



Preparatory study on Smart Appliances

Task 4 Technologies – Technical Analyses of Existing Products

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

Task 4 report - draft

Version: 10 November 2015



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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
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 are not yet fully available and have not been taken up by the market to their full potential.

The analysis has to determine relevant technical parameters that have an influence on the environmental life cycle performance of the products. This may include energy and material related product specifications. The Task 4 report provides the main input data for the later environmental product assessment and definition of the base cases in Task 5.

We focus exclusively on the impact on energy consumption in the use phase of the appliances, because this is far the most importance phase for smart appliances. We will just include brief descriptions of the production, distribution and end-of-life phase.

In this chapter we focus only the energy consumption at the end user level, i.e. of the appliances and related products and systems in the use situation in homes and offices etc. Energy impact at the power supply system is not assessed in this chapter but will be considered in Task 5.

Finally, we focus on the additional components necessary to achieve the smart appliance functionality i.e. the demand response enabling. Some of the components may also provide other functionality than the demand response and some may be integrated in the products' design. This is further described in section 1.1.

We base 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.

1.1. TECHNOLOGIES FOR SMART APPLIANCES

Smart appliances will - in the context of this study - be Demand Response (DR) enabled devices, 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 can be a virtual energy manager in the cloud.

The appliances will be traditional household appliances, HVAC units etc., which have been modified and redesigned for DR by adding components and functionalities to be smart. There are several changes needed, which involves the functionalities of the appliance, because in most cases, it is not possible just to cut the power connection to the appliance. Instead, it is needed to do a more intelligent powering up and down the appliance, which involves the full control system and the functionality of the product to maintain 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), which depends on the network protocol and network interface technology used.
- Other control systems needed to be built in to process and react on the DR response signals.
- Other components needed for the demand response ability e.g. energy storage (electricity, heat, cold), safety circuits, measurement circuits, sensors etc.
- Possible modifications in existing control system programming to take into account needed changes related to the DR 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, re-start after a DR mode etc.
- In some cases an additional power supply to handle the voltage requirements by the electronics and the low electricity consumption in a waiting for signal mode in order to comply with networked standby requirements.

There are already coming networked appliances to the market – some of them are called “smart” in the meaning of having the capability to be controlled by a smart phone, computer etc. These appliances will typically not need a further network connection, but can use the existing one. There would typically be a need for other modifications to be DR 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 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

There will typically be impacts 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 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 typically 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

In Table 1 below we show examples of power consumption levels for selected network technologies.

Table 1: Examples of of power consumption levels for selected network technologies.

Network type	Power consumption, Watt		
	Min	Max	Average
Bluetooth Classic			1
Bluetooth 4.0	0.000147	0.5	0.250074
Wi-Fi	0.51	1.9	1.205
ZigBee	0.068	0.589	0.3285
Z-Wave			0.07
Ethernet, active link, 1000 Mbps	0.425	1.64	1.0325
Ethernet, active link, 100 Mbps	0.22	0.65	0.435
Ethernet, active link, 10 Mbps	0.22	0.69	0.455

1.4.3. APPLIANCE EXAMPLES

In this section, we assess 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 DR 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

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

Description

Description of dishwashers

Dishwashers mainly consist of a square tub and baskets on either two or three levels, where dishes are placed in. 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 heating process may be shortly interrupted for equalizing the temperature of water and load. A circulation pump pumps the water through a piping system into the spray arms, which are located below the baskets and on the top of the machine. Caused by the water pressure, the spray arms start to rotate and water is sprayed on the dishes. 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. Short heating periods may be used to speed up or increase the drying effect. The heat is used in the drying process to evaporate the water film from the surface of the dishes. The water condenses at the cold surface of the tube and is drained off. 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/ user interfaces. The rated power input of water circulation pumps is about 15-30 W. (JRC, 2015¹)

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). (Stamminger et al., 2009²).

Description of washing machines

Washing machines most common in Europe consist of a tub and a drum rotating around a horizontal axis. The laundry is normally loaded through a glass door at the front of the machine. There are also machines with vertical axis available on the European market, but they are not that common as the horizontal ones.

