elementenergy

Department for
Business, Energy
& Industrial Strategy

Barriers and Benefits of Home Energy Controller Integration

Final report

for

DECC

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Acronyms

CAD	Consumer Access Device
DCC	Data Communications Company
DNO	Distribution Network Operator
DSR	Demand-side Response
HAN	Home Area Network
IHD	In-home Display
NPV	Net present value
SMETS	Smart Metering Equipment Technical Specifications
TPI	Time Proportional Integral
TRV	Thermostatic Radiator Valve

Glossary of terms

Communications protocol. The set of rules that defines how information is transmitted between the elements of a communications network.

Consumer Access Device (CAD). A device that can be used to link the smart meter Home Area Network to a range of consumer energy technologies. In the DECC definition, a CAD contains ZigBee Smart Energy Profile functionality.[1]

Data and Communications Company (DCC). The organisation responsible for providing communication services between smart meters and energy suppliers, network operators and other authorised DCC users.[2]

Demand Side Response (DSR) services. Actions taken by consumers to change the amount of electricity they take off the grid at particular times in response to a signal.[3]

Dual meshed communications systems. Systems that can communicate through electric wiring and over radio frequencies, where each device on the network acts as an interoperable transmitter between both media.

Home Area Network (HAN). The network used to facilitate communication between devices in the home (or in close proximity to the home). In GB, this will be a local ZigBee wireless network.[4]

In-home Display (IHD). A device which will allow consumers to see what energy they are using and how much it is costing in near real-time.[5]

Internet-of-Things. A connected network of physical objects each with integrated communications functionality.

Licence exempt spectrum. Several frequency bands are reserved for industrial, scientific and medical equipment, and are exempt from licencing.

Smart Metering Equipment Technical Specifications (SMETS). This defines the minimum capabilities for gas and electricity smart metering systems and the IHD in GB.[6]

Thermostatic Radiator Valves (TRV). Valves which control the flow of water through the radiator to which they are fitted when the temperature goes above some setpoint.[7]

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[1] Department of Energy and Climate Change (DECC), *Smart Meters, Smart Data, Smart Growth* (URN: 15D/021)
[2] Ibid
[3] Department of Energy and Climate Change (DECC), April 2016.
[4] Department of Energy and Climate Change (DECC), *Smart Meters, Smart Data, Smart Growth* (URN: 15D/021)
[5] Department of Energy and Climate Change (DECC), *The Smart Metering System* (URN: 14D/154)
[6] Department of Energy and Climate Change (DECC), *Smart Metering Implementation Programme: Explanatory document to support the designation of the first version of the Smart Metering Equipment Technical Specifications (SMETS 1),* 2012 (URN: 12D/487)

Time Proportional Integral (TPI) control. A boiler optimisation control algorithm for a thermostat which operates on a time and temperature basis. A TPI thermostat calculates the optimum firing rate of the boiler based on information such as previously learnt characteristics of the building it is in.[8]

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[7] http://www.energysavingtrust.org.uk/domestic/thermostats-and-controls (Accessed April 2016)

[8] Department of Energy and Climate Change (DECC)/Energy Saving Trust, *Final Report for – In-situ monitoring of efficiencies of condensing boilers – TPI control project extension*, 2010

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Geotogether

Glen Dimplex

Honeywell

Institution of Engineering and Technology (IET)

Netatmo

Passiv Systems

Pilot Systems

Smart Energy Networks

Tempus Energy

Xsilon

Executive Summary

The home energy management sector is evolving rapidly, with an increasing range of 'smart' energy products[9] – including smart home heating controls, smart domestic lighting and appliance controls and domestic energy generation and storage products – now available on the UK market. The Department of Energy and Climate Change (DECC) recognises that significant cost and energy savings could be available through the integration of these devices in a complete home energy system, but also that there are risks to the consumer in terms of the potential for energy rebound effects, vulnerability to changes in energy pricing and data security implications. Furthermore, DECC understands that there may be potential barriers to the deployment of home energy controls, and new challenges for other stakeholders in the energy system, such as distribution network operators, energy suppliers and electricity generators.

In response to this requirement, DECC commissioned Element Energy to examine the barriers to the greater integration of energy controllers in the household, and to evaluate the potential costs and benefits to consumers of the deployment of such energy controllers.

The objectives of the study were to:

- **Carry out a capability assessment** of key energy controllers which will feature in the market over the next 10 years to understand the functionality which could be available;
- **Identify the key barriers to the deployment** of integrated home energy control systems, how these barriers might be overcome and over what timescale;
- **Evaluate the potential costs and benefits** of home energy controllers to the household.

Home energy control product capability assessment

Through a combination of desk-based research and consultation with industry, we have carried out a review of well over 100 home energy controller products on the market, including the following product classes:

- Smart **heating** controls;
- Smart **lighting** controls;
- Smart **plugs and sockets**;
- Smart **wet and cold appliances**;
- Smart home **micro-generation management**, **electric vehicle charging** and **storage**;
- Enabling technologies such as **gateway devices** and **sensors**;
- Smart product **communication protocols**.

For each category, we have considered the current **functionality** available on the market, whether and **how the product can be integrated** with the wider home energy system and

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[9] Smart technologies are defined here as those that use digital and communications technology based on signals.

the **technology readiness and market price**. We also consider, in particular through our industry consultation, the **potential future development** of the functionality, integration potential and price of each product class.

The key findings of the product capability assessment are described in this report; the detailed data collected are also recorded in the accompanying *Home Energy Controller Product Review* database.

Barrier analysis for the deployment of integrated home energy controllers

In partnership with DECC, we have identified a range of stakeholders representing the range of organisations expected to play a role in the emerging smart home energy control industry. The 17 organisations consulted include manufacturers of home energy controllers, manufacturers of gas and electric heating appliances, developers of communications protocols for smart products and industry bodies representing manufacturers, utilities and contractors[10]. Through this consultation, as well as through a literature review, we have identified a range of barriers to the uptake and integration of home energy controllers.

The barriers fall into the following categories:

- Technical
- Interoperability and standardisation
- Security and privacy
- Economic
- Regulatory and market barriers
- Consumer behaviour and awareness

We have assessed each barrier in terms of ‘risk’ (how likely it is to apply) and ‘relevance’ (the importance of its potential impact). The full list of barriers and their associated risk and relevance are described in Section 7. The key barriers we have identified through this process are as follows (not ranked by importance):

1. **Lack of engagement of customers in heating and home energy use** (*Consumer behaviour and awareness*)
2. **Usability issues for consumers in relation to heating controls** (*Consumer behaviour and awareness*)
3. **High initial costs for smart control devices** (*Economic*)
4. **Barriers to half hourly settlement, needed for some DSR services, and availability of time-of-use and other smart tariffs** (*Regulatory and market barriers*)

For each of these barriers, we have examined a number of potential solutions. To address the consumer behaviour and awareness barriers to the uptake of advanced and smart heating controls, potential solutions include education of consumers and heating control installers on the benefits of heating controls, improvements in the usability of the controls

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[10] A full list of organisations consulted is provided in the Acknowledgements section at the front of this report.

themselves, and the inclusion of advanced heating controls in building regulations, among others.

For the economic barrier relating to high upfront investment cost, potential solutions include bundle deals with energy suppliers to reduce or remove the upfront cost to the customer, inclusion of advanced or smart heating controls in building regulations, and subsidisation through Government schemes such as the Energy Company Obligation or another future scheme. We note that Government subsidisation of smart energy controls is highly likely to require an evidence base on the potential energy and carbon savings, in the case that savings can be demonstrated by field trials.

In order to address the regulatory barrier to half hourly settlement, as required to access the value of many of the DSR services described here including TOU tariffs, further clarity will be required on whether and when suppliers will be required to settle domestic customers on a half hourly basis. The final key barrier identified, relating to how the potential benefit of DSR services would be passed back to the customer, is closely related to this point. One way in which DECC could help to address this barrier is through the development of a roadmap for how this issue could be addressed within the framework of electricity market regulation.

Evaluation of potential costs and benefits of home energy controllers

In the final part of this study, we describe and evaluate a range of potential costs and benefits of home energy controllers for domestic consumers. Within the scope of our analysis, we include the following costs and benefits:

- **Initial capital investment** in the smart home energy control equipment;
- Potential **heating fuel bill savings** due to energy savings and/or **potential increases in the heating fuel bill** due to energy rebound effects;
- Potential value generated through **demand-side response** (DSR) activities, including **peak demand reduction** and **frequency response**.

We assess these costs and benefits for a range of representative household types, for a series of **home energy control scenarios**. The home energy control scenarios were defined based on the product capability assessment to reflect the key relevant functionalities which are likely to be available on the market over the next 10 years. We place an emphasis on smart heating controls, given the high energy intensity of heating in comparison to other end-uses within the household. The full set of home energy control scenarios studied, and the functionalities included in each scenario, is shown in **Error! Not a valid bookmark self-reference.**.

The investment cost for each scenario was derived from the product review, by mapping the products reviewed to the home energy control scenarios. The remaining potential costs and benefits were derived through a variety of modelling approaches, as described in detail in Sections 10-12.

Table 1: Home energy control scenarios: matrix of functionalities included

Home energy control scenario	**Heating**				**Lighting and appliances**	**Microgeneration**
	Central time and temperature control	Remote/ external control	Zonal heating control (wireless)	Passive control and learning algorithms	Smart lighting and appliances	Smart management of microgeneration
Baseline	✓					
Smart heating (Basic)	✓	✓				
Smart heating (Advanced - Zonal)	✓	✓	✓			
Smart heating (Advanced - Passive control)	✓	✓		✓		
Smart heating (Advanced - Zonal + Passive control)	✓	✓	✓	✓		
Smart home	✓	✓	✓	✓	✓	
Prosumer home	✓	✓	✓	✓	✓	✓

The key findings of the modelling include the following.

The plausible ways the consumer may interact with the original and ‘smart’ heating controls lead to very different outcomes in the change in fuel bill

We have modelled the impact of a number of plausible mechanisms through which the installation of home energy controls could lead to either energy savings or energy rebound effects. We have also related the likelihood of these mechanisms occurring to a range of heating behaviours observed in the case of non-smart heating controls.

Across the full range of mechanisms, as upper bounds, we find the potential for the annual fuel bill to reduce by approximately 50%, or for it to increase by approximately 55%. To compare the potential costs and benefits, we have quantified the net present value of each cost and benefit component over a 15 year product lifetime, using a discount rate of 3.5%. For a typical household, the net present value of the change in heating bill then varies between -£2,500 to +£4,000. The magnitude of this cost or benefit is many times larger than the typical cost of the smart heating controls, which are in the range £100-300.

It is therefore clear that how consumers interact with the energy controllers once they have been installed (as well as how the consumer interacted with the previous controls) is of great importance. In order to gain a better view of the relevance of the different outcomes studied here, as well as how those outcomes can be influenced, it will be necessary to undertake field trials of the controls in question. A number of such field trials are underway, including the DECC Behavioural Insight Team’s Nest field trials.

DSR activities to reduce peak demand and provide frequency response could lead to significant value for the household, particularly in households with electric heating

We find that a typical household using a heat pump for space heating and hot water could access value on the order of £33 per year for peak demand reduction, through some form of time-of-use tariff (here assuming a peak/off-peak differential of around 21 p/kWh), and on the order of £42 per year to provide frequency response to National Grid. The majority of this is attributable to the heat pump; a similar household without a heat pump could expect to access on the order of £12 per year for peak reduction and £5 per year for frequency response.

The net present value over 15 years of providing these two DSR services with the heat pump alone is nearly £900. This is several times the initial investment cost for the required smart heating controls, in the range £100-300, and this suggests that a business case can be made for smart heating controls in combination with a heat pump on the basis of these services alone.

As a caveat to this, it is important to note that the market for frequency response is relatively limited, at around 1,000 MW at present, and it is expected that a wide range of players from power plant operators, renewable generators and battery storage operators will take some share of this market. This could limit the potential value of frequency response for domestic consumers.

Smart lighting and appliances offer a relatively poor economic return in the domestic sector, but uptake is likely to be driven to a greater extent by improved user experience and convenience

As described above, the potential economic value of the DSR services studied for households *without* a heat pump – where the services are provided only by lighting and appliances – is significantly lower than for households with a heat pump. This is a result of (i) the lower energy intensity of lighting and appliances versus heating and (ii) the significantly higher cost of smart lighting and appliance controls compared with smart heating controls.

It is important to acknowledge here that the primary selling point of smart lighting and appliances, to a greater extent than for smart heating controls, is not economic benefit or energy savings, but enhanced consumer experience and/or greater convenience. Furthermore, we note that smart appliances are at a somewhat less mature stage of development than smart heating controls, and the costs may be expected to fall more rapidly. Nonetheless, the greater energy demand associated with heating than with lighting and appliances means that the potential value of smart heating controls is always likely to exceed that of smart lighting and appliances.

The economic case for smart management of micro-generation with electrical or thermal storage is marginal, but could become attractive under falling battery prices or large peak/off-peak electricity price differentials

We have studied the economic case for the smart management of solar PV with electrical and thermal storage. The value proposition in this case is that increased on-site use of generated electricity, and the ability of the storage to shift demand from peak to off-peak periods, allows a reduction in the export of electricity at low prices and a reduction in the import of electricity at high prices.

In the case of electrical storage, we find that the potential value of this smart management functionality is of the order £4,000 over the 15 year lifetime. This is very comparable to the current capital cost of the battery storage system (found through our review to be approximately £4,000 for a fully-installed 4 kWh domestic system), indicating that the break-even point is similar to the product lifetime. The business case for electrical storage, when applied in combination with solar PV, is therefore fairly marginal at present battery prices and under the peak/off-peak price differential assumed here of around 21 p/kWh. The case for thermal storage with solar PV, in the case of a household with a heat pump, is currently more favourable, with a payback period of less than 10 years according to the modelling assumption described in this report. However, we note that the cost of electrical storage is expected to fall relatively quickly; as such, the economic offer for this could improve significantly over the next several years.

Part A: Home Energy Controller Capability Assessment, Roadmap and Barrier Analysis

1 Home Energy Controller Capability Assessment

Rapid developments in the areas of low cost networking, communications and data analysis have made the possibility of device level intelligence and whole-home remote control a reality. In the context of the home, products are increasingly becoming connected to the internet and to each other, forming a so-called ‘Internet-of-Things’. This is referred to as ‘smart’ control, where controls have advanced functionality, such as motion detection, and may communicate with each other using signals.

The increased uptake of such controllers, driven by the desire for increased user convenience and comfort, will inevitably have an effect on the energy consumption of the home. There is little evidence available on the impact of smart home energy controls on domestic energy demand, and it is conceivable that such technologies could lead either to energy savings or increases in energy demand. Some of the mechanisms by which energy demand could be affected are described, and modelled in Section 10.

Home energy management products can be classified into three basic categories:

- *Communications technologies:* these technologies form the infrastructure on which the smart home rests. They are responsible for supporting data processing and transmission.
- *Control devices:* which allow remote or automated control of appliances, such as lights that can be controlled externally or can respond to information from other elements of the system (such as sensors), or heating controls.
- *User interfaces:* the devices with which users interact. They allow the user to send orders to the control devices, or simply present information to the user.
- *Sensors:* sensors supply information to the system, enable automation and collate information to be sent to the user.[11]

Within each of these categories a number of key product classes have been identified. These are given in Table 2 below. Figure 1 is a schematic illustrating the basic structure of communication and energy transmission within a smart home, with reference to the categories listed above.

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[11] Note, that where a control device integrates a sensor, we have not included this in the sensors section (examples of this are wireless thermostatic radiator valves and smart heating controls)

Table 2: Classes of products by category

Communications Technologies	Control Devices	User Interfaces	Sensors
Communication Protocols	Smart Heating Controls	In-home Displays	Temperature sensors
Gateways	Electric Heaters with Integrated Smart Controls	Smartphone, tablet and Web Based Applications	Weather compensators
	Heat Pumps with Integrated Smart Controls		Occupancy sensors
	Smart Wet Devices		Open door and window sensors
	Smart Electric Vehicle Chargers		Light intensity sensors
	Smart Cold Devices		Multiple sensors
	Smart Lighting		
	Smart Plugs		
	Smart Storage		
	Smart Diverters (for micro-generation)		

For each of the product classes, a database of the products that are currently available has been compiled, including their core functionalities and current price. This is focused on the UK market. The *Home Energy Controller Product Review* database containing this data is presented in the form of a table (one per product class), and can be found to accompany this report. To accompany the database an overview of the current status and development roadmap for each product class is provided in this report. For each product class the following are considered:

- Functionalities and features of the products
- Interaction of the products with home energy systems, and the wider Internet-of-Things (IoT)
- The current market for the products
- Roadmaps for the future development of the products

A number of industrial stakeholders were consulted in order to construct a broad view of the status of, and expected developments in, the smart home sector.

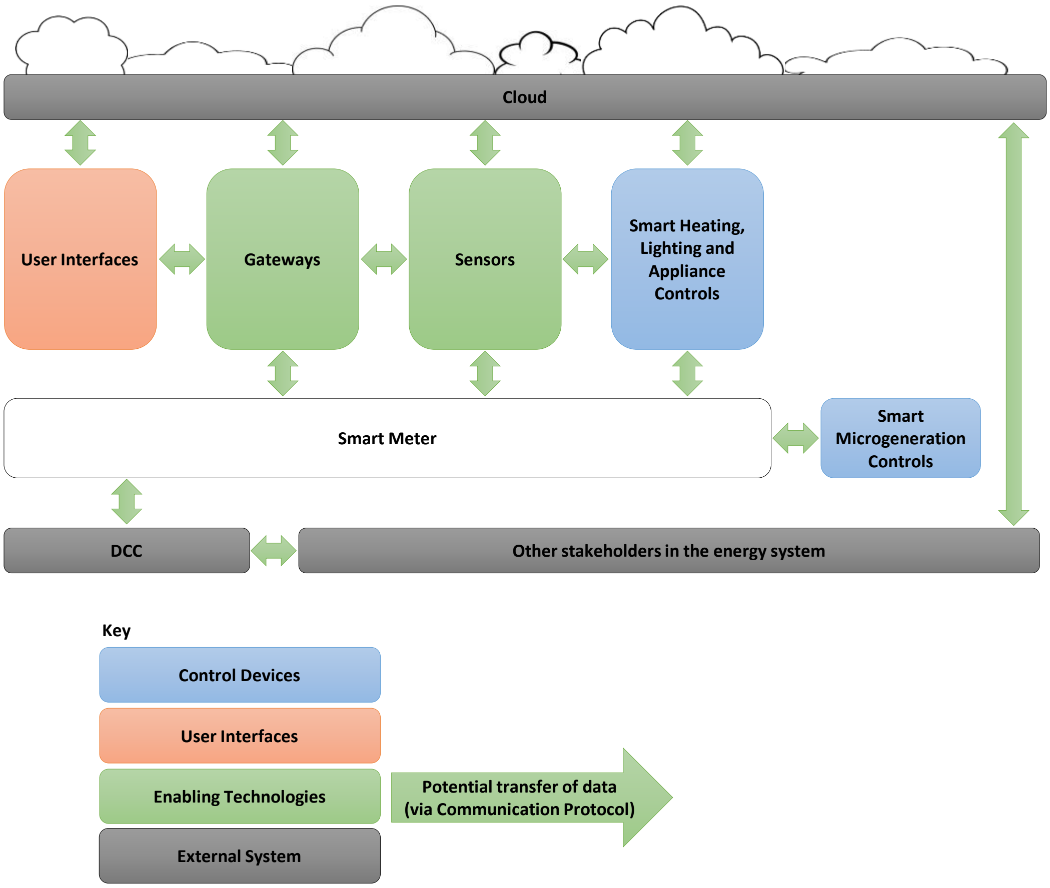

Figure 1: Schematic showing the smart home energy product categories and potential transmission of information in the context of the smart home

2 Overview of Current Communications Technologies

2.1 Communication Protocols

A communications protocol is the set of rules that defines how information is transmitted between the elements of a communications network. Generally, these rules define the semantics, synchronisation and syntax of communication and any error detection and correction methods. Protocols may be implemented by hardware and/or software, but within the context of the smart home implementation is handled by software.

2.2 Overview of Typical Features

Open and closed systems

Communications systems are either *open* or *closed*. An *open* system enables communication between different devices (with different manufacturers), without the need for a proprietary gateway or hub to pass information from one system to another. *Closed* systems cannot be accessed by any external device (other than those using the same closed protocol) without the use of a suitable interface or gateway.

Furthermore, protocols may be *closed*, where a single manufacturer or group of manufacturers has rights to them, or *open*, where they can be used by many manufacturers. Although closed protocols reduce the interoperability of products, there are several reasons a developer might choose to keep a protocol closed, such as:

- *Intellectual property*: if a protocol is especially useful for a class of products, then a developer may keep it closed in order to retain their advantage over competitors;
- *Security*: some proprietary protocols are highly encrypted to prevent data theft.

Transmission media

As shown in Figure 1, it is expected that in many cases smart home technologies will communicate with each other without information being passed to the cloud; such in-home communication is referred to as the Home Area Network (HAN). Within the HAN, smart home technologies usually communicate using protocols that are transmitted wirelessly. Additionally, some protocols may be transmitted using wires or cables, for example, using the Alternating Current (AC) wiring in a house or fibre-optic cables. Furthermore, some protocols may be transmitted using more than one communication medium, allowing interoperability, for instance, over radio frequencies and through power distribution lines.

Some radio frequency protocols used in smart home communications systems operate inside the licence exempt spectrum, originally allocated to products such as microwave ovens. A key advantage of this is that there is no cost associated with applying for a licence for dedicated frequency band. Consequently, communication over these bands may be susceptible to interference from other devices working at the same radio frequency. Design features (and trade-offs) may need to be incorporated to avoid such interference. Networks (or segments of networks) that operate over power lines are not susceptible to this kind of interference, but can be susceptible to mains borne interference. However, powerline communication can interfere with other radio services and so there are strict limits on the power and frequencies of such transmissions, thus limiting their range.

Range, Latency and Data Transfer Rate

Important signal qualities such as range, latency, the maximum data transfer rate and transmission frequency are interrelated. It has been noted by several parties[12] that the 868MHz radio band is the most suitable low-power band to be used in the UK, due to its good range and minimal attenuation through walls. However, the limited bandwidth at 868 MHz compared to the 2.4 GHz ISM bands limits the rate of data transmission and can cause particular problems in moving some radio protocols into this band.

Latency, the time delay between the initiation of the transmission of data and the final delivery of the data, typically arises from several distinct effects. In the case of in-home communication, important causes of latency may include[13]:

- *Serialisation delay*: the time taken to convert data from bytes (units of memory on a computer) into the bit streams that are transmitted over communications media
- *Delay associated with protocols*: many communication protocols send signals that underlie the transmission of information (for example, signals that address any errors). These signals have their own latency which in turn contribute to the latency of the information transmission
- *Queuing latency*: the amount of time information waits in a queue prior to transmission over an over-utilised link

Many devices also have standby periods, where they periodically check to see if messages have been sent to them in order to save power. These could be from orders of seconds to tens of minutes and for most protocols would be the limiting factor in response time.

The maximum data transfer rate[14] is the maximum amount of information that can be conveyed in a unit of time. The importance of this rate varies with application. For example, on/off signals may require a very low transfer rate, whereas live video transmission could require a much higher transfer rate.

Signal range defines the area in which transmissions may be received. Some technologies are capable of extending this range when more devices are connected, so that each connected device becomes a transmitter. These are called *meshed networks*, which increase range at the expense of increased latency and power consumption. Barriers such as walls can cause significant attenuation for many in-home communication systems. Powerline protocols (which transmit information through electric wiring) are also available. In consultation, developers stated that these can generally cover a whole building. However, powerline transmission can only reach mains connected devices, so portability is an issue. To avoid these problems, some communication systems are '*dual meshed'*: they can communicate through electric wiring and over radio frequencies, and each device on the network acts as an interoperable transmitter between both media. Hence, the wireless signal may be extended into multiple rooms using the building's electric wiring. Similarly,

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[12] Industry consultation (2016)

[13] An instructive introduction to this area is available at the following link; note, however, that this document is not peer-reviewed: https://www.o3bnetworks.com/wp-content/uploads/2015/02/white-paper_latency-matters.pdf (Accessed April 2016)

[14] Elsewhere, this bit-rate may be referred to as bandwidth. This is avoided in this report to avoid confusion: in the context of communications this can also refer to the difference between the upper and lower frequencies in a signal frequency spectrum.

some powerline protocols have been developed that are built on the same basic structure as prominent wireless protocols. This makes translation between the two protocols easy, and can also be used to extend the range of a network.

Prominent Communication Protocols

ZigBee

The ZigBee specification defines a group of communication protocols. It is usually used with low power radios, and as such has a low range (~50m maximum)[15], however, it is a meshed network, so may be readily extended. ZigBee is only available in the 2.4 GHz ISM band. An 868 MHz version is being standardised. It is an open standard and there are already over 950 ZigBee-certified products, 392 of which are smart energy products[16]. ZigBee forms the basis of GB smart meter HAN communications.

Z-wave

Z-wave is another meshed (for mains powered units) protocol, which operates at 868 MHz. Unlike ZigBee, Z-wave is a (partly) closed protocol[17], owned by Sigma Designs. The range of available Z-wave devices includes numerous home energy products and smart home devices. At present, there are two suppliers of Z-wave transceiver chips – Sigma Designs and Mitsumi.

It is a low powered protocol, meaning that devices can be battery powered. Like ZigBee, Z-Wave battery devices can go into ‘sleep’ mode, and hence have a high latency. Due to the lower frequency, Z-Wave has a larger range than ZigBee.

Wi-Fi

The Wi-Fi Alliance claims that Wi-Fi is used in one quarter of the world’s homes[18]. It is not a meshed network but it has a much higher data transfer rate than Z-wave or ZigBee. Wi-Fi has become prominent because it is used to facilitate wireless connection to the internet. Similarly to Z-wave and ZigBee, some smart-home devices use Wi-Fi to receive and send information. However, Wi-Fi has another important role. Most smart devices mentioned in this report upload information to the internet, which can then be accessed using a web portal or a smartphone or tablet based application (which acts as the user interface). As a leading wireless internet connection method, Wi-Fi is likely to form the link between control devices and user interfaces in many cases. Moreover, connection to the internet has several benefits: data processing and aggregation can occur in the cloud, and remote control is possible from beyond the home.

There has recently been rapid progress in the development of a low power, long range version of WiFi, WiFi HaLow[19], intended for use in Internet-of-Things applications and the domestic HAN market. WiFi HaLow is expected to operate in the 2.4 GHz, 5 GHz and 900 MHz bands. It will use the same MAC layer as standard WiFi, which will enable straightforward connection to the internet.

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[15] http://www.tutorial-reports.com/wireless/ZigBee/ZigBee-characterstics.php

[16] http://www.ZigBee.org/

[17] This has a degree of openness, for example an organisation called OpenZWave (http://www.openzwave.com) are developing an open source C++ library allowing developers to incorporate Z-Wave functionality into their applications.

[18] http://www.wi-fi.org/who-we-are

[19] http://www.wi-fi.org/news-events/newsroom/wi-fi-alliance-introduces-low-power-long-range-wi-fi-halow

Bluetooth

Bluetooth communication can act as an alternative to Wi-Fi where communication does not occur over the internet[20]. It is a short range, wireless technology and allows close range control of devices. However, there are several different varieties of Bluetooth designed for different applications such as: Bluetooth Low Energy, which allows devices to communicate for months on coin-cell batteries without need for replacement, and Bluetooth High Speed, which has a high data transmission rate. Most smartphones and laptops are Bluetooth-enabled so can be used in conjunction with Bluetooth as user interfaces. Compared to Wi-Fi, standard Bluetooth has a low data transfer rate and a higher latency.

Layers, TCP/IP and the OSI Model

The Open Systems and Interconnection (OSI) Model was developed to increase the interoperability of computing and communication systems by standardising and characterising their communication functions, though the not the hardware and software which form them. It splits the system into *abstraction layers* which characterise and standardise elements of the underlying structure of the system. This structure is generally hierarchical, and each layer serves the layer above it, and is served by the layer below it.

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[20] Bluetooth does have some internet interface capacity, but this is comparatively limited.

Table 3. Summary of the OSI model

Layer	Description
Layer 7: ***Application***	Specifies how different *hosts*[21] can communicate with one another and displays transmitted information to the user
Layer 6: ***Presentation***	Checks that information is transmitted in the correct format for the recipient, for example, the presentation level may check data formatting
Layer 5: ***Session***	Tracks communication between *hosts* and controls and coordinates their interconnection
Layer 4: ***Transport***	Provides services for *host to host* communications such as ensuring data is delivered reliably
Layer 3: ***Network***	Responsible for forwarding packets across a network. For example, the layer may forward packets through intermediate routers, thus instructing the data link layer to translate data and pass it to the physical layer
Layer 2: ***Data Link (MAC)***	Translates bits into packets (in transmission) and packets to bits (at reception) and passes to and receives packets from the physical layer also checks errors in transmission
Layer 1: ***Physical (PHY)***	Defines the physical aspects of communication, and converts information from the data link layer into signals

Another model is the Transmission Control Protocol / Internet Protocol (TCP/IP), the standard on which the internet is based. This has a similar structure to the OSI model, but essentially combines the functionality of the data link and physical layers into one layer, the *Network Interface*, and combines the *Session, Presentation* and *Application* layers in a single *Application Layer*. It also differs somewhat from the OSI model in that there is no strict hierarchy; the layers are simply groups of functions.

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[21] Here a host is a device connected to a communications network

Table 4. Overview of the TCP/IP Model

Layer	Description
Layer 4: *Application*	Ensures that the network's services are available to applications that need to access and utilise them
Layer 3: *Transport*	Ensures that the data is transmitted reliably
Layer 2: *Internet*	Responsible for constructing the packet of data to be transmitted, this involves assigning source and destination addresses to the packet
Layer 1: *Network Interface*	Prepares internet protocol data for transmission

ZigBee was designed to fit the OSI model, and Wi-Fi is formed of the lower two levels of this model. Conversely, Z-wave has a five layer format, which has enabled connectivity with local IP networks[22]. Bluetooth has its own eight layer system, which roughly aligns with the ISO model.

ZigBee	Z-Wave	Wi-Fi	Bluetooth
Layer 7: Application	Layer 5: Application		Layer 8: Application
Layer 6: Presentation			Layer 7: RFCOMM/BNEP/SDP
Layer 5: Session			Layer 6: L2CAP
Layer 4: Transport	Layer 3: Transport		Layer 5: Host Control Interface
Layer 3: Network	Layer 4: Network		Layer 4: Link Manager
			Layer 3: Link Controller
Layer 2: Data Link (MAC)	Layer 2: MAC	Layer 2: MAC	Layer 2: Baseband
Layer 1: Physical (PHY)	Layer 1: PHY	Layer 1: PHY	Layer 1: Radio

Table 5. Outlines the layering of ZigBee, Z-Wave, Wi-Fi and Bluetooth

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[22] http://z-wave.sigmadesigns.com/docs/brochures/ZIPR_br.pdf

Current Market and Future Development

Among the Smart Energy Controllers reviewed, communications were dominated by the common protocols introduced above. There are also a number of less frequently used, proprietary protocols that are used either for standalone devices or for smart home systems produced by one manufacturer (or a co-operating group of manufacturers).

Current market costs have been collected for a wide range of smart home energy products. The sources for these costs are provided in the accompanying *Home Energy Controller Product Review* database. The cost of integrating a communications protocol varies between protocols and the level of integration. ZigBee, for example, costs $1.50 (~£1) for a silicon chip and $2.50 to $3.00 (£1.75 to £2.10) for a full solution[23]. Cost data is largely unavailable for other protocols, but the information collected suggests that the cost of enabling devices to use common protocols in products is usually in the order of a few dollars.

In the short term, more entrants can be expected into this space, including dual-meshed protocols and powerline protocols. There was a broad consensus among the stakeholders consulted that the communication protocol used by the majority of smart home energy control technologies would converge towards a common protocol, and that this would happen over a relatively short timeframe. One of the stakeholders suggested that such a convergence may be likely to occur within the next 3-5 years[24]. However, it is important to note that such a convergence is not necessarily a pre-requisite for wide deployment of smart controls, and a scenario can be envisioned where several communication protocols co-exist (for example, in different regions, households or product groups). Indeed, a large number of new protocols are currently under development. It was also generally felt among most industry stakeholders that Government intervention in this area is not desirable, due to potential adverse impacts on the level of innovation. In one case, it was indicated that the promotion of one protocol or standard by the government would help the market to settle this issue. The protocol which may eventually dominate could already be prominent; it could be an upgraded version of an existing protocol or it could be yet to emerge. In the latter case, this convergence could be delayed, since it takes many years to develop a protocol. One stakeholder also suggested that this communications protocol is likely to be based on a sub-GHz frequency band (e.g. 868MHz), as this is best suited to low power wireless communications within a typical UK home[25,26]. Ultimately, it is likely that communications will be wireless in order to reduce costs, however, they may incorporate powerline communications with radio to provide a more reliable Home Area Network (HAN).

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[23] A full solution consists of a module which includes the electronics accompanying a transceiver chip allowing it to interact with the device in which it is embedded.

[24] BEAMA, February 2016.

[25] BEAMA, February 2016.

[26] The only prominent smart-home protocol currently operating in the 868MHz band is Z-wave. The ZigBee alliance are in the process of standardising a version in the 868 band, and Bluetooth does have a solution in this band, but this is not typically found in smart home products.

2.3 Gateway Devices

Function

A gateway is a piece of hardware that can interface between two or more networks. Hence its basic function is to provide system interoperability. Interoperability may require processes such as protocol conversion, fault isolation and signal translation.

The most relevant requirement of interoperability to this report is protocol conversion, whereby the gateway translates one protocol to another. Translation enables a network of smart products to extend beyond one communications protocol and allows communication between two devices that are built to communicate using different protocols. For example, the latest version of the Vera Plus controller (released in early 2016) can act as an interface between ZigBee, Bluetooth and Z-Wave (and Z-Wave Plus), and connect a network of up to 220 devices.

Though not strictly a gateway functionality, many gateways integrate their own user interface that can control an entire network of devices, even if each connected device has a dedicated user interface. For instance, the hub Vera Plus can control the Nest thermostat (which has its own smartphone application) and a Yale Keyless Connected lock (which cannot be controlled from the Nest application), and enables simultaneous user control of both through a single smartphone application.

Some gateways are designed to incorporate non-smart devices into a network. Suppose a home has Infra-Red (IR) and radio controllers for an air conditioner and a television, the radio-frequencies of these controls may be programmed into a gateway that interfaces between traditional IR communications protocols and Wi-Fi. One example is the RM-Pro universal remote control centre; each gateway can control up to seven devices. Control of these devices is enabled by a single smart phone application which accesses a library of clones of different controls. In this case, incorporation of new devices is very open: a user can build a clone of the desired remote on the application, if a suitable clone is not already available.

Figure 2. The SmartThings Hub[27]

Current Market and Future Development

Several smart home systems require dedicated gateways which interface between their proprietary protocols and the internet. There are also multiple gateways designed to give

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[27] Photo from (http://www.amazon.com/Samsung-SmartThings-STH-ETH-001-Hub-Generation/dp/B00FWYESVQ)

ZigBee or Z-wave internet connectivity. A few multi-protocol hubs have been produced which interface between prominent protocols, for example the SmartThings Hub which is a gateway between ZigBee, Z-wave and other protocols such as wired ethernet. Typically, gateways cost £100 and upwards[28]. Given the cost of ensuring operability via gateways, according to the consensus among industry stakeholders consulted, it is deemed likely that consumer preference will drive convergence towards a dominant protocol (or a small number of dominant protocols). However, existing gateways have high costs because current devices need to replicate the complete stack of all of the protocols they need to interface with. Power line and radio protocols which share layers above the physical layers will be less complex, and could save costs (indeed, this is the motivation for the use of the OSI model). Furthermore, they are currently sold in relatively low volumes, and it is anticipated that the cost could drop significantly with greater deployment.

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[28] For example, the smart things hub costs £100 (http://www.cnet.com/uk/products/smartthings-hub-and-sensors/)

3 Overview of Sensors

3.1 Sensors

Overview of Typical Product Functionality

Sensors monitor the external environment and provide data to a network. This data can be used to inform active control (where a user is informed by the User Interface (UI) and operates the controller in response) or to trigger passive control (where the controller responds automatically). From a home energy management point of view, the most relevant sensing capabilities are open door and window sensors, weather compensators, motion sensors, temperature sensors, humidity sensors, and light intensity sensors. Other common capabilities include vibration sensing and ultra violet sensing. Several sensors combine a few or all of these capabilities into one sensor.

