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DE MONTFORT UNIVERSITY
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Demand side response in the non-domestic sector

Final report

for

Ofgem

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Contents

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Power Efficiency
Prupim
RLtec
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Vinci Facilities

Glossary

AC	Air conditioning
AHU	Air handling unit
BM	Balancing mechanism
CHP	Combined heat and power
CPP	Critical peak pricing
CRC	Carbon reduction commitment
CSR	Corporate social responsibility
DECC	Department of Energy and Climate Change
Defra	Department for Environment, Food and Rural Affairs
DNO	Distribution network operator
DSR	Demand side response
DUKES	Digest of UK Energy Statistics
DUoS	Distribution use of system
GHG	Greenhouse gas
GW	Gigawatt (unit of power equal to 1,000MW)
GWh	Gigawatt hour (unit of energy)
HHM	Half-hourly metered
HVAC	Heating, ventilation and air conditioning[1]
IEA	International Energy Agency
LED	Light emitting diode
MW	Megawatt (unit of power equal to 1,000kW)
RTP	Real-time pricing
STOR	Short term operating reserve
T&D	Transmission and distribution
TOU	Time of use
TWh	Terawatt hour (unit of energy equal to 1,000GWh)
US	United States of America

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[1] HVAC is used in this report to refer to the combined electricity demands of heating, ventilation and air conditioning. Although a distinction is made between *Heating* and *AC & ventilation* (e.g. see Figure 8 section 3.2), the HVAC term is used to cover all of these sub-loads.

1 Summary

1.1 Overview

1.1.1 Context

Secure electricity supplies are largely taken for granted in the UK and are fundamental to our economy and society. The expected increase in electricity demands over the coming years[2], combined with significant changes to the generation mix will result in challenges to maintaining secure, affordable supplies.

The UK's electricity system is currently sized to meet peak demands (that only occur infrequently), which leads to generating plant and transmission and distribution networks being under-utilised for much of the time. Various measures may be used to encourage consumers to reduce demands for electricity during peak periods, or to shift consumption to times of low demand. Economy 7 electricity tariffs are a familiar example in the UK, targeted at domestic consumers (particularly those that use electric heating), offering a lower electricity price overnight (when overall demands on the grid are lower). Demand side response (DSR) is a broad term that refers to a range of mechanisms designed to reduce peak demands on the electricity system, potentially delivering a number of benefits including reduced cost of electricity supply and improved efficiency of investment in transmission and distribution networks (see section 2.3.2).

Although uptake in the UK has been low to date, DSR has been identified as one of the mechanisms that could contribute to future security of electricity supply.[3] The UK energy regulator Ofgem requires an understanding of the potential impact of DSR and its role in managing future load growth on the electricity network. This study has been undertaken to explore the potential for DSR in the non-domestic sector.

1.1.2 Aims, scope and methodology

The principal aims of this research are to:

- Quantify the technical potential for demand side response in non-domestic buildings.
- Assess the barriers to further uptake of demand side response and identify enabling mechanisms required for the potential to be realised.

The study is limited to considering electricity demands in the non-domestic building sector, excluding energy-intensive industrial processes. For the purposes of this study's analysis all non-domestic buildings are represented by ten *sub-sectors* (see section 3.1). In terms of geographical coverage, the focus of the modelling work is Great Britain only.

Two main tasks were undertaken to achieve these objectives:

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[2] Demand increases are expected due to population growth and increased electrification of sectors such as heat and transport. A shift from fossil fuels to electricity, combined with greater uptake of renewables, has been identified as a means of improving diversity of energy supply and meeting GHG emission reduction targets.

[3] For example, see the UK Government's technical update to the White Paper on Electricity Market Reform. http://www.decc.gov.uk/en/content/cms/legislation/white_papers/emr_wp_2011/tech_update/tech_update.aspx.

- A consultation with energy consumers and other stakeholders in the relevant sub-sectors to gather information on electricity demands and the current levels of engagement with and barriers to DSR.
- A data modelling exercise in which demand profiles for a selection of building types were analysed (based on half-hourly metered electricity consumption data), and overall demands from non-domestic buildings on the national grid were estimated.