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. At the beginning of the washing process, water is filled into the machine until reaching a predefined low level. Some of the water is soaked by the laundry. 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 rotation 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 $\frac{1}{4}$ to $\frac{1}{3}$ 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, 2015³)

¹ 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_FI_NAL_v2.pdf

² R. Stamminger (2009): Synergy potential of smart domestic appliances in renewable energy systems. Shaker Verlag, Aachen.

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_FI_NAL_v2.pdf

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). (Stamminger et al., 2009⁴). The power input needed is covered by the amended standby regulation (COMMISSION REGULATION (EU) No 1275/2008) or the networked standby regulation, respectively.

Description of tumble dryers

European type tumble dryers consist of a large rotating drum located inside a body made of sheet steel. Wet laundry is loaded into the drum through a glass door situated at the front of the machine.

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/ 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 gateway connection or frequency sensing are already available from a few manufactures in the European market.

Additional components

For all DR-functions descibed below, a network connection device as well as a switch to activate smart operation is needed.

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

Appliance modifications

Enabling periodical appliances for DR-functions requires new control software and an extension of memory capacities. The software needed depends on the level of smartness that is anticipated.

- In the case of signal activation, a software is required that recognizes signals from the grid (e.g. frequency sensing or direct signal from aggregator or via an energy manager) and activates the device before a predefined deadline is reached. Defining the deadline can be realized either by a start time function or an internal time function.
- Remote activation requires a software that allows bidirectional communication (e.g. to exchange of information on the expected energy demand of the programme or on the deadline set by the consumer) and activates the machine in response to the remote signal.
- As far as altered electricity consumption pattern is concerned, a signal recognition software as well as an energy management software are necessary. The signal coming for example from the grid should include information on the shortage of energy and how long it may last. The energy management software needs to be able to find the most suitable reaction and transform it into action.

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 or activated by a signal coming from the grid 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, 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 or started by a signal from the grid, 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 (cf. Task 3).

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. Periodical appliances may react to the signal by their own intelligence to find the right answer. Possible answers include short-term interruptions, changes in temperatures or shifts of single programme phases (e.g. cleaning or final rinsing phase, spinning). This may change the power demand curve of a single appliance and the overall duration of a cycle.

Cost impact

The need for additional components depends on the level of smartness that is anticipated. The complexity of technical adjustments and redesign needed is higher for the second (altered electricity consumption pattern) than for the first option (remote or signal activation). In the case of signal activation, a signal recognition unit as well as a start-time delay function / time function are needed (10-50 €). Regarding remote activation, a switch is needed to signal activation and a communication module is required enabling bidirectional communication (additional costs 30-130 €). As far as altered electricity consumption pattern is concerned, a signal recognition unit as well as an energy management software are necessary (additional costs 10-100 €).

Energy impact

For the additional energy consumption of the network connection, maximum values stipulated in the amended standby regulation (COMMISSION REGULATION (EU) No 1275/2008) should be assumed.

In the case of remote/signal activation, the machine consumes additional standby energy while waiting for a start and possibly after the end of the machine, if the machine is not switched off automatically (standby-power is maximum 0.5 W (1 W in case of an informative display)).

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)² 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)⁵, (Bézian et al. 1997)⁶.

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 Wi-Fi. More precisely, the communication between the electronic thermostat and the energy control manager it is done by pilot cable, frequency/electric current signals or wireless signals (Da Silva 2011). Wireless signal may also include Bluetooth, Zigbee, Z-Wave etc.

⁵ 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

⁶ Bézian, Jean-Jacques ; Barles, Pierre ; Claude François & Inard Christian. 1997. Les émetteurs de chaleur. Presses de l'école des Mines.

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

If the radiator already has a thermostat that allows communication and external control, 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. If the radiator does not have a communicating electronic thermostat, hardware changes must take place, in order to enable data transfer between the heating device and the control system. Software changes may refer to adapting the appliance to respond to different external signals (room temperature, energy pricing, external orders from the grid).

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 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 built-in inertia radiators (see next section), the radiators store heat in the building components.

Cost impact

According to (RTE, 2015) 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).

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-heat to a higher temperature than normal, there would be an additional heat loss from the building.