Door and window sensors are typically used by security systems, but may also be used by heating systems to signal that the boiler should cease to fire when a window or door is open in order to avoid energy wastage.

Weather compensators are used to optimise heating operation based on the outside temperature (and potentially other parameters including wind speed and humidity). This capability does not necessitate smart functionality; mechanical weather compensators, for example, predate smart heating controls. In fact, internet connectivity can negate the need for individual weather monitoring altogether: many controls use an online weather forecast instead.

In-home temperature sensors may also be used for optimisation of heating operation. When used in conjunction with temperature sensors, remote-controlled, wireless Thermostatic Radiator Valves (TRVs) can be used to automate temperature control in each room.

Current Market and Future Development

The sensors reviewed are priced between £5 (for a temperature sensor[29]) and £170 (for a weather compensator[30]). Predominantly sensors are battery powered, although there are also some that are mains powered. Energy harvesting sensors, where energy required for the sensor operation is harvested from ambient light, the heat of its surroundings, or, in the case of self-powered switches, the kinetic energy used to push a switch are emerging.

As sensors reach mass market, it is expected that manufacturing costs will drop. Energy harvesting sensors may become more prominent: these would reduce power consumption and would require minimal maintenance.

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[29] The Fibaro DS-001 (http://zwave-products.co.uk/epages/c52574ce-7814-4e39-8602-e19657ce0eaf.sf/?Locale=en_GB&ObjectPath=/Shops/c52574ce-7814-4e39-8602-e19657ce0eaf/Products/109&ViewAction=ViewProductViaPortal&gclid=CMmpu92S_MoCFQUFwwodt4AC1w)

[30] The Netatmo Weather Station (https://www.netatmo.com/en-GB/product)

4 Overview of Current Smart Energy Controller Functionalities

4.1 Smart Heating Controls

Overview of Typical Product Features and Functionality

Among the smart heating controls reviewed, all products include remote/external control of temperature and the programming of heating schedules; this was the only functionality common to all products. Where a home has multi-zonal heating (i.e. several plumbed zones or several electric heaters), most products can control zones separately; however, many systems require a thermostat or temperature sensor per zone to do this. Most products allow separate control over hot water and heating.

On top of these, many products display more advanced functionalities. Multi-zonal temperature control can be achieved (in a hydronic system) by the incorporation of wireless TRVs[31], where the thermostat is incorporated into the valve. The set point of the TRVs is typically be set by the central heating control. As required by current building regulations, such systems require the functionality whereby once the TRVs have reached the set temperature, the controller shuts off the boiler.

Some systems can use Passive Infrared Sensors (PIRs) to detect movement in a room: this enables a control to heat only occupied rooms. Similarly, several devices have geo-fencing functionality. Geo-fencing uses the Global Positioning System (GPS) in a phone (or another device) to detect when the user is within a given distance of their home. This differs from Geo-location because Geo-fencing detects when a device enters a pre-set zone, whereas Geo-location pinpoints the location of a user. This functionality allows the system to heat up the house as the user approaches. It could also reduce the likelihood of redundant heating, for example, when the user is late home from work; alternatively, depending on the geo-fencing distance, it could also increase redundant heating if the user is near their home but does not require heating.

Several products have learning capabilities whereby they can learn the user’s occupancy routine and the user’s desired temperature settings for each room and adjust the heating accordingly. Similarly, some intelligent controls are capable of advanced environmental response. For example, a few systems can learn how long it takes a house to warm up (optimisation), and thus the optimal time to fire the boiler. Other products are able to detect open windows and shut off the boiler in response.

In some cases, products gather weather information via an internet connection or weather monitoring station and use this to optimise the heating system’s operation. For example, the system could adjust the heating schedule according to the outside temperature. Additional advanced control methods to optimise boiler operation include Time Proportional and Integral (TPI) control, and other algorithms designed to minimise boiler firing time. Some products go beyond TPI and enable modulating control of boilers. Modulation control can improve the efficiency of condensing boiler operation by delivering a more appropriate amount of heat to the radiator and thus minimising the return

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[31] TRVs regulate the flow of hot water into a radiator.

temperature of the water. Nest and Honeywell systems use OpenTherm, an open protocol to do this[32]; whilst Vaillant use a proprietary V-bus system to do this[33].

Monitoring of bills, energy usage and/or greenhouse gas equivalent emissions is available in a small number of controls. Many other controls simply inform the user of how long the boiler was switched on for or the temperature profile of their home.

Interaction with Home Energy Systems and the Internet of Things

Several smart heating controllers are manufactured by companies with a wider interest in the Internet-of-Things (IoT). For example, the Nest Learning Thermostat can be incorporated with other Nest products including smart cameras (Nest Cam) and smoke alarms (Nest Protect). Furthermore, Nest (among other Smart Heating Controls) is compatible with a range of smart energy products, including Whirlpool washing and drying machines and Lifx bulbs.

Current Market and Future Development

Current Market

Typical features of smart heating controls include external control, separate heating and hot water control, and multi-zonal control (either using TRVs or multiple thermostats). The rarer advanced functionalities are monitoring of electricity costs and emissions, geo-fencing and occupancy sensing.

The way these products are being marketed varies between manufacturers. For example, Google’s Nest Thermostat is marketed as a product that provides both energy savings and convenience. On the product website[34], energy saving statistics and claims that the thermostat constitutes “[A] brighter way to save energy” are presented with details of how Nest can reduce user interaction. Conversely, the website for Hive Active Heating[35] emphasises design and increased control rather than energy savings, with one short reference to how reduced heating can lead to financial savings.

Almost all smart heating controls require a gateway and a range of communications protocols are used, some proprietary, some open. On the basis of frequency among the products studied, ZigBee is the most common protocol used.

The smart heating controls reviewed, as shown in the accompanying *Home Energy Controller Product Review* database, currently cost in the range £165-249 for the main control device, excluding installation costs. Installation, as discussed in more detail in Section 9, is expected to cost a further £145. An important exception to this is that certain suppliers including Nest and British Gas[36] have offered installation included in the basic price. We note that the installation cost of standard (non-smart) heating controls is expected to be the same, so this cost is only additional to the counterfactual case where standard controls are being replaced before end-of-life. Non-smart digital programmable thermostats are typically priced between £25[37] and £120[38]. In many cases, additional

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[32] http://www.honeywelluk.com/documents/Literature/pdf/1084.pdf
[33] http://www.vaillant.co.uk/installers/products/vaillant-vsmart-13184.en_gb.html
[34] https://nest.com/uk/thermostat/meet-nest-thermostat/
[35] https://www.hivehome.com/products/hive-active-heating/?gclid=CMuS6-OdkMsCFbEy0wod7IMNxA
[36] https://www.britishgas.co.uk/products-and-services/hive-active-heating.html
[37] https://www.google.co.uk/shopping/product/6807721447800576255?q=thermostat+timers&espv=2&biw=1093&bih=566&site=webhp&bav=on.2,or.&bvm=bv.113034660,d.ZWU&ion=1&tch=1&ech=1&psi=2TmrVsuQBML8O-

equipment may be required, incurring additional cost. For example, wireless TRVs are not included in the above cost, and are priced between £20[39] and £65[40], compared to manual TRVs which are priced between £7[41] and £37[42]. This cost excludes installation cost. The cost of installing TRVs is discussed in Section 9, and is expected to be approximately up to an additional £80 in the case where (non-smart) TRVs are not already in place. Where non-smart TRVs are already in place, the installation cost could be zero, as converting them can be done quickly by the user themselves.

Figure 3. The Nest Learning Thermostat, a smart heating control[43]

Future Development

If marketing succeeds in turning heating controls into an aspirational product, then mass market uptake of smart heating controls could be driven by the market. Alternatively, or in parallel, uptake could also be driven by Government policy, either through regulation or through a public subsidy or grant scheme, or low cost financing (this is already the case for advanced heating controls in the Republic of Ireland[44]). Any Government role in driving the uptake of smart heating controls is likely to be on the basis of the energy savings, cost savings, usability and carbon emissions savings that they may bring; hence, we may

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iFkqgB.1454062043051.5&prds=paur:ClkAsKraXyiwh-j4hfRgx6c_HtX_-u-BRGOV16nlFb8dhZU9y2e0z4JCGJ6GW9Q1UddnpQa7PPWxXFVgxNZyvSdxlnOpCPbNEb4APPTmP-lwMHgItzer32yglBIZAFPVH72lvBzM6z7J06O37IyAGoj1xAeoaw&sa=X&ved=0ahUKEwit6rSe487KAhUCYA8KHdnCAlgQ8wIIwwIwAw

[38] Raychem TC Timer thermostat (https://www.rubberduckbathrooms.co.uk/raychem-tc-timer-thermostat?source=googlebase&kw=&fl=1000&ci=84151422735&network=pla&gclid=CMGa3K_jzsoCFSMHwwodrM0EEQ)

[39] Eq3 Wireless thermostat head (CC-RT-BLE) (http://www.conrad-electronic.co.uk/ce/en/product/1364875/?WT.srch=1&WT.mc_id=sea_shoppingWT.srch=1&WT.mc_id=google_search_UK&scamp=shopping&saddg=home-garden&gclid=CN6LsYTgzsoCFWsJwwodLAIBsA)

[40] Devolo Home Control 9356 Wireless Thermostatic Radiator Valve (

[41]http://www.screwfix.com/p/15mm-angled-trv-with-lockshield-white-chrome/31811?kpid=31811&cm_mmc=Google-_-Product%20Listing%20Ads-_-Sales%20Tracking-_-sales%20tracking%20url&cm_mmc=Google-_-Shopping%20-%20Heating%20and%20Plumbing-_-Shopping%20-%20Heating%20and%20Plumbing&gclid=CJeTkLjdzsoCFWsJwwodLAIBsA

[42] These costs do not include the larger costs of fitting manual TRVs, Which magazine estimated in 2012 that for small to large households (two bed to four bed) the typical cost of fitting manual TRVs is between £275 and £429 (http://local.which.co.uk/advice/cost-price-information-boiler-repair-central-heating).

[43] From http://www.pcmag.com/article2/0,2817,2412535,00.asp

[44] In the form of grants in the Home Energy Saving (HES) scheme (http://www.seai.ie/Grants/better_energy_homes/)

expect that the extent of Government intervention will depend on the emerging evidence base relating to the energy reductions or increases in energy consumption, associated with such products. While this evidence base continues to be weak, it is highly unlikely that smart heating controls could be regulated.

More systems are expected to become OpenTherm compatible or to develop and utilise their own proprietary or open methods of boiler communication and optimised modulation. There are also expected to be incremental improvements to functionality. For example occupancy sensing may become increasingly 'intelligent'. This could either result in boilers being operated for longer periods, increasing their energy consumption, or result in lower operating times when users are not present, decreasing their energy consumption.

Remote diagnostics may also become a widely available feature, with smart controls monitoring boiler operation and alerting users, installers and/or manufacturers when there are irregularities.

4.2 Electric Heaters with Integrated Smart Controls

Overview of Typical Product Features and Functionality

An alternative to the smart heating controls described above are electric heaters with integrated smart controls. Of such products reviewed, all can set schedules and be controlled externally. Moreover, they can all be used for multi-zonal heating (though usually this requires one heater per room).

Most products have in-built optimisation software that can learn how quickly the house reaches the target temperature, and some can learn the user's occupancy routine, respond to weather reports or monitor the system's energy consumption.

Interaction with Home Energy Systems and the Internet-of-Things

There appears to be little interoperability between the smart electric heating products currently on the market and the wider smart home ecosystem. Greater interoperability could deliver a number of benefits, which extend beyond simply having many devices linked by one user interface. For example, if a smart light is turned on, a smart heater could be set to respond to this, and start heating a room if it is below a given temperature.

Current Market and Future Development

Current Market

Smart Electric Heaters are currently priced between £280[45] (for a 2kW smart radiator) to £950[46] (for a 6kW hot water cylinder). Similar capacity non-smart electric radiators and hot water cylinders cost of the order of £100 less[47]. Most of the standard heating control

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[45] http://www.electricpoint.com/heating/electric-heating/dimplex-quantum-energy-system/dimplex-quantum-heaters.html?gclid=CJCL69H0ksoCFQTlwgodsToLhw

[46] https://www.fruugo.co.uk/dimplex-quantum-ecsd125580-100l-unvented-direct-fill-cylinder/p-4190076-9621202?gclid=CNSRsJf0ksoCFSX3wgod-kUA0w

[47] For example, the 2kW Adax Neo Electric Panel Heater costs £151 (https://adax-solaire.com/presta/gb/adax-neo-electric-panel-heaters-convectors-wall-mounted-neo-np/63-2000w-adax-neo-white-electric-panel-heater-wall-mounted-adax.html?gclid=CNzBqMC428oCFYPnwgodGoQFgg) and the Heatrae Sadia PremierPlus Industrial Cylinder www.discountedheating.co.uk/heatrae-sadia-premierplus-industrial-cylinder-6kw-300l-

measures are widely available, but electric systems that can heat water and provide separate heating control are not. Occupancy sensing, energy usage monitoring and weather compensation are also uncommon features.

Figure 4. The Dimplex Quantum Electric Heater[48]

Future Development

As electric heating systems such as heat pumps and next generation storage heaters become more widespread, motivated by the desire to decarbonise the heating system and due to the impact of schemes such as the Renewable Heat Incentive (RHI), smart electric heating may too become more widespread. As it becomes more widespread, the costs of smart electric heating are expected to decline. Due to the Eco-Design standards, a basic level of non-connected intelligence and smart control may become standard in electric heating controls. Furthermore, the potential of smart heating controls to provide Demand Side Response (DSR) services could further decrease their costs.

Smart Heat Pumps

Heat pumps with integrated smart controls typically allow remote temperature control and scheduling, and with multiple heat-pumps, multi-zonal control. Occupancy sensing is also available. The only smart heat-pump with available price information was the Daikin Emura, an air-to-air heat pump priced at £780 to £830 for a 2.5kW system and £1,200 to £1,300 for a 5kW system. Compared with the Mitsubishi Zen MSZ-EF, which is priced at around £700[49], the smart models are slightly more expensive than their non-smart counterparts. We note that these costs do not include the cost of installation.[50]

94050817.html?istCompanyId=900a3bad-522b-4af6-8801-046f5bc03260&istItemId=mrxxmamlm&istBid=tztx&gclid=CO3mtqTB28oCFRS6GwodmioPtA&gclsrc=aw.ds

[48] www.jcelectrics.com/

[49] www.airconditioningworld.co.uk/mitsubishi-electric-zen-black-msz-ef25ve-b-muz-ef25ve-b-2-5kw?gclid=CJ6f1Kfzg8sCFSH4wgodM34Aqw

[50] A quote for installation cost was not obtained.

Figure 5. The Daikin Emura[51]

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[51] From http://www.archiproducts.com/en/products/154170/split-air-conditioners-split-wall-mounted-daikin-emura-ftxg-l-daikin-air-conditioning-italy-s-p-a.html

4.3 Smart Lighting Controls

Overview of Typical Product Features and Functionality

Most products allow remote control of lights from inside and outside the home. Smart lighting can usually be dimmed, turned on and off and many change colour.

While this report is focussed primarily on more energy-intensive products than lighting (such as heating systems), it may be the case that consumer engagement with smart controls is stronger for these less energy-intensive products. This may influence the choice of communications protocols and home energy control architectures in favour of those that include and are compatible with systems that enable these products.

Many devices are compatible with sensors. These could be Passive Infrared Sensors (PIRs) that trigger the light to come on when motion is detected or sunlight detectors, which allow the light to adjust to external light intensity. Similarly, some controls can link with an alarm clock, turning the lights up as the clock sounds.

Several additional functionalities have been identified which are unrelated to the provision of lighting itself. For example, some lights can respond to text messages and emails; others have integrated speakers so they can play music and take calls.

Interaction with Home Energy Systems and the Internet-of-Things

Several smart lighting systems may be integrated into wider smart home systems such as Nest, SmartThings and Harmony. Furthermore, smart lighting controls have adopted the most prominent communication protocols, engendering significant interoperability potential.

Current Market and Future Development

Smart bulbs and lighting controls are an example of a product that may be technologically integrated and reactive to smart home systems. All energy-related functionalities are available across the majority of products.

Bluetooth-enabled bulbs are priced between £25[52] and £75[53] and other smart bulbs between £15 and £50. However, prices are lower when bulbs are bought in bulk, which may be anticipated for smart home systems controlling property-wide lighting.

It is expected that smart lighting controls will become increasingly integrated into smart-home systems and more widely adopted. As they become more widely adopted, manufacturing costs are expected to be reduced.

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[52] http://www.cnet.com/uk/products/osram-lightify-led-starter-kit/

[53] http://www.pcadvisor.co.uk/test-centre/digital-home/11-best-smart-lightbulbs-2016-uk-best-smart-bulbs-smart-lighting-3601758/

Figure 6. The Lifx bulb and smart phone app[54]

4.4 Smart Plugs and Sockets

Overview of Typical Product Features and Functionality

Predominantly, smart plugs[55] allow in- and out-of-home remote control, allowing the power to the socket to be turned on and off. Scheduling is also widely available. Many smart plugs allow energy usage monitoring and can send alerts when a limit of energy consumption is exceeded. More advanced monitoring is possible and some plugs can inform users of the cost of the energy a connected appliance has used.

Some smart plugs can be used in conjunction with PIRs to allow occupancy response, and, if they can connect to a hub, can respond to geo-fencing. If programmed to do so, some devices can detect when a connected appliance is in standby, and automatically switch off.

Interaction with Home Energy Systems and the Internet of Things

Many smart-plugs are Wi-Fi enabled, although a number of ZigBee and Z-wave enabled products are available. Similarly to the case of smart lighting interoperability, wide adoption of popular communication protocols lends smart plugs to integration with wider smart home networks.

Current Market and Future Development

At present, the smart plug market has a wide selection of products, but they don’t cover the full range of functionalities. Automatic standby shutdown, for instance, is rarely featured alongside external remote control functionality. The price of a plug with external remote control varies from £16[56] to £70[57], compared with standard plugs and sockets, which are typically priced at a few pounds.

Smart plugs are expected to become increasingly popular, and to drop in price as they are produced on a greater scale. As DSR services become more widespread, in some cases

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[54] From http://coolmomtech.com/2015/04/lifx-bulb-review/

[55] For brevity, from here on, this report refers to the category smart plugs and sockets as smart plugs.

[56] http://www.pocket-lint.com/news/133631-always-forget-to-turn-plugs-off-here-are-five-smart-plugs-with-smartphone-control

[57] http://shop.greenologic.co.uk/smart-plug-uk, this has additional features, such as standby disabling.

(e.g. electric resistive heaters, lamps, freezers and refrigerators) smart plugs may be used to enable these services. However, this functionality is limited to devices that may be directly switched on and off at the plug; many appliances such as washing machines, kettles and televisions would be unsuitable.

Figure 7. The Belkin Wemo smart plug and app[58]

4.5 Emerging Smart Devices

Overview of Typical Product Functionalities and Current Markets

Smart Electric Vehicle Chargers

Several Electric Vehicle (EV) chargers are able to respond automatically to tariffs, and can be pre-programmed with charging schedules. Remote control of this scheduling is also available along with remote monitoring of energy consumption. Remote diagnostics is also a potential functionality.

Currently, smart EV chargers are priced between £380 and £474[59]. However, EV chargers currently benefit from the Electric Vehicle Homecharge Scheme which provides a 75% contribution to the price of an installation (capped at £700 including VAT). This is expected to run until 31st March 2016 or until the budget is exhausted[60].

Figure 8. The WallPod EV Economy Boost[61]

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[58] From http://www.domotics.sg/reviews-on-belkin-wemo-home-automation/

[59] These are the EVlink Residential Garage (http://www.homedepot.com/p/Schneider-Electric-EVlink-30-Amp-Generation-2-5-Enhanced-Model-Indoor-Electric-Vehicle-Charging-Station-EV230WS/203670265) and the WallPod: EVeconomyBoost (http://evonestop.co.uk/shop/wallpods-ev/wallpodev-economy-boost-16amp-iec62196-5m-tethered-lead-type-2/)

[60] https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/418525/electric-vehicle-homecharge-scheme-guidance-for-customers-2015.pdf

[61] From http://www.elmev.co.uk/wallpod-ev-economy-boost-tethered/

Smart Electrical Storage

Domestic electrical storage may be used to manage micro-generation[62]. Examples include the Tesla PowerWall and the PowerVault, which charges automatically from the mains or from solar panels when on a low tariff, and supplies power when the tariff is high. This sort of technology maximises in-home consumption of micro-generated power.

Advanced storage is currently emerging in the UK, but current prices appear to be approximately £1,000 per kWh for a fully-installed 2-4 kWh domestic-scale system (see Section 9). All systems reviewed are basic on some form of lithium-ion battery technology. Overall, the cost of lithium ion batteries are expected to drop significantly over the coming years, particularly in batteries with higher power to energy ratios than the PowerWall, which are suitable for use in electric vehicles[63].

Figure 9. The Tesla Powerwall[64]

Smart Diverters

Another device that could be used for the management of micro-generated energy is a smart power diverter. A smart diverter is a device which can control the dispatch of any electricity generated that is surplus to the immediate electricity demand of the home to an alternative device, such as a battery or an electric immersion heater, rather than it being exported to the grid. Often these devices may be controlled remotely and can monitor energy diversion and some devices can adjust diversion schedules based on weather data. These devices have costs of the order of hundreds of pounds.

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[62] Defined as up to 50kW of electricity and 45kWth of heat.
[63] http://www.mckinsey.com/business-functions/sustainability-and-resource-productivity/our-insights/battery-technology-charges-ahead
[64] From https://www.teslamotors.com/presskit/teslaenergy

Figure 10 The Solar iBoost[65]

Smart Wet Devices

Smart washing machines, tumble dryers and washer-dryers can currently send alerts, respond to remote control, allow scheduling and facilitate remote diagnostics. No products have yet been identified that respond automatically to other devices (for example, an appliance that could respond to the availability of micro-generated power). Similarly, no products have been identified that respond to geo-fencing or motion sensing (for example, to ensure a user is in the home when the device operates). Motion sensors may not detect occupancy when occupants are immobile (e.g. asleep at night), but more complex intelligence could be incorporated (e.g. if a user was moving around the house after 10pm and then movement stopped, the system could be programmed to register occupancy).

Currently, smart washing machines and tumble dryers are available from Hotpoint, Samsung and LG[66]. These products are priced between £660 and £1,700, but there are relatively few products of this sort on the market.

Other smart wet devices include shower management systems that can minimise and monitor water use and leaks from taps. These also allow for remote control of taps and direct communication between taps and boilers for the optimisation of operation. The only example of this with energy saving capabilities reviewed was SmarTap, which is currently available in Israel (and not the UK).

Figure 11. The Samsung WW9000[67]

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[65] From http://www.reuk.co.uk/Water-Heating-with-Surplus-Solar-PV.htm

[66] For example, the Hotpoint WMFUG742, Samsung WW9000 and LG F14U1FCN8 washing machines, and the Samsung DV8000 tumble dryer.

[67] From http://home.bt.com/tech-gadgets/tech-news/samsung-unveils-smart-washing-machine-11363870485486

Smart Cold Devices

Smart cold devices (including fridges and freezers) can allow remote monitoring, programmable routines, motion sensing, can send alerts to users, facilitate remote diagnostics, monitor their energy use and respond to tariffs to minimise the cost of cooling.

These products are expected to become available for the home in the UK in 2016. Two products of this type[68] have been reviewed; both were recently showcased in Las Vegas. Upon release in the US, these products are expected to be priced between £2,600 and £3,500.

Figure 12. The Whirlpool French-Door Refrigerator[69]

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[68] For example, the Whirlpool Smart French Door Refrigerator (http://www.cnet.com/products/whirlpool-wrf995fifz-smart-french-door-refrigerator/) and the SAMSUNG Family Hub (http://www.cnet.com/uk/products/samsung-family-hub-refrigerator/)

[69] From http://www.dealerscope.com/article/pantry-inspired-smart-refrigerator-by-whirlpool-debuts-at-ces-2016/

5 User Interfaces

User Interfaces (UIs) fulfil two important functions in the Smart Home:

1. **Providing information to the user**. This can be raw data (for example, the amount of time a boiler in a house has been firing), or data that has been analysed (for example, energy savings achieved by automatically shutting off unused devices).
2. **Enabling active user control**. This could be from inside the house, by means of short range control, or external control over an internet connection.

User operability of UIs is paramount. To ensure correct and routine use by a non-technical user, UIs must be simple and intuitive.

5.1 In-home Displays

These UIs are intended for in-home use only and are usually displayed on screens dedicated to one controller, or to one class of controller. Alternatively, one device could form the user interface for many controllers. This type of UI could be a computer or a television. Another possibility is a user interface that draws together data from a number of devices, one example of this is a home energy display that draws together aggregated or disaggregated energy usage data from several devices across the home[70]. Incorporation of In-home displays into a product will increase its cost, however, dedicated in home displays are often provided with products such as smart heating controllers to increase operability for users who are not smartphone savvy, and to supply a back up to smartphone and web-based applications.

5.2 Smart Personal Devices and Web-Based Applications

Smart personal devices running web-based applications (apps) are another type of UI. Typically, these UIs communicate with controllers using the internet and enable remote control and monitoring of appliances. However, a number of Apps work with transmission systems that only allow smartphones to be used in close range of appliances.

Apps that enable remote control can usually simultaneously provide information. This allows real-time response of users to energy consumption within the home, for instance, if a smart home can detect its own occupancy and monitors its heating system, then it could respond by sending a notification to a smartphone based app, prompting the user to turn down the heating.

Often devices have dedicated Apps, but there are also Apps that control and link many appliances across different classes, allowing remote control of an entire smart home. Since Apps are software based, they are generally highly extendable and upgradable.

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[70] For example, the Efergy Engage System (https://engage.efergy.com/#appliances).

6 Roadmap for Future Development

6.1 International Experiences and Research

Internationally, uptake of smart controls has been predominantly market driven, but some Governments have taken measures to incentivise the uptake of certain components of the smart home energy system, such as battery storage and to research the potential benefits in areas such as DSR. Two interesting examples are Japan and Germany.

Japan

In 2011, the estimated value of the smart home market in Japan was £7.6bn (¥1.2tn), predicted to rise to £21.4bn (¥3.5tn) in 2020[71]. Following the Fukushima nuclear disaster in March 2011, all of Japan's 43 operable nuclear reactors were shut down, and a safety review introduced before operation could resume[72]. At the time of writing (Q1 2016), three reactors are in operation[73]. As a result of the reduced use of nuclear power, demand side management and efficiency became prominent issues, prompting significant interest in smart-home technology and DSR[74].

Founded in 1997 and promoted by the Japanese Ministry of Economy, Trade and Industry (METI), the ECHONET consortium, which includes members such as Panasonic, Toshiba, Mitsubishi Electric and Hitachi, released the ECHONET and ECHONET Lite protocols, the latter of which has been recommended by the Government as the best candidate for use with Home Energy Management Systems (HEMS)[75]. It is hoped that this will drive the uptake of smart home energy control technologies by offering greater interoperability within the smart home. Furthermore, all smart meters in the Japanese rollout can interface with ECHONET Lite and so this standardisation could enable device level DSR services[76]. Approximately 3.66 million smart meters were installed in Japan in 2014, with approximately 50 million expected to be installed throughout Japan by the end of 2024.

These protocols may be transmitted using either low power radios or powerlines. Work is currently underway to incorporate eight key groups of devices into the standardisation, thus incorporating them into a unified HEMS. These groups include: smart meters; electric storage units; photovoltaic (PV) solar panels; fuel cells; gas and oil water heaters; air conditioning; lighting and electric vehicle chargers.

In Japan the market for many of these groups of devices is large. As of 2014 there were approximately 1.7 million residential PV systems in Japan[77] and the country was the second largest producer of power from solar PV, with over 23 GW of installed capacity. This has put significant strain on the Japanese grid: RTS Corporation reported in March 2015 that 17.5 GW of Feed in Tariff-approved PV projects were in jeopardy due to insufficient grid capacity. In response to the growing strain the Japanese government introduced legislation. In 2014, METI began accepting subsidy applications from individuals and corporations for lithium ion battery storage with a capacity of 1 kWh or

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[71] http://www.fujitsu.com/global/documents/about/resources/publications/fstj/archives/vol50-2/paper05.pdf
[72] http://www.wsj.com/articles/japan-restarts-first-reactor-since-fukushima-disaster-1439259270
[73] http://www.nei.org/News-Media/News/Japan-Nuclear-Update
[74] Another significant driver for the uptake of smart-home technology in Japan is its potential role in the care of its aging population (http://siliconangle.com/blog/2015/03/30/the-latest-in-japanese-smart-homes-why-this-market-is-central-to-rd/)
[75] https://www.semiconportal.com/en/archive/news/main-news/111222-echonet-lite-specifications.html
[76] https://www.w3.org/2013/07/mmi/slides/Umejima.pdf
[77] http://www.iea-pvps.org/index.php?id=93

more[78]. The project has a total budget of ¥7bn and will give a subsidy of two-thirds of the device cost. For individuals the upper limit is ¥1mn.

Germany

According to a report by the Building Services Research and Information Association (BSRIA), Germany dominates the European share of the smart home market[79], and other studies predict[80] that there may be as many as 1.5 million smart homes in Germany by 2020. This has been emphasised by some utilities. For example, E.ON has partnered with GreenWave Reality to provide home automation and HEMS to customers. This will include management of PV and lighting. Furthermore, their platform will enable remote diagnostics. This decision was made after E.ON trialled GreenWave Reality's Home2Cloud system for two years in 75 households, and found a number of benefits including energy savings and increased user awareness of their energy usage[81].

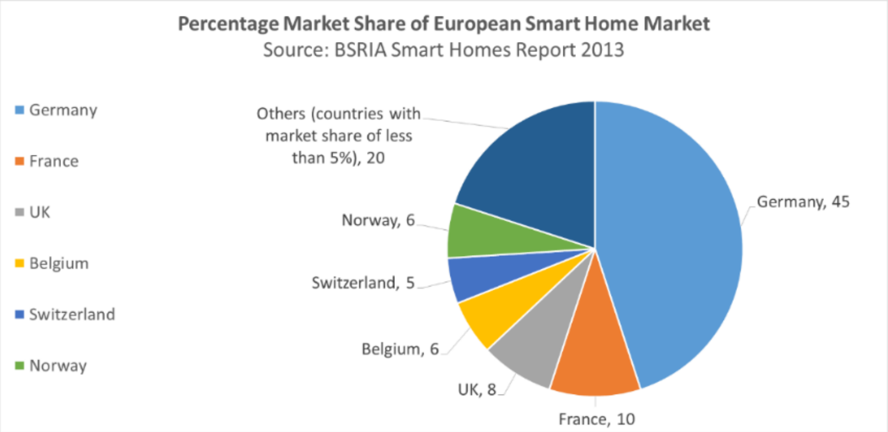

Figure 13. Division of the European smart home technology market by country[82]

Similarly to many other countries, legislation is driving a roll-out of Smart Meters. The German Energy Economy law sets out plans to ensure that 23% of German power meters are smart by 2020[83] and that by 2029 there are 14 million smart gas meters and 50 million intelligent meters and Smart Metering Systems[84].

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[78] http://www.meti.go.jp/press/2013/03/20140317004/20140317004.html (METI announcement in Japanese), http://www.energytrend.com/news/20140318-6379.html (press report in English)

[79] BRSIA https://www.google.co.uk/url?sa=t&rct=j&q=&esrc=s&source=web&cd=3&cad=rja&uact=8&ved=0ahUKEwjFw4nVz5DLAhWG7xQKHTTzBrIQFggsMAI&url=https%3A%2F%2Fwww.bsria.co.uk%2Fdownload%2Fasset%2Flow-carbon-heat-residential-network-.pdf&usg=AFQjCNGO6NC5qvyRlgPBSP0KXmNe4sGhoQ&bvm=bv.114733917,d.bGs

[80] http://www.engerati.com/article/million-plus-smart-homes-germany-2020

[81] http://www.eon.com/en/media/news/press-releases/2014/1/28/eon-extends-partnership-with-greenwave-reality-for-smart-home-solutions.html

[82] BRSIA Smart Homes Report 2013 (2013)

[83] This is significantly slower than the GB rollout which plans to install smart meters in all 26 million homes by 2020

[84] http://www.gtai.de/GTAI/Content/JP/Meta/Events/Reviews/JGIF13/jgif-staubitz-gtai-8.pdf?v=3

Prompted by the Japanese Fukushima disaster in 2011, the closure of nuclear power plants in Germany was brought forward to 2022 (rather than the previous date of 2036)[85] and Germany increased its emphasis on renewables with subsidies, energy efficiency with a proposed €1 billion tax reduction incentivising building efficiency[86] and DSR strategies.

Though smart home energy controls are still emerging in Germany, the Government has organised research into their potential, particularly in the area of DSR. In order to investigate the potential energy savings of smart home energy controls, the Federal Ministry for Economic Affairs and Energy (BMWi) launched the "E-Energy: ICT-based Energy System of the Future" project which explores smart energy management in Germany. As part of this initiative research is underway in areas such as business models, legislation and technical aspects of smart energy systems including investigation of the domestic DSR market.

The E-DeMa project[87], one of the projects under the E-Energy framework, considered data-driven electricity consumption management, with a focus on combined heat and power generators and domestic electric appliances. E-DeMa established field trials where gas-fired micro Combined Heat and Power (mCHP) units (1kw electrical power, 2.5kw heating) were installed and, along with over 1,500 homes and businesses, were managed by an aggregator. The study found that products available on the market can shift up to ten percent of electricity usage to off-peak periods.

The MeRegio[88] project tested local load shifting in conjunction with smart homes. The devices used in the test included smart dishwashers and deep freezers. Consumers were provided with an iPhone application ('Stromradar'), capable of monitoring energy use on the timescale of seconds to inform users of their energy usage. Domestic DSR was trialled at Freiarnt, where in-home systems were installed that received priority, price and efficiency signals from operators and responded by adjusting the power consumption of smart devices. The project is ongoing and is currently in its third of four phases.

Similar projects include the Moma project[89], which experimented with HEMS systems in 200 households which were programmed to minimise electricity costs for the home-owner, and the trial of dynamic pricing. They found 89% of users accepted the system and that variable tariffs had a significant impact on customers' energy use, with average price elasticities between 10-18%. This was shown to increase to as high as 30 – 35% for engaged customers[90]. Furthermore, they found that changing price could shift energy usage by 11 – 35%[91].

The Smart Watts system[92] in Aachen is another HEMS that shifts energy consumption to cheaper periods. The study found that 6-8% of demand could be shifted manually.

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[85] http://www.gtai.de/GTAI/Content/EN/Meta/Events/Invest/2014/Reviews/Powerhouse/Media/geiger-texas.pdf.pdf?v=2
[86] http://www.world-nuclear.org/information-library/country-profiles/countries-g-n/germany.aspx
[87] http://www.bmwi.de/English/Redaktion/Pdf/smart-energy-made-in-germany,
[88] http://www.meregio.de/en/index.php?page=eenergy-modell
[89] http://www.smartutilitiesscandinavia.com/Pages/Detail/3573
[90] http://www.advancedfp7.eu/Home/AD-Projects-Map/Model-City-Mannheim
[91] http://www.engerati.com/sites/engerati/files/01-Day3-1440-FriederSchmitt-EUW2013.pdf.PdfCompressor-399049.pdf
[92] http://www.smartwatts.de/aktuelles.html

6.2 Development of In-home Controls

It is expected that increased uptake of smart home energy controllers will be driven over the next decade by the advantages for the consumer, such as convenience[93], comfort and potential energy and fuel bill savings. Increasing spread of internet connections, low cost computing technology, smart phones and wider development of the IoT will enable growth of the smart-home market. Other ancillary drivers of smart home technology uptake include the potential for remote diagnostics and aggregated heating for landlords' estates and housing associations. However, stakeholders indicated that as the IoT becomes more developed, data privacy and protection issues will become increasingly prominent.