Further details of the methodology are provided in sections 2.4 and 7.1.

1.2 Electricity demands in the non-domestic sector

From an understanding of annual electricity consumption by sub-sector and typical demand profiles of premises within each sub-sector we estimate the contribution of non-domestic buildings to peak electricity demands.

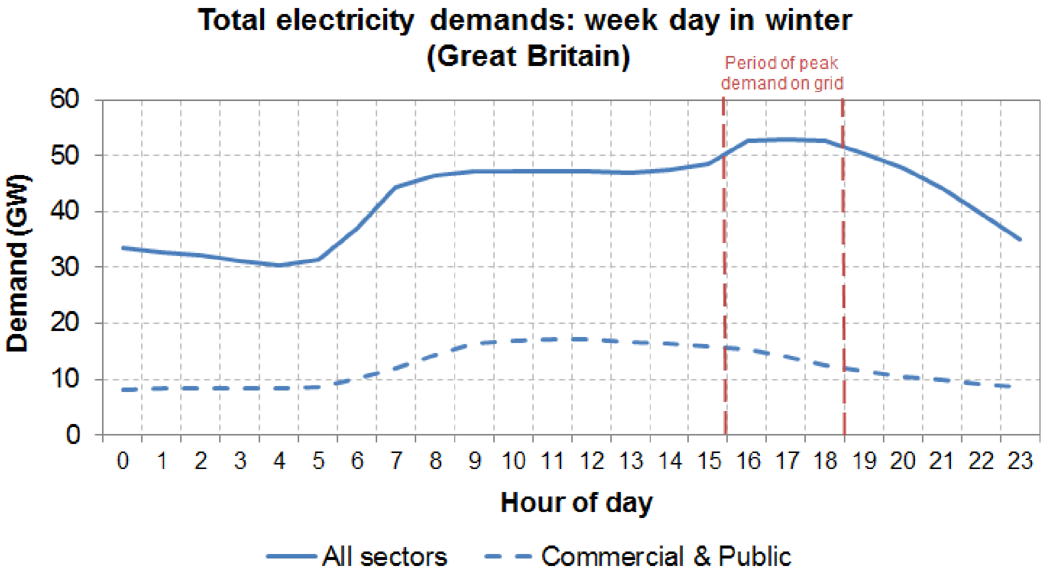

Figure 1: Demand on British national grid for a week day in winter[4]

This graph shows the demand profile for non-domestic buildings (excluding industry), compared to total demands on the grid from all sectors. We see from the above that peak demands due to non-domestic buildings occur at around 11am, and that this sector contributes around 15GW (30%) to the evening peak on a typical winter week day. The overall demand profile for non-domestic buildings is comprised of consumption in ten sub-sectors, as shown below.

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[4] All sectors demand data from Initial Demand Outturn figures based on National Grid operational generation metering (14/12/11). www.nationalgrid.com/uk/Electricity/Data/Demand+Data/. Commercial & Public profile from this study's modelling.