→ Built-in inertia radiators

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 built-in inertia radiators 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 wifi. (Da Silva 2011).

Additional components

No extra components needed to optimize the curtailment of built-in inertia electric radiators, if the appliance already has an electronic thermostat that can switch off/on the appliance given an external signal.

Appliance modifications

If the radiator already has a thermostat that allows communication and external control, 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.

Demand response mechanisms

The inertia 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

According to (RTE, 2015) 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).

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 increase temperatures in boiler or the storage tank, there would be an additional heat loss.

→ **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.

Appliance modifications

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

Demand response mechanism

Boilers efficiency is independent of external variables (outside temperature i.e.), so its activation can be postponed freely, an even in a more flexible way if there is a storage tank coupled to the boiler.

Cost impact

According to (RTE, 2015) 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).

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.

→ **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%. For some environments where outside temperature falls below 0°C air-air heat pumps' efficiency drops drastically, making them in many cases unsuitable for really cold climates. In order to profit the inertia of the heat source, geothermal pumps or water-air heat pumps are used instead. Controlled variables of a heat pump system are: indoor temperature (set point), 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 Wi-Fi. (Da Silva 2011).

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 an 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 (Dimplex, Neura, Nibe...), 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 an intelligent thermostat that sends on/off signals).

Demand response mechanism

Many demand-response projects have been developed by heat pumps' manufacturers (Dimplex, Neura, Nibe etc.), regarding mainly variable-tariffs signals as an input. According to manufacturers, in order to ensure the maximum flexibility between the grid and the clients, deployment of smart meters and variable tariffs is considered mandatory. This program already has been widely developed in Sweden (Nibe), where these two conditions are well instituted in the electrical utility service.

Cost impact

According to (RTE, 2015) 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).

Nevertheless, 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.).

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. However, the combination of high temperature and pressure results in conditions that require special sealing devices. (Hydraulic Institute, 2013). The controlled variable corresponds to the water temperature, that will indicate to stop or run the circulator pump. Some new 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, which 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 demand response mechanism for circulator pumps that are integrated to the boiler's control system will be an on/off signal. For newer pumps where variable speed drives are installed, a modulating signal (% of the nominal speed).

Cost impact

There is no available information regarding the costs of enabling demand response in boilers circulator pumps.

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 air conditioners (< 12 kW)

Thermodynamic refrigerating system to transfer heat from two different sources (indoor air and outdoor air i.e.). 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 (ASHRAE). Mainly residential units are 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.

Appliance modifications

Most air conditioners already have a thermostat that allows communication and external control, 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. Nevertheless, Australian normative AS 4755 enabled Demand Response for all new air conditioners built after 2014, imposed all manufacturers to enable their equipments to adapt an external box (demand response hardware).

Demand response mechanism

Two different mechanisms are described in Air conditioning Australian Normative AS 4755, on/off of the air conditioners and modulating the charge of the air conditioner (25%, 50%, and 75%).

Cost impact

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\$. According to another manufacturer, enabling demand-response would rise the retail price of the air conditioner by 100€ to 200€.

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

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.

Additional components

No additional components are needed to enable demand response to ventilation.

Appliance modifications

If the ventilation system already has a control unit that allows communication and external control, 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.

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.

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.

Current constraints using a residential energy storage system

For existing systems on the market and in the homes intended to work with PV systems or other electricity sources, the attractiveness depends firstly on the electricity metering and tariff structure in a region or country. If net metering or net billing is used then the yearly generation (from PV, wind or combined heat and power) and electricity use are subtracted from each other. This is like the electricity grid behaves like an ideal battery. In that case it makes little economic sense to install a battery. This kind of tariff structure is only used in 4 European countries⁷.

A second condition is that the PV-based electricity fed to the grid is rewarded with a lower price than the electric energy buy-back tariff and off course certainly not higher. The latter was the case in countries that used PV stimulating feed-in tariffs. In Germany this system has been replaced by a commercial sell tariff that appears much lower than the buy tariff. It has been pre-scribed to be 13 €/ct/kWh and decreasing depending on the growth rate of PV installations in Germany⁸. For households the electricity price is around 30 €/ct/kWh⁹. Since the self-consumption of solar electric energy is around 20 % and maximum 30 % if demand side management is applied, it is of interest to install a storage system. The rate of self-consumption depends off course on the user profile¹⁰.