If significant energy and carbon savings are demonstrated through the use of smart controllers, then these could also be promoted by government legislation, and perhaps by grant support schemes (as is already the case for heating controls in Ireland under the Better Energy scheme). This will require the development of an appropriate policy framework, which works in parallel with effective performance in the commercial market.

Stakeholders indicated that they expect cost reduction of home energy controls due to increased competition and the economies of scale mass market uptake could unlock. Several companies indicated that they were focussing on ease of use and setup of their products in order to avoid customer queries and the associated costs.

Consultation with one stakeholder indicated that user desire for interoperability of smart control devices is anticipated to lead to the dominance of a single communication protocol within the next three to five years[94].

Electric technologies with reduced power consumption could be adopted alongside smart home technology, including a shift to low voltage DC circuits and the development of energy harvesting sensors.

There are several relevant directives, in place and planned, that could drive the uptake of heating controls. These include:

- **Directive 2010/31/EU of the European Parliament (2010):** All new buildings must be nearly zero-energy (NZE) by the end of 2020, though there is not yet a strict definition of NZE[95].
- **Part L of the UK Building Regulations (2016):** This will set out the energy efficiency requirements for new buildings and buildings undergoing substantial refurbishment. These could (in theory) mandate the use of advanced or smart controls.
- **Energy Company Obligation (2017):** Energy suppliers will be required to show evidence of implementation of carbon emissions savings within the domestic sector. The inclusion of advanced or smart heating or other controls in these requirements could be encouraged by conclusive evidence of significant energy savings (if any).

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[93] From increased automation and remote control

[94] BEAMA, February 2016.

[95] https://ec.europa.eu/energy/en/topics/energy-efficiency/buildings/nearly-zero-energy-buildings

- **Energy related Products Directive (2015):** In 2015, an EU Energy related Product (ErP) directive came into force that set efficiency requirements for boilers. A rating system was introduced, and products were labelled according to an efficiency rating (in percentage points). Poorly rated water heating products (rated F or G) ceased to be permitted. For heating systems the efficiency rating is assigned, and then an additional percentage rating is added based on the standard of the heating controls, this combined indicator of the whole system's efficiency then defines the overall rating of the control.

Table 6. Class rating for heating controls in the ErP legislation

Class rating[96]	Product / Usage	% rating
Class I	**On / off room thermostat:** Room thermostat that controls the on / off operation of heaters	1%
Class II	**Weather compensation:** When used with modulating heaters	2%
Class III	**Weather compensation:** When used with on / off output heaters	1.5%
Class IV	**TPI room thermostat:** When used with on / off output heaters	2%
Class V	**Modulating room thermostat:** When used with on / off output heaters	3%
Class VI	**Weather compensation and room sensor:** When used with modulating heaters	4%
Class VII	**Weather compensation and room sensor:** When used with on / off output heaters	3.5%
Class VIII	**Multi-sensor room temperature control:** For use with modulating heaters	5%

Table 7. Combined class ratings of heating control and system efficiency in the ErP legislation

A+++	A++	A+	A	B	C	D	E	F	G

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[96] Tables adapted from (https://www.plumbcenter.co.uk/wcsstore/PlumbCenter/Attachment/static/static-content/erp-zone/erp-pdf/New-ErP-Info-Guide.pdf)

≥150%	≥125%	≥98%	≥90%	≥82%	≥75%	≥36%	≥34%	≥30%	<30%

6.3 Demand Side Response Market

The non-domestic DSR market is developing, initially with large industrial energy users, and is expected to grow over the next five years, with increasing participation of smaller energy users. In large part the predominance of large industrial users in the DSR market is driven by the large cost premium for customers to be on fixed energy price contracts, with the very energy-intensive industries preferring to take on the risk of variable energy pricing themselves to avoid this premium. It is likely that the opposite is true of other commercial, SME and domestic users, who are likely to prefer to pay the premium for fixed contracts.

A domestic DSR market is likely to develop over a longer timescale, but most industry stakeholders expect that such a market could become well established within the next decade. However, we note that this is strongly dependent on whether domestic customers can be persuaded to switch to DSR tariffs, when the majority of evidence suggests a large barrier to switching due to the perceived hassle of doing so.

Several trials are underway that provide domestic DSR and look at the arrangements required for full commercial provision. These include: the ACCESS[97] project which matches storage heater demand to local renewable generation in real time in Scotland; the Real Value project[98], a Horizon 2020 funded project installing Glen Dimplex Quantum Storage Heaters, controlled as a virtual power plant (mainly in Ireland); and the Sunshine Tariff trial[99], a WPD and Tempus Energy project investigating the shifting of domestic consumption to periods of high solar generation. Furthermore, VCharge have secured a contract with National Grid to provide up to 60MW of frequency response from domestic storage heaters[100], approximately 5% of National Grid's primary frequency response contracted requirement.

During consultations, a number of stakeholders indicated that they have plans to develop domestic DSR offerings. A number of companies are active in this space, mainly on a trial basis currently, but intend to develop domestic DSR as a significant part of their business. One motivation for suppliers to provide domestic DSR services is the opportunity for enhanced customer retention that these services can bring.

While smart controls are not necessary for DSR, their uptake by customers (driven by other benefits such as convenience, comfort and efficiency) offers a low cost route to automated domestic DSR services, because control technology is already in place. The participation of domestic users in DSR is likely to be closely linked to the uptake of smart home energy controllers, and will be reinforced by the wider deployment of electric or hybridised heating and of EVs. However, as the DSR service becomes more widespread and profitable, the cost of smart controls may be driven down, with aggregators offering discounts in return for service contracts.

At present, technology developers are focussed on large loads for domestic DSR such as heating, EV and domestic energy storage. It is not clear when this may be extended to other loads such as wet devices, however this is being trialled in Germany.

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[97] http://www.accessproject.org.uk/
[98] http://www.realvalueproject.com/
[99] http://www.wren.uk.com/sunshine#about
[100] https://www.ofgem.gov.uk/sites/default/files/docs/2015/09/consultation_response_-_vcharge.pdf

Currently, the technology to enable DSR seems to be developed, but commercial structures are not. For example, it is unclear how a commercial structure will be created that delivers savings to consumers, utilities, suppliers and other stakeholders. This could be facilitated by time of use tariffs for the end customer; alternatively this could be handled ‘behind the scenes’ with third parties optimising system operation, with limited active participation from the end user.

The developments described in the above sections are illustrated in the timeline below.

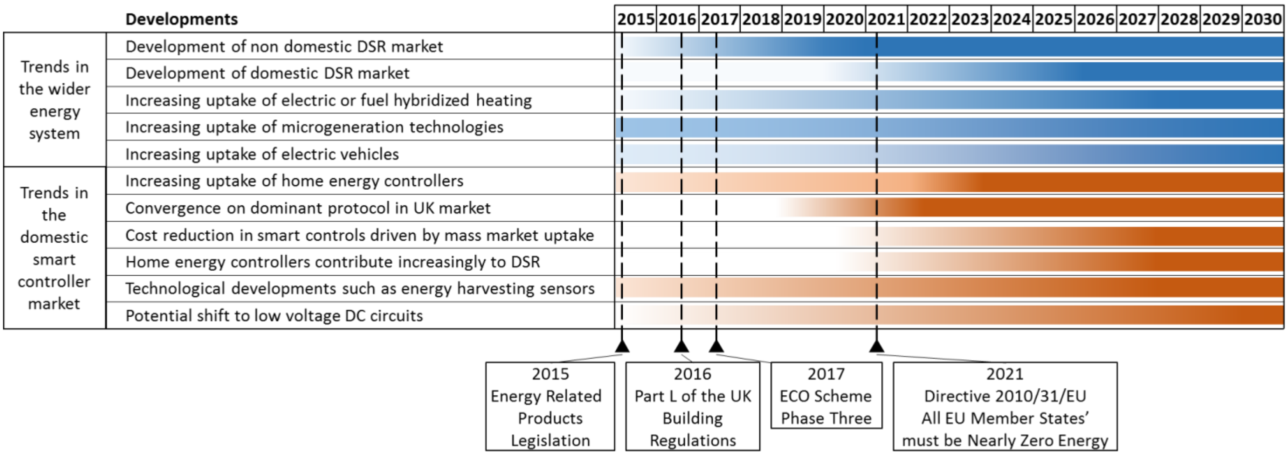

Figure 14: Illustrative timeline of anticipated developments in the smart home - energy sector

7 Home Energy Controller Barrier Analysis

7.1 Methodology for barrier analysis

In partnership with DECC, we have identified a range of stakeholders representing the range of organisations expected to play a role in the emerging smart home energy control industry. The 17 organisations consulted include manufacturers of home energy controllers, manufacturers of gas and electric heating appliances, developers of communications protocols for smart products and industry bodies representing manufacturers, utilities and contractors[101]. Through this consultation, as well as through a literature review, we have identified a range of barriers to the uptake and integration of home energy controllers. We have also assessed each barrier qualitatively in terms of ‘risk’ (how likely it is to apply) and ‘relevance’ (the importance of its potential impact) based on the input from industry.

In order to provide context to the barrier analysis, we describe in the following sections the various stakeholders in the connected home, and the existing standards and legislation.

7.2 Connected home stakeholders

There are a large number of interacting stakeholders that have a role in the connected home, either through a direct relationship with the customer or through smart home impact on their business functions. These stakeholders are mapped in the diagram in Figure 15 below. The roles of the stakeholders are described in more detail in Table 8.

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[101] A full list of organisations consulted is provided in the Acknowledgements section at the front of this report.

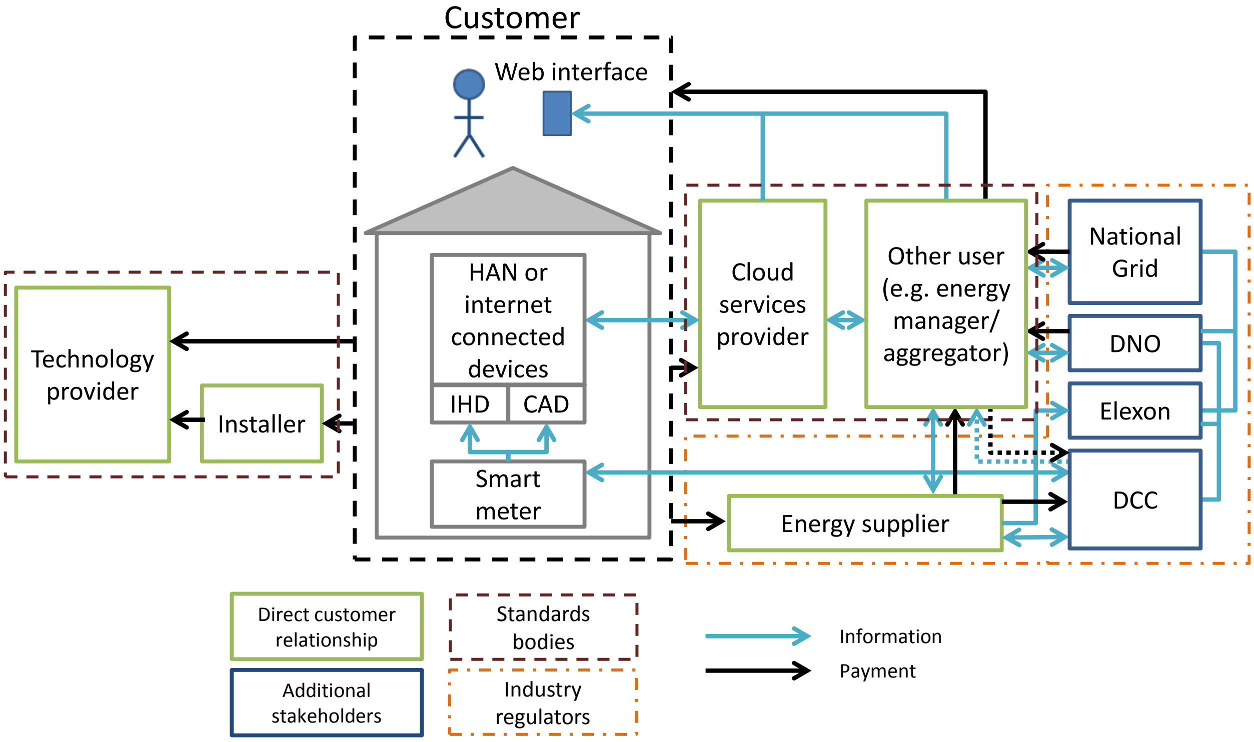

Figure 15: Map of stakeholders with a role in the connected home, energy supply and demand-side response

The activities and interfaces between stakeholders are governed by agreed standards, maintained by standards bodies. The stakeholders covered by these are indicated in the above diagram. Further information on the relevant standards in the connected home space, both current and under development, are given in Section 7.3.

Energy industry stakeholders have a role in the connected home through the smart meter infrastructure, and through the potential benefit that connected devices can offer them. Connected demand side devices that have some degree of flexibility can offer services to energy suppliers, Distribution Network Operators (DNOs) and to National Grid. This service provision would be via an aggregator who would manage the demand of a large number of customers, and thus offer a robust and reliable service.

Users of the Data Communications Company will need to pay DCC subscription fees, the level of which will depend on the type of DCC user they are. This will give them access to smart meter data (subject to consumer consent). Aggregators need to have a DCC relationship, as indicated by the dotted arrows in the above diagram, where they require access to smart meter data; we note this may not be required if data is available from smart home devices directly. Smart meter data may also be available in the home via a Consumer Access Device, which can communicate with the smart meter over the smart meter HAN and, in many cases, with other devices via the user's own HAN. The smart meter HAN communications will use ZigBee (Smart Energy profile), while the user HAN may use any of a range of HAN communication technologies.

It is worth noting that a single entity can take on a number of the stakeholder roles shown. For example, the provider of a technology may also take on the role of cloud services provider, or the energy supplier may also act as the customer's energy manager and a demand side response aggregator.

Table 8: Description of smart home stakeholder roles

Stakeholder	Description of role
Customer	The customer purchases or is given home energy control devices, typically for reasons of convenience, comfort and cost saving benefits. The customer can interact with these devices remotely via a web app, and, if desired, can access additional revenue by allowing external control of some devices by an energy manager within parameters set by the customer.
Energy supplier	Provider of customer's electricity and/or gas, responsible for smart meter roll out and for tariff provision and billing. The supplier can use demand side flexibility to balance its internal portfolio, and can thus benefit from services provided by the energy manager.
Technology provider	Provides home energy control devices, such as those described in Section 0. These may or may not require installation by a professional installer.
Installer	If the home energy control device(s) require professional installation, the installer carries out this installation. The installer may be chosen by the technology provider and/or the customer (or may be the technology provider) and may require certification.
Cloud services provider	Provides cloud services to allow the customer to access information from and control their in-home devices remotely via a web application. This access can also be granted to an energy manager, with the customer's consent, for external control of devices within parameters set by the customer.
Energy manager / Aggregator	On agreement with the customer, the energy manager or aggregator may access information from and control in-home devices so as to benefit electricity system stakeholders. This control will be within parameters set by the customer, and the customer will be paid by the energy manager for providing this service. The energy manager will use its aggregated portfolio of demand side flexibility to provide services to the TSO, DNO and energy suppliers. It will be paid by these stakeholders for service provision.
National Grid	National Grid is responsible for system stability and residual system balancing. Demand side response offered by flexible domestic loads may contribute to ancillary services it contracts. This contribution would be contracted via an aggregator (in this case, the customer's energy manager).
DNO	The customer's local DNO is responsible for maintaining the electricity network in its designated area. Domestic flexibility can

	help manage constraints on the local network and defer the need for network reinforcement. These services would be procured by the DNO through the customer's energy manager.
Elexon	Administers the Balancing and Settlement Code, ensuring that payments to electricity generators and charges to suppliers reflect the actual volume of electricity produced or consumed.
DCC	The DCC is responsible for establishing and managing the data and communications network to connect smart meters to the business systems of energy suppliers, network operators and other authorised service users of the network.
Industry regulators	Ensure that stakeholder internal operations, the interactions between stakeholders, and interactions between the customer and industry are conducted in accordance with legislation and with industry regulations.
Standards bodies	Maintain and, in some cases, certify standards that apply to the products and interfaces to ensure quality of service to the customer, value to the system as a whole and interoperability between devices.

7.3 Overview of existing and developing standards

7.3.1 Communications standards

Smart device interoperability

There are a number of activities currently ongoing at European level to standardise interaction between devices in the home. A range of initiatives has been launched to develop a single data model and communication architecture standard that would be applicable for smart appliances in all EU member states. This standardisation work aims to achieve common data objects and use cases that will apply across smart technologies, thus ensuring interoperability.

The ongoing standardisation initiatives at EU level include:

- The European Commission (DG connect) is collaborating with the European Telecommunications Standards Institute (ETSI) to develop standards for 'Machine to Machine' communications, termed ETSI M2M.
- DG Connect has also launched a study, carried out by TNO (Netherlands organisation for applied scientific research), that aims to define the semantic tools and data models to be used in the ETSI M2M architecture. These can then be applied by industry to produce ETSI M2M compliant devices. This study includes the development of a common ontology language called SAREF (Smart

Appliances REFerence) that can then be adapted for different standards and protocols to facilitate interoperability[102].

In order to achieve interoperability between devices for energy management purposes, CEN-CENELEC ETSI is proposing a standard architecture with a neutral interface. In this architecture, the individual device specific communication language (e.g. ZigBee, Z-wave etc.) and information model is translated into a common, neutral information model. This is then accessible via a neutral interface. A representation of this architecture is shown in Figure 16.

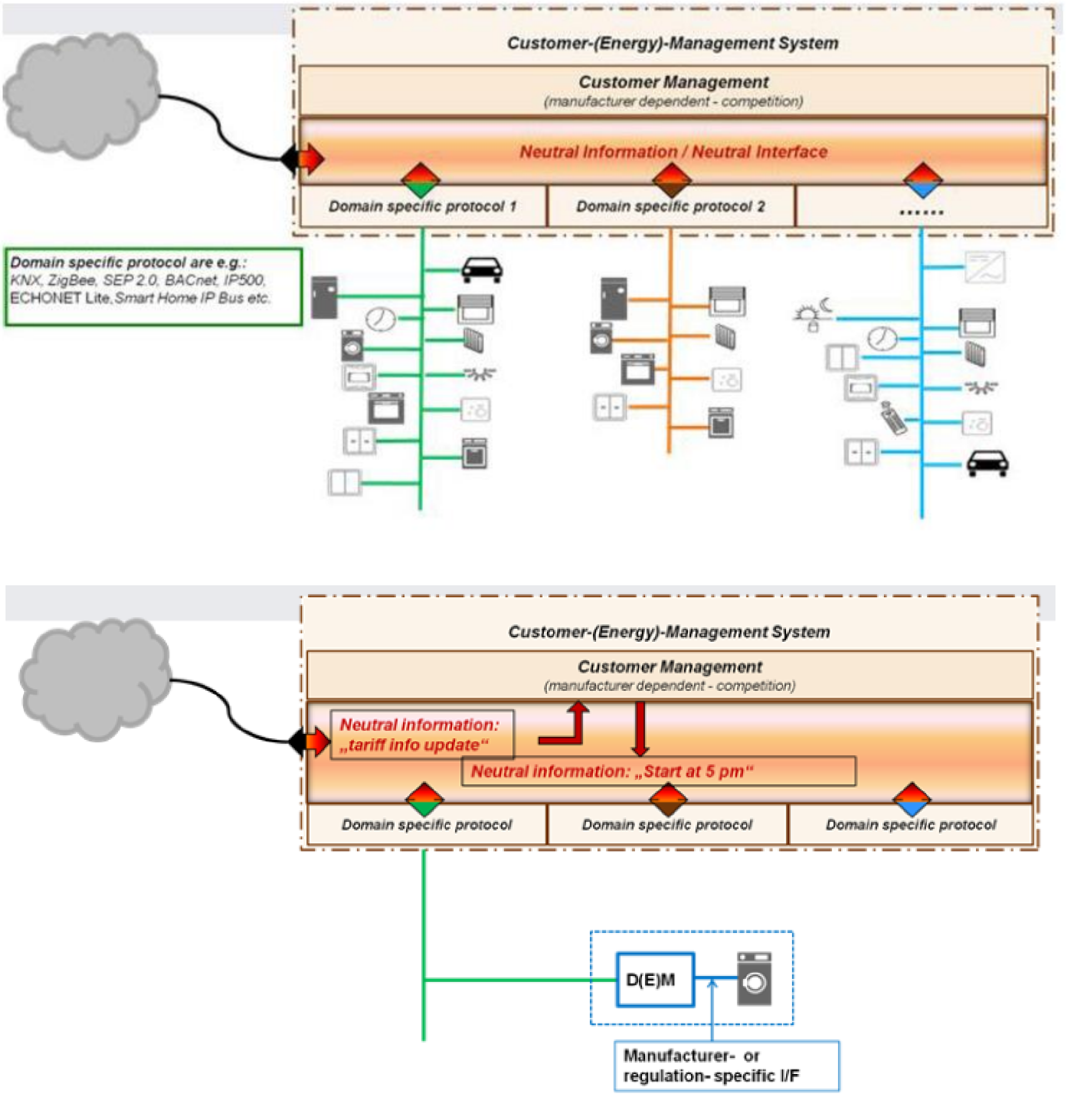

Figure 16: Neutral interface concept for smart device energy management, as proposed by CEN-CENELEC ETSI[103].

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[102] The final report of the study can be found at https://sites.google.com/site/smartappliancesproject/deliverables and the first version of the SAREF ontology can be accessed at http://ontology.tno.nl/saref/.

[103] Ecodesign Preparatory study on Smart Appliances, Task 1 report

A translator function must be implemented between each domain-specific protocol and the neutral information model. This translator can be integrated by manufacturers either into the gateway or directly into the smart device. The latter method would limit the number of domain specific protocol translators that would need to be included in the gateway.

In addition to EU level standardisation work, many consortia, commercial alliances and standard groups have been formed in the past few years to address the question of interoperability between internet connected devices. This is part of the wider desire for internet of things connectivity, of which smart appliances form a subset. The goal is to agree on a universal set of technical standards that will allow products to discover, connect and interact with other nearby devices, systems and services in a secure way, regardless of device type, operating system or brand. The development of such standards would allow developers to concentrate on creating innovative and useful services.

The question still remains of whose standards will be used and will come to dominate the market. Another point to note is that while different manufacturers may use the same standard communication technology and protocols, the information layer on top of this may be proprietary, hindering full interoperability. This barrier may be addressed by standardisation work such as that ongoing at EU level, described above.

Table 9: Selection of standardisation groups, consortia and alliances relevant in this space

Group	Description
Allseen Alliance	Industry consortium that provides the Alljoyn open source framework that allows devices and apps to discover each other and communicate. Includes certification program.
ZigBee Alliance	Alliance of businesses, universities and government agencies that creates, maintains and promotes ZigBee standards. Offers a ZigBee Certified program.
Thread Group	Group that develop, maintain and promote the Thread standard. Also run the Thread certification process.
Wi-Fi Alliance	Industry association that develops and promotes Wi-Fi standards. Runs Wi-Fi Certified process to designate products with certain standards of interoperability and security.
The ECHONET Consortium	Japan based organisation promoting the development of monitoring and remote control software and hardware for home appliances. Have developed a number of smart technology standards.[104]

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[104] Ecodesign Preparatory study on Smart Appliances, Task 1 report

Japan Smart Community Alliance	Japanese alliance of private and public sector members, including universities and local municipalities, with an interest in the smart technology and smart home sector.
OpenADR Alliance	Alliance of industry stakeholders who want to promote and ensure compliance with the Open Automated Demand Response (OpenADR) standard. This standard allows utilities to communicate demand response signals with each other and their customers using a common language.
American National Standards Institute	Private non-profit organisation that oversees the development of voluntary consensus standards.
National Institute of Standards and Technology	US Federal agency that works with industry to develop and apply standards. Have been given primary responsibility in the US to develop a framework for interoperability of smart grid devices and systems.
OASIS	International consortium of public and private bodies that develops and promotes the adoption of open standards. OpenADR is based on their Energy Interoperation Standard.
AGORA, Energy@Home and EEBus	These groups have agreed to establish a common language for the European smart home. Their aim is a plug and play solution that will ensure interoperability through an open standard communication protocol.
Z-Wave Alliance	Alliance of industry players that have adopted the Z-Wave standard, aiming to raise awareness of Z-Wave ensure interoperability (including via conformance testing) between Z-Wave devices.
Bluetooth Special Interest Group	Body that oversees the development of Bluetooth standards and licensing of Bluetooth products and trademarks.
European Telecommunications Standards Institute (ETSI)	Independent institute that produces globally applicable ICT standards, officially recognised by the EU as a European Standards Organisation. They are currently developing standards for machine to machine communications. Members include private companies and R&D organisations.
European Committee for	Association of National Standardisation bodies of 33 European countries, officially recognised by the EU as

Standardisation (CEN)	a European Standards Organisation. They provide a platform for the development of European standards and associated technical documents.
European Committee for Electrotechnical Standardisation (CENELEC)	CENELEC is designated a European Standards Organisation by the EU and is responsible for standardisationin the electrotechnical engineering field. They prepare voluntary standards and other reference documents like technical specifications and reports.
OneM2M	OneM2M[105] develops technical specifications addressing the need for a common M2M (machine to machine) Service Layer that can be readily embedded within various hardware and software.

Smart meter and smart grid interaction standards

The following European and international groups cover current ongoing activities relating to smart meter interface standardisation:

- *IEC/CLC/TC 13 "Electrical energy measurement and control" WG14 (Electricity Metering data exchange):* Have developed standards for the exchange of information between the utility head end system and the smart meter (the IEC 62056 series). Have also recently developed a new international standard for the provision of metering data from a meter to an external device, such as an IHD (IEC 62056-7-5).
- *CEN/TC 294 "Communication systems for meters and remote reading of meters"*: Similar work to the above, but focused on information exchange with non-electricity meters (gas, water etc.) and other supporting equipment (the EN 13757 series).

CLC/TC 205 Home and Building Electronic Systems WG 18 (Smart Grids) and WG 16 (Display): Currently working on the interface with the IHD and the customer interface. This includes looking at the frequency of information updates and the implementation of advanced tariff structures. They are developing standards for data models that can be used on top of the communication profiles identified by the above two groups (they will also link to existing data models of the IEC 62056 series).The European Commission set up a Smart Grids Task Force in 2009 in order to advise on issues related to smart grid deployment. This included an expert group on smart grid standards, who issued mandates between 2009 and 2011 (see, for example, EU mandate M/490) to European Standardisation Organisations to develop and update technical standards for smart grids and smart meters[106].

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[105] http://www.onem2m.org/

[106] More details on the work carried out by the Smart Grid Task Force can be found at https://ec.europa.eu/energy/en/topics/markets-and-consumers/smart-grids-and-meters/smart-grids-task-force.

In addition to European smart meter interface standard development work, there are a number of additional working groups at international level that are relevant for the interface between smart appliances and smart grid operation. These include:

- IEC/TC 57 WG21 “Interfaces and protocol profiles relevant to systems connected to the electrical grid”
- IEC/TC59 “Performance of household and similar electrical appliances“ WG15 “Connection of household appliances to smart grids and appliances interaction”
- CLC/TC59x “Performance of household and similar electrical appliances” WG7 “Smart household appliances”
- ETSI M2M
- ISO/IEC JTC 1/SC 25/WG 1 – Home Electronic System

These groups are working on various aspects of the development of standard demand response functionalities and commands for smart appliances. A joint working group of IEC/TC 57 WG21, CLC/TC 205 and CLC/TC 59X has been collecting use cases and requirements for the interaction between smart in-home appliances and the smart grid (these are listed in IEC TR 62746-2).

In GB, smart meters in the main rollout must adhere to the SMETS2 specification[107]. This defines the physical and functional requirements for smart gas and electricity meters. Smart meters will establish a smart meter Home Area Network (HAN) that will use the ZigBee Smart Energy communications protocol. This communications protocol has enhanced security over other ZigBee profiles and includes a common appliance interface command set which supports demand response and load control commands and the transmission of price data between devices[108]. It is currently going through the process of becoming a European standard through CENELEC. The smart meter HAN will allow consumption and tariff data to be passed from the smart meter to the In-Home Display (IHD) and a minimum of four Consumer Access Devices (CADs).

7.3.2 Efficiency standards

Ecodesign requirements

The efficiency and emissions requirements for appliances are set out in European Ecodesign requirements[109]. These may drive manufacturers to include appliance controls as the least cost way of achieving the requirements.

An Ecodesign Preparatory study on smart appliances is currently underway[110]. This work for the European Commission will examine the technical, economic, environmental, market and societal aspects of the introduction of smart appliances. This includes analysis of:

- Smart appliance functionalities
- Associated standards

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[107] The SMETS2 specification can be found at https://www.gov.uk/government/consultations/smart-metering-equipment-technical-specifications-second-version.

[108] http://www.ZigBee.org/ZigBee-for-developers/applicationstandards/ZigBeesmartenergy/

[109] The implementing regulations for Ecodesign requirements can be accessed in https://ec.europa.eu/energy/sites/ener/files/documents/list_of_ecodesign_measures.pdf.

[110] http://www.eco-smartappliances.eu/Pages/projectsummary.aspx

- Data and information exchange requirements for demand side response and energy efficiency
- Environmental impact and potential of smart appliances to reduce energy consumption and integrate renewables
- The potential for smart appliances to save energy compared to the potential to increase consumption

A number of initial scoping reports for this study have been published[111]. In addition, work has commenced which looks at the potential benefits, both economic and environmental, that smart appliance flexibility could offer the electricity system[112]. This examines the use cases for smart appliance flexibility and looks at the potential benefits such as RES integration, reduction in CO_2 emissions and reduced system costs.

Energy consumption requirements

The addition of smart capability to appliances may increase the energy consumption of their control electronics, both through the additional electronics and through the fact that they are always connected to the network in order to receive control signals.

The most relevant regulation setting consumption limits for smart devices and appliances is the EU amended standby regulation (COMMISSION REGULATION (EU) No 1275/2008). This sets a power consumption limit of 6W for relevant appliances (including household appliances and other consumer equipment connected to the mains) in network standby, effective from 1st January 2015. This limit is to reduce to 3W from 2017 and to 2W from 2019 (subject to review). This regulation also requires products to automatically switch into network standby when not providing a main function.

Building requirements

The recommended minimum standards for domestic heating systems controls in the UK are set out in the Department for Communities and Local Government publication 'Domestic Building Services Compliance Guide' (2010 edition)[113]. For a gas-fired wet central heating system, the recommended minimum controls include:

- A boiler control interlock which ensures that the boiler and pump are switched off when there is no heating demand
- Two space heating zones with separate timing and temperature controls for dwellings with floor area greater than $150m^2$
- Time control of space and water heating
- Temperature control of space heating via room thermostats in all zones and individual radiator controls such as TRVs on all radiators other than in rooms with a thermostat and bathrooms
- A separate hot water zone in addition to space heating zones, unless hot water is produced instantaneously such as with a combi boiler

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[111] http://www.eco-smartappliances.eu/Pages/documents.aspx

[112] http://www.eco-smartappliances.eu/Documents/5_Stakeholder%20meeting_151119_Task%205_final.pdf

[113] This provides guidance on what is reasonable provision for compliance with energy efficiency requirements and can be accessed at http://www.planningportal.gov.uk/permission/commonprojects/boilersheating.

The above apply to new and replacement heating systems, and are similar for other wet central heating systems.

7.4 Barriers and possible solutions

A number of barriers to the uptake of home energy controllers, or to the realisation of their potential benefit have been identified. These were gathered through consultation with industry stakeholders, and through a literature review. The barriers fall into the following categories:

- Technical
- Interoperability and standardisation
- Security and privacy
- Economic
- Regulatory and market barriers
- Consumer behaviour and awareness
- Barriers related to the smart meter rollout

The barriers in each of these areas are discussed in the sections below, along with any potential solutions. An overview of the barriers, and an indicative rating of their severity, are presented in a table at the end of this section.

7.4.1 Technical

The barriers to achieving the potential benefits of smart devices in the home are not generally deemed to be technical. Recent developments in low cost computing and communications, as well as the prevalence of high quality internet connectivity in homes, have driven the development of smart in-home devices. The challenge in many instances lies not with the technology (e.g. sensors, controllers, communication technologies), but in finding an appropriate use case for that technology and linking this to an attractive customer proposition. For example, some smart thermostat developers consulted for this project are wary of using occupancy sensing for heating control, as they feel that this method is not useful or robust enough to add value for the customer.

The main (potential) technical barrier raised during the stakeholder consultation is the (potential) insufficient reliability of in-home communications associated with some communications technologies. Industry stakeholders were not able to provide a measure of materiality for this concern, but overall this is not expected to be a key barrier for smart home energy systems.

Home communication requirements may be met by a combination of technology options, for example a meshed network of radio and powerline communications. Many industry stakeholders consulted agreed that the best wireless communications technology for a typical UK home was a meshed network using the 868MHz radio band for wireless communications within the Home Area Network (HAN). Currently the only standards available in this frequency band are proprietary, though a version of ZigBee in this band is being developed.

These communications reliability issues will need to be primarily addressed by the vendors of smart devices, as they must ensure that communications between their devices are reliable throughout the home in order secure consumer confidence in their products.

One stakeholder consulted also noted some issues associated with the use of a customer's internet connection for Wide Area Network (WAN) communications. This can cause issues with initial set-up or ongoing access (e.g. difficulties in authentication of devices on the network when users change their Wi-Fi password), resulting in longer installation times or increased customer support calls, which drive up costs for smart devices and erode vendor profit margins. As a result of this some smart device vendors, e.g. Climote, have opted to use alternative WAN communications technologies such as GPRS[114].

Summary of barriers described above:

- Communications between devices in the home may be unreliable with communications protocols currently in use.
- The use of a customer's internet connection for WAN communications can lead to set-up or ongoing access problems.

Potential solutions:

- Mesh network topologies may offer enhanced reliability of communications in the home, if there are multiple devices that use the same communications protocol at the disadvantage of longer latency times and increased power consumption
- Many industry players agree that 868 MHz radio communication is the most appropriate wireless communication technology in the typical UK home, though there are currently no open standards available that use this frequency band. The low bandwidth available at this frequency makes porting radio standards into this band more complex
- A combination of radio and powerline communications in the home could offer more robust HAN communications, but would cost more
- Use of alternative WAN communications technologies can aid ease of use and reduce support requirements, but at extra cost
- Ensuring that device errors (e.g. if the device loses its internet connection) are easy for customers to diagnose and fix without calling technical support services

7.4.2 Interoperability and standardisation

Barriers associated with interoperability and standardisation in the Home Area Network (HAN) were raised frequently in stakeholder consultations and are immediately relevant for the interaction of consumers with currently available smart home devices. Most stakeholders consulted, however, expect that these barriers will be overcome by the market in the next 3-5 years. In addition, there are a number of short term solutions that can offer interoperability to customers, as discussed below.

There are multiple communications protocols currently in use for smart devices in the home area network. A selection of these is discussed in Section 2.1. Stakeholders consulted noted that this range poses a barrier to HAN interoperability between smart devices offered by different vendors. This lack of interoperability may slow consumer uptake, or may mean that customers cannot access the full potential benefit of devices.

Some technology developers consulted expect a single communications standard to come to dominate in the next 5 years. Industry representatives, such as BEAMA (British

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[114] Industry consultation, https://recombu.com/digital/article/climote-hands-on-scottish-power-smart-heating-system

Electrotechnical and Allied Manufacturers Association) believe that, due to customer demand for interoperability between different vendors' devices, this will be an open standard. Ongoing standardisation work at European level may offer a common information model for interactions between smart home devices.

We note that it is by no means a prerequisite that a single standard will become dominant. To the extent that different applications have different requirements (for example, in terms of bandwidth or latency), products operating based on different standards could co-exist in the same household. In this case, interoperability between devices may be assured by using multi-protocol hubs (though these may currently have limited plug and play functionality and may have high associated costs, particularly if the standards use different protocol stacks), or by cloud interaction between different vendors' devices. Many technology developers consulted said that cloud interaction is currently the easiest method. However, the reliability of the service then depends on the internet connection. This method also often involves multiple hubs for different devices being situated in the home, decreasing the convenience for consumers and increasing the overall system cost (as many systems will be duplicated across the different vendors' hubs).

Summary of barriers described above:

- Currently multiple different communications protocols, with no clear picture of whether one, and if so which, will come to dominate.
- Devices which use the same open standard communication protocol may sometimes be unable to communicate (e.g. different ZigBee profiles), confusing consumers.
- Might offer barrier to interaction between smart technologies and full home integration, and may discourage consumers.