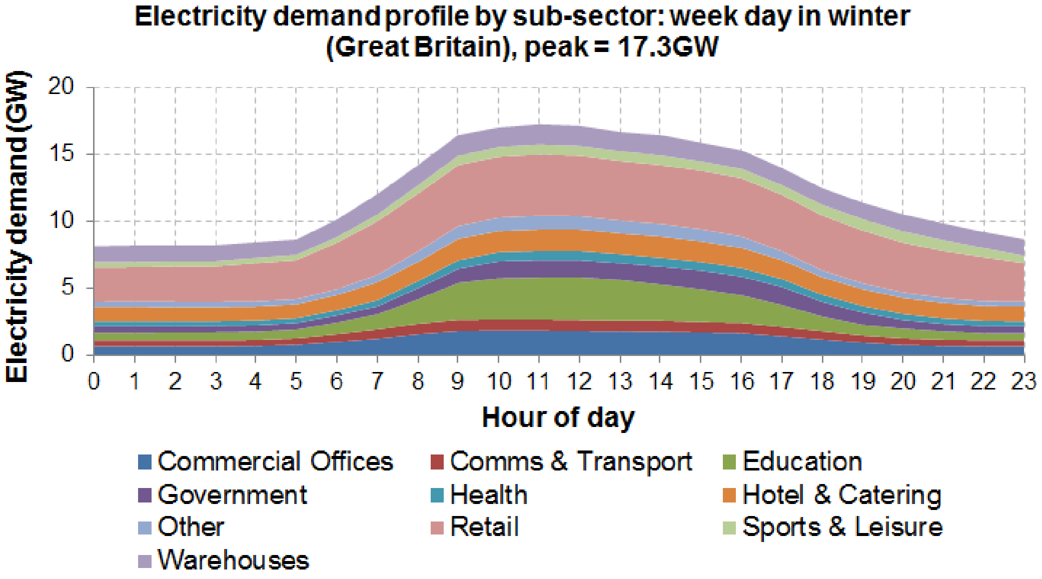

Figure 2: Electricity demand profile of non-domestic buildings by sub-sector for a winter week day

The shape of each sub-sector's profile is derived from real half-hourly metered electricity consumption data gathered from organisations within each sub-sector. The contribution of each sub-sector to the overall peak is then based on a combination on the demand profile and data on the annual electricity consumption within each sub-sector. As expected, profiles vary by sub-sector (due to the nature of activity and occupancy patterns, for example).[5]

Figure 2 suggests that the three sub-sectors that contribute most to peak demands are *Retail*, *Education* and *Commercial Offices*, with a relatively even contribution from each of the remaining sub-sectors. This suggests that exploiting the full potential for DSR will require participation from buildings across all sub-sectors.

The potential for DSR measures to reduce peak demands depends on the flexibility of electricity end uses, i.e. the extent to which demand can be reduced or delayed in response to price signals for example. The greatest flexibility is typically associated with demands related to loads with storage or in-built inertia (e.g. hot water, heating, air conditioning). Flexible loads may be interrupted for a period with minimal or no impact on building occupiers. On the other hand, some loads (e.g. computing) exhibit very limited flexibility and are therefore unsuited to DSR measures. Given that a key aim of this work is to assess the potential for DSR, we also analyse the contribution of different end uses (*sub-loads*) to overall demands.

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[5] Note that since the analysis of demand profiles is based on a complete year's data for each building in the sample, we are able to capture daily and seasonal variations in demands. For example, see section 3.3.3.

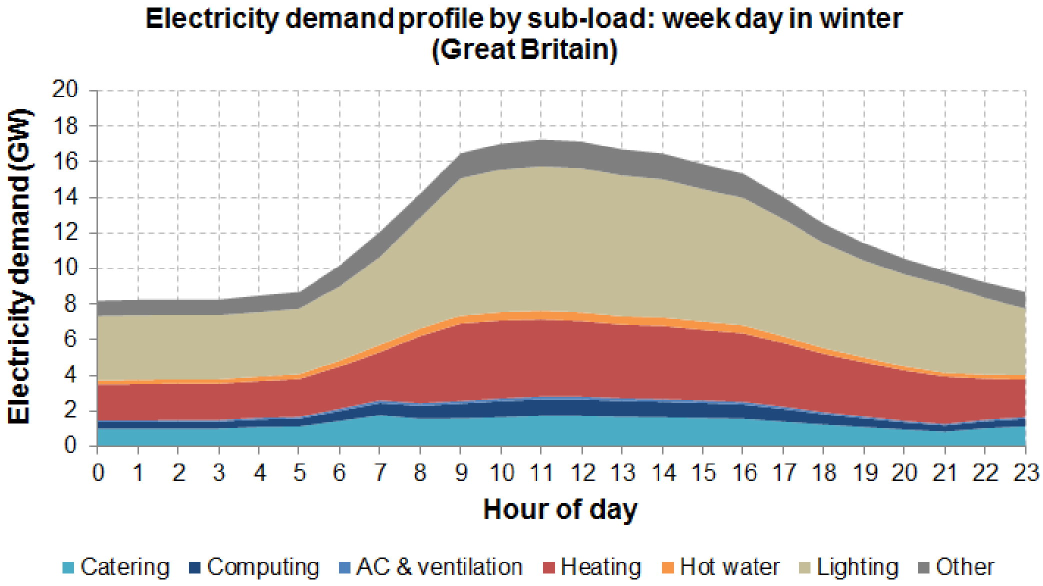

Figure 3: Electricity demand profile of non-domestic buildings by sub-load for a winter week day