The aggregator role that storage systems can play is an extra incentive for storage. A new expression is used for aggregation of residential energy storage systems: swarm power. Often for storage systems multiple revenue sources are needed. Due to the high cost of the battery, every kWh stored should generate revenue, hence a tariff structure which encourages storage is indispensable. This can be achieved e.g. by a feed-in tariff well below the (residential) electricity price.

⁷ 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*, vol. 111, pp. 1126-1135, 2013.

⁸ „Gesetz für den Ausbau erneuerbarer Energien (EEG 2014),” Bundesministerium für Wirtschaft und Energie, Berlin, 2014.

⁹ Eurostat. Electricity – domestic consumers – half-yearly prices. Available <http://appsso.eurostat.ec.europa.eu/nui/show.do?dataset=nrg_pc_204&lang=en> [Accessed 5.11.15].

¹⁰ G. Mulder, F. De Ridder, D. Six, „Electricity storage for grid-connected household dwellings with PV pannels,” *Solar Energy*, vol. 84, pp. 1284-1293, 2010.

Characteristics

Since 2014 the ‘Centrales Agrar-Rohstoff Marketing- und Energie-Netzwerk e.V.’ publishes an overview of the available storage systems. Up to 200 systems from over 40 suppliers are given¹¹. The overview is for systems on the German market. In Europe this is by far the most advanced market due to their electricity tariff system and a subsidy for residential storage systems. In other countries few systems are available: despite the European market integration, grid-connected storage systems, like PV inverters and all other electricity sources, have to be approved for each European country according to the rules of the local electricity grid operators.

In Austria and Switzerland the market has set-off as well. The second market worldwide is Australia, where energy companies promote storage. Many more countries are nevertheless envisaged by storage manufacturers. A short overview of countries and systems can be found in the footnote.¹² The C.A.R.M.E.N. study is a worthwhile synopsis to get insight in the characteristics. The useful capacity is between 0,5 and 85 kWh. For household dwellings a capacity of 3 to 10 kWh is useful, depending on the size of the PV installation and the user profile¹³. Also concerning the power the manufacturers do not have a specific preference for a certain value, being mostly between 1,5 and 8 kW.

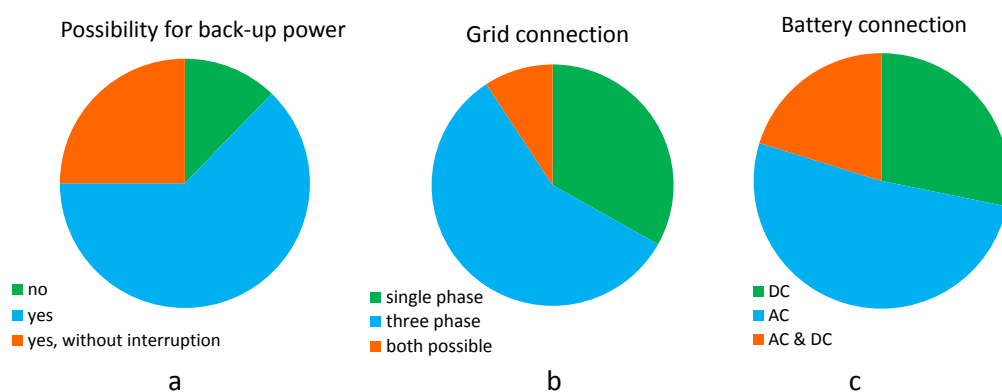


Figure 1: Apportionment of home batteries per back-up power supply, grid connection and battery connection possibility. Data from footnote 11 and compiled by VITO.

Almost all systems can also be used as a back-up power supply, although a small powerless transition period of up to 10 s is present. So, most of them are not true uninterruptable power supplies. The possibility to act as back-up power when the distribution grid is down is a helpful comfort option for the owner (see Figure 1a), but it is not an appliance function that supports the electricity grid and thus out of the impact scope of this study.