Potential solutions:

- Use of multi-protocol hubs (which currently have issues with plug and play capabilities) or interaction between different devices happening in the cloud (depends on internet connectivity).
- Clear and robust certification processes to ensure that customers are aware which devices are interoperable and which are not.
- Market convergence on one or more dominant communication protocols.
- EU level and industry standardisation initiatives.

7.4.3 Security and privacy

A number of stakeholders highlighted that security risks need to be considered, and are currently underestimated. Stakeholders generally felt that this was preventable through appropriate security measures being taken in the design of smart home products. We note, however, that home smart systems are likely be susceptible, like most internet-connected systems, to poor security practices on the part of the consumer (for example, setting a weak password). It was suggested that government should monitor this area closely so as to identify if current data privacy regulations are insufficient.

A related issue is the way companies use the data that they gather from smart devices in people's homes. The Data Protection Act[115] means that a consumer must agree to share the data for the purposes stated by the company. Nonetheless, this could be a source of concern for some potential users. It was also noted by some stakeholders, on the other hand, that overly restrictive regulation on how customer data can be used could restrict the opportunities for developing novel energy services. While current data protection legislation may be sufficient to ensure sufficient transparency, it was suggested that this is an area that should be monitored by government in order to identify any gaps arising in the future.

The issue of smart home security has been addressed in a recent report on smart home security, published in December 2015 by the European Union Agency for Network and Information Security (ENISA)[116], which identifies the various risks associated with smart home security and sets out good practice guidelines and a number of recommendations to policymakers and technology developers.

Smart home security and consumer confidence in providers of smart technology and associated services are particularly important for provision of demand side services from domestic loads. If confidence is undermined this may result in customers being wary of external control of their appliances and may limit participation in DSR.

Summary of barriers described above:

- Lack of consumer understanding of how to use security measures effectively.
- Risk of consumer distrust in controls as a result of inappropriate use of their personal data.
- Risk of lack of consumer engagement in DSM due to fears associated with outside control of their appliances.
- If devices are poorly designed, vulnerabilities in individual smart devices can cause vulnerabilities to be shared at large scale.

Potential solutions:

- Consumer engagement and education to ensure correct use of security measures.
- Consensus among stakeholders on minimum security requirements.
- Industry inclusion of security as a key feature of their product.
- Enhanced transparency from providers of smart technology and associated cloud services on how they use customer data.
- Government monitoring of effectiveness of legislation/guidelines (mainly the Data Protection Act) on level of transparency companies should provide on use of consumer data.
- Development of smart device security assessment methods and frameworks.
- Technology developers' cooperation with security testing of smart devices.

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[115] https://www.gov.uk/data-protection/the-data-protection-act (Accessed April 2016)

[116] "Security and Resilience of Smart Home Environments: Good practices and recommendations", ENISA December 2015

7.4.4 Economic

Smart heating controls have high initial costs for customers, which may constitute a significant barrier to mass market uptake of these devices. While these devices may offer energy savings, and provide a short payback period, the high upfront cost will remain a barrier for non-engaged consumers. The initial costs for other smart devices and appliances are also significantly higher than their non-smart counterparts. This may mean that in the short term, these devices will be confined to early adopters with an interest in smart technology, and with high levels of disposable income. This lack of mass market adoption would limit the overall potential benefit of these advanced energy controllers.

This is particularly an issue for advanced and smart heating controls as customers are not typically engaged with their heating or knowledgeable about heating controls and so will choose the lowest cost control option when installing or refitting their boiler. Many of the stakeholders consulted suggested that the uptake of these controls should be driven by regulation. However, there is currently limited evidence on the benefits of advanced heating controls, in terms of energy and cost savings, usability, and carbon emissions savings.

The uptake of smart controls is expected to be more market driven, as the extensive marketing campaigns around new entrant products (e.g. Nest, Hive etc.) have engaged customers and made these products more aspirational. It is as yet unclear whether this interest will extend to the mass market. The lack of clear and verified evidence on the potential energy savings and other system benefits associated with smart heating controls currently prevents these products being subsidised by government or being included in building regulations.

This barrier is unlikely to be overcome through future cost reductions alone, as stakeholders noted that this control technology is mature and savings will only be achieved with economies of scale. Enhanced competition between technology providers in this space may also drive down prices, though the potential saving here is expected to be limited. An alternative solution, adopted by a number of smart thermostat developers, is to partner with energy suppliers so as to offer bundle deals that provide the product to customers with no upfront cost. In the future, if demand-side response revenue can be captured from these devices, the device may be supplied free of charge to customers in return for the ongoing revenue stream that can be exploited by managing the customer’s demand flexibility.

Summary of barriers described above:

- Initial costs for addition of smart energy controls are often prohibitively high.
- Lack of engagement in heating means lowest cost control option is typically installed, which may not offer greatest benefit to the customer or to the energy system.
- Smart heating controls have unclear/unverified energy savings potential.

Potential solutions:

- Bundle deals with energy suppliers to reduce or remove upfront cost for the customer.
- A trial or innovation allowance for people rolling out these solutions so as to test and certify their energy saving potential and other system benefits

- Contingent on evidence for such benefits, subsidisation through the Energy Company Obligation or through any future energy efficiency scheme (Green Deal replacement).
- Contingent on evidence for such benefits, inclusion of smart controls in building requirements or improved contribution of controls to a building's SAP energy rating.

7.4.5 Regulatory and market barriers

There are barriers to the inclusion of advanced and smart controllers in building regulations due to the lack of robust evidence on their energy saving potential. However, as the energy savings associated with these devices are largely based on customer actions and engagement and are highly site and behaviour specific, obtaining this robust evidence will be expensive and difficult. Some stakeholders consulted therefore feel that government should allow inclusion of these controls in building regulations and subsidy programmes based on current evidence of the technically feasible energy savings and benefits that these products can offer. This, however, is at odds with the government's evidence-based approach to policy, and may promote the installation of devices that could increase energy consumption.

Various market barriers exist to realising the potential benefit of domestic demand side response (DSR). A number of the companies consulted noted that the fragmented value chain, with revenue potentially coming from a number of energy system stakeholders (see Figure 15), makes it difficult to realise the full potential benefit of DSR to the electricity system and to pass this benefit back to customers. Particularly, to realise any potential supplier or DNO benefits, customers must be settled half hourly (their actual half hourly consumption must be used to determine the supplier's balancing position, and must be used for the calculation of the distribution use of system charges that they pay). Though this is currently possible, it is only done by a small number of suppliers and is significantly more costly and complicated than non-half hourly settlement.[117]

Ofgem have work underway considering half-hourly settlement from both an elective (i.e. on a voluntary basis) and mandatory perspective.[118] While they have expressed their view that, at some point in the future, it will be necessary to mandate all suppliers to settle their customers on a half-hourly basis to realise the full benefits, it is currently unclear whether half-hourly settlement of domestic and smaller non-domestic consumers will be mandated in the future (this or other actions may be necessary in order to encourage large suppliers to use half hourly settlement for domestic customers).

There is also uncertainty around the form of smart/ToU tariffs that will be available once settlement processes are reformed, and whether these will have a significant impact on customer consumption patterns. Many smart technology developers wish to offer a service (similar to that currently offered by Tempus Energy) whereby the customer inputs their requirements and the energy system benefit is then optimised by the energy manager or demand side aggregator. In this set-up, the customer is offered a lower flat tariff in return for allowing their load to be controlled to meet energy system requirements.

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[117] For example, one stakeholder consulted stated that costs can be up to 15 times higher for half hourly settled domestic customers over a customer who is settled non-half hourly.

[118] See: www.ofgem.gov.uk/publications-and-updates/elective-half-hourly-settlement-publication-responses-december-open-letter

These issues will need to be resolved for the full potential benefit of domestic DSR to be realised.

The current capacity market design also creates a barrier to realising the potential value of DSR, as it does not offer a level playing field to demand side assets, for example by offering them shorter contracts than generation assets. This has also been raised in parliament by the Energy and Climate Change Select Committee[119].

Many of the organisations consulted stated that a clear vision from DECC on the development of demand side response in the UK would be desirable. This roadmap would include a statement of DECC's intentions on incentivising demand side response including how it envisions the full system benefit would be realised and by what mechanism these benefits would be passed back to customers.

Summary of barriers described above:

- Government requirement for robust evidence of energy and cost savings associated with heating control products for inclusion in regulation or subsidy programmes.
- The fragmented value chain for demand-side response makes it unclear how value can be passed back to the customer.
- Complexities associated with aggregating the response of many small domestic loads, including contracting, guarantee and verification of response. Additional difficulties in marketing to and signing up domestic customers.
- Certain benefits can currently only be accessed by settling customers half hourly, which increases costs and is not done by large suppliers currently. Smart meters can record consumption in each half-hour period, though it is as yet unclear whether suppliers will be required to use this data to settle consumers on a half-hourly basis, and whether the costs associated with this will decrease.
- There are also uncertainties as to how the market for smart/TOU tariffs, enabled by smart meters and half-hourly settlement, will evolve.
- Unequal market access for DSR e.g. the non-access for demand-side assets to capacity market contracts longer than one year.

Potential solutions:

- Government funded and independently designed trial to test the energy saving potential of smart heating controls. This, in conjunction with other evidence, could then be used to assess whether these products should be included in regulations or subsidised.
- Roadmap from DECC on development of domestic DSR, including how the appropriate incentives would be put in place, how full system benefit would be realised and how this would be passed back to the customer.

7.4.6 Consumer behaviour and awareness

The majority of customers are not engaged with their energy use or with their heating system controls. Most do not think about their heating system or consider upgrading it

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[119] http://www.parliament.uk/business/committees/committees-a-z/commons-select/energy-and-climate-change-committee/news/emr-publication1/

unless it breaks. While some new entrant smart heating controls have succeeded in engaging customers and making smart controls more aspirational, it is currently unclear whether this appeal will extend to the mass market. This lack of engagement severely limits the potential uptake of advanced energy controllers and hence limits their overall potential benefit.

For smart or advanced heating technology to appeal to the mass market, industry must develop use cases, product and service propositions that appeal to customers. This could for example be the enhanced comfort or convenience offered by smart controls. These use cases are already being developed for smart heating controls, but may be much more difficult for other “behind-the-scenes” advanced controllers. An alternative option for overcoming this customer engagement barrier is the inclusion of advanced or smart heating controls in building regulations. This measure would also have to be accompanied by education of heating installers to ensure maximum uptake.

We note that the relevance of the consumer engagement barrier varies for different types of smart heating control. Those which use automation (such as through learning algorithms, weather compensation and optimisation) are likely to face less severe barriers due to consumer engagement than those that are reliant on consumer behaviour (such as those with programmable thermostats, programmable TRVs and so on).

Education of consumers in the potential multiple benefits of heating controls may also play a role. Many customers do not know how to use their current heating controls, and advanced heating controls are often too complex and non-intuitive, which may discourage customers from installing them. A 2012 report by Consumer Focus found that 70% of the population do not have the full set of controls recommended by building regulations, and that, once installed, customers have difficulty using these controls to best effect[120]. This is also supported by anecdotal evidence from industry stakeholders on the lack of awareness on how, for example, TRVs, should be used. This is an issue that the smart heating control industry is actively addressing as it attempts to design user friendly heating controls.

In addition to the lack of engagement in energy use, there are barriers around the lack of customer knowledge of DSR and its potential benefits. For customers to participate in demand side programs, they must be aware of the forms they can take (Time of Use tariffs, direct control of their flexible loads etc.) and have confidence that their requirements will still be met (house will still be warm, washing done by the specified time etc.). In addition, some customers will be wary of external control of their loads and so in this case security and adherence to customer requirements are particularly important. Even if these requirements are met, encouraging customers to switch to a DSR tariff will be difficult, as can be seen from current customer reluctance to switch suppliers despite the significant savings available.

Summary of barriers described above:

- Current lack of engagement of consumers in heating and home energy use.
- Lack of smart home technology use cases that appeal to the consumer mass market.

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[120] http://webarchive.nationalarchives.gov.uk/20130103075417/http:/www.consumerfocus.org.uk/files/2012/01/Consumers-and-domestic-heating-controls-a-literature-review.pdf

- Complexity of some current heating controls and usability issues for consumers, particularly in their use to achieve the desired balance between comfort and energy consumption.
- Lack of consumer trust in energy suppliers (who are at the forefront of offering smart heating technology to consumers).
- Reluctance of customers to switch tariffs or suppliers may pose a challenge to uptake of DSR tariffs.
- Lack of awareness of DSR and its benefits among domestic customers.
- Wariness among customers of consenting to their energy consumption being controlled externally.

Potential solutions:

- Education of consumers on benefits of heating control, perhaps via an awareness campaign or during installation.
- Education of heating control installers on the benefits of advanced heating controls.
- Industry development of use cases for their technology that appeal to customers (e.g. comfort, convenience etc.).
- Improvement of heating control usability.
- Inclusion of advanced heating controls in building requirements.
- Contribution of heating controls to SAP rating of a building.
- Education of customers on DSR and its potential benefits. This could be linked to the smart meter rollout and subsequent introduction of time of use tariffs.

Table 10: Summary of barriers identified including RAG rating for barrier risk and relevance (a key to the colour scheme is given below)

Category	Barrier	Barrier risk (how likely)	Barrier relevance (potential impact)	Existing solution
Technical	In-home communications reliability	A	A	Yes
	Issues in internet set-up and ongoing access	G	G	Yes
Interoperability and standardisation	Proliferation of communication protocols, both open and proprietary	A/G	G	Yes
	Incompatibility of devices using the same communication protocol	A/G	G	Yes
	Lack of choice of communication protocols for a given product class	A/G	G	Yes
Security and privacy	Underestimation of the need for smart home security	A	G	Yes
	Lack of incentives to enhance security	A	G	Yes
	Consumer distrust of organisations handling their personal data or controlling their devices	G	A	Yes
	Vulnerable smart devices in the home can cause vulnerabilities to be shared at a large scale	A	A	Yes
Economic	Initial costs for smart control devices are high	A	R	Yes

	Lowest cost option for heating control is typically installed	A	A	Yes
	Unverified energy saving potential	G	A	No
Regulatory and market barriers	Evidence needed for inclusion of controls in regulation too difficult to obtain	A	A	No
	Fragmented value chain for DSR makes it difficult to capture revenues	A	A	No
	Barriers to half hourly settlement, needed for some DSR services	A	A	No
	Uncertainty over availability of time-of-use and other tariffs	A	A	Yes
	Unequal market access for DSR e.g. capacity market	A	A	No
Consumer behaviour and awareness	Lack of engagement of customers in heating and home energy use	R	R	Yes
	Usability issues for consumers in relation to heating controls	R	A	No
	Consumer distrust of energy suppliers	G	G	Yes
	Lack of awareness of DSR benefits	R	G	Yes
	Consumer wariness of external control of	G	A	Yes

	devices	🟩	🟧	

Table key					
Low risk / Low relevance	G	Medium risk / Medium relevance	A	High risk / High relevance	R

Part B: Modelling of Potential Costs and Benefits of Home Energy Controllers

8 Approach to Modelling Potential Costs and Benefits of Home Energy Controllers

8.1 Scope: Summary of Costs and Benefits Modelled

In Part B, we describe and evaluate the potential costs and benefits of home energy controllers to domestic consumers. The scope of this analysis, as shown in Table 11, includes the initial capital cost of the home energy control equipment, the potential impact on heating bills and the potential for additional revenue or bill savings due to the provision of demand-side response services. Table 11 also briefly describes the modelling approach we have taken to evaluate each of the costs/benefits included; the modelling is described in more detail in the later sections.

We evaluate the potential costs and benefits of a variety of home energy control scenarios (where a scenario refers to a set of control technologies) in a series of representative household types. The home energy control scenarios and representative household types studied are described in the following sections.

Table 11: Summary of costs and benefits modelled

Cost/benefit modelled	Description	Modelling approach
Cost of home energy control equipment	• Capital cost of equipment	• Cost data collected through product market review
Impact on annual heating demand	• Potential energy savings • Potential rebound effect	• Derived using a steady-state analysis based on potential impact of controllers on the length of the household heating period
Potential for additional revenue streams	• Potential value of peak demand flexibility • Potential value of frequency response	• Derived using an analysis based on hourly electricity demand profiles and a consideration of the potential flexibility and responsiveness of particular sub-loads

8.2 Home Energy Control Scenarios

Based on the home energy controller market review and product capability assessment presented in Part A, we have defined a set of home energy control scenarios for which to assess the potential costs and benefits to the domestic consumer.

The home energy control scenarios are based on a number of key controller functionalities identified during the product capability assessment. The scenarios place an emphasis on heating control functionalities, since heating is the greatest single source of energy consumption (and carbon emissions) in the household, and hence an important focus of this study. However, we also include scenarios for lighting, appliances and microgeneration. The key functionalities include:

- *Heating*
    - Central time and temperature control (defined as the Baseline)
    - Remote/external control
    - Zonal heating control through use of wireless thermostatic radiator valves
    - Passive control and learning algorithms
- *Lighting and appliances*
    - Smart lighting and appliances (including remote control as a minimum)
- *Microgeneration*
    - Smart management of solar PV microgeneration with electrical or thermal storage

The home energy control scenarios are defined in terms of these controller functionalities in Table 12. We note that examples of products currently available on the market with the functionalities included in the home energy control scenarios are given in Section 9, where the cost of the scenarios is estimated.

The applicability of the costs and benefits in the scope of this modelling analysis is given in Table 13. As shown, in the Smart heating scenarios we focus on the costs and benefits associated with the heating system only; in general, this could also include the value of additional revenue/savings due to demand-side response using the heating system. In the Smart home scenario, we include the Smart heating (Advanced – Zonal + Passive control) functionality in addition to smart lighting and appliance functionality; we therefore include the costs and benefits associated with heating, lighting and appliances. Finally, in the Prosumer[121] home scenario, we include all functionality included in the Smart home scenario, as well as the smart management of solar PV with electrical or thermal storage.

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[121] We here define a *Prosumer* as a producer and consumer of energy.

Table 12: Home energy control scenarios: matrix of functionalities included

Home energy control scenario	**Heating**				**Lighting and appliances**	**Microgeneration**
	Central time and temperature control	Remote/ external control	Zonal heating control (wireless)	Passive control and learning algorithms	Smart lighting and appliances	Smart management of microgeneration
Baseline	✓					
Smart heating (Basic)	✓	✓				
Smart heating (Advanced - Zonal)	✓	✓	✓			
Smart heating (Advanced - Passive control)	✓	✓		✓		
Smart heating (Advanced - Zonal + Passive control)	✓	✓	✓	✓		
Smart home	✓	✓	✓	✓	✓	
Prosumer home	✓	✓	✓	✓	✓	✓

Table 13: Applicability of costs and benefits for each scenario

Home energy control scenario	**Applicability of costs/benefits**		
	Cost of home energy control equipment	*Impact on annual heating demand*	*Potential for additional revenue streams*
Smart heating (Basic) Smart heating (Advanced - Zonal) Smart heating (Advanced - Passive control) Smart heating (Advanced - Zonal + Passive control)	• Heating controls only	• Heating fuel bill	• Heating system only (only applicable if electrical heating)
Smart home	• Heating, lighting and appliance controls	• Heating fuel bill	• Heating system (if electrical), lighting and appliances
Prosumer home	• Heating, lighting and appliance controls • Microgeneration management and thermal/electrical storage	• Heating fuel bill	• Heating system (if electrical), lighting and appliances • Microgeneration management and thermal/electrical storage

8.3 Representative Household Types

The potential costs and benefits of the home energy control scenarios are examined for a series of representative household types, as shown in Table 14. The purpose of studying the costs and benefits of the scenarios across these household types is to illustrate how the value to the consumer varies according to certain properties of the household type. For example, the capital cost of certain home energy controllers (such as a centralised smart heating control device) is independent or only weakly dependent on the property type (terraced/semi-detached vs detached vs flat) or age (existing vs new build), whereas the potential value of the control device may be strongly dependent on the property type and age, through the size of the ‘baseline’ annual heating bill. A comparison of Household types 1-3 would illustrate this effect. Similarly, the value of the home energy control scenario may be dependent on the type of heating system. For example, the potential value a household could generate through the provision of Frequency response to the National Grid may be significantly higher in a household heated with a heat pump than in a household heated with a gas boiler. A comparison of Household types 1 and 4 would illustrate this effect.

Table 14: Representative household types used to illustrate costs and benefits

Household type	Age	Property type	Heating system
1	Existing	Terraced/Semi-detached	Gas boiler
2	Existing	Detached	Gas boiler
3	Existing	Flat	Gas boiler
4	Existing	Terraced/Semi-detached	Heat pump (Ground-source)
5	New build	Terraced/Semi-detached	Gas boiler
6	New build	Terraced/Semi-detached	Heat pump (Ground-source)

In order to undertake the cost/benefit modelling, as explained in more detail in the following sections, it is necessary to define a variety of characteristics of the representative household types. Those characteristics include the size of the building, the number of appliances of each type, the annual energy consumption by end-use, the mean internal temperature and an appropriate size for a solar PV and electrical/thermal storage system to apply to the household in the Prosumer home scenario. These characteristics are shown in the series of tables from Table 15 to Table 18.

Table 15 shows the size and appliance number characteristics of the household types. The floor area and living area fraction characteristics are taken from Element Energy’s *Housing Energy Model*, a detailed stock and energy model of the UK domestic building stock. The energy demand calculations within the *Housing Energy Model* are based on the UK Standard Assessment Procedure (SAP). According to the high-level definition of the household types shown in Table 14, a closely corresponding and representative building ‘archetype’ (in terms of the UK stock) was selected from the *Housing Energy Model*, and the associated data applied to the household type. The number of heated rooms and the number of fridge-freezers, washing machines and tumbler dryers per household are Element Energy assumptions, and intended to be illustrative. The number of light fittings per household is based on a data point from the *UK Housing Energy Fact File 2012*[122] which states that the average UK home has 34 lighting fittings; we assume based on this that there is an average of six light fittings per heated room, and calculate the total number accordingly.

Table 15: Geometry and number of appliances for household types

Household type	Property size			Number of appliances			
	Floor area (m^2)	Living area fraction	Number of heated rooms	Light fittings	Fridge-freezer	Washing machine	Tumble dryer
1	77	0.31	6	36	1	1	1
2	94	0.25	8	48	1	1	1
3	61	0.35	4	24	1	1	0
4	77	0.31	6	36	1	1	1
5	77	0.31	6	36	1	1	1
6	77	0.31	6	36	1	1	1

Table 16 presents the annual energy demand by end use. The annual energy demand for Space heating, Cooling, Hot water and Lighting is taken from Element Energy's SAP-based *Housing Energy Model*. The annual energy demand for Appliances, split by appliance type, is taken from *Chapter 3: Domestic data tables* of DECC's *Energy Consumption in the UK* (ECUK)[123] dataset, the original source for which is the *Household Electricity Use Survey* 2010-11[124].

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[122] *United Kingdom housing energy fact file*, DECC (2012)

[123] https://www.gov.uk/government/statistics/energy-consumption-in-the-uk [Accessed 21st March 2016]

[124] https://www.gov.uk/government/publications/household-electricity-survey--2

Table 16: Energy demand by end-use for household types

Household type	Energy demand (kWh/m^2/yr)									
	Space heating	Cooling	Hot water	Lighting	Appliances					
					Cold - Freezer	Cold - Other	Wet	Electr-onic	Comp-uting	Cooking
1	95	0	44	8	2	5	5	7	3	6
2	136	0	39	8	2	5	5	7	3	6
3	46	0	51	8	2	5	5	7	3	6
4	71	0	44	8	2	5	5	7	3	6
5	46	0	44	8	2	5	5	7	3	6
6	46	0	44	8	2	5	5	7	3	6

Table 17 presents the mean internal temperature during the heating period in the Living areas[125] and the non-living areas ('Elsewhere') for each household type. We note that this data will be used in the modelling to understand the potential impact of smart heating controls in the case that they lead to an increase in the temperature of the non-living areas. It is typical for the non-living areas of the home to experience a slightly lower temperature than the living areas, due to a combination of different occupant comfort preferences, higher gains from cooking, appliances and occupants, and perhaps also in part to a different balance between radiator size and local heat loss rate in different areas of the home. The UK SAP, and hence the *Housing Energy Model*, captures this effect; the data derived from the model is that presented in the table.

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[125] In SAP, the Living area is defined as follows: "*The living area is the room marked on a plan as the lounge or living room, or the largest public room (irrespective of usage by particular occupants), together with any rooms not separated from the lounge or living room by doors, and including any cupboards directly accessed from the lounge or living room. Living area does not, however, extend over more than one storey, even when stairs enter the living area directly*."

Table 17: Mean internal temperature during heating period for Living area and Elsewhere

Household type	Age	Property type	Heating system	Mean internal temperature (ºC)	
				Living area	Elsewhere
1	Existing	Terraced/Semi-detached	Gas boiler	19.2	17.6
2	Existing	Detached	Gas boiler	18.9	17.1
3	Existing	Flat	Gas boiler	19.2	17.7
4	Existing	Terraced/Semi-detached	Heat pump	19.1	17.5
5	New build	Terraced/Semi-detached	Gas boiler	19.2	17.8
6	New build	Terraced/Semi-detached	Heat pump	19.2	17.8

Finally, Table 18 presents the default sizing for solar PV and electrical and thermal storage for each household type, to be applied in the Prosumer home scenario. The size of the solar PV system is based on Ofgem's *FIT Installations Statistical Report*[126] data, using which we have determined the average size of domestic solar PV systems installed under the feed-in tariff between 1st April 2010 and 11th March 2016 to be 3.5 kW_p. Here, we have applied this value to the terraced/semi-detached households and derived the default size for the other property types by scaling the system size according to floor area. This results in a system size of 4.3 kW_p for detached properties and 2.8 kW_p for flats. For thermal storage, we have based the system size for each household type on a standard 150 litre hot water storage tank. Assuming a 40ºC temperature difference between storage and delivery temperatures, this corresponds to approximately 7 kWh of thermal storage. For electrical storage, we base the system size on the typical products available in the UK market. A list of such products is given in the *Home Energy Controller Product Review*[127] database accompanying this report; they include the Moixa Maslow battery (2-3 kWh), the Powervault battery (4 kWh), the Sonnen SonnenBatterie (2-4 kWh typically, modular), the BYD EnergyHub (3 kWh) and the Tesla Powerwall (basic version 7 kWh). We assume an electrical storage capacity of 4 kWh for terraced/semi-detached households, 5 kWh for detached household and 3 kWh for flats.

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[126] https://www.renewablesandchp.ofgem.gov.uk/Public/ReportManager.aspx [Accessed 21st March 2016]

[127] See database accompanying this report.

Table 18: Default sizing for Solar PV and storage (where relevant) for household types

	Age	**Property type**	**Heating system**	**Solar PV (kW_p)** ***[if included]***	**Thermal storage (kWh)** ***[if included]***	**Electrical storage (kWh)** ***[if included]***
1	Existing	Terraced/Semi-detached	Gas boiler	3.5	7	4
2	Existing	Detached	Gas boiler	4.3	7	5
3	Existing	Flat	Gas boiler	2.8	7	3
4	Existing	Terraced/Semi-detached	Heat pump	3.5	7	4
5	New build	Terraced/Semi-detached	Gas boiler	3.5	7	4
6	New build	Terraced/Semi-detached	Heat pump	3.5	7	4

9 Capital cost of home energy control scenarios

The capital cost of the home energy control scenarios is based on the extensive review of home energy control products described in Part A of this report. The data collected during the product review is provided in full in the *Home Energy Controller Product Review* database accompanying this report.

The series of tables below presents a summary of the capital cost data collected as it relates to the home energy control scenarios modelled, including the Baseline scenario. Each table corresponds to a certain component of the home energy control system. For each home energy control scenario, we have listed the most relevant example products reviewed and an indicative range of prices for those products. In the same tables, we state the price used in the modelling for the relevant component.

Smart heating controller costs

The following set of tables relates to the Smart heating scenarios: Table 19 presents the costs collected for the main heating control device (that is, the central controller); Table 20 presents the costs for standard and wireless/smart thermostatic radiator values (TRVs);

Table 21 presents the installation costs used[128]; Table 22 then summarises the total cost implied for the Smart heating scenarios.

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[128] Heating control installation costs based on consultation with BEAMA, February 2016.

Table 19: Cost of main heating control devices[129]

Home energy control scenario	Main control device (excluding installation)			
	Description	Example products	Indicative price range	Price used in model
Baseline	Central time and temperature control (examples include 1-day and 7-day programmable controls)	Vaillant VRT350, Honeywell CM907, Salus RT500, Horstmann DRT2, Harmoni 25, Heatmiser Slimline, Raychem TC, Energymizer T32, Sol*Aire PR-1, Flomasta 22199SX	£27-149	**£79**
Smart heating (Basic)	Central time and temperature control with external control	PassiveLiving Heat, Netatmo Thermostat, OWL Intuition, Connect, Climote, Wave Smart Control, Salus iT500, Cosy	£140-299	**£194**
Smart heating (Advanced - Zonal)	Central and Zonal time and temperature control using wireless TRVs, with external control	Honeywell Evohome, Lightwave RF	£121-210	**£165**
Smart heating (Advanced - Passive control)	Central time and temperature control with passive control/learning algorithm and external control	Nest, Heat Genius	£199-249	**£224**
Smart heating (Advanced - Zonal + Passive control)	Central and Zonal time and temperature control using wireless TRVs, with passive control/learning algorithm and external control	Heat Genius	£249	**£249**

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[129] We note that the cost of the main heating control device for Smart heating (Basic) scenario is higher than that in the Smart heating (Advanced – Zonal) scenario. We note that, including the additional components of the smart heating system – in particular the TRVs – the Smart heating (Advanced – Zonal) scenario is found to be more costly, as shown in Table 22. In any case, it is rather notable that the cost variation between the different Smart heating scenarios, based on the products currently available on the market, is relatively small.

Table 20: Cost of thermostatic radiator valves (TRVs)

Home energy control scenario	Thermostatic radiator valve (TRV) (excluding installation)			
	Description	**Example products**	**Indicative price range**	**Price used in model**
Baseline	Thermostatic radiator valve (TRV) [not wireless]	Drayton RT212, Danfoss RAS-C2, Pegler Terrier II, Honeywell VT117-15a	£7-18 per TRV	**£13 per TRV**
Smart heating (Basic)	Thermostatic radiator valve (TRV) [not wireless]	Drayton RT212, Danfoss RAS-C2, Pegler Terrier II, Honeywell VT117-15a	£7-18 per TRV	**£13 per TRV**
Smart heating (Advanced - Zonal)	Wireless thermostatic radiator valve (TRV)	Honeywell Evohome, Lightwave RF, John Guest Speedfit JGTRV, Drayton Electronic Radiator Controller, Devolo Home Control 9356	£20-62 per TRV	**£35 per TRV**
Smart heating (Advanced - Passive control)	Thermostatic radiator valve (TRV) [not wireless]	Drayton RT212, Danfoss RAS-C2, Pegler Terrier II, Honeywell VT117-15a	£7-18 per TRV	**£13 per TRV**
Smart heating (Advanced - Zonal + Passive control)	Wireless thermostatic radiator valve (TRV)	Honeywell Evohome, Lightwave RF, John Guest Speedfit JGTRV, Drayton Electronic Radiator Controller, Devolo Home Control 9356	£20-62 per TRV	**£35 per TRV**

Table 21: Cost of installation of heating controls

Home energy control scenario	Installation costs		
	Description	**Time required**	**Indicative cost***
All scenarios (all scenarios have either manual or wireless TRVs)	Installation of main heating control device	1 hour	-
	Installation of TRVs	30 mins per valve, plus 1 hour to drain system (if required)	-
	Total (*Depends on house type via number of TRVs)*	*No draining of system required*	**£145-225**
		Draining of system required	**£185-265**

**Assume installation is performed by a certified electrician at a cost of £65 for the first hour and £20 for each 30 mins after that.*

Table 22: Total cost of heating control scenarios (including main control device, manual or wireless TRVs and installation)

Home energy control scenario	Description of home energy control system	Main control device (£)	Thermostatic radiator valves (£)*	Installation (£)*	Total (£)
Baseline	Central time and temperature control, Manual TRVs in each room	£79	£52-104	£145-225	**£276-408**
Smart heating (Basic)	Baseline + Remote/external control, Manual TRVs in each room	£194	£52-104	£145-225	**£391-523**
Smart heating (Advanced - Zonal)	Baseline + Remote/external control + Zonal control via wireless TRVs	£165	£140-280	£145-225	**£450-670**
Smart heating (Advanced - Passive control)	Baseline + Passive control/learning algorithm, Manual TRVs in each room	£224	£52-104	£145-225	**£421-553**
Smart heating (Advanced - Zonal + Passive control)	Baseline + Passive control/learning algorithm + Zonal control via wireless TRVs	£249	£140-280	£145-225	**£534-754**

**Assume installation is performed by a certified electrician at a cost of £65 for the first hour and £20 for each 30 mins after that.*

Smart lighting, appliances and microgeneration management costs

The following set of tables relates to the Smart home and Prosumer home scenarios. Table 23 describes the set of home energy control products included in each of those scenarios; Table 24 presents the costs collected through the product review for smart lighting and appliances; Table 25 presents the costs for smart management of solar PV and electrical/thermal storage. Finally, Table 26 summarises the total additional cost versus the Baseline of each home energy control scenario, by household type.

Table 23: Home energy control products included in Smart home and Prosumer home scenarios

Home energy control scenario	Home energy control products included		
	Heating	Lighting and appliances	Microgeneration and storage
Smart home	• Smart heating (Advanced - Zonal + Passive control)	• Smart lighting • Smart washing machine • Smart tumble dryer • Smart fridge-freezer	• None
Prosumer home	• Smart heating (Advanced - Zonal + Passive control)	• Smart lighting • Smart washing machine • Smart tumble dryer • Smart fridge-freezer	• Smart Solar PV diverter • Thermal OR Electrical storage

Table 24: Cost of lighting and appliances

Appliance type	Baseline				Smart home			
	Description	**Example products**	**Indicative price range**	**Price used in model**	**Description**	**Example products**	**Indicative price range**	**Price used in model**
Washing machine	Non-smart washing machine	Whirlpool 6th Sense WWDC9440, Zanussi ZWF81441W, Samsung ecobubble WF80F5E2W4W, LG F1296TDA7	£269-499	**£392**	Smart washing machine (with remote control as a minimum)	Samsung WW9000, LG F14U1FCN8, Hoover Wizard DWTL413AIW3	£699-1,700	**£699**
Tumble dryer	Non-smart tumble dryer	Hotpoint Signature TCUD97B6HM, Indesit Eco-Time IDV75W, Candy GVCD91CBB, Hoover VTV590NCB	£160-379	**£252**	Smart tumble dryer (with remote control as a minimum)	Samsung DV8000	£660	**£660**
Fridge-freezer	Non-smart fridge-freezer	Samsung RS7567BHCBCEU, Beko ASL141W, Hotpoint SXBD925FWD, Whirlpool WTV45952NFCIX	£750-879	**£810**	Smart fridge-freezer (with remote control as a minimum)	Samsung Family Hub, Whirlpool Smart French Door Refrigerator	£2,650-3,500 (showcased)	**£1,783**[1]
Lighting – controller	None	N/A	-	**-**	Smart lighting hub[2]	Philips Hue, WeMo Smart LED, Lightwave RS, Easybulb Plus, Osram Lightify, Connected by TCP LED	£19-55 (where required)	**£26**
Lighting – bulbs	Non-smart light bulb (LED)	Lighting Ever A60 B22 7W LED, Lampenwelt E27 15W LED, Lampenwelt 3.5 W MR16 LED, Lighting Ever 6W E14 R50 LED, Megaman 146731 5.5 W LED	£11-17 per bulb[3]	**£13**	Smart light bulb (LED)	Philips Hue, WeMo Smart LED, Lightwave RS, Easybulb Plus, Lifx Original A21, Osram Lightify, Connected by TCP LED	£14-50 per bulb	**£27**

(1) Since examples identified are not fully commercial, we base this value on the average premium of the smart washing machine and smart tumble dryer versus the corresponding non-smart appliances. (2) A separate hub is required for most smart lighting products currently on the market. (3) The Lifx Original A21 is the only product shown which does not require a separate hub. (3) RRP prices - prices in the region of £5 can be found on online retailer websites.

