regulation (EU) No 1194/2012 (directional lamps, light emitting diode lamps and related equipment) the requirement is that the no-load power of a lamp control gear intended for use between the mains and the switch for turning the lamp load on/off shall not exceed 1.0 W. From stage 3 (1 September 2016), the limit shall be 0.50 W. For lamp control gear with output power (P) over 250 W, the no-load power limits shall be multiplied by P/250 W.

→ Smart Meters

Smart Meters may be part of a DSF system. There is already roll-out of smart meters in many EU Member States (see Task 2 report) though typically mainly for other reasons. The impact on energy and costs is therefore not included in the analyses.

One example of energy and cost impact can be provided here based on the planned roll-out of about 1 million meters in the supply area of Dong Energy (Denmark), which will take place from 2017-2020. The selected smart meter is Kamstrup Omnipower, which has a ZigBee communication channel.

Own power consumption of the meter is maximum 0.2 W[21].

The total contract value of the change of the 1 million meters is about 240 million EUR resulting in a cost of 240 EUR per meter including the replacement[22].

1.5. END-OF-LIFE PHASE

The impact of the connectivity and DSF functionality on the end-of-life phase is assumed to be marginal of the same reasons described under the production phase and this is why the impact will not be further assessed.

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[21] http://products.kamstrup.com/ajax/downloadFile.php?uid=5162b47e9a3ff&display=1

[22] https://ing.dk/artikel/kamstrup-skal-udskifte-1500-elmaalere-om-dagen-dong-175081