The storage systems differ in the grid connection (see Figure 1b) that can be single phase, or a combination of three single phase inverters to supply three phase loads. Three-phase inverters to supply three-phase loads are also available.

Part of the storage systems are directly connected to the DC side of the PV installation and have a common grid connection for the battery and PV modules (see Figure 1c). Some of these systems

¹¹ „Marktübersicht zu Batterien,” C.A.R.M.E.N., February 2015. [Online]. Available: http://www.carmen-ev.de/files/Sonne_Wind_und_Co/Speicher/Marktübersicht-Batteriespeicher_Web.pdf . [Accessed 4.11.15]

¹² PV Magazine. Meldung with the market. Available <http://www.pv-magazine.com/archive/articles/beitrag/melding-with-the-market-_100021374/630/#axzz3qbjRT1s1> [Accessed 4.11.15].

¹³ Grietus Mulder, Bert Claessens, „Insights in storage as a solution for local renewable electricity generation,” *Elektrotechnik & Informationstechni*, vol. 129, pp. 116-121, 2011.

currently do not allow to charge the battery with grid power, but this limitation can be removed by a software adaptation.

Some systems have two grid connected inverters, one for the battery and one for the PV modules, i.e. the connection between battery and PV is indirect through the AC-grid. A possibility to connect both ways is also possible. Both systems are intrinsically able to store both PV and grid power, they enable to provide grid services and to offer flexibility by charging and discharging according to the needs of the grid. This is important for added smart appliance functions. Figure 2 shows the division in the three categories.

The storage batteries for home use are connected to the domestic grid in almost all cases at the main distribution board. This is also prescribed by a German guideline¹⁴. This makes a difference with many other appliances that can be connected at a wall plug.

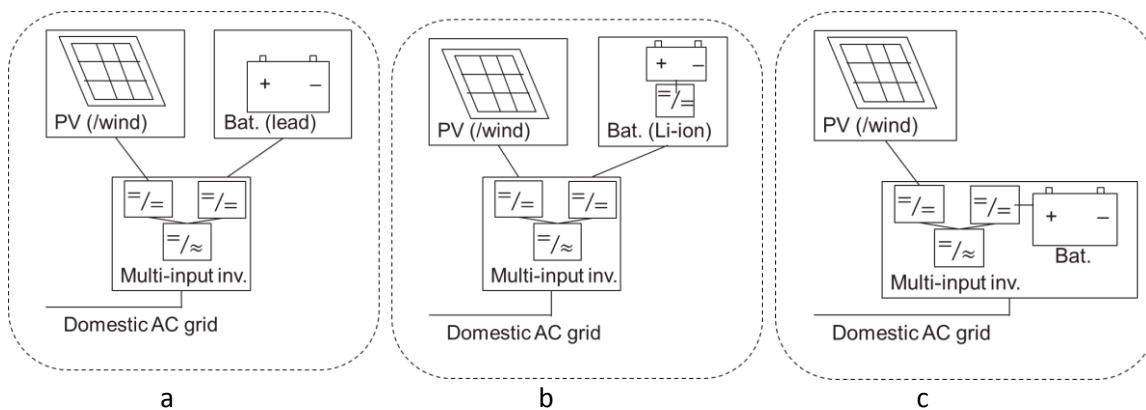


Figure 2: Combinations of battery, PV installation and inverter for new installations

Smart control

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’.

- Some systems are able to provide primary frequency reserve by activating part of the portfolio of the aggregator when the aggregator activates this service during some periods. This service exists to keep the grid frequency between normal operating frequencies, e.g. between 49.8 and 50.2 Hz. The manufacturers emphasize that the power delivery is in short bursts, hence the discharging of the battery is very limited and the impact on the cycle life becomes negligible.
- Some systems provide secondary frequency reserve in down-regulation, by charging the battery at instances of over-production of e.g. wind-power, but these are not autonomous decisions, they are based on requests by an aggregator. It is worth mentioning that none of the systems

¹⁴ Forum Netztechnik/ Netzbetrieb im VDE, „FNN-Hinweis Anschluss und Betrieb von Speichern am Niederspannungsnetz,“ FNN/ VDE, Berlin, 2014.

provide secondary frequency reserve for up-regulation as this would discharge the battery and stress the battery with additional cycles.