Table 25: Cost of smart solar PV diverter, thermal storage and electrical storage

Appliance type	Description	Example products	Indicative price range	Price used in model
Smart solar PV diverter	Smart PV diverter to manage dispatch of PV-generated electricity to serve household appliances, charge an electrical or thermal store or export to the grid	SMA Sunny Home Manager, SolarImmersion, Solar iBoost	£199-295	**£249**
Thermal storage	Thermal storage tank with built-in immersion heating (140-170 litres range)	Gledhill Torrent ECO OV Thermal Store, Telford Tristor Thermal Store, Ariston Classico Thermal Store	£755-1,158	**£133**
Electrical storage	Electrical storage for use with solar PV (PV + inverter assumed included in Baseline), including installation	Tesla Powerwall, Moixa Maslow, BYD EnergyHub, Sonnen Sonnenbatterie, Powervault	£300-1,400 per kWh (3-7 kWh range)	**£924 per kWh (3-7 kWh range)**

Table 26: Total additional cost versus Baseline of each home energy control scenario by household type

Home energy control scenario	Household type					
	1	2	3	4	5	6
Smart heating (Basic)	£115	£115	£115	£115	£115	£115
Smart heating (Advanced - Zonal)	£218	£262	£174	£218	£218	£218
Smart heating (Advanced - Passive control)	£145	£145	£145	£145	£145	£145
Smart heating (Advanced - Zonal + Passive control)	£302	£346	£258	£302	£302	£302
Smart home	£2,520	£2,732	£1,900	£2,520	£2,520	£2,520
Prosumer home	£6,465	£7,601	£4,921	£6,465	£6,465	£6,465

We note two caveats to the cost data presented. The first caveat is that the costs shown are limited to the capital cost of the equipment, and do not include any operating costs. There is the potential for smart home energy controls to lead to additional operating costs over and above those for the Baseline case. One such potential cost is the cost of more frequent customer service/troubleshooting, particularly relating to IT, internet connection or communications issues. This could potentially be an important issue, and one that was raised by a number of stakeholders consulted. Another such potential cost is the additional data cost itself; in the case that the household has an existing broadband connection this is likely not to be applicable. A third potential additional operating cost is that of the higher level of power consumption of the smart devices themselves. However, the low and falling power consumption of devices, and the trend towards energy-harvesting devices, is expected to render this immaterial.

The second caveat is that the costs presented reflect the current market price for the control products, which is developing very quickly. It should be expected that the cost of many of the products included will reduce significantly as they reach higher levels of deployment in the mass market. Based on our product review, it is felt that this applies especially to the smart appliances, which are at a less mature stage of development than the smart heating controls. For example, the market for smart fridge-freezers is particularly immature, to the extent that the only products reviewed were two examples showcased at the Consumer Electronics Show (CES) in Las Vegas earlier in 2016. It is therefore expected that these products, in particular, will decrease rapidly in price. It is important to note, however, that we do not expect the cost of all (or even many) smart products to follow a technological learning curve as for, for example, solar PV or silicon microprocessors. Many of the products in question are not marketed in simple economic or performance-based terms, but on improved convenience and user experience. It may be expected that the market will develop with a wide range of products with large variations in price, from systems designed to provide cost or performance-based functions at low cost (such as a smart heating controller in a heat pump system installed by an energy supplier, designed to allow the supplier to perform price arbitrage, but not particularly targeted at improving user experience), to systems designed almost entirely for enhanced user experience at higher cost (such as many of the smart lighting controller available on today’s market).

10 Potential Impact of Home Energy Controllers on Annual Heating Demand

10.1 Mechanisms for energy savings and rebound effects

The Smart heating control scenarios described above are defined in terms of the functionality they provide to the consumer. However, the ways in which the consumer could interact with this functionality are many. With even brief consideration, it is clear that the new functionalities could lead to patterns of behaviour which lead to either a decrease in the heating energy demand (energy savings), or an increase in demand (an energy rebound effect). Whether the new functionality leads to energy savings or an energy rebound effect will depend to a large degree on the ‘baseline’ heating behaviour prior to the installation of the smart heating controls.

In this modelling exercise, we seek to quantify the potential size of the energy savings and energy rebound effects, and to provide insight into the cases where energy savings may be the more likely outcome and the cases where a rebound effect may be the more likely outcome. However, we emphasise strongly that the scope of the modelling undertaken here is not intended to predict the likely energy savings or energy rebound effect resulting from the deployment of smart heating controls across the UK buildings stock. In order to develop robust evidence on that theme, it would be necessary to undertake detailed field trials of the systems in question. A number of such field trials are underway, including the DECC Behavioural Insights Team’s Nest field trials[130]; however, there is currently no detailed evidence available to use as an input to this modelling work.

Therefore, our approach to quantifying the potential savings or potential rebound effect resulting from the installation of the various Smart heating control scenarios is based on an elucidation of the potential outcomes in a likely ‘worst case’ and a likely ‘best case’. The first step in this approach is to elucidate the mechanisms by which energy savings or a rebound effect could occur for each scenario. The mechanisms driving our scenario modelling are presented in Table 27. In the next section, we attempt to address the dependence of the outcome on the ‘baseline’ heating behaviour of the household by developing a set of baseline heating schedule typologies.

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[130] According to discussions with the project steering committee, results of this trial are expected to be published in Spring/Summer 2016.

Table 27: Mechanisms for energy savings and rebound effects by scenario

Home energy control scenario	Example energy savings mechanisms	Example rebound effect mechanisms
Smart heating (Basic)	• Increased user interaction with heating system may reduce length of heating period (e.g. where heating system previously on by default even during unoccupied periods)	• Increased user interaction with heating system may increase length of heating period (e.g. where heating system previously on during occupied periods only, and the smart functionality leads to the heating system being on outside these periods)
Smart heating (Advanced - Zonal)	• As for Smart heating (Basic) • In addition, heating in non-living (e.g. bedroom) areas may be restricted to the evening period only	• As for Smart heating (Basic) • In addition, the temperature in non-living (e.g. bedroom) areas may be increased where previously those areas were cooler
Smart heating (Advanced - Passive control/learning algorithm)	• Automated, occupancy-based heating may lead to a decrease in length of heating period where previously heating system on by default even during unoccupied periods	• Automated, occupancy-based heating may lead to an increase in length of heating period where previously heating system not operated during all occupied periods
Smart heating (Advanced - Zonal + Passive control/learning algorithm)	• As for Smart heating (Advanced – Passive control) • In addition, heating in non-living (e.g. bedroom) areas may be restricted to the evening period only	• As for Smart heating (Advanced – Passive control) • In addition, the temperature in non-living (e.g. bedroom) areas may be increased where previously those areas were cooler

10.2 Derivation of Baseline heating schedule typologies

As described above, the impact of the installation of smart heating controls on the household heating demand is strongly dependent on the ‘baseline’ heating behaviour of the household prior to the installation of the smart controls. As described in Table 27, for example, the installation of Passive heating controls could lead to large energy savings in the case that the heating system was operated continuously prior to installation of the controls; on the other hand, it could lead to a large rebound effect in the case that the heating system was previously used more sparingly and frequently ‘off’ even when the home is occupied.

In order to capture this dependence, and link it to heating behaviours observed across the UK stock, we have defined a number of heating schedule typologies based on data from

BRE’s 2011 *Energy Follow-Up Survey* (EFUS)[131]. The EFUS was carried out on a sub-sample of the households surveyed as part of the English Housing Survey 2010-2011. The aim of the EFUS was to collect new and more detailed data on domestic energy use to inform building energy modelling and the development of energy efficiency policy. During the survey, a wide range of types of data were collected. Of most relevance to this study is the temperature monitoring survey data, carried out on a sample of 823 households.

In the temperature monitoring part of the survey, up to three temperature monitors were placed in three rooms of the home, recording temperatures every twenty minutes for approximately one year. Among other things, this allowed the heating schedule of the households to be deduced. Based on an analysis of this data, BRE grouped the households into those employing one, two, three or an unknown number of heating periods per day, separately for weekdays and weekend days. The result, for weekdays, for three different sample months, is shown in Table 28 (the data in which is taken directly from Report 4 of the EFUS[132]). It can be seen that the majority of the households surveyed employ either one or two heating periods per day, with two heating periods being slightly more common. Only a small minority of households employ three heating periods.

Table 28: Energy Follow-Up Survey data on number of heating periods per day

Number of periods heating is on weekdays	**% of households (n=823)**		
	November (2011)	**December (2011)**	**January (2012)**
1	38.0	37.9	39.1
2	49.2	49.1	48.8
3	4.1	6.4	5.6
Unknown	8.7	6.7	6.5
Total	**100.0**	**100.0**	**100.0**

Source: Energy Follow-Up Survey, BRE (2012)

The same report[133] records the ‘time on’ of the first and second (where relevant) heating period, as shown in Figure 17 (taken directly from the report). It can be seen that the modal ‘time on’ for the first heating period is around 07.00, and the modal ‘time on’ for the second heating period is around 17.00. The report also, finally, records the average number of hours for which the heating system in on for each heating period.

Based on this data, we have developed a set of Baseline heating schedules for three heating schedule typologies: ‘One heating period’, ‘Two heating periods’ and ‘Three heating periods’. The target temperatures for each period are taken from the Element Energy SAP-based Housing Energy Model, with distinct values for ‘Living area’ and ‘Elsewhere’, as previously described in Section 8.3. The Baseline heating schedules are shown in Figure 18. In the next section, we develop a set of modified heating schedules for

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[131] https://www.gov.uk/government/statistics/energy-follow-up-survey-efus-2011
[132] *Energy Follow-Up Survey Report 4: Main heating system*, BRE (2013)
[133] Ibid.

each Smart heating scenario, based on the mechanisms for energy saving and energy rebound effects listed in Table 27, to quantify the potential ‘best case’ and ‘worst case’ outcomes for the annual heating demand within each scenario.

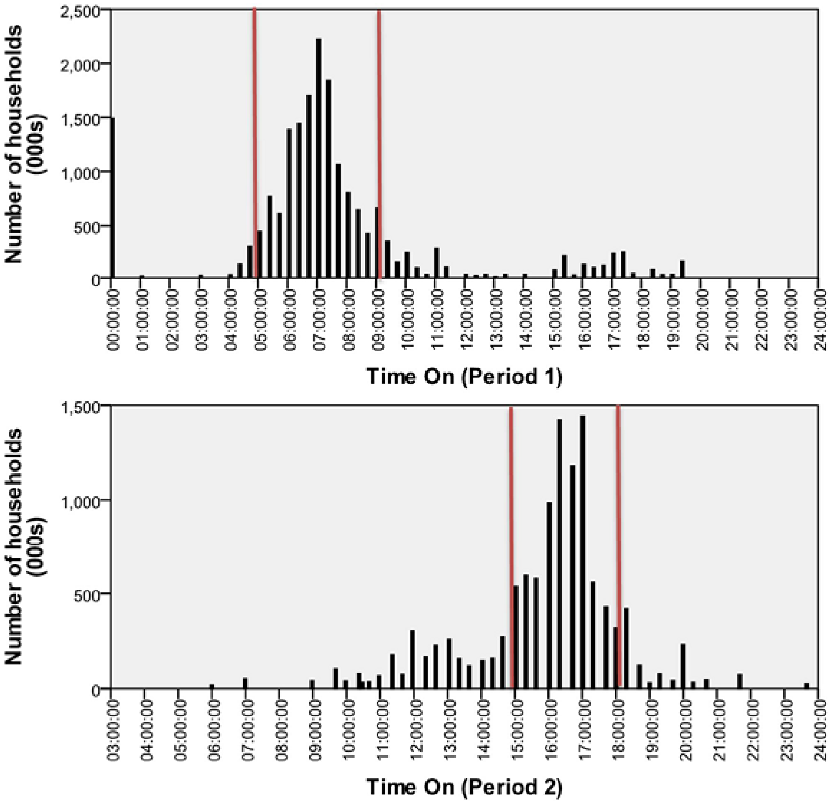

Figure 17: Energy Follow-Up Survey data on ‘time-on’ for the first and second heating periods (Source: *Energy Follow-Up Survey*, BRE, 2012.)

10.3 Low (energy savings) and High (rebound effect) cases studied for each scenario

Figure 18 shows the Baseline heating schedules defined to represent the key differences in heating patterns across households prior to the installation of smart heating controls. In this section, we seek to quantify the size of the potential energy savings or energy rebound effect which could results from the installation of smart heating controls, and then provide high-level insight into the likelihood of either savings or a rebound effect for different baseline heating behaviours.

In Table 25 above, we described the range of mechanisms which we suggest could lead to energy savings or a rebound effect for each Smart heating scenario. We have used these qualitative mechanisms to develop a set of modified heating schedules for each Smart heating scenario, defining a ‘best case’ (labelled “Low”) and a ‘worst case’ (labelled “High”) schedule for each combination of Smart heating scenario and Baseline heating schedule typology. These modified “Low” and “High” case heating schedules are shown from Figure 19 to Figure 22, with one figure for each of the four Smart heating scenarios. The mechanisms described by these modified schedules are discussed in more detail alongside the results in the next section.

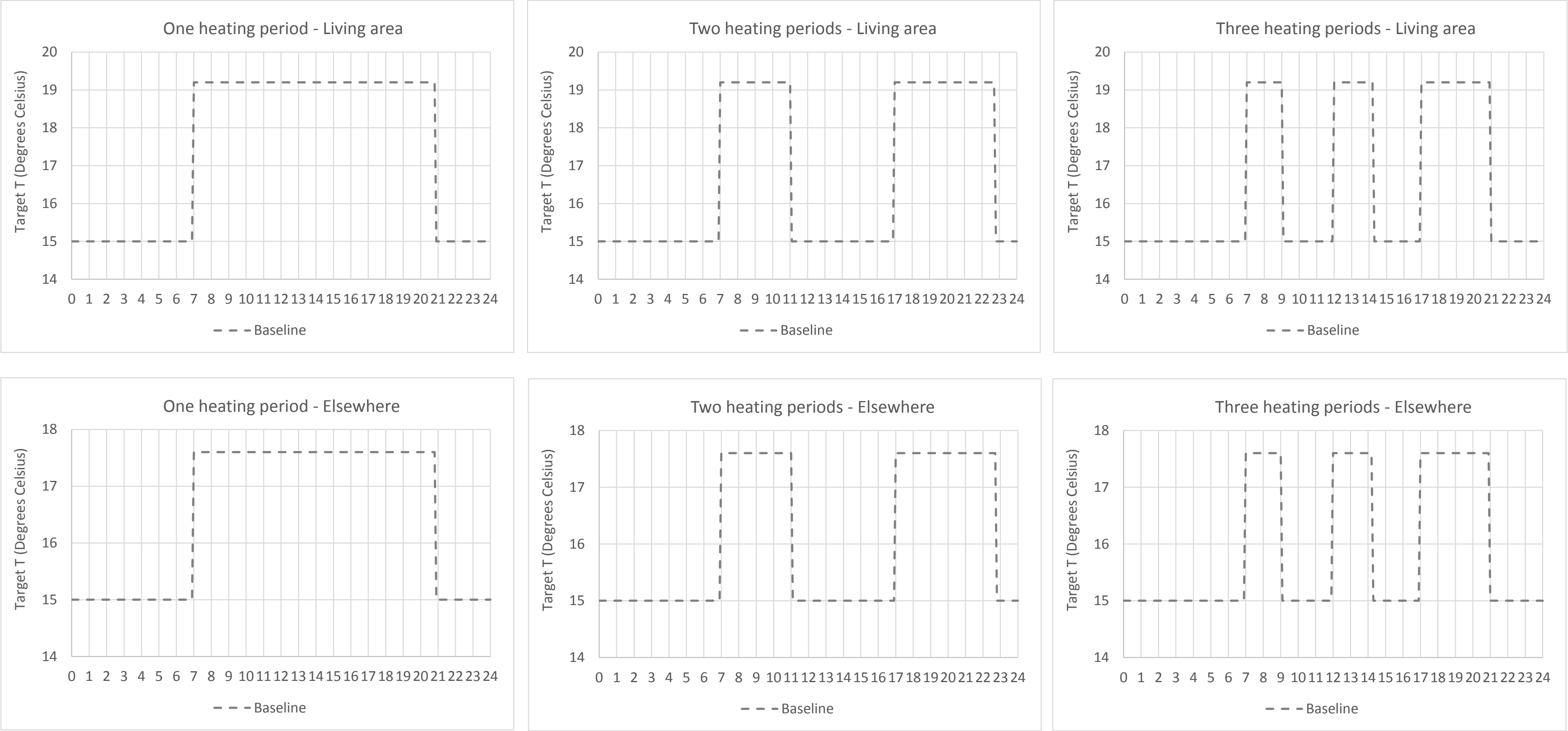

Figure 18: Baseline heating schedules for the groups 'One heating period' (left), 'Two heating periods' (centre) and 'Three heating periods' (right). The upper charts correspond to the Living area; the lower charts to Elsewhere.

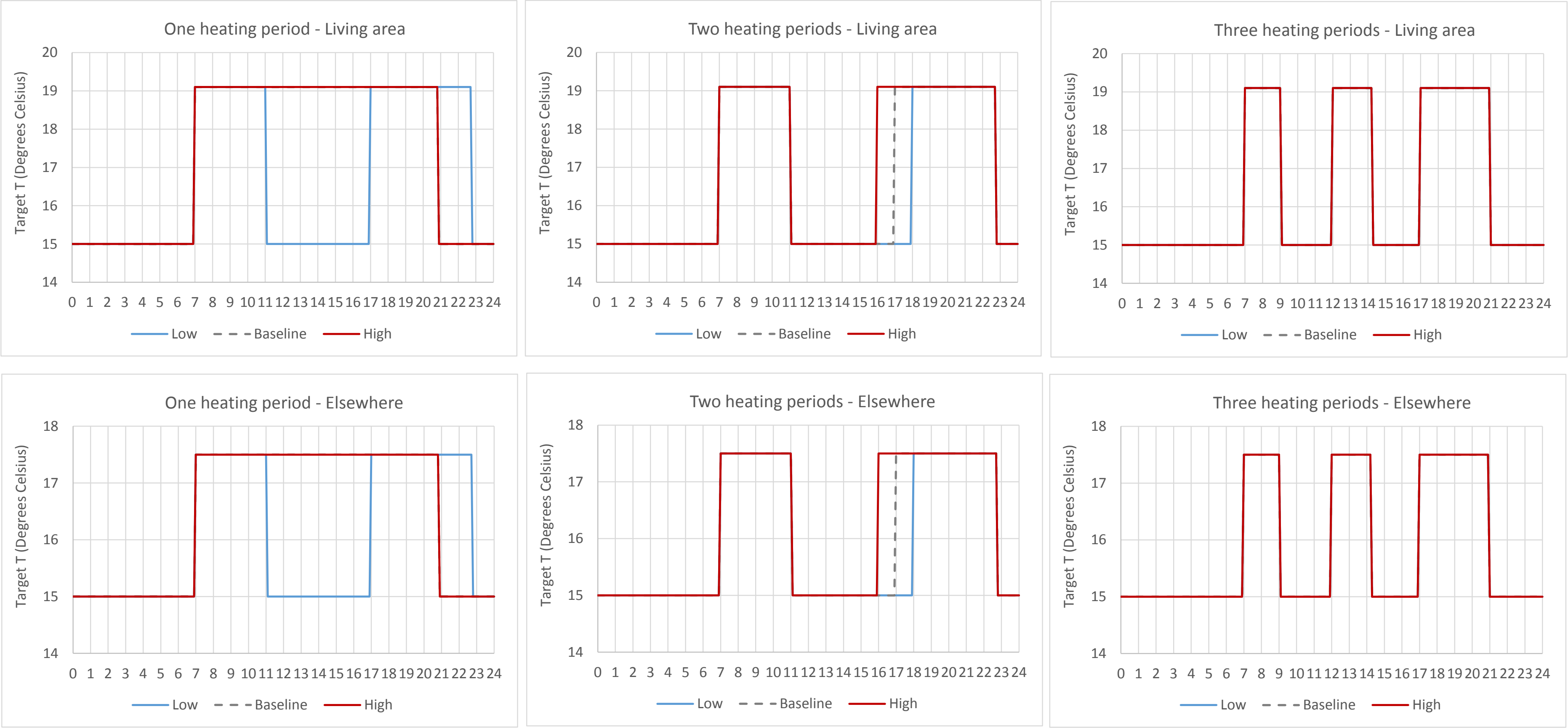

Figure 19: Heating schedules for Smart heating (Basic) scenario, showing the ‘Low’ (energy savings) and ‘High’ (rebound effect) cases.

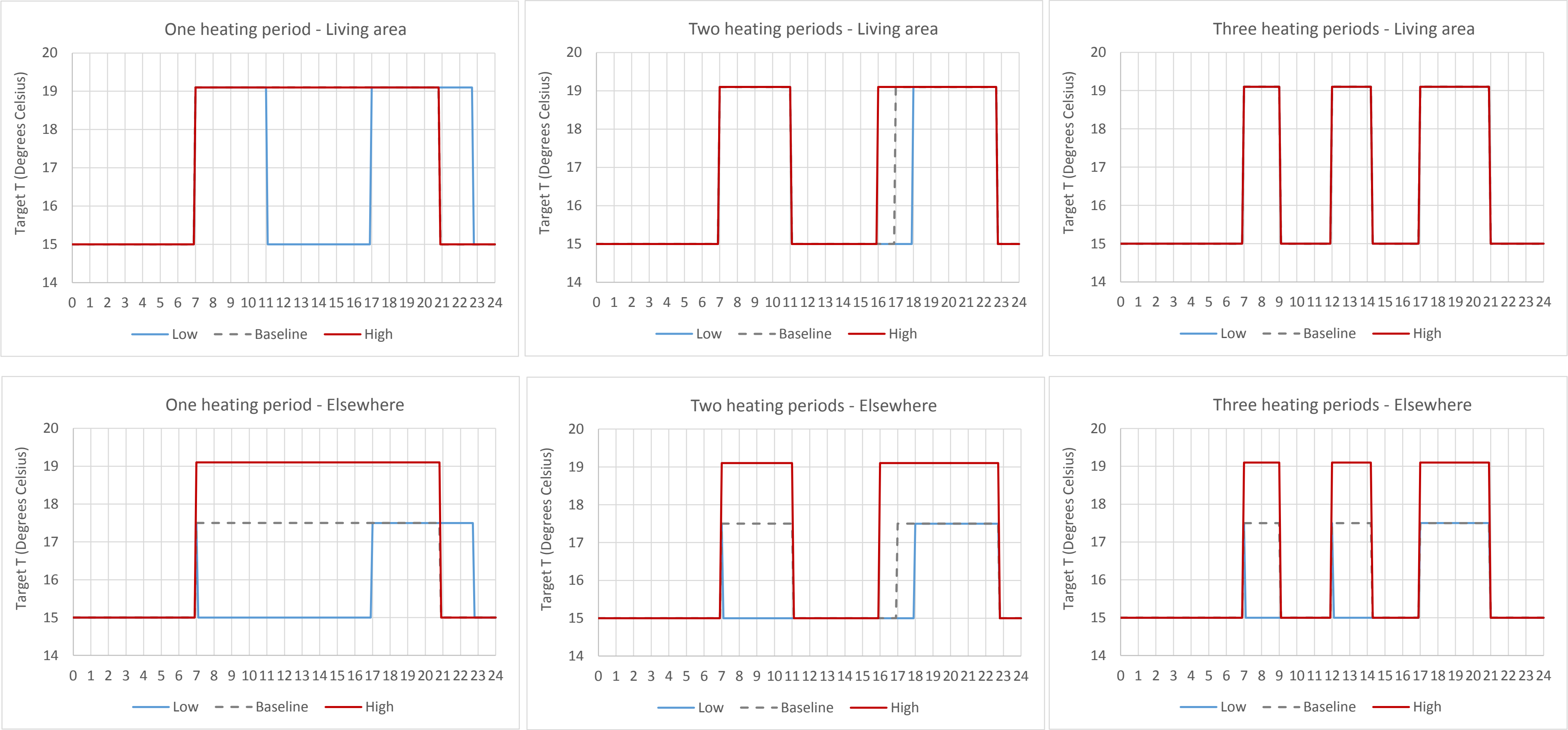

Figure 20: Heating schedules for Smart heating (Advanced – Zonal) scenario, showing the 'Low' (energy savings) and 'High' (rebound effect) cases.

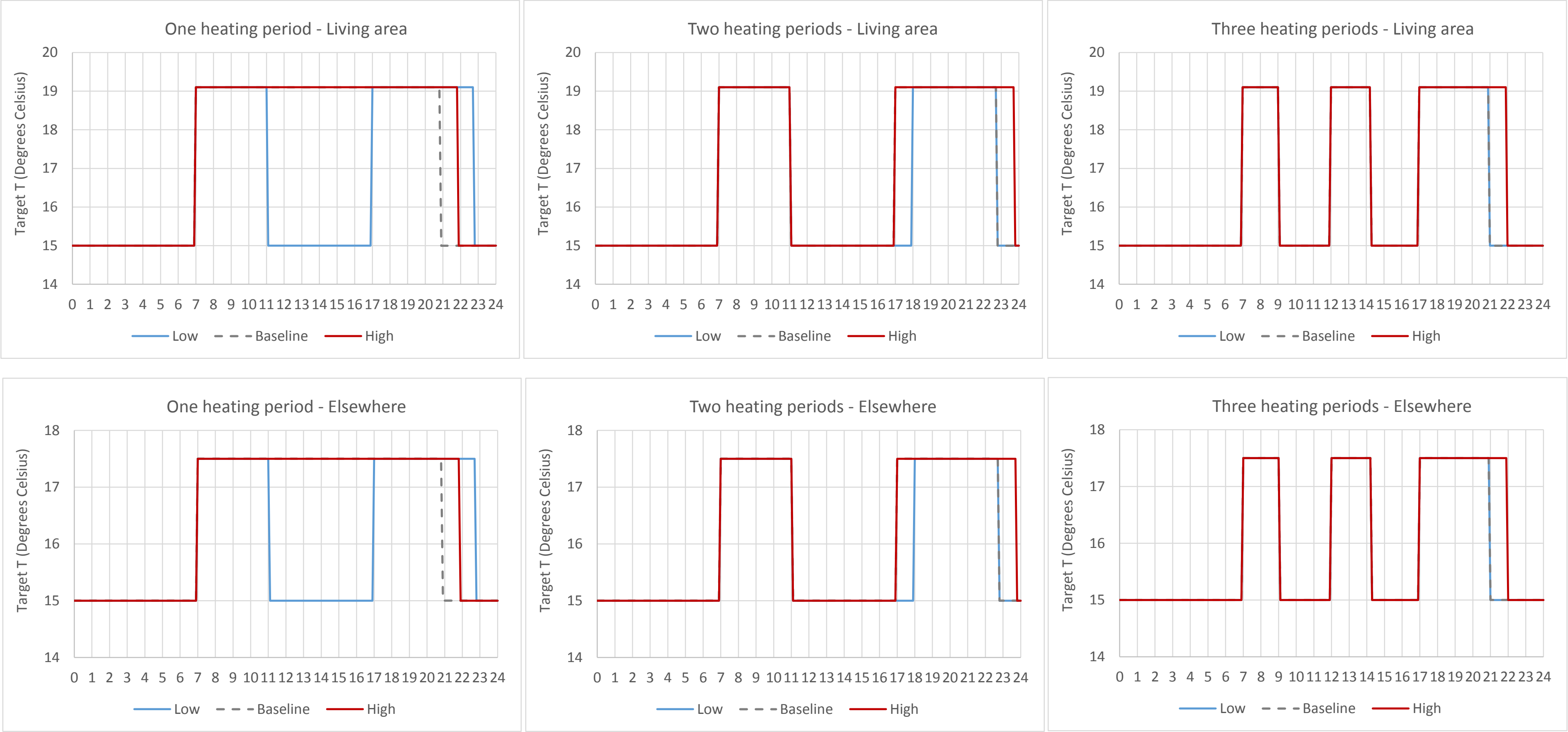

Figure 21: Heating schedules for Smart heating (Advanced – Passive control) scenario, showing the ‘Low’ (energy savings) and ‘High’ (rebound effect) cases.

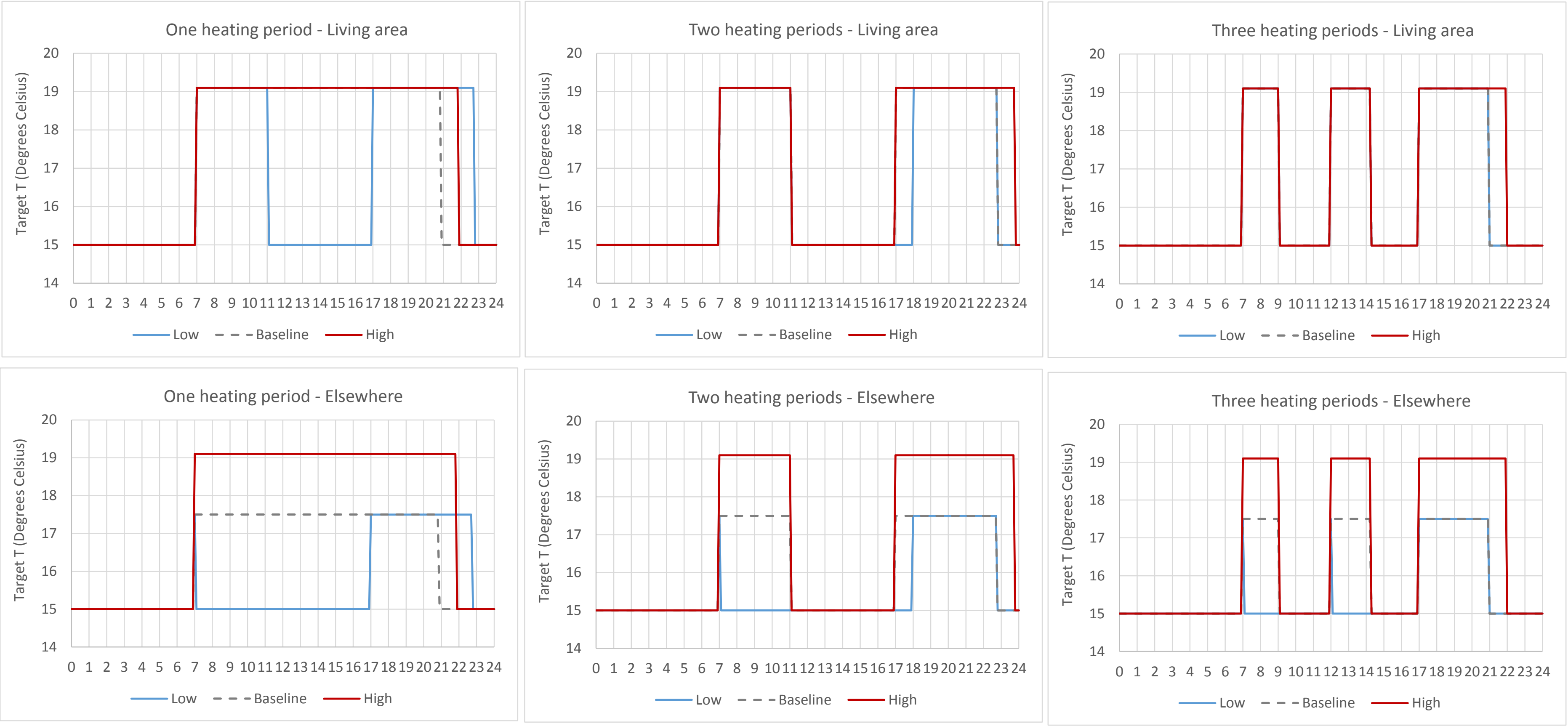

Figure 22: Heating schedules for Smart heating (Advanced – Zonal and Passive control) scenario, showing the 'Low' (energy savings) and 'High' (rebound effect) cases.

10.4 Results: Impact on annual heating fuel bill

Impact of smart heating on the annual heating fuel bill

Based on the modified heating schedules shown in Figure 19 to Figure 22, we have quantified the potential 'best case' and 'worst case' impact on the annual heating bill for each Smart heating scenario.

For the purposes of modelling the change in annual heating bill, we have derived the steady-state heating demand during the periods where the heating schedule shows a target temperature >15ºC (i.e. when the heating is 'on'). Outside these periods, we assume the heating demand is zero. Thus a household with a heating schedule of ten hours of heating per day (with any number of heating periods) would show a heat demand twice as large as another household, of the same Household type, with a heating schedule of five hours per day (also with any number of heating periods). We note that this approach neglects the impact of the 'warming up' period at the start of a heating period, and its dependence on the overall heating schedule; however, in the context of the high level of uncertainty on the household heating behaviour cases, this modelling simplification is deemed appropriate.

Figure 23 shows the annual heating bill savings for each heating schedule typology and for each Smart heating scenario, for the Low (energy savings) and High (rebound effect) cases and in the case of Household type 1 (Gas-heated). It can seen that, under the assumptions described above, there are significant potential impacts on the annual heating fuel bill both in the direction of energy savings and the direction of a rebound effect. The potential energy savings range from £0-306 per year, while the potential rebound effect ranges from £0-197 per year. For comparison, the annual heating fuel spend for Household type 1 (excluding standing charges and boiler maintenance contracts) is £620 for the 'One heating period' case, £420 for the 'Two heating periods' case and £352 for the 'Three heating periods' case, based on the 2015 gas price for domestic customers of 4.7 p/kWh. Therefore, the upper bound savings modelled are up to 49% of the annual fuel spend for the 'One heating period' case, and the upper bound rebound effect up to 56% of the annual fuel spend for the 'Three heating periods' case.

Figure 23: Annual heating bill saving for each heating schedule typology, for the 'Low' (energy savings) and 'High' (rebound effect) cases. The values shown are for Household type 1.

Table 29 shows the corresponding results for all household types for the Smart heating (Advanced – Zonal) scenario, in order to demonstrate the variation in the size of the potential savings or rebound effect. We note that the modelling assumptions are applied in the same way for all household types, and that the variation between household types is due to differences in the size of the household, the thermal efficiency of the building and the price of the heating fuel. Since the modelling assumptions are applied in the same way across the different household types, we focus on Household type 1 to draw out the key messages of the analysis.

Table 29: Annual heating bill savings for different household types for the Smart heating (Advanced – Zonal + Passive control) scenario

Household type	Age	Property type	Heating system	Annual fuel bill savings					
				Low case (energy savings)			High case (rebound effect)		
				One heating period	Two heating periods	Three heating periods	One heating period	Two heating periods	Three heating periods
1	Existing	Terraced/Semi-detached	Gas boiler	£306	£151	£121	-£136	-£185	-£197
2	Existing	Detached	Gas boiler	£554	£282	£231	-£287	-£364	-£380
3	Existing	Flat	Gas boiler	£115	£55	£43	-£47	-£67	-£72
4	Existing	Terraced/Semi-detached	Heat pump	£215	£106	£85	-£96	-£130	-£138
5	New build	Terraced/Semi-detached	Gas boiler	£149	£74	£59	-£60	-£85	-£91
6	New build	Terraced/Semi-detached	Heat pump	£139	£69	£55	-£56	-£79	-£85

In the case of households with the ‘One heating period’ Baseline heating schedule, it is clear that the potential energy savings modelled are larger than the potential rebound effect. For each of the Smart heating scenarios, the potential savings are in the range £200-306 per year, while the potential rebound effect is in the range £0-136. The key assumption leading to the result of large potential energy savings is that, for each Smart heating scenario, one potential outcome is that the household switches to a ‘Two heating periods’ heating schedule. The EFUS data in Table 28 shows that nearly half of the household surveyed use a single heating period during the weekdays. It is deemed likely that a substantial fraction of these cases correspond to household which are unoccupied during the weekday daytime, and which could therefore turn off the heating during the daytime without loss of occupant comfort. The modelling shows that for Household type 1 this change in heating schedule could lead to savings of up to £200 per year. Clearly, some fraction of these cases corresponds to households which are occupied during the weekday daytime; we reiterate that the potential heating fuel savings values shown are upper bound values, which would not apply to the cases where the household is occupied during the weekday daytime.

The key assumption leading to the relatively low potential rebound effect in the ‘One heating period’ case across most scenarios is that the heating schedule is already so long that there is little opportunity for to be made longer by the installation of smart heating controls. This is in contrast to an important potential mechanism for rebound identified in the ‘Two heating periods’ and ‘Three heating periods’ households, in the particular case of the Smart heating scenarios with Passive control (i.e. with occupant behaviour learning algorithms). With Passive control, it is expected that the heating schedule will be driven strongly by occupancy. This suggests the possibility that a household where previously the heating was not operated during certain periods of occupancy might experience a rebound whereby the heating is on during all periods of occupancy and, potentially, additional periods of ‘pre-heating’ leading up to occupied periods. The modelling finds that for

Household type 1 this change in heating schedule could lead to an increase in heating bill of up to £112 for the ‘Two heating periods’ household and up to £131 for the ‘Three heating periods’ household.

The modelling also shows that the mechanisms identified for potential energy savings and potential rebound effects due to wireless TRVs in the Smart heating (Advanced – Zonal) scenario, allowing the temperature and heating schedule of each room to be controlled independently, could have a large impact. The key potential energy savings mechanism identified is that the non-living areas of the household could be heated only during the last heating period of the day (i.e. before bedtime), and for a slightly shorter period in the ‘Two heating periods’ case. The modelling finds that for Household type 1 this change could lead to additional savings beyond those in the Smart heating (Basic) scenario of £106 in both the ‘One heating period’ and ‘Two heating periods’ cases.

The key potential rebound mechanism identified for the Smart heating (Advanced – Zonal) scenario is that the non-living areas of the household could experience an increase in temperature (i.e. in comfort level). As described in Section 8.3, it is typical for the non-living areas of the home to experience a slightly lower temperature than the living areas, due to a combination of different comfort preferences, higher gains from cooking, appliances and occupants, and perhaps also in part to a different balance between radiator size and local heat loss rate in different areas of the home. It is conceivable that, once an occupant is able to set the temperature of each room independently through the use of wireless TRVs, the target temperature of the non-living areas could be increased beyond the previous level. The modelling shows that for Household type 1, an increase in the temperature of the non-living areas to the same temperature as the living areas could lead to an additional increase in heating bill – beyond that of the Smart heating (Basic) scenario – of up to £85 per year for the ‘One heating period’ case and up to £63 per year in the ‘Two heating periods’ case.

Net Present Value of Smart heating based on the impact on fuel bill

Figure 24 and Figure 25 present the net present value (NPV) of the Smart heating scenarios in the Low (energy savings) and High (rebound effect) cases respectively, for Household type 1. At this stage, the NPV calculation includes the cost of the smart heating controls as derived in Section 9 and the change in annual heating fuel bill described above. It does not include the additional benefits accessible through demand-side response as described in the following sections. The NPV calculation is carried out over a 15 year lifetime[134] from 2015, using a 3.5% discount rate.

It can be seen that, in the majority of cases, the NPV is dominated by the value of the change in heating fuel bill, which is in the range -£2,555 to +£3,983 over the 15 year period, rather than the value of the smart heating control equipment itself, whose value is the range -£115 to -£302. As a result, the trends in the NPV with Smart heating scenario and with Baseline heating typology follow the trends in the annual heating fuel bill as described at length above.

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[134] We note that the 15 year lifetime is based on the typical lifetime of electronic controls used by CIBSE. We acknowledge that the smart controls may become obsolete before that time, but see no technical reason they could not be used over that period. In any case, the NPV values generated carry a high level of uncertainty as described above, and varying the lifetime assumption does not change the conclusions significantly.

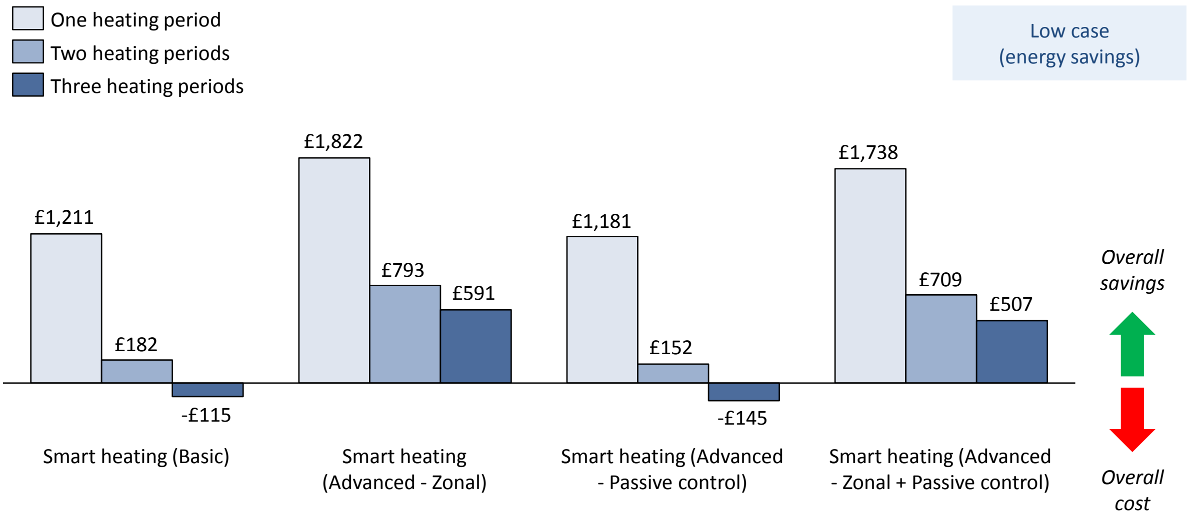

Figure 24: Net Present Value for the Smart heating scenarios for the 'Low' (energy savings) case. The calculation assumes a 3.5% discount rate and 15 year lifetime.

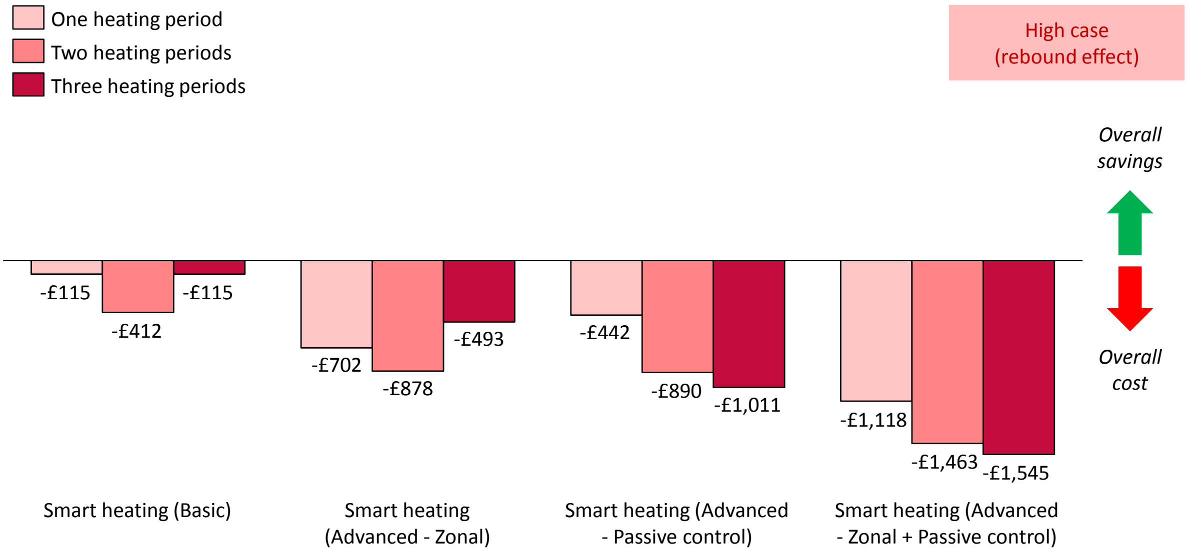

Figure 25: Net Present Value for the Smart heating scenarios for the 'High' (rebound effect) case. The calculation assumes a 3.5% discount rate and 15 year lifetime.

Summary

To summarise these results, the modelling shows that we might expect a wide distribution in the change in heating fuel bill on the installation of each type of smart heating controls, and that the upper bound potential savings or costs are significant at up to around 50% of the annual fuel spend. The wide range of outcomes reflects differences in both the baseline heating behaviour before installation of smart heating controls and in the heating behaviour after installation of the smart controls. The heating behaviour after installation of smart heating controls is clearly difficult to predict, and extensive field trials will be required in order to understand the frequency of the different outcomes studied here (as well as how those outcomes can be influenced). However, we do have some indication of the occurrence of the baseline heating behaviour through data of the type shown in Table 28. This data indicates that we might expect that something slightly less than half of households currently operate their heating system with one heating period, with slightly more than half operating with two or more heating periods.

The modelling therefore offers some insight into the direction of the possible outcomes of the most relevant cases studied in the modelling, namely the ‘One heating period’ and ‘Two heating period’ cases. For the nearly half of household operating with one heating period, we should still expect a wide distribution in the change in heating fuel bill before and after installation of smart heating controls, but we might expect that the distribution may be biased somewhat towards positive savings as a result of the greater potential for savings than rebound shown in Figure 23. For the ‘Two heating periods’ case, in contrast, the modelling suggests that the potential rebound effects are approximately as significant as the potential energy savings.

11 Potential Benefits through Demand-Side Response

11.1 Demand-side response services considered

A connected home can provide a variety of demand-side response (DSR) services to the various stakeholders across the energy system shown in Figure 15. Provision of these services will allow households to access a range of potential revenue streams to reduce their energy bills. The range of DSR services a household could provide includes peak reduction for distribution network operators, frequency response, short-term operating reserve (STOR) and demand turn-up services for National Grid, and balancing and supply optimisation services to suppliers.

An assessment of the potential value of the full range of DSR services is beyond the scope of this study. To illustrate the potential value of DSR services for household with smart energy controllers, we focus on an assessment of the potential value of two DSR services:

- *Peak demand reduction*
- *Frequency response*

A brief description of these services is given in Table 30. We select these two DSR services to study since previous analysis by Element Energy has indicated that these are likely to be among the most important sources of value for domestic DSR; Frequency response in the near term, and peak demand reduction in the longer term. Our previous work also identified supplier balancing as a similarly important source of value; however, this is not included here since this does not lend itself to transparent evaluation within the level of detail we are able to model in this study.

Table 30: Demand-side response services included in the modelling

DSR service	Description
Peak demand flexibility	• Ability to shift demand from the peak period, typically the evening hours, may allow the DNO to avoid the cost of reinforcement to the distribution infrastructure
Frequency response	• Ability to reduce or increase demand on a short (seconds) timescale can be used by the transmission system operator to help maintain system frequency at 50 Hz, replacing a service typically provided by large power plant

We note that, to a greater or lesser extent, the various DSR services given in the long list above could be in competition, and that extent to which this is the case could vary over time. For example, where a high level of low cost generation (such as wind power) is available to energy suppliers on the wholesale market at a time coincident with a peak in domestic demand, it may be preferable for the supplier for the consumer *not* to reduce this peak demand. This is clearly in opposition to the preference of the distribution network operator, which would prefer the consumer to reduce the peak demand in order to avoid infrastructure reinforcement costs. Aside from the challenges this presents for the electricity system regulation, this suggests that the consumer will not in general be able to derive value simultaneously from all (or perhaps even many) of the above DSR services.

An assessment of the extent to which this effect applies, and hence the extent to which the value of the DSR services as evaluated is not additive, is beyond the scope of this study. This therefore serves as an important caveat to the results presented later in the report.

11.2 Energy demand profiles used for DSR modelling

Our evaluation of the potential benefits of Peak demand reduction and Frequency response are based on an assessment of the extent to which electrical loads can be modulated or shifted during various periods of the day. In order to carry out this analysis, we have derived a set of hourly electricity demand profiles for different end-uses. The sources used to derive these profiles are described in Table 31.

Table 31: Sources for hourly electricity demand profiles

End-use	Source for profile
Appliances (split by appliance type)	• Derived from DECC's *Household Electricity Survey 2010-11*[135] • Separate profiles given for a variety of appliance types
Heat pump	• Based on UKPN Low Carbon London heat pump trial data[136]
Solar PV	• Based on insolation profiles from the JRC *Photovoltaic Geographical Information System Interactive Maps*[137]

The derived profiles are shown in Figure 26, for the case of Household type 1 (Gas-heated). The profiles shown correspond to the average day of the year; we note that for certain parts of the modelling we make use of distinct hourly demand profiles for each month of the year. Figure 27 presents the corresponding profiles for Household type 4, which also includes an electrical load for heating using a heat pump.

We note that these profiles are 'diversified'; that is, they represent the average electrical load of a large number of households. We also note that this is appropriate for the purpose of this modelling, since households are likely to contribute DSR services only after the individual household loads have been aggregated by an aggregator, the combined load offering a larger and more predictable resource for DSR.

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[135] https://www.gov.uk/government/collections/household-electricity-survey
[136] *Impact of Electric Vehicle and Heat Pump loads on network demand profiles*, Low Carbon London Report B2, UK Power Networks (2014)
[137] http://re.jrc.ec.europa.eu/pvgis/apps4/pvest.php [Accessed 21st March 2016]

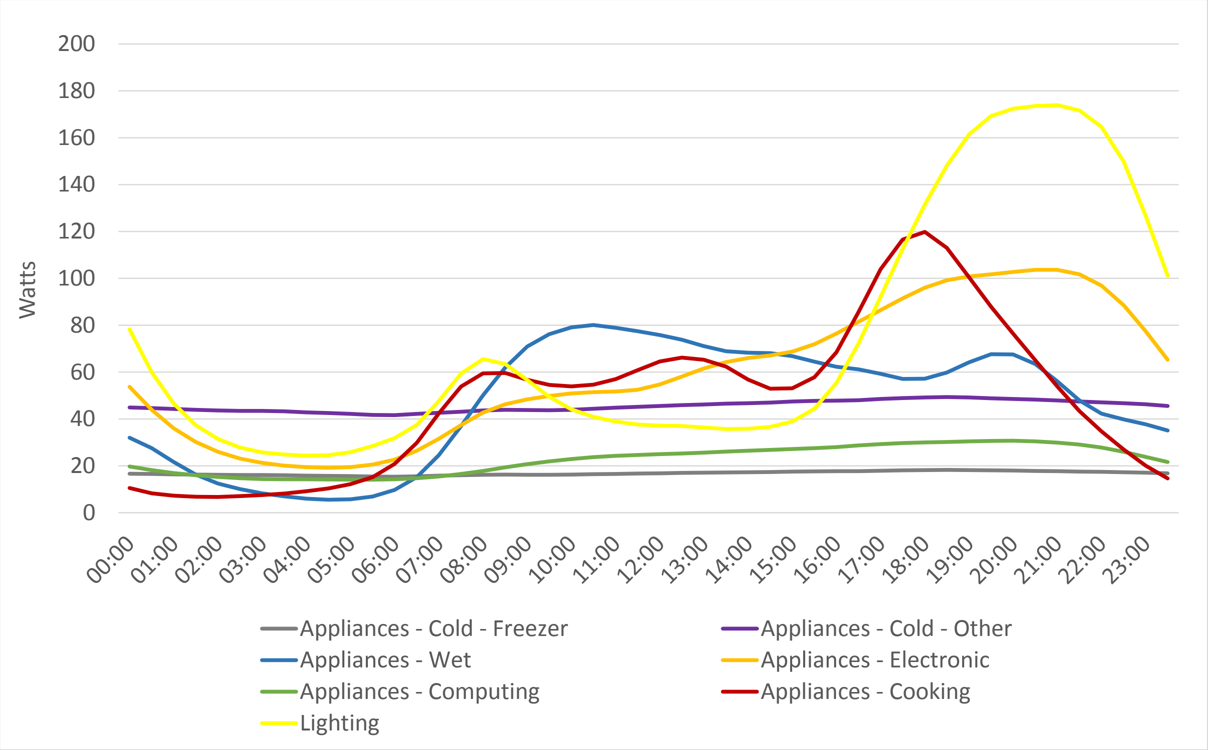

Figure 26: Electricity demand profiles for Household type 1 on the average day of the year, including lighting and appliances.

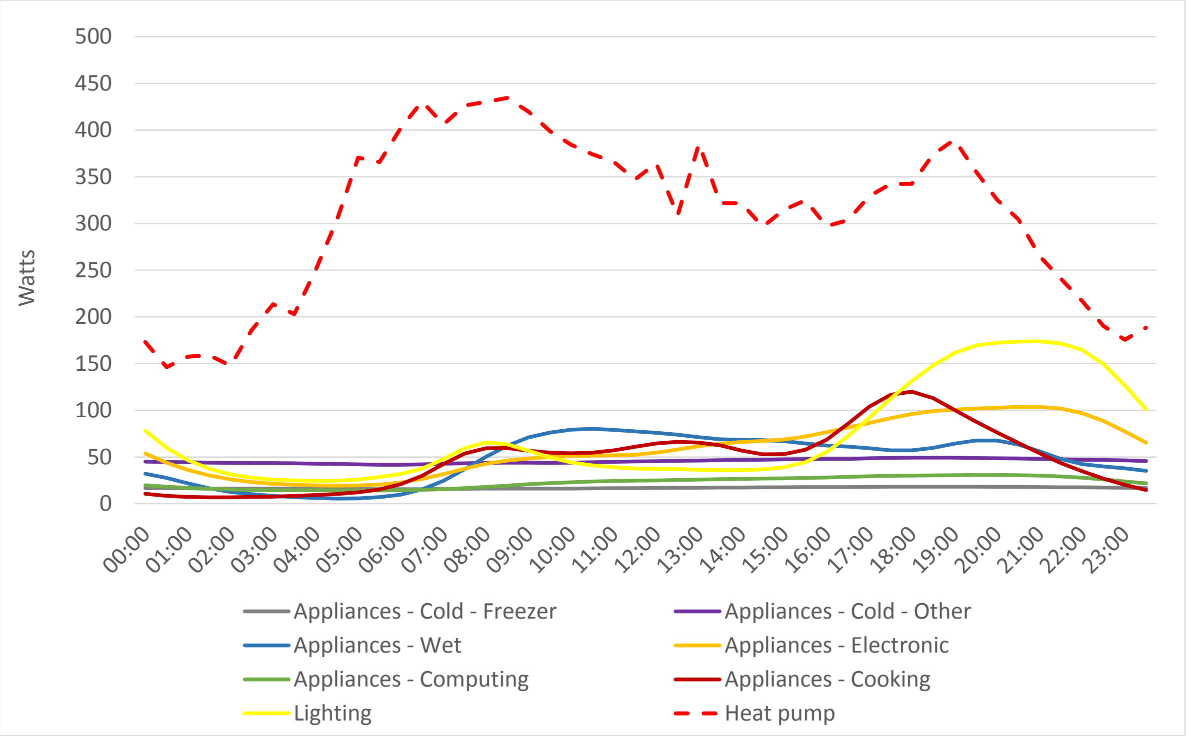

Figure 27: Electricity demand profiles for Household type 4 on the average day of the year, including heat pump (heating and hot water), lighting and appliances.

12 Peak Demand Flexibility

Value of peak demand flexibility

One of the important ways in which smart home energy controllers may allow domestic consumers to reduce energy bills is by providing peak demand flexibility. The value proposition is that by reducing the peak level of electricity demand, the local distribution network operator (DNO) is able to avoid or defer network reinforcement, with significant cost savings. As such, it is expected that the DNO may, by some means, offer economic incentives to the domestic consumer to shift electricity demand from peak periods to off-peak periods.

Future requirements

Aside from the very limited case of the use of night storage heating and associated Economy 7 and Economy 10 tariffs, domestic DSR of this type is not widely practised at present (according to Ofgem,[138] there were approximately 1.9 million customers with static or dynamic teleswitched[139] meters in Great Britain in 2012). Furthermore, our consultation with a number of DNOs suggests that they do not expect to make use of domestic DSR in the near term (up to roughly the mid-2020s). However, it is expected that domestic DSR will provide an important alternative to network reinforcement in the medium to long term, as the technical capability to provide such services within households becomes more widespread and as the regulatory and institutional framework for those services to be incentivised and provided becomes better developed.

With this in mind, a number of high profile trials of domestic DSR have been carried out. Two prominent such examples are the Customer Led Network Revolution (CLNR)[140] led by Northern Powergrid, and the Low Carbon London (LCL)[141] project, led by UK Power Networks (UKPN). The CLNR time-of-use trials found that the electricity demand during peak periods for customers on the variable tariff was up to 11% lower than in the control group, and that laundry and dishwashing were the activities re-scheduled most frequently.[142] In the LCL time-of-use tariff study of 922 customers, mean bill savings of 4% were achieved.[143]

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[138] Ofgem, *The state of the market for customers with dynamically teleswitched meters*: *Analytical report*, 2013 (Ref: 133/13)

[139] A radio teleswitch is the mechanism used by electricity suppliers to switch customers between tariffs; as such, the number of teleswitched meters is the upper bound for the number of customers using the Economy 7 and 10 tariffs.

[140] http://www.networkrevolution.co.uk/

[141] http://innovation.ukpowernetworks.co.uk/innovation/en/Projects/tier-2-projects/Low-Carbon-London-(LCL)

[142] *CLNR Insight Report: Domestic Time of Use Tariff*, Durham University and Newcastle University, 2013 *(Document CLNR-L093)*

[143] UKPN/EDF, *Residential demand response – the dynamic Time-of-Use tariff, Session 2 presentation* (Available at http://innovation.ukpowernetworks.co.uk/innovation/en/Projects/tier-2-projects/Low-Carbon-London-%28LCL%29/Presentations/Low+Carbon+London+-+Time-of-Use+Trials.pdf, accessed April 2016)

Communications requirements

The domestic peak period occurs in a reproducible way during the evening, in the 4-8pm period. The desired flexibility would therefore involve shifting demand out of this period, either into the daytime before around 4pm or into the overnight period.

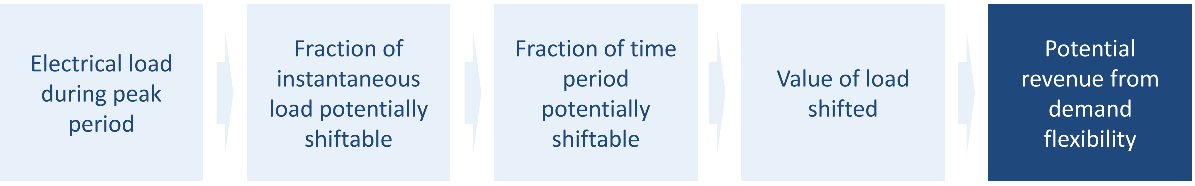
As such, the household could receive the signal or incentive to shift their demand in a range of ways. Since the peak time period is reproducible, a static time-of-use tariff could be sufficient to drive peak reduction. Alternatively, the signal could be provided through a dynamic time-of-use tariff[144], critical peak pricing[145], a critical peak rebate[146] or other mechanism.

Furthermore, since the timescale over which the response would be required is long – a minute-scale, or even half-hourly response would be sufficient – the requirements for the home energy controller is not stringent. Indeed, providing that the electricity demand could be metered on a half-hourly basis (through the smart meter or another device) the demand shifting could be performed manually by the consumer, for example through a programmable thermostat or even on/off controls. A more sophisticated control system would, alternatively, be able to respond to dynamic price signals.

12.1 Summary of approach

A high-level summary of our approach to modelling peak demand flexibility is shown in Figure 28. We first quantify the electrical load over the peak period (assumed to be 4-8pm) for each end-use category, on a given day. We then assess what fraction of the instantaneous load is potentially flexible, and for what fraction of the peak period that load reduction can be sustained. The combination of these three variables (once multiplied by the four hours of the peak period) gives the total electricity demand which can be shifted out of the peak period on the day in question.

Finally, we apply the value of the shifted load on a per unit energy basis, in order to derive the potential value of peak demand flexibility per day. Our approach to valuing the shifted load is described in the next section.



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[144] Whereby the electricity price, in general, varies continuously over the day.

[145] Whereby the electricity price is raised substantially for certain peak periods (typically only on a small fraction of days), which are announced in advance.

[146] Whereby the electricity price during certain peak periods (typically only on a small fraction of days), which are announced in advance, remains at the normal value, but customers who are able to reduce their demand during these periods receive a rebate in proportion to the demand reduction.

Figure 28: Peak demand flexibility modelling approach

12.2 Value of peak demand flexibility

As described above, a variety of pricing structures could be used to incentivise domestic consumers to shift demand out of the peak period. These include static and dynamic time-of-use tariffs, critical peak pricing, peak time rebates and other mechanisms. To illustrate the potential value of peak demand flexibility in our modelling analysis in a transparent way, we examine the case of static time-of-use tariffs.

We take representative values for a potential static time-of-use tariff structure from the Customer-Led Network Revolution. The pricing structure is presented in Table 32, and comprises a price for Peak (4-8pm), Day (7am-4pm) and Off-peak (all other times) periods. The values shown are assumed to apply to 2015, and we apply an increase in all prices over time, at the same rate, according to the Retail fuel price projections in the DECC and HM Treasury Green Book Guidance.[147] It can be seen that the associated value of peak demand flexibility in 2015 is 17 p/kWh for a shift from Peak period to Day period, and 21 p/kWh from Peak period to Off-peak period.

Table 32: Customer-Led Network Revolution time-of-use tariffs used to illustrate potential value of peak demand flexibility (2015 values)

Tariff band	Times	Value	Sources
Day tariff	07:00-16:00 (Mon-Fri)	15 p/kWh	• Taken from CLNR[148]
Peak tariff	16:00-20:00 (Mon-Fri)	32 p/kWh	• Derived using price ratios from CLNR[149] (Day=0.96, Peak=1.99)
Off-peak tariff	All other times	11 p/kWh	• Derived using price ratios from CLNR (Day=0.96, Off-peak=0.69)

12.3 Modelling assumptions: Peak demand flexibility without storage

The first step in the modelling, the identification of the electricity demand associated with each end-use during the peak period, follows in a straightforward way from the demand profiles presented in Section 11.2. Figure 29 shows the electricity demand profiles for Household type 4, and indicates the coincidence of the load with the peak 4-8pm period. Not surprisingly, the load over this period includes a large contribution from the heat pump, lighting, cooking and electronic appliances, as well as smaller contributions from the other appliance types.

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[147] https://www.gov.uk/government/publications/valuation-of-energy-use-and-greenhouse-gas-emissions-for-appraisal

[148] *CLNR Closedown report: SMEs Test cells 2b, 9b, 10b*, Frontier Economics (2014) [Table 1, Day peak, Profiles 1-4 value]

[149] *CLNR Post Trial Analysis: Residential DSR for Powerflow Management (CLNR-L223)*, Jiang et al. (2015) [Table 1]

The next step in the analysis is to assess the extent to which each load can be shifted out of the peak period. It is important to note that in the analysis presented in this section, the assumptions on flexibility apply to the case with no electrical storage (i.e. a battery). Where electrical storage is present, all electrical load is potentially flexible (constrained by the electrical storage capacity available). This case is studied in a later section. Here, any demand shifting relates to a 'real' shift in time of the electricity-consuming end-use.

At this stage, several of the end-use categories are excluded; this includes Electronic appliances, Computing, Cooking and Cold appliances which are not freezers. In the case of Electronic appliances, Computing and Cooking, the load is excluded on the assumption that the consumer will be very unlikely to change behaviour to such an extent that these activities can be moved fully out of the 4-8pm period. In the case of cooking, this is supported by domestic consumer survey results from the Low Carbon London study[150], which found that Wet appliances were felt by consumers to be most flexible, followed by space heating and immersion heating, with the least flexible appliances reported as lighting, cooking and showering. It should be noted that, in that study, even the cooking appliances were deemed somewhat flexible – on average, somewhere between "Occasionally" and "Half the time", where the wet appliances were deemed, on average, somewhere between "Half the time" and "Usually". Our analysis could therefore be seen as somewhat conservative in relation to the flexibility of cooking and, potentially, the other end-uses excluded. In the case of Cold appliances which are not freezers (mainly fridges), these are excluded on the basis their thermal inertia is likely to be too low to allow significant shifting of the associated load.

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[150] *Residential consumer attitudes to time-varying pricing*: Low Carbon London Report A2, Carmichael et al. (2014)

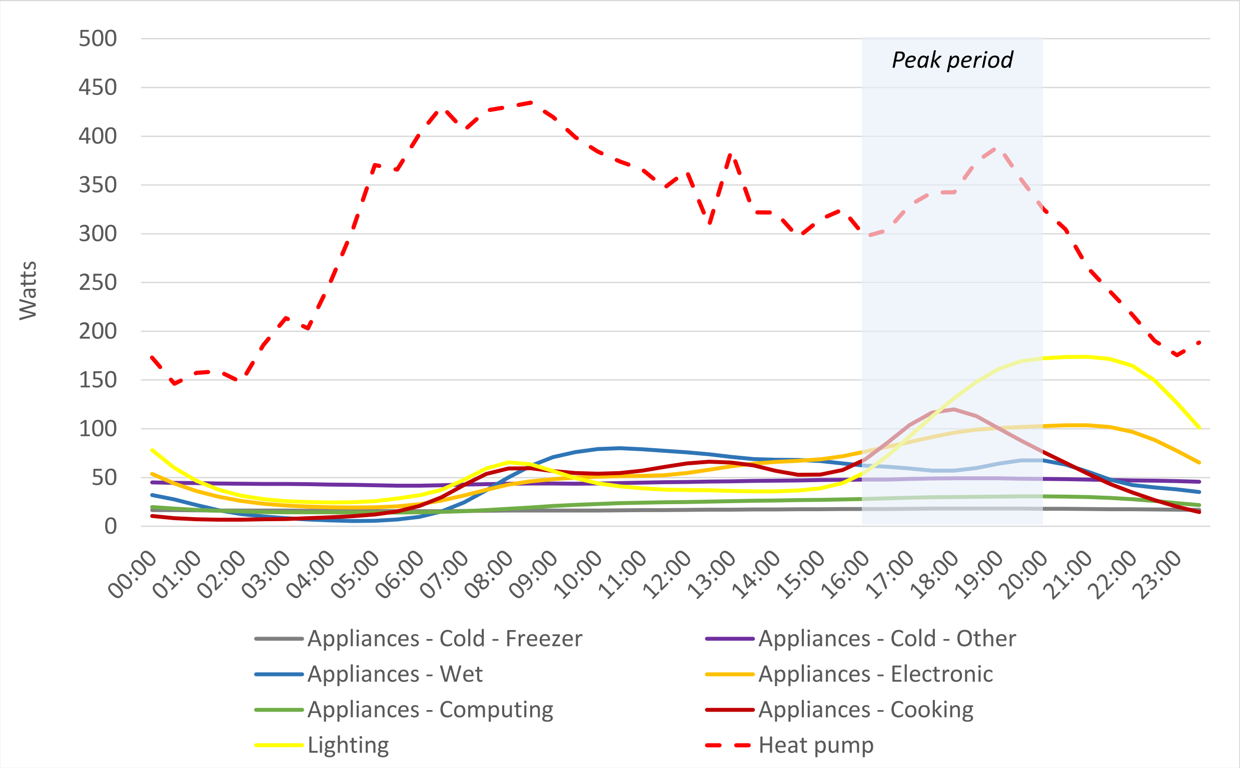

Figure 29: Electricity demand profiles for Household type 4 on the average day of the year, showing the coincidence of load with the peak period (4-8pm).

The modelling assumptions for the remaining four end-uses – heat pump, lighting, cold appliances (freezers) and wet appliances – are shown in Table 33. As shown, we assume that it is technically feasible for heat pump load to be removed for up to 25% of the four hour peak period. This corresponds to a shifting forward of the heating period by one hour. This assumption is based on evidence[151] that for a typical household heating can be shifted forwards by one hour without significant loss of comfort, defined as a drop below 18ºC. However, we only apply this technically feasible shift for scenarios with Passive heating control. The rationale for this is that the consumer is most likely to define the heating system operational schedule to achieve the desired target temperature during the desired periods. It is only with a Passive control system that the target temperature schedule can (in theory, at least) differ from the actual operating schedule.

For lighting, we assume that 15% of the instantaneous load can be removed across the entire Peak period. This is based on evidence[152] that dimmable LED lights can be modulated by 14-23% without occupants noticing, over a timescale of ten seconds to minutes. Since this demand flexibility is a result of dimming, the demand is not shifted but removed entirely, and the value of the flexibility is the full value of the peak electricity price.

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[151] *Assessing heat pumps as flexible load*, Hong et al., Proceedings of the Institution of Mechanical Engineers Part A 227 (1) 30-42 (2013)
[152] *Lighting Redesign for Existing Buildings*, DiLouie (2011)

For freezers, we assume that 30 minutes of the full freezer load can be shifted out of the Peak period and into the Day period. The rationale for this is that the freezer could be pre-cooled prior to the peak period such that it can be turned off for half an hour of the four peak hours. This assumption is based on literature suggesting that the relatively low thermal inertia of domestic freezers makes them unsuitable for demand shifting for periods longer than 15 minutes[153]; we take a somewhat more generous assumption of twice this length. Finally, we assume that wet appliance load can be shifted out of the Peak period entirely; in this case, the wet appliance cycles (such as washing machine, tumble drying and dishwasher cycles) are performed during the day, such that the load is shifted from the Peak to the Day price.

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[153] *Predictive Control of a Domestic Freezer for Real-Time Demand Response Applications*, Baghina et al. [http://www.e-price-project.eu/website/files/PID2481791%20-%20Final%20submission.pdf]

Table 33: Peak demand flexibility assumptions (without thermal or electrical storage)

End-use category	Item	Value	Comment
Heat pump	Fraction of peak load flexible	0-100%	• Assume that heating can be shifted forward by one hour of the four hour peak period without loss of comfort (see text) • Assume this is only implemented in systems with Passive control of the heating system
	Fraction of peak period over which load flexible	25%	
	Tariff period to which peak demand shifted	Day	
Lighting	Fraction of peak load flexible	15%	• Assume that LED lighting can be dimmed by 15% without adverse impact on occupant (see text) • Demand flexibility here is due to light dimming, so demand is not shifted but removed
	Fraction of peak period over which load flexible	100%	
	Tariff period to which peak demand shifted	-	
Appliances - Cold - Freezer	Fraction of peak load flexible	100%	• Assume that system can be pre-cooled such that it can be turned off for 30 minutes during the peak period
	Fraction of peak period over which load flexible	12.5%	
	Tariff period to which peak demand shifted	Day	
Appliances - Wet	Fraction of peak load flexible	100%	• Assume that wet appliance runs are carried out during the day rather than the peak period
	Fraction of peak period over which load flexible	100%	
	Tariff period to which peak demand shifted	Day	

12.4 Results: Value of peak demand flexibility without storage

The potential annual value of peak demand flexibility for Household type 1 is shown in Figure 30, for two home energy control scenarios: the Smart heating (Advanced – Passive control) scenario and the Smart home scenario. Since this household type is Gas-heated, there is no heat pump load to shift. Thus, in the Smart heating (Advanced – Passive control) scenario, the household cannot access any value from peak demand flexibility. In the Smart home scenario, **flexibility in the lighting, freezer and wet appliance demand provides an annual value of £12, with lighting making up more than half of this**.