- Due to the fact that these systems can prohibit injecting the full PV power into the grid, they inherently provide voltage support against over-voltages for the local distribution grid. Otherwise this results in the shut-down of PV installations when the overvoltage is detected.
- At the same time these systems inherently provide voltage support for the distribution grid against under-voltages through the use of battery power, mainly in the evening, when the consumers are operating at peak consumption.
- The two services described above can also be regarded as peak shaving services, both on the production side as well as the consumption side and/or as a sort of demand side management, although this is strictly speaking not true (see the earlier argument).
- These systems could also provide reactive voltage support to the local distribution grid by changing the $\cos \phi$ of the grid-connected inverter. By injecting or consuming reactive power, the grid voltage can be influenced to a certain degree without sacrificing active power.
- These systems are suited to deliver emergency power supply services, covering a period of several hours without grid availability.

Many home storage systems have implemented demand side management functionality to switch on 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.

Overview of the ICT possibilities and the grid support possibilities of the available storage systems

To help better understanding the current possibilities of home batteries as smart appliances, an inventory is made by studying systematically the information that home battery suppliers provide. The brochures of the residential energy storage system manufacturers mention various aspects that are of interest for smart appliances, like that they can switch on extra electric energy consumers as a heat pump or tumble dryer.

Also many systems can absorb power from the domestic AC grid. Some brochures mention the coupling to weather forecast to optimize the moment to store energy, prohibiting that a high power is fed into the grid at noon during a sunny day. One brochure mentions that its control is ready for dynamic pricing of electricity.

The brochures also give information on ICT possibilities. Many systems are connected to internet possessing an in-built webserver that can be accessed with help of an app for the mobile phone or via a website. Some systems have data storage in the cloud. Also quite some systems can be controlled over internet including appliances coupled to the storage e.g. with help of smart wall plugs. A minority of system suppliers indicate that they are ready to aggregate storage systems together to act on the power reserve markets. The possibility to act as back-up power when the distribution grid is down, is a helpful comfort option for the owner, but it is not an appliance function that supports the electricity grid. It has been included in the study, but as a category apart.

Over 40 home battery system suppliers have been analysed based on the overview of brands in footnote 11. Some of them appear to deliver the battery only with a DC connection, needing an external inverter (like there are brands that are specialized in inverters that can be coupled to various batteries, but they remain included in the overview since they provide grid support features). When these are subtracted, still over 30 manufacturers remain. One brand is selling an energy management system without an own inverter.

12 subjects are identified of which manufacturers mention explicitly the possibility, see Table 2. It does not mean that the option is available in all the products of a specific brand. Also it may be available, but not mentioned in the brochures or data sheets.

The AC charge possibility shows that the storage can be charged over the distribution grid. For many storage systems this fits the purpose of being independent of the PV installation or other energy source. It does not imply that today the storage can be charged with help of smart grid signals. It is merely a requisite for doing so, what can be realised by a future software update if the system has an internet connection and a smart grid/ smart energy controller. *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.

Table 2 gives a summary of the findings, counting the hits.

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.

Table 2: Summary of ICT and grid support properties found in the brochures of home battery brands.

	Aspect	Occurrences (out of 36 brands)
ICT aspects	ICT connection	26
	cloud based database	4
	internal web-server	18
	external control poss.	8
Distribution grid relief	feed-in limiting ^a	4
	load mgt. poss.	14
	power consumption limiting	1
	weather forecast connection poss.	4
Electricity system relief	AC charge poss.	15
	aggregation	6
	dynamic pricing poss.	2
Personal comfort	automatic islanding ^b	19

poss. = possibility

- a) All storage systems that are subject to the KfW Förderprogramm need to have a feed-in power restriction of 60% of the nominal capacity of the PV installation (footnote **Error! Bookmark not defined.**). Since the majority of the residential solar storage systems are placed with help of this subsidy programme, the devices have this restriction in-built. However, almost no documentation states this explicitly, otherwise many crosses should have appeared in this column.