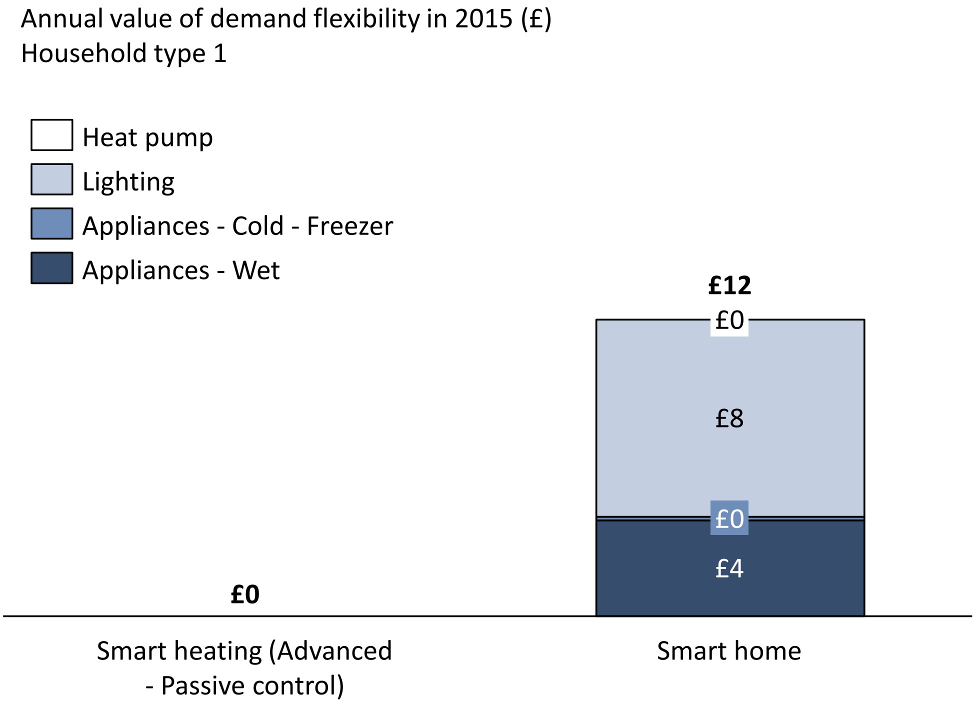

Figure 30: Value of peak demand flexibility for Household type 1 (Gas heating) for two selected home energy control scenarios

Figure 31 shows the potential annual value of peak demand flexibility in the same scenarios for Household type 4, where a heat pump provides the space heating and hot water. In this case, the **heat pump provides up to £20 of bill savings per year**, applicable to both scenarios. To put this in context, the annual electricity bill for Household type 4 is of the order £900 (based on 5,400 kWh/year at the standard rate of 16 p/kWh). Therefore, an annual saving of £20 corresponds to just over a 2% saving, and an annual saving of £33 to a nearly 4% saving.

Considering the additional cost of the Smart heating (Advanced – Passive control) scenario versus the Baseline, at £145, it can be seen that the potential **value of shifting the heat pump load alone could achieve payback in 7-8 years**. We emphasise that this is a maximum potential value, dependent upon the Passive control system being used to shift peak demand in the way described.

Making the same comparison for the Smart home scenario, it is clear that the value provided by peak demand shifting, at £33 per year, is very **unlikely to justify the additional cost of the full set of smart appliances** included, at more than £2,000 (albeit that this is likely to fall significantly in the future). As well as the high cost of the smart appliances, this is due in large part to the significantly lower annual load of the non-heating appliances than the heating appliances. This demonstrates that, at least in the near term, the significant premium for smart appliances is unlikely to be justified by the potential savings on the electricity bill. Rather, the savings are more likely to be a side-benefit, with the uptake of smart appliances being driven by their enhanced convenience and improved user experience.

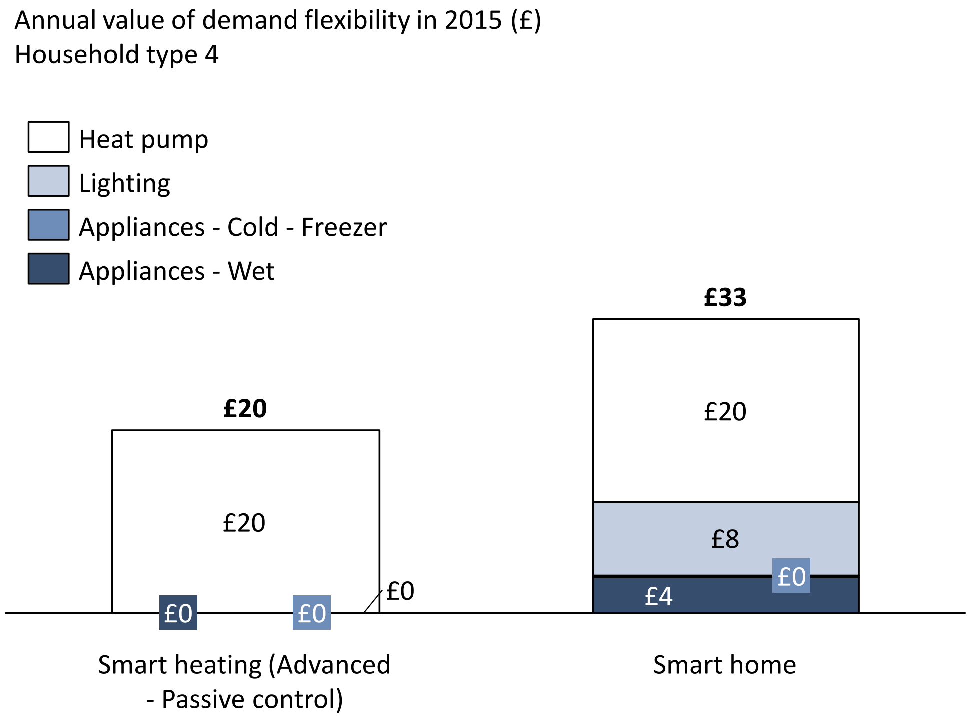

Figure 31: Value of peak demand flexibility for Household type 4 (Heat pump heating) for two selected home energy control scenarios

12.5 Peak demand flexibility with Solar PV and storage: modelling approach

The above analysis of the potential value for peak demand flexibility applies to the case where there is no electrical or thermal storage. Here, we examine how the potential value increases when there is electrical or thermal storage. We focus on a case where the value is likely to be greatest, and then the likelihood of storage being present is largest: that is, the case of the Prosumer home, where there is on-site electricity generation through solar PV.

Since the price the Prosumer household receives for export of electricity to the grid is significantly lower than the price the same household pays to purchase electricity, there is a strong economic incentive for the household to maximise on-site consumption of electricity. Given that the period of solar PV generation (largely during the middle of the day) and the period of greatest electricity demand (the evening) are not well-aligned, this provides an incentive for the household to purchase some form of electricity storage, in order to be able to use the energy generated during the day at a later time.

We study the potential economic benefit of adding electrical or thermal storage, along with a smart electricity management system (to optimise the dispatching of the generated and stored electricity) to a household with an existing solar PV system with no storage.

Figure 32 shows a high-level summary of our approach to modelling the smart management of solar PV either with electrical battery storage (upper boxes) or with thermal storage (lower boxes). In each case, the first step is to find the “excess” solar PV generation on the typical day of each month of the year. The excess generation is defined as that which cannot be used to meet on-site electrical load at the time of generation and which would, in the case of no storage, be exported to the grid.

Figure 33 illustrates the derivation of excess solar PV generation for Household type 1, which is Gas-heated, for typical days in January and July. Not surprisingly, the excess generation is largest in July, where generation is significantly higher and electricity demand somewhat lower. Figure 34 shows the same for Household type 4, where heating is provided by heat pump. In this case, there is no excess generation in January, where the electricity demand exceeds the generation for all hours on the typical day; however, there is a significant excess generation in July.

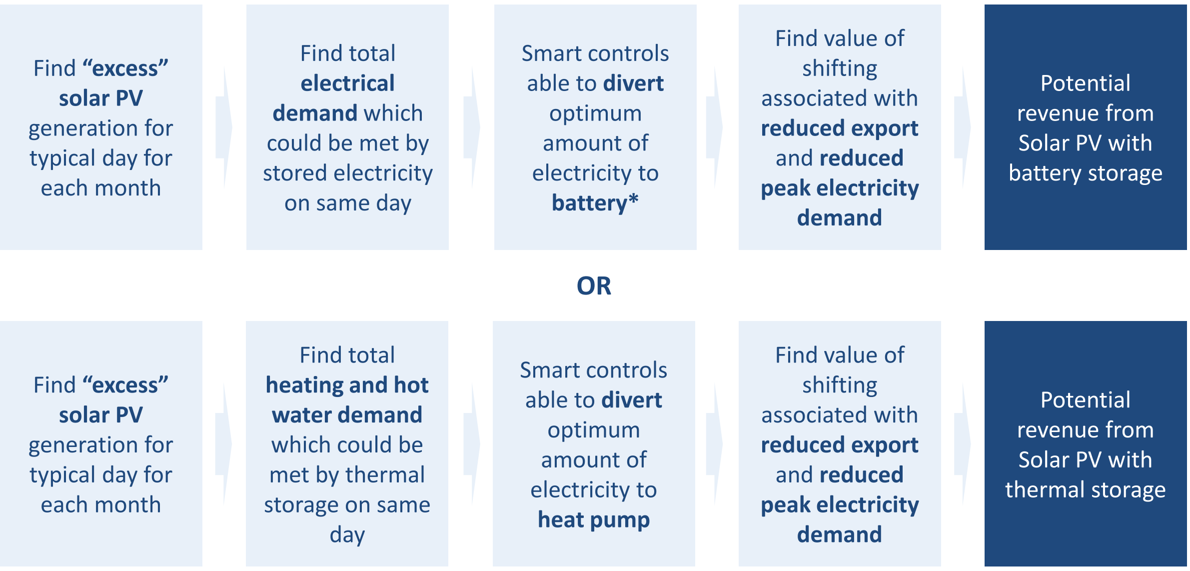

Figure 32: Smart management of Solar PV with electrical battery (upper boxes) or thermal (lower boxes) modelling approach

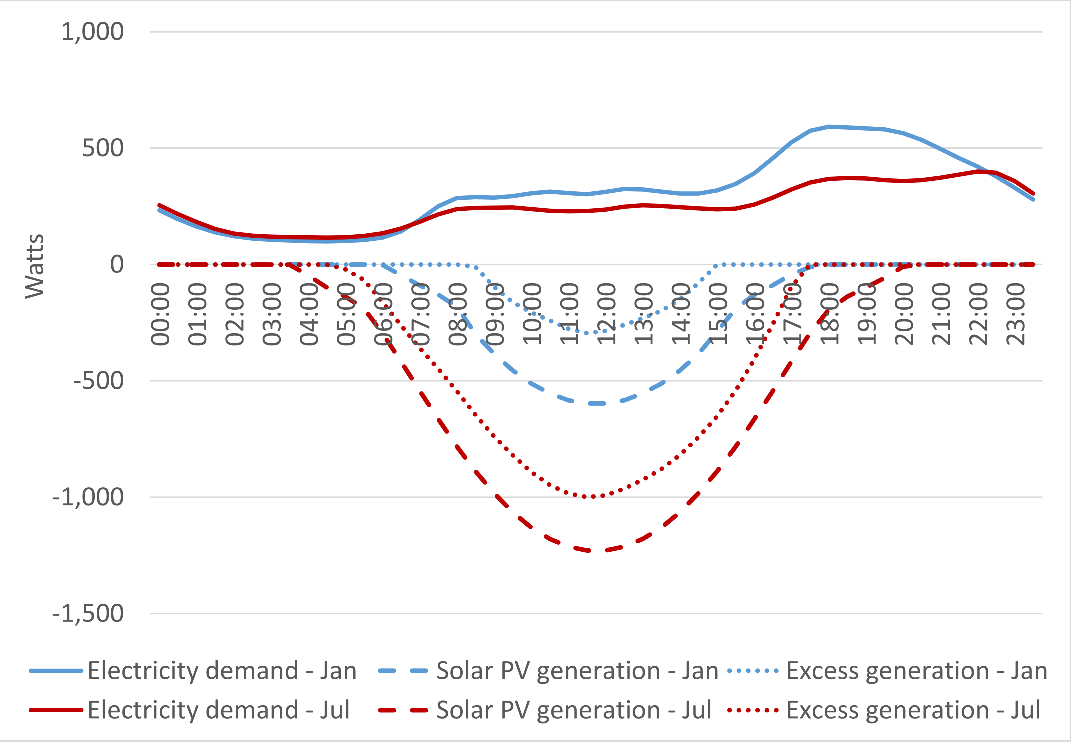

Figure 33: Derivation of excess solar PV generation for Household type 1 (Gas heating), for January and July. The solar PV system is 3.5 kW$_p$.

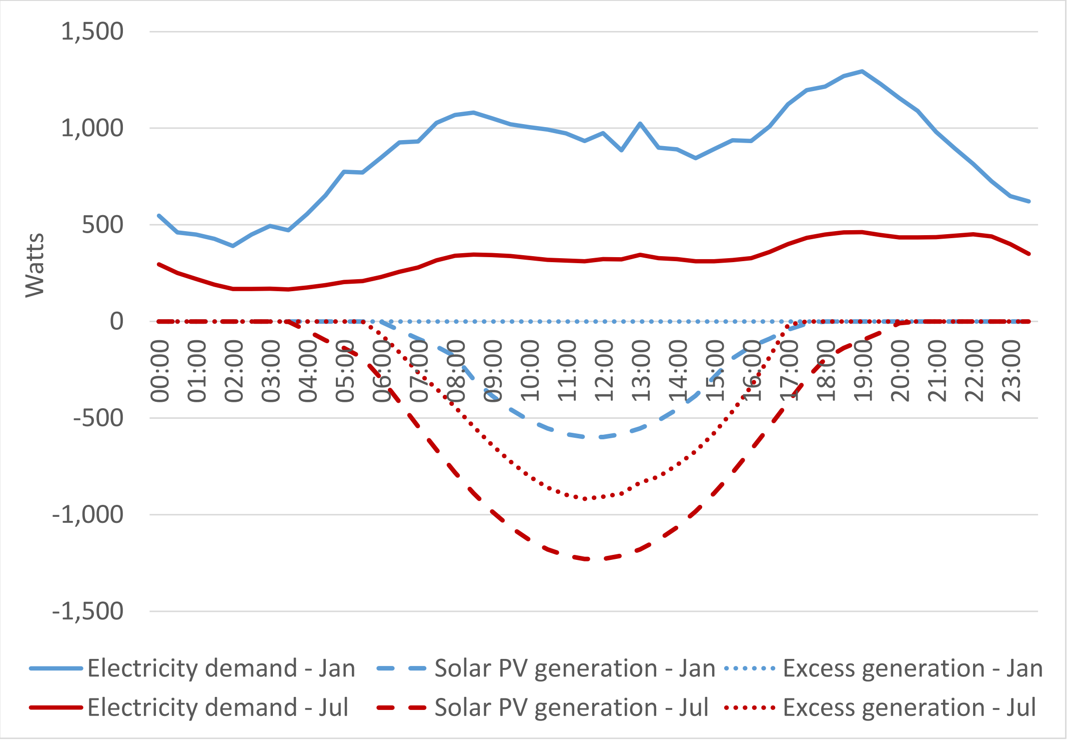

Figure 34: Derivation of excess solar PV generation for Household type 4 (Heat pump heating), for January and July. The solar PV system is 3.5 kW$_p$.

In the next modelling step, we find the total demand which could be met by the stored energy on the same typical day (which could in reality be either the same day or the following day). In the case of electrical storage, this demand can be any electrical load; in the case of thermal storage, it must be heating or hot water demand. Following this, we optimise the dispatch of the excess solar PV electricity to meet this demand to maximise the value to the household.

The storage system (whether electrical or thermal) can provide value to the household by shifting demand in a number of ways. Importantly, the value that can be generated by the storage is not limited to the storage and dispatch of excess solar PV. Additionally, the storage can shift demand from Peak periods to Day or Off-peak periods, and from the Day period to the Off-peak period. The value of each of these shifting options depends on the tariff structure, as well as on the solar PV export price. As shown in Table 34, we assume here the same static time-of-use tariff structure as in the previous section. For the solar PV export price, we assume a value of 5 p/kWh in 2015, on the basis of the export tariff set for domestic solar PV within the UK feed-in tariff framework as of March 2016[154]. We allow the export price to increase in proportion with the electricity purchase prices in future years.

Table 34: Solar PV export price assumed, compared with time-of-use tariffs modelled (2015 values)

Item	Value
Solar PV export price	5 p/kWh
Day tariff	15 p/kWh
Peak tariff	32 p/kWh
Off-peak tariff	11 p/kWh

Table 35 then shows the value of the range of shifting options described above. The options have been arranged in order from most valuable to least valuable, indicating the merit order applied within the modelling for the import, export and dispatch of electricity. As such, the modelled value of the smart management and storage system should be seen as an upper bound or maximum potential, given that in reality the smart management system will not have perfect foresight of electricity generation and demand over the following 24 hours. It can be seen that the most valuable shifting option is to meeting Peak demand using excess solar PV generation, with a value of 27 p/kWh. The next most valuable option, however, does not involve excess solar PV generation, but instead involves shifting Peak demand to the Off-peak period with a value of 21 p/kWh. Shifting Daytime demand to excess PV carries a value of 10 p/kWh, and Off-peak to excess PV a value of 6 p/kWh. Finally, shifting Day period demand to Off-peak carries the lowest value of 4 p/kWh.

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[154] https://www.ofgem.gov.uk/environmental-programmes/feed-tariff-fit-scheme/tariff-tables (accessed 20th March 2016)

Table 35: Merit order for demand shifting performed by the smanths rt management system with thermal or electrical storage

Shift merit order	Value
Peak to Excess PV	27 p/kWh
Peak to Off-peak	21 p/kWh
Day to Excess PV	10 p/kWh
Off-peak to Excess PV	6 p/kWh
Day to Off-peak	4 p/kWh

12.6 Results: Value of peak demand flexibility with Solar PV and electrical storage

Figure 35 shows the results of the optimisation of the use of 4 kWh electrical storage in Household type 1 (Gas-heated) with a 3.5 kW_p solar PV system, for a typical day of each month of the year. The bars show the electrical energy shifted on that typical day, by shifting option. The shifting options are ordered top to bottom from most valuable to least valuable.

It can be seen that the full 4 kWh of electrical storage is used on the typical day of every month. In all months, some shifting of Peak demand to excess PV is possible, but this type of shifting can be performed to the greatest degree during the ‘shoulder’ seasons, in particular February and October for Household type 1. This because although the amount of excess PV generated is largest in June and July, the low Peak demand in these months means that only a small amount of the excess PV can be used to meet Peak demand. The balance of higher excess PV towards the summer months, but higher Peak demand towards the winter months, means that Peak to excess PV shifting occurs to the greater degree in the ‘shoulder’ months. The degree to which the next most valuable shifting option, of Peak to Off-peak demand, can be performed also varies strongly by month, being greatest in December and January. This is determined by the balance of the same two factors described above, and the fact that Peak demand is only met by Off-peak demand if it cannot be met by excess PV – since the amount of excess PV generation is low in December and January, the level of Peak to Off-peak shifting peaks in these months. The remaining daily shifting capacity of the storage system is utilised by the remaining shifting options.

Figure 36 shows the corresponding results for Household type 4, in which the heating and hot water is provided by a heat pump. In this case, as compared with Household type 1, there is less opportunity for meeting Peak demand with excess PV generation, since the higher daytime demand form the heat pump means there is less excess PV generation. However, the larger Peak demand in Household type 4 during the winter months, again due to the heat pump, means that there is much greater opportunity for shifting demand from Peak periods to Off-peak periods. As a result, a much greater proportion of the shifting performed by the storage system is associated with these two most valuable shifting options.

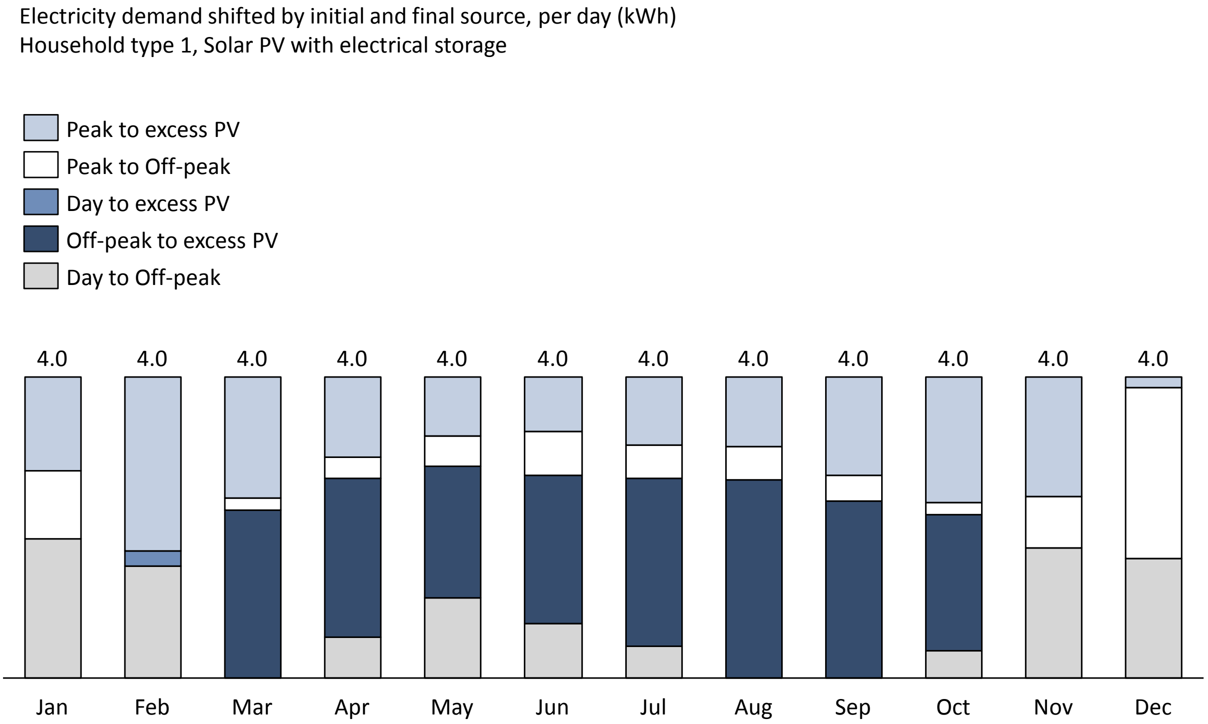

Figure 35: Electricity demand shifted in the case of Solar PV with 4 kWh electrical storage, for Household type 1 (Gas heating)

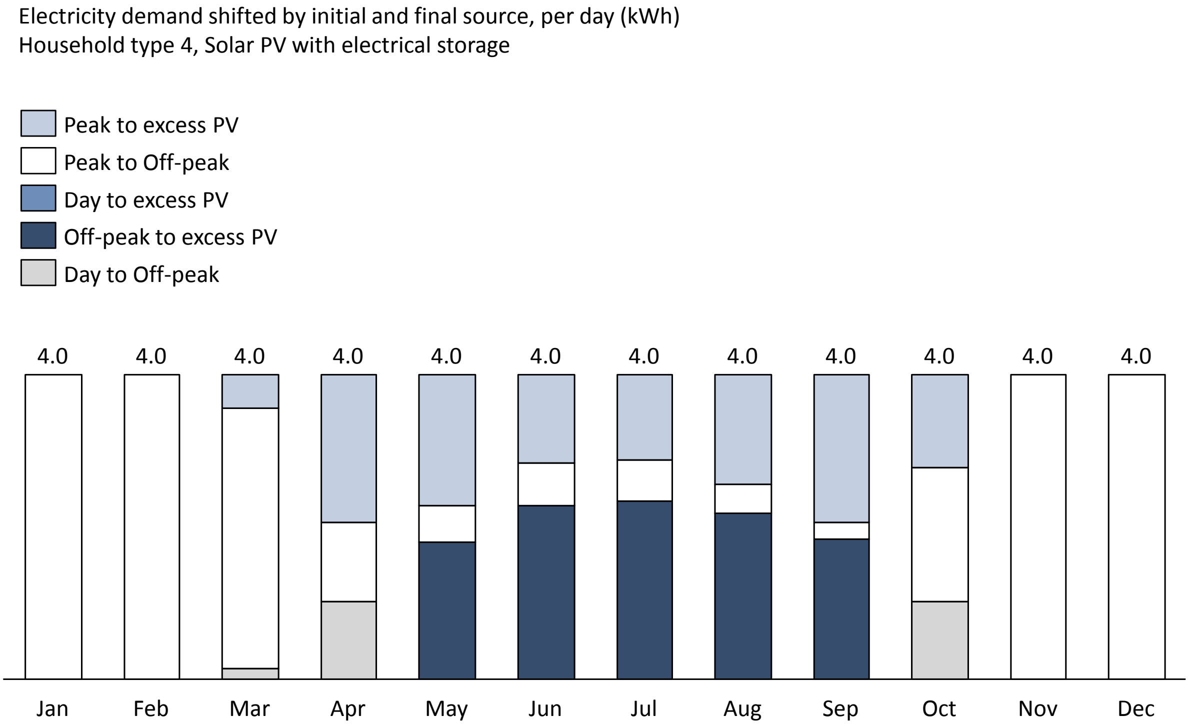

Figure 36: Electricity demand shifted in the case of Solar PV with 4 kWh electrical storage, for Household type 4 (Heat pump heating)

The implication of this for the potential value provided by the smart management and electrical storage system for the two household types is shown in Figure 37. **The potential annual value for Household type 1 is £210**, as compared with **£269 for Household type 4**. As would be expected from the preceding discussion, this is due largely to the much larger value provided through the shift of Peak demand to Off-peak periods. It is of interest to note that much of this value could be provided by the smart management and electrical storage system even in a household without a solar PV system.[155]

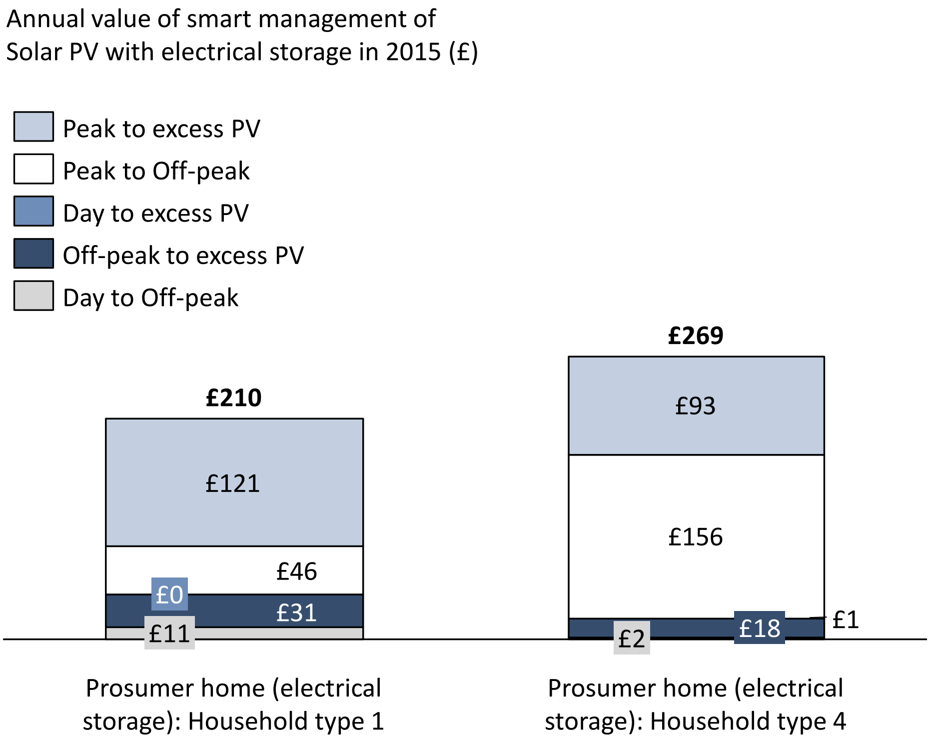

Figure 37: Value of smart management of Solar PV with electrical storage (2015 figures), for Household types 1 and 4

We can now make a rough assessment of the economic case for the smart management of solar PV with electrical storage within the Prosumer home scenario. The cost of this scenario was shown in Section 9 to be of the order £6,500, of which £250 is attributable to the smart diverter and around £3,700 attributable to the electrical storage (with the remainder attributable to the smart appliances and heating controls). Taking a capital cost of ≈£4,000 for the smart management of solar PV and storage system, therefore, the £269 annual saving implies **an approximate payback period of 15 years** for the case of Household type 4. We note that this is based on the 2015 electricity prices; the straight average of the electricity prices over the period 2015-2030 is approximately 25% higher

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[155] As an additional high-level calculation exercise, we point out that the maximum value that a 4 kWh electrical system could provide in a household with no solar PV system is £420 per year (based on the 21 p/kWh value of Peak to Off-peak shifting), as compared with the maximum value of £540 per year in a household with a solar PV system (based on the 27 p/kWh value of meeting Peak demand with excess PV).

than the 2015 price. Using this average, the corresponding payback period becomes 12 years.

At current electricity storage prices and with the **typical 10 year warranty of battery storage systems, therefore, the economic case based on the value stream assessed above is marginal**. It is important to note, however, that variations in the assumptions above, particularly in the differential between export and purchase prices, carry a relatively high uncertainty. Furthermore, the cost of battery storage is expected to continue to fall significantly. It can be seen that a **20% decrease in the cost of battery storage would be enough to achieve a payback of less than 10 years** with all other assumptions above remaining fixed.

12.7 Results: Value of peak demand flexibility with Solar PV and thermal storage

We have repeated the analysis of the previous section for the case of thermal storage. This is most relevant to households where the heating is electric, where the cost of heating during Peak periods is high; accordingly, we study the case of Household 4, which uses a heat pump. We examine the impact of 7 kWh of thermal storage. It is important to note that, assuming a heat pump efficiency of 330%, 7 kWh of thermal storage corresponds to 2.1 kWh of effective electrical storage.

Figure 38 shows the results of the optimisation of the use of the thermal storage in Household type 4 with a 3.5 kW_p solar PV system, for a typical day of each month of the year. It can be seen that, as seen in the analysis above, the greatest opportunity to meet Peak demand using excess PV generation (in this meeting heating demand through the charging of the thermal store by the excess PV generation) is in the shoulder season, here in the months of April and November. As in the case of electrical storage, there is a very large opportunity to shift Peak demand to Off-peak periods, given that there is very large Peak demand for heating. The utilisation of the thermal store is very high, with the full 2.1 kWh effective electrical capacity used during all months except for July. The under-utlilisation of the store in July is attributable to the low heating demand during that month.

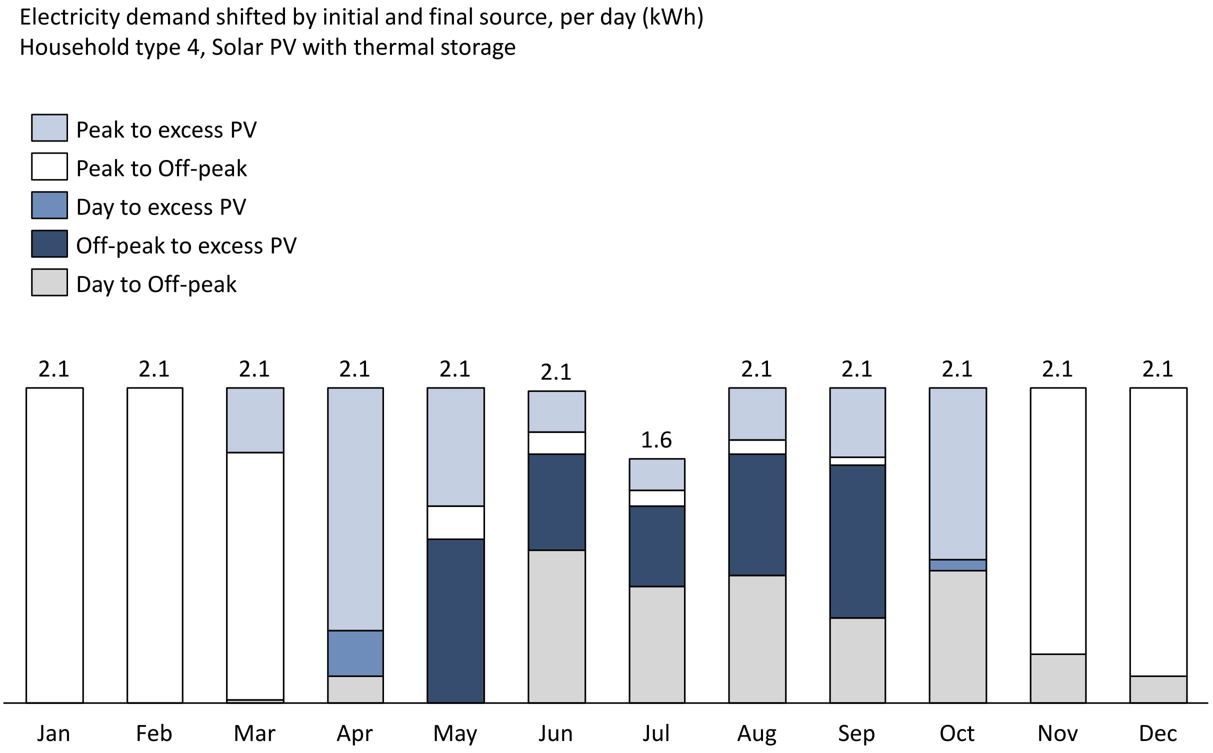

Figure 38: Electricity demand shifted in the case of Solar PV with 7 kWh thermal storage (equivalent to 2.1 kWh of electrical capacity), for Household type 4 (Heat pump heating)

The associated annual value to the household is shown in Figure 39. To emphasise the fact that smart management of solar PV with thermal storage (as opposed to electrical storage) has no value to households with no electrical heating capacity, we show the results for Household type 1 (Gas-heated) as well as Household type 4. **For Household type 4, however, the figure shows that the scenario achieves a value of £122 per year**.

In order to perform a similar payback period calculation as was performed above for the case of electrical storage, we note that the cost of the 7 kWh thermal store is approximately £900, and that of the smart solar PV diverter approximately £250. Taking a total capital cost of £1,150 and the annual value of £122, we find a **payback period of approximately 9-10 years**. Using the average electricity price over the period 2015-2030, as was also considered in the case of electrical storage, we find a payback period of approximately 7-8 years. While the value of the thermal store is lower than that of the electrical store, therefore, the economic case appears to be more favourable at current costs. In addition to the caveats described in Section 12.6, we note that household thermal storage is much more mature than household electrical storage technology, and its cost is not likely to fall at the same rate.

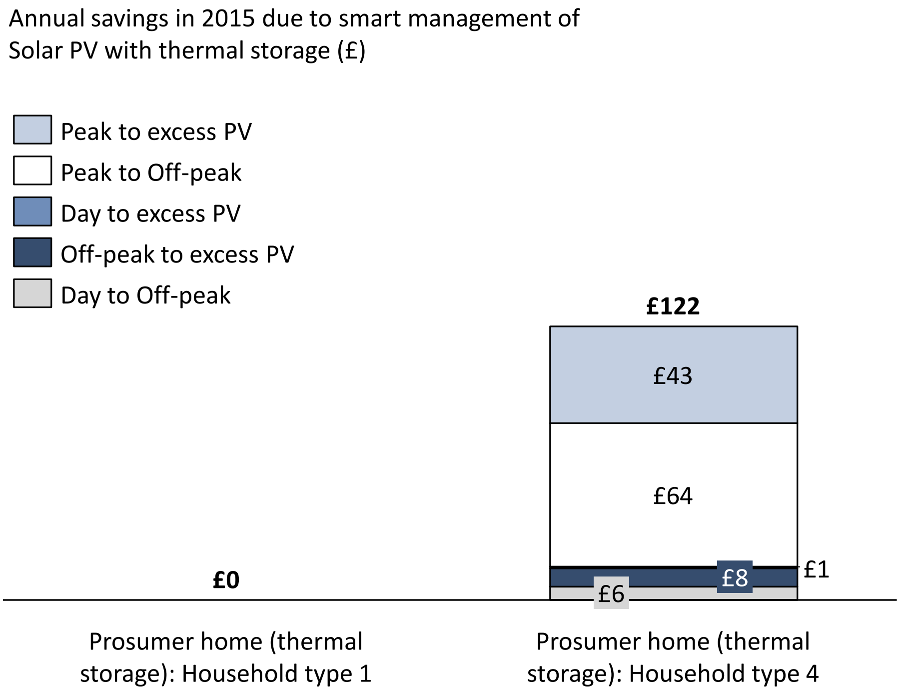

Figure 39: Value of smart management of Solar PV with thermal storage (2015 figures), for Household types 1 and 4

13 Frequency Response

Current requirements and value

National Grid procures Frequency response services in order to maintain the balance between supply and demand on a second by second timescale to maintain system frequency within ±1% of 50 Hz. For a high frequency event, an increase in load is required; for a low frequency event, a reduction in load is required. Frequency response can be ‘dynamic’, where the responsive load is varied in proportion to deviations in the system frequency, or ‘non-dynamic’, where the responsive load is added or removed in full when the system frequency deviates by a certain amount.

The requirement for Frequency response is highest when demand is low, when the impact of a single outage is largest. As a result, the requirement for Frequency response is highest at night, as shown in the example data in Figure 40. It can be seen that the requirement peaks at around 1,200 MW in the 11th settlement period (that is, from 5am), falling to around 600 MW in the 43rd settlement period (that is, from 9pm). We note that this represents a relatively limited market size; this is important to consider when assessing the potential value of providing Frequency response, and is discussed further below.

The current value of Frequency response is in the range 11-20 £/MW/hour (by hours of availability) for >90% of the response provided[156], with a small number of events per year carrying a higher value.

Future requirements and value

National Grid projects an increase in the requirement for Frequency response of up to 30-40% over the next five years, and could be 3-4 times higher than present levels by 2025-2030[157]. However, it should be noted that this refers to the requirement during peak periods (summer nights), and that the annual requirement is not expected to increase by the same fraction. Furthermore, this requirement will be procured through a range of providers in addition to DSR providers, including wind and solar PV generators and battery storage operators[158].

The value of Frequency response is not expected to change dramatically, since the majority of Frequency response services can be provided by, for example, conventional thermal plant or battery storage, which is not expected to increase in cost. As noted, the market for Frequency response is relatively limited (on the order of 1,000 MW currently). In a plausible scenario, the large number of providers entering the future marketplace (including non-domestic and domestic DSR providers, as well as battery storage operators and potentially solar PV and wind power generators) could lead to an oversupply and associated drop in value of the service.

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[156] *Enhanced Frequency Response Webinar*, National Grid (October 2015)
[157] *System Operability Framework 2015*, National Grid (November 2015)
[158] Ibid.

Communications requirements

In order to provide frequency response, the controller will be required to respond on a timescale of seconds. It will also be necessary to verify that the service has been provided, which will require second-by-second power metering. At present, the load is required to respond to the frequency of the incoming power directly, meaning that the controller would require local frequency sensing. In some countries, a specific signal is sent by the system operator to request the response; it is possible that National Grid may employ such an approach in the future.

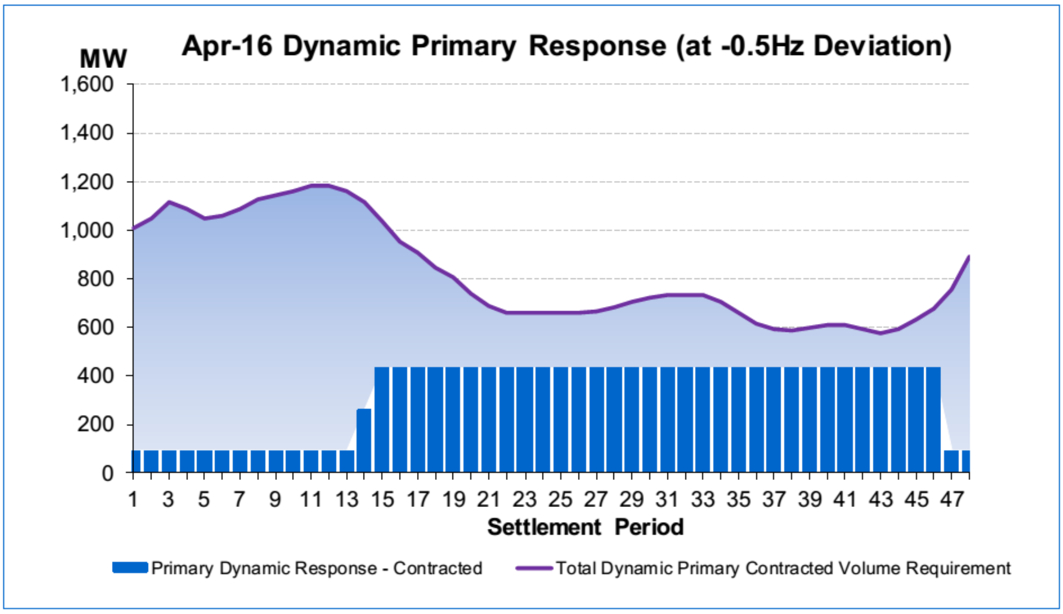


Figure 40: Illustrative example of Frequency Response (Dynamic Primary Response) requirement over a day (half-hourly periods from midnight), for April 2016. Source: *Firm Frequency Response Market Information for Apr-16*, National Grid, February 2016.

13.1 Summary of approach

Our approach to modelling the potential value of Frequency response to households in various home energy control scenarios is shown in Figure 41. In this approach, we first identify which loads are suitable for the provision of Frequency response, given the ability for the load to be modulated at the speed of response required and the level of associated disruption for consumers. For each, we determine the fraction of the instantaneous load which is potential responsive, and the number of hours per year over which the load is available. Finally, we apply the value of Frequency response on a £/MW/hour availability basis to find the potential annual revenue to a single household.

Figure 41: Frequency response modelling approach

Table 36 shows our assessment of the suitability of the various end-uses for Frequency response. Of the loads included within the modelling, three are deemed suitable for the provision of Frequency response: heat pumps, freezers and other cold appliances. Those loads could, when fitted with smart controls allowing response over a timescale of seconds, be turned on or off or modulated in output, and maintain that response over a timescale of minutes without significant disruption to the consumer.

The other loads are not deemed suitable for Frequency response. Although lighting is technically capable of responding over a timescale of seconds, it is excluded on the basis of likely disruption to consumers. While it was argued in Section 12 that the lighting load can be reduced by up to around 15% through dimming, without the consumer experiencing disruption, it is assumed that this applies only to a slow rate of dimming on the order of minutes at the fastest. It is assumed that a variation in the lighting load on the order of seconds, as required for Frequency response, would lead to significant disruption. Wet appliances are also deemed unsuitable.

While we have not identified any underlying technical reason that integrated smart controls in wet appliances could not allow modulation of the load on a timescale of seconds, we suggest that wet appliances are less suitable than cold appliances for Frequency response due to the potential disruption to the system operation. For example, it is expected that the thermal inertia of a washing machine or dishwasher is somewhat lower than that of a fridge or freezer, meaning that an interruption during the water heating period could have a more disruptive impact on the system. During the ‘spin’ cycle, as another example, it is not deemed likely that the load could be modulated down over a timescale of seconds without an adverse effect on the system operation and perhaps on the product lifetime. Therefore, we exclude wet appliances from this analysis. Finally, we deem consumer electronics, cooking and computing unsuitable for Frequency response due to the obvious disruption to the consumer.

Table 36: Suitability for Frequency response

Load	Deemed suitable for frequency response?	Comment
Heat pump	✓	• Up to 100% of the load can be modulated for short time periods (up to 30 minutes or more), with fast level of response
Lighting	✗	• Modulation of lighting level on a timescale of seconds is likely to be disruptive to occupants
Appliances – Cold – Freezer	✓	• With integrated controls, up to 100% of the load can be modulated for short time periods (up to 30 minutes), with fast level of response
Appliances – Cold – Other	✓	• With integrated controls, up to 100% of the load can be modulated for short time periods (up to several minutes), with fast level of response
Appliances – Wet	✗	• Modulation on a timescale of seconds could be possible, but may be disruptive to the operation of the system; this load is not included here
Appliances – Electronic	✗	• Any modulation likely to be disruptive to occupants
Appliances – Computing	✗	• Any modulation likely to be disruptive to occupants
Appliances – Cooking	✗	• Any modulation likely to be disruptive to occupants

13.2 Modelling assumptions: Frequency response

In order to capture the potential value of Frequency response in a straightforward and transparent way, we make the simplifying assumption that the requirement for Frequency response, and the number of high or low frequency events, is distributed uniformly over the year. We can then assess the availability for Frequency response based on the average instantaneous load associated with each appliance. We note that this assumption is supported by the observation that any individual household will be one of a large ensemble of households whose loads would be aggregated and managed by a third party (such as an ESCO), with the aggregated load being contracted to provide Frequency response to National Grid. There would be a high level of diversity within the aggregated load, meaning that the approach of averaging the load of a single household over the year becomes more representative.

Table 37 shows the modelling assumptions made within this approach. Since the full load of these appliance types can be modulated at any given time (i.e. they can be turned on or off), it is assumed that 100% of the average annual load is available for Frequency response. However, this load will not be available for every hour of the year, since each appliance is required to maintain the average level of heating or cooling load over the year. An estimate of the required annual run hours for a heat pump can be made based on a comparison of the typical annual heating requirement and the typical heat pump size. For Household type 4, the annual heating and hot water demand is approximately 8,900 kWh, which entails an electricity demand of around 2,700 kWh with an efficiency of 330%. A typical domestic heat pump is 2-5 kW$_e$. Taking a heat pump size of 3 kW$_e$, this implies that the heat pump is required to operate for around 1,000 hours per year, suggesting that the heat pump is available (not required to run) for around 8,000 hours (around 90%) of the year. A similar analysis for the appliances suggests that a typical domestic freezer (with power rating 150 W and an annual demand of around 150 kWh) may also be assumed available for around 8,000 hours per year, and that a typical domestic fridge (with power rating 100 W and an annual demand of around 400 kWh) may be assumed available for around 5,000 hours per year. The maximum potential value of Frequency response is then found by applying the availability payment of £10-20/MW/hour, based on the current and expected future value as described at the start of this section.

Table 37: Frequency response modelling assumptions

Load	Fraction of load modulated in frequency response period	Average responsive load over year	Availability at annual average load (hours per year)	Availability payment (£/MW/hour)		
				Low	Central	High
Heat pump	100%	Varies by household type	8,000	10	15	20
Appliances – Cold – Freezer	100%		8,000	10	15	20
Appliances – Cold – Other	100%		5,000	10	15	20

13.3 Results: Value of Frequency response

The resulting potential annual value for Frequency response for a single household of type 1 (a typical existing Gas-heated home) is shown in Figure 42. The value is shown for two home energy control scenarios, Smart heating (Advanced – Passive control) and Smart home, to emphasise that the value of Frequency response can only be accessed when the relevant appliances are fitted with smart controls allowing external control of the load. The value shown here is calculated using the Central value of £15/MW/hour. The potential value for the Smart home scenario is found to be £5 per year. Given that Household type 1 is Gas-heated, this value is generated by the cold appliances only.

This is clearly a very modest value proposition for the individual household, and suggests that the provision of Frequency response by domestic cold appliances is unlikely to be driven by households attempting to access this value, but more likely by the aggregator attempting to access the potential value over a very large number of households.

We can make a very approximate estimate of the number of households which could access this value, through a consideration of the overall requirement for Frequency response for National Grid. This was demonstrated above to be of the order 1,000 MW. The annual value of £5 per year for Household type 1 corresponds to the availability of around 30 W of suitable load on average across the year. With this level of load available per household, approximately 30 million households could access the value shown within the market size of 1,000 MW. We note immediately that for this illustrative estimate, we have made the assumption that all Frequency response is provided through cold domestic appliances. This is clearly unlikely to be the case, given the likely competition for this service from the non-domestic sector, battery storage operators and renewable electricity generators, as well as other appliances in the domestic sector such as heat pumps and electric vehicles. We examine below how these results change in the case of a household with a heat pump.

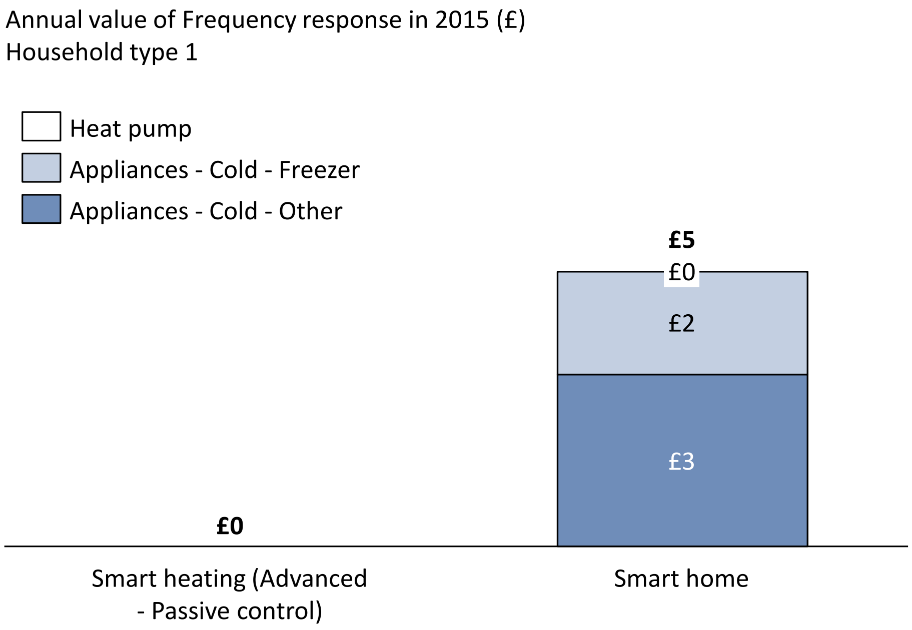


Figure 42: Value of Frequency response for Household type 1 (Gas heating) for two selected home energy control scenarios

Figure 43 shows the potential annual value for Frequency response in a single household of type 4, in which the heating and hot water is supplied by a heat pump. The figure shown is based on the Central value for the availability payment of £15/MW/hour. It can be seen that the **potential value of the heat pump for this service is significantly higher than for the cold appliances, at £37 per year**. This is simply a result of the much higher average load of the heat pump across the year, of around 300 W. It is also worth highlighting that this annual value of £37 for the heat pump is available in the Smart heating (Advanced – Passive control) and not only in the Smart home scenario. As shown in Section 9, the Smart heating scenario is significantly less costly than the Smart home scenario given the high current cost of the smart appliances; on the basis of this analysis it can be seen that the additional cost of the smart appliances is certainly not justified solely by the value for Frequency response.

Repeating the analysis above to estimate the maximum number of households which could potentially access this value, we note that the average annual load suitable for Frequency response for Household type 4 is of the order 300 W. At this level, approximately 3 million households would be required to provide the full demand for Frequency response. Accounting for the observation that the domestic sector is likely only to access some fraction of the full market for Frequency response, this suggests that in the long term (that is, in the case where there is a wide deployment of smart domestic energy controllers) it is highly feasible that there may be more load available for Frequency response at domestic level than there is required by the National Grid. In this case, the value of this service is likely to fall. Nonetheless, Frequency response clearly presents the opportunity in the short to medium term for significant value to be accessed by households with heat pumps.

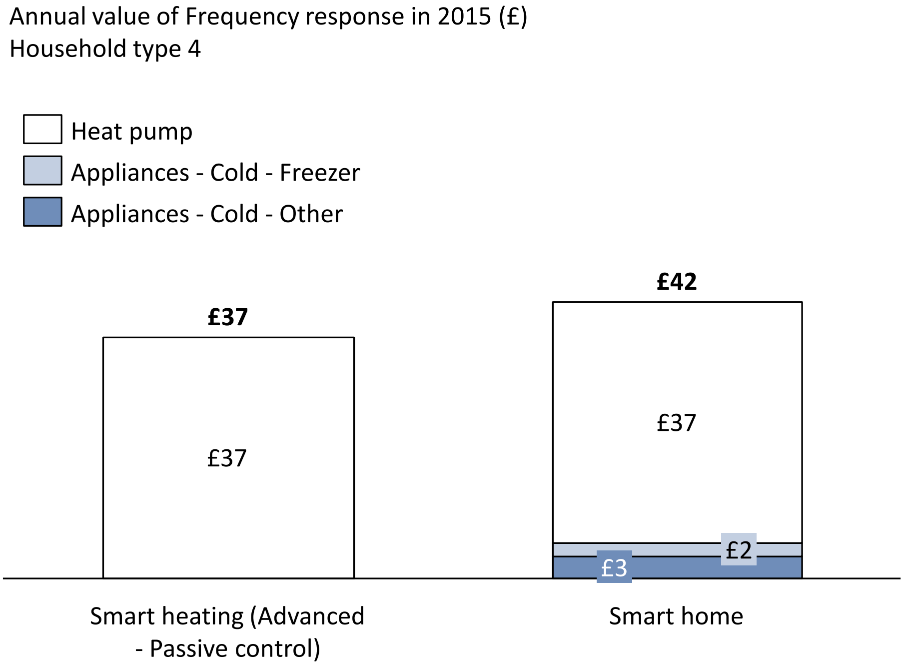


Figure 43: Value of Frequency response for Household type 4 (Heat pump heating) for two selected home energy control scenarios

14 Summary of Potential Costs and Benefits

In this section, we collate the results from the above analyses to provide an overall picture of the potential costs and benefits of home energy controllers. Here, we present the collated results of a selection of the home energy control scenarios for Household type 4. This household type was chosen as the case with the largest potential benefits available through demand-side response, in order to illustrate an upper bound case. The full set of collated results, for all home energy scenarios and all household types, is provided in Appendix 1.

Figure 44 to Figure 46 below present the collated results for four home energy control scenarios in turn: the Smart heating (Advanced – Passive control) scenario, the Smart home scenario, the Prosumer home scenario with electrical storage and the Prosumer home scenario with thermal storage. The NPV calculations, as in the above sections, we carried out over a 15 year lifetime and using a 3.5% discount rate. In each case we present the ‘Maximum High (rebound effect)’ case, which is the High case for the ‘Three heating periods’ heating schedule typology, and the ‘Maximum Low (energy savings)’ case, which is the Low case for the ‘One heating period’ heating schedule typology. These represent the ‘worst’ and ‘best’ case respectively.

We note here the caveat described in Section 11 that potential competition between the different DSR services is likely to mean that the consumer may not be able to access the full value of multiple DSR services simultaneously. A detailed assessment of this is beyond the scope of this study; however, this serves as an important caveat to the results presented here.

Considering the three figures below, the first point to make in summary is that the single largest determinant of the overall NPV, by some distance, is the size of the decrease or increase in annual heating fuel spend. As discussed at some length in Section 10, the range of potential outcomes for the change in annual heating fuel spend is large, from several thousand pounds of negative value over the 15 year lifetime in the worst case, to several thousand pounds of positive value in the best case. It is therefore clear that behaviour, and how consumers interact with the energy controllers once they have been installed (as well as how the consumer interacted with the previous controls) is of great importance. In order to gain a better view of the relevance of the different outcomes studied here, as well as how those outcomes can be influenced, it will be necessary to undertake extensive field trials of the controls in question. A number of such field trials are underway, including the DECC Behavioural Insight Team’s Nest field trials.

Smart heating (Advanced – Passive control)

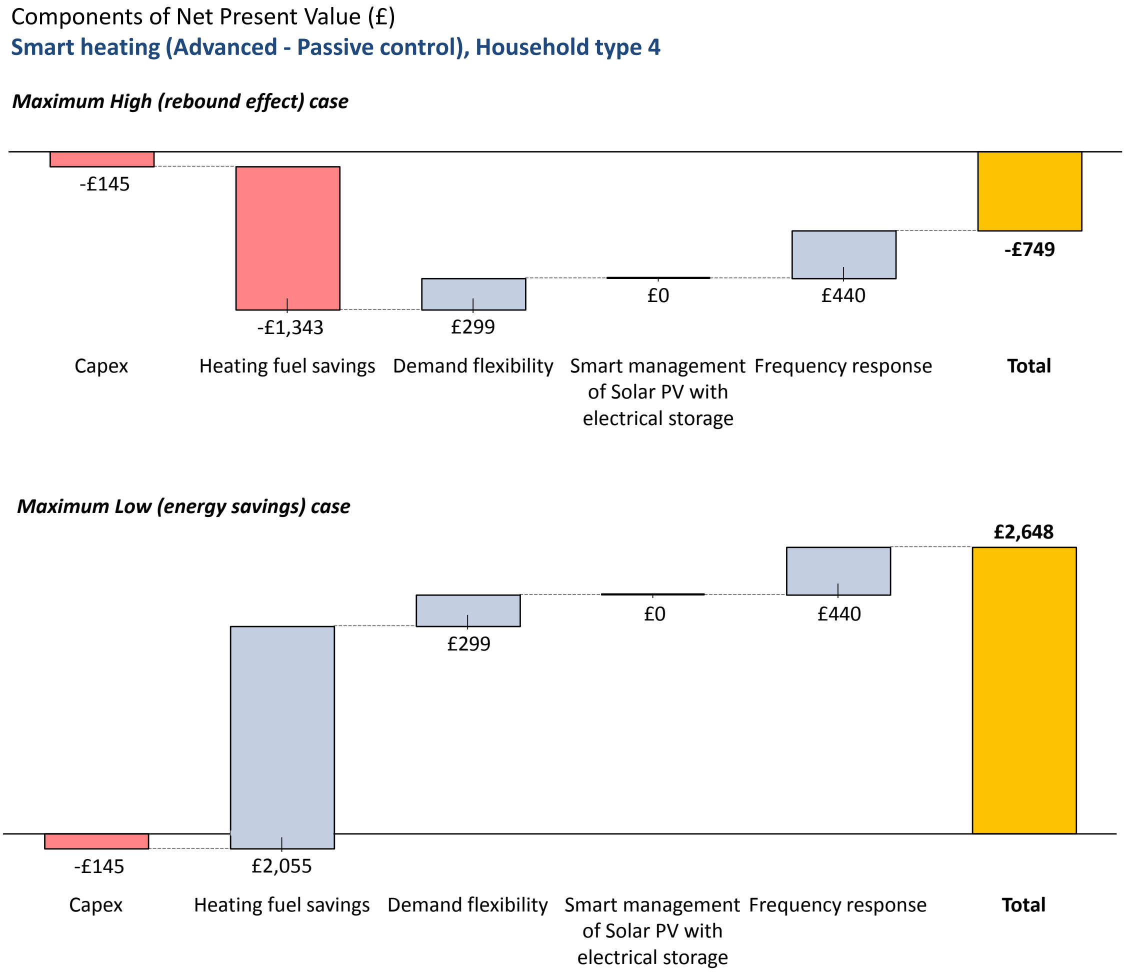


Figure 44: Components of Net Present Value for the Smart heating (Advanced – Passive control) scenario for Household type 4, for the High and Low heating fuel cases. The analysis assumes a 3.5% discount rate and a 15 year lifetime.

By comparison with the impact on basic annual heating fuel spend, the potential value of peak demand reduction and Frequency response appear somewhat more modest. As shown in Figure 44 and Figure 45, the value of these services are **in the range £300-600 for peak demand reduction and £500-600 for frequency response** over the 15 year lifetime, in the case of Household type 4. However, it is important to note that this value is relatively independent of the change in basic annual heating fuel spend. Considering only the balance of these two value streams with the capex of the controls, in Figure 44, it can be seen that for the Smart heating (Advanced – Passive control) scenario, **the potential value of these services (at up to £739 combined) is many times the initial investment in the smart heating controls (at £145)**. This indicates that, under the value assumptions described in Sections 12 and 13, the economic case for this type of heating controls could be made on the basis of the value of peak demand reduction and Frequency response alone. It is also worth noting that even if the overall NPV for the consumer is not positive, due to the impact on annual heating fuel spend, there would still be a business case for a third party (such as an aggregator) to make use of the energy controls to provide the DSR services. This can be seen as an opportunity for revenue to be generated and shared with the consumer, but it could also be seen as a potential risk to the consumer, given the potential for a large rebound effect and associated increase in heating bill.

Smart home

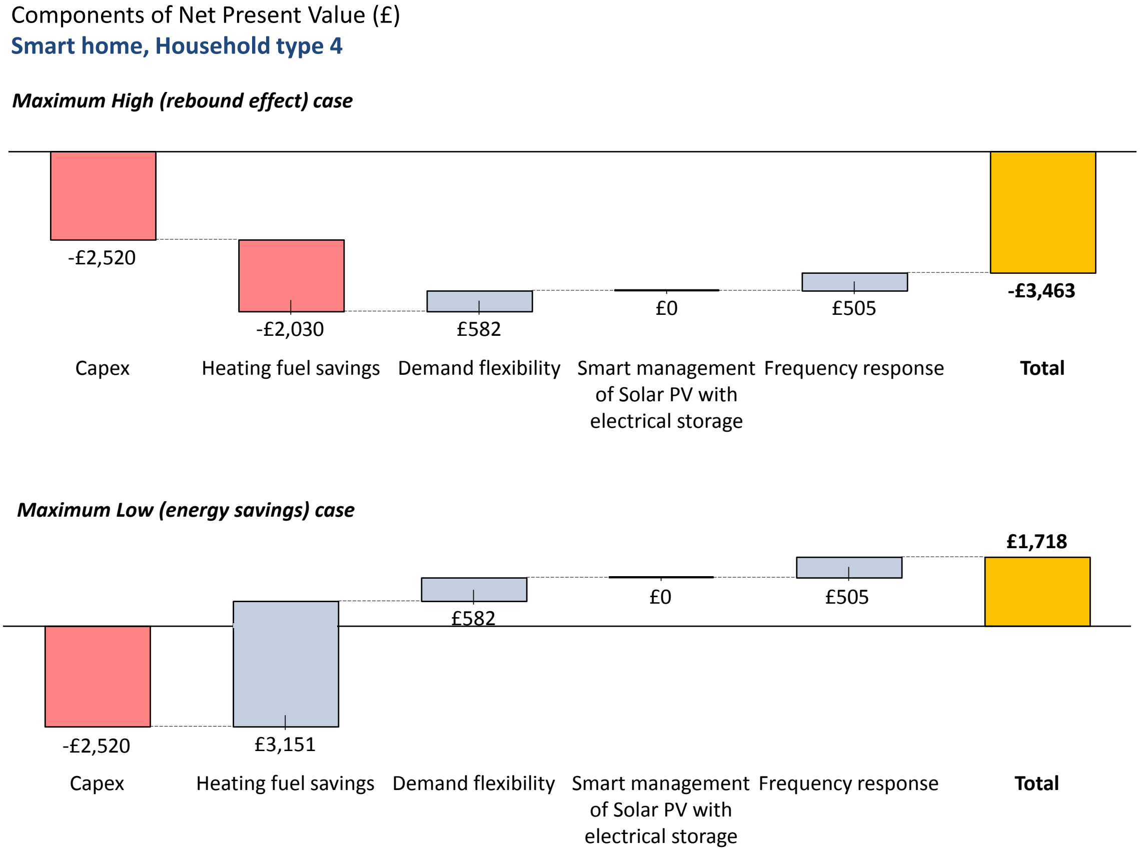
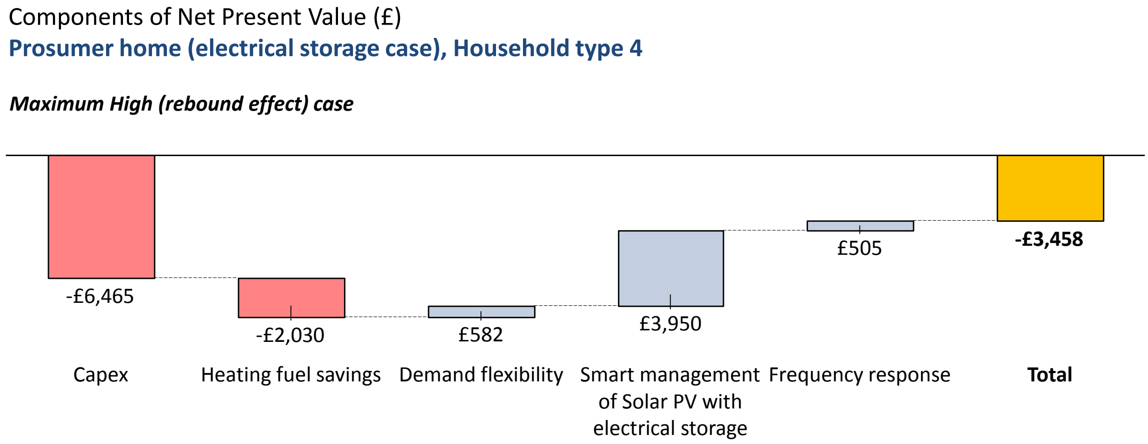


Figure 45: Components of Net Present Value for the Smart home scenario for Household type 4, for the High and Low heating fuel cases. The analysis assumes a 3.5% discount rate and a 15 year lifetime.

Making the same comparison for the Smart home scenario, in Figure 45, it can be seen that the **value of the peak demand reduction and Frequency response revenue streams (at up to £1,087 combined) is not sufficient to pay back the initial investment in the range of smart lighting and appliance controls modelled here (at £2,520)**. This is a result of two factors: the lower electrical load associated with appliances and lighting as compared with the heat pump, and the significantly higher cost of smart lighting and appliance controls on the current market as compared with smart heating controls. As discussed in Section 9, it is important to acknowledge here that the primary selling point of smart lighting and appliances is not economic benefit or energy savings, but enhanced consumer experience and/or greater convenience. While this applies to some extent to smart heating controls, the economic and energy saving case is a more important part of the offer for smart heating controls. Furthermore, we note that smart appliances are at a somewhat less mature stage of development than smart heating controls, and the costs may be expected to fall more rapidly. Nonetheless, the greater energy demand associated with heating than with lighting and appliances means that the potential value of smart heating controls is always likely to exceed that of smart lighting and appliances.

Finally, Figure 46 shows the potential costs and benefits of smart management of solar PV with electrical storage. As discussed in some detail in Section 12, the case for this use case of electrical storage is quite marginal. Figure 46 shows that the **potential value for Household type 4 of smart management of solar PV with electrical storage over the 15 year lifetime is of the order £4,000**, which is close to the capital cost of the electrical storage system and smart diverter, indicating that the **break-even point is similar to the product lifetime**[159]. The business case for the Prosumer home scenario will therefore depend strongly on the peak/off-peak electricity price differential accessible, and the future development of the cost of electrical storage.

Prosumer home


Components of Net Present Value (£)

Prosumer home (electrical storage case), Household type 4

Maximum High (rebound effect) case

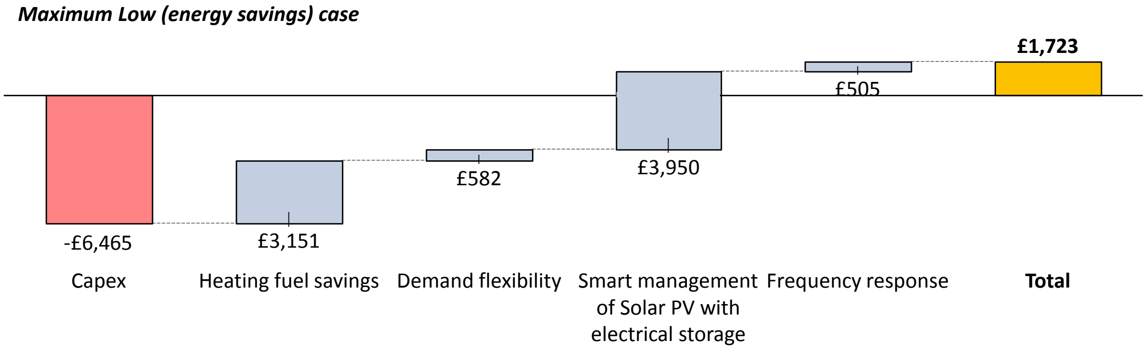

Maximum Low (energy savings) case

Figure 46: Components of Net Present Value for the Prosumer home scenario with electrical storage for Household type 4, for the High and Low heating fuel cases. The analysis assumes a 3.5% discount rate and a 15 year lifetime.

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[159] We note that the typical warranty on electrical storage systems is currently 10 years, less than the 15 year lifetime studied here.

15 Appendix 1: Summary of potential costs and benefits for all home energy control scenarios and household types

The summary tables on the following pages present the full breakdown of the upper and lower bound potential costs and benefits for each home energy control scenario and each household type.

Household type	Home energy control scenario	Component of Net Present Value							
		Capex	Heating fuel savings		Demand flexibility	Smart management of PV with electrical storage	Frequency response	Total	
			Maximum High (rebound) case	Maximum Low (energy saving) case				Maximum High (rebound) case	Maximum Low (energy saving) case
1	Smart heating (Basic)	-£115	£0	£2,597	£0	£0	£0	-£115	£2,482
	Smart heating (Advanced - Zonal)	-£218	-£626	£3,983	£0	£0	£0	-£844	£3,765
	Smart heating (Advanced - Passive control)	-£145	-£1,697	£2,597	£0	£0	£0	-£1,842	£2,452
	Smart heating (Advanced - Zonal + Passive control)	-£302	-£2,555	£3,983	£0	£0	£0	-£2,857	£3,681
	Smart home	-£2,520	-£2,555	£3,983	£283	£0	£65	-£4,727	£1,811
	Prosumer home (electrical storage case)	-£6,465	-£2,555	£3,983	£283	£3,078	£65	-£5,594	£944
2	Smart heating (Basic)	-£115	£0	£4,550	£0	£0	£0	-£115	£4,435
	Smart heating (Advanced - Zonal)	-£262	-£1,438	£7,196	£0	£0	£0	-£1,700	£6,934
	Smart heating (Advanced - Passive control)	-£145	-£2,974	£4,550	£0	£0	£0	-£3,119	£4,405
	Smart heating (Advanced - Zonal + Passive control)	-£346	-£4,945	£7,196	£0	£0	£0	-£5,291	£6,850
	Smart home	-£2,732	-£4,945	£7,196	£345	£0	£79	-£7,253	£4,888
	Prosumer home (electrical storage case)	-£7,601	-£4,945	£7,196	£345	£3,783	£79	-£8,339	£3,803

Household type	Home energy control scenario	Component of Net Present Value							
		Capex	Heating fuel savings		Demand flexibility	Smart management of PV with electrical storage	Frequency response	Total	
			Maximum High (rebound) case	Maximum Low (energy saving) case				Maximum High (rebound) case	Maximum Low (energy saving) case
3	Smart heating (Basic)	-£115	£0	£994	£0	£0	£0	-£115	£879
	Smart heating (Advanced - Zonal)	-£174	-£208	£1,493	£0	£0	£0	-£382	£1,319
	Smart heating (Advanced - Passive control)	-£145	-£650	£994	£0	£0	£0	-£795	£849
	Smart heating (Advanced - Zonal + Passive control)	-£258	-£935	£1,493	£0	£0	£0	-£1,193	£1,235
	Smart home	-£1,900	-£935	£1,493	£224	£0	£51	-£2,560	-£133
	Prosumer home (electrical storage case)	-£4,921	-£935	£1,493	£224	£2,389	£51	-£3,192	-£764
4	Smart heating (Basic)	-£115	£0	£2,055	£0	£0	£440	£325	£2,380
	Smart heating (Advanced - Zonal)	-£218	-£501	£3,151	£0	£0	£440	-£279	£3,373
	Smart heating (Advanced - Passive control)	-£145	-£1,343	£2,055	£299	£0	£440	-£749	£2,649
	Smart heating (Advanced - Zonal + Passive control)	-£302	-£2,030	£3,151	£299	£0	£440	-£1,593	£3,588
	Smart home	-£2,520	-£2,030	£3,151	£582	£0	£505	-£3,463	£1,718
	Prosumer home (electrical storage case)	-£6,465	-£2,030	£3,151	£582	£3,950	£505	-£3,458	£1,722

Household type	Home energy control scenario	Component of Net Present Value							
		Capex	Heating fuel savings		Demand flexibility	Smart management of PV with electrical storage	Frequency response	Total	
			Maximum High (rebound) case	Maximum Low (energy saving) case				Maximum High (rebound) case	Maximum Low (energy saving) case
5	Smart heating (Basic)	-£115	£0	£1,261	£0	£0	£0	-£115	£1,146
	Smart heating (Advanced - Zonal)	-£218	-£261	£1,940	£0	£0	£0	-£479	£1,722
	Smart heating (Advanced - Passive control)	-£145	-£824	£1,261	£0	£0	£0	-£969	£1,116
	Smart heating (Advanced - Zonal + Passive control)	-£302	-£1,182	£1,940	£0	£0	£0	-£1,484	£1,638
	Smart home	-£2,520	-£1,182	£1,940	£283	£0	£65	-£3,354	-£232
	Prosumer home (electrical storage case)	-£6,465	-£1,182	£1,940	£283	£3,078	£65	-£4,221	-£1,099
6	Smart heating (Basic)	-£115	£0	£1,326	£0	£0	£313	£198	£1,524
	Smart heating (Advanced - Zonal)	-£218	-£275	£2,040	£0	£0	£313	-£180	£2,135
	Smart heating (Advanced - Passive control)	-£145	-£866	£1,326	£213	£0	£313	-£486	£1,707
	Smart heating (Advanced - Zonal + Passive control)	-£302	-£1,243	£2,040	£213	£0	£313	-£1,019	£2,264
	Smart home	-£2,520	-£1,243	£2,040	£496	£0	£378	-£2,889	£394
	Prosumer home (electrical storage case)	-£6,465	-£1,243	£2,040	£496	£3,790	£378	-£3,044	£239