- b) Automatic islanding means that the storage inverter automatically takes over the power supply in islanding mode within milliseconds up to 10 s, depending on the manufacturer. So, not all indicated systems are uninterrupted power supplies since then millisecond reaction time is needed.

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. This will be explained further below.

Partial load use has little impact on the system efficiency in most cases. The battery efficiency becomes better at lower currents. The efficiency of most inverters and converters is rather flat from 40 % to 100 % of the nominal power, with a slight decrease from 40 to 10 % of nominal power and steep decrease below 10% of power. Inverters have an efficiency of some 98 %¹⁵, while dc-dc converters have an efficiency of some 97 %^{16,17} when using common Si-based power electronics. Assuming a 90 % battery efficiency¹⁸, the efficiency of storing PV energy in the battery and releasing it later to the grid is 97 % * 90 % * 97 %, which is equal to 85 %. The inverter efficiency is omitted as these losses are also present when the PV energy is directly injected in the grid. When energy is drawn from the grid and stored for later use, the efficiency is 98 % * 97 % * 90 % * 97 % * 98 %, which amounts to 81% efficiency compared to direct use of the grid power. Thus, using the battery to store PV energy or grid energy for later use, will result in some 15 to 20 % of the energy being wasted in conversion losses. The chain efficiency for over 40 brands is given in the overview in footnote 19. An average of 88±5% can be deduced, in line with our calculation. One vanadium redox flow system is given. It has a given efficiency of 66%, so much lower than for batteries. The manufacturer gives as advantages of its system that there is no limit on the number of discharge cycles and that the product is non-toxic, in contrast with battery-based storage solutions.

The devices also have a stand-by consumption due to the controllers, power electronics and internet connection. The source in footnote 19 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'.

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 dwelling²⁰.

Network connection

¹⁵ M. Valentini, A. Raducu, D. Sera, R. Teodorescu, J. Hantschel, "PV Inverter Test Setup for European efficiency, Static and Dynamic MPPT Efficiency Evaluation" 11th International Conference on Optimization of Electrical and Electronic Equipment, 2008. OPTIM 2008.

¹⁶ C. Pham, R. Teodorescu, T. Kerekes, L. Mathe, "High efficiency battery converter with SiC devices for residential PV systems", IEEE Power Electronics and Applications conference (EPE), 2013.

¹⁷ D. Han, J. Noppakunkajorn, B. Sarlioglu, "Efficiency Comparison of SiC and Si-Based Bidirectional DC-DC Converters", IEEE Transportation Electrification Conference and Expo (ITEC), 2013.

¹⁸ PV Magazine. Advancing Li-ion. Available <http://www.pv-magazine.com/archive/articles/beitrag/advancing-li-ion-_100006681/501/#axzz3ocJhMoi1>. [Accessed 15.10.15].

¹⁹ PV Magazine. Storage Special. Available <http://www.pv-magazine.com/fileadmin/PDFs/pv-magazine_Storage_Special_Jul_2015.pdf>. [Accessed 15.10.15]

²⁰ Forum Netztechnik/ Netzbetrieb im VDE. „FNN-Hinweis Anschluss und Betrieb von Speichern am Niederspannungsnetz“, Berlin, Juni 2014,

The residential energy storage system all seem to have at least an internet connection (see *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.

Table 2). 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 demand response to maximise the use of solar power or other renewable power by enabling load management. This management can be achieved by digital outputs on the inverter, by special AC connections on the inverter, by controllable wall plugs, e.g. over Z-wave or with help of a communication protocol between the smart appliances like the EEBus protocol²¹ and OpenHAB²².

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 management²³:

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

²¹ www.eebus.org

²² www.openhab.org

²³ F. Geth, e.a., „Multi-objective battery storage to improve PV integration in residential distribution grids,” *IEEE Trans Sust Energy*, vol. 4, 2013.

injection in the grid and to maintain the voltage and frequency in island-grids is already available. 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 production, 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

This is already described above. 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 production 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 3 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 3: 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 intensity will result in a comfort loss.

This section will therefore only briefly assess lighting.

There are already systems on the market for remote 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.

Additional components

Light bulbs 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 switch off the light.

Cost impact

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

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.

1.5. END-OF-LIFE PHASE

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

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