This graph shows the estimated demand by hour for seven sub-loads across all sub-sectors presented in Figure 2 above.[6] It is clear that lighting and space heating loads dominate the total demands on a winter week day in non-domestic buildings, accounting for around 70% of the peak demand.

1.3 DSR technical potential

As discussed above, *demand side response* encompasses various measures that could reduce peak electricity demands. The potential flexibility of each sub-load and the technical potential of each of the main DSR measures are discussed in the main report (sections 4.1 and 4.3). Here we focus on an assessment of the overall potential for DSR measures to reduce peak demands from non-domestic buildings.

Estimating the technical potential for DSR is inherently uncertain. For example, the extent to which heating demands in a particular building may be delayed depends on the building's characteristics and the temperature range deemed acceptable to maintain comfort levels. Assessing the potential for DSR at the national level is therefore a challenging task. To reflect such uncertainties we calculate the technical potential for DSR under a range of scenarios, differentiated by the assumed level of demand flexibility. The scenarios are:

- ***Conservative*** – includes cautious assumptions regarding the level of demand flexibility, this scenario represents our lower estimate of the technical potential.
- ***Moderate*** – the moderate scenario is an intermediate case, with reasonably ambitious flexibility assumptions.
- ***Stretch*** – represents an optimistic case, where high levels of flexibility may be possible. This scenario is consistent with high levels of awareness of energy issues and acceptance of a certain level of impact on service levels in buildings.

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[6] Note that in the absence of detailed sub-metered data, profiles by sub-loads are based on their overall contribution to annual demands and aggregate demand profiles by sub-sector.

To estimate the technical potential for DSR, we define the level of flexibility by sub-load under each scenario (see section 4.2) and calculate the potential peak demand reduction based on the load profiles presented above. The results are summarised in the following table.

Table 1: Estimated overall potential for DSR to reduce peak demands due to non-domestic buildings

	Estimated load flexibility during peak hour by scenario (winter week day, Great Britain) (GW)		
	Conservative	**Moderate**	**Stretch**
All non-domestic sub-sectors – including lighting	1.2	2.5	4.4
All non-domestic sub-sectors – excluding lighting	0.6	1.2	1.8

The initial assessment of the potential for DSR to reduce peak demands includes assumed flexibility in hot water, HVAC, other (mainly refrigeration) and lighting loads. This leads to an estimated technical potential of 1.2–4.4GW, i.e. between 8–30% of demands during the peak hour. We include some flexibility in lighting loads based on experience from more developed DSR markets (such as in California).[7] However, the majority of stakeholders consulted during this study believed the flexibility in lighting loads to be highly limited. To reflect this feedback, we also calculate the DSR potential with no contribution from lighting loads. As the results above suggest, the technical potential falls by 50–60% if lighting loads play no part in providing load reduction during peak periods.

1.4 Barriers and enablers

While the technical potential for DSR to reduce peak demands may be significant, there has to date been relatively low uptake of DSR measures in the building types of interest for this study. This can be largely attributed to the wide range of barriers that act to restrict demand for DSR. This study's consultation provided an opportunity to understand consumers' experiences of DSR and to gather qualitative data on the perceived barriers to further uptake. An invitation to participate in the consultation (which took the form of telephone interviews) was issued widely via trade associations and through direct contact with certain organisations. In total, 16 interviews were held during March and April 2012, covering organisations from facilities management companies, to demand aggregators, to major retailers, thus providing coverage across all of the main sub-sectors of interest. Each interviewee was asked to list the barriers that prevent further engagement with DSR and we summarise the responses in the diagram below.

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[7] A discussion of how lighting loads may be flexible is provided in section 4.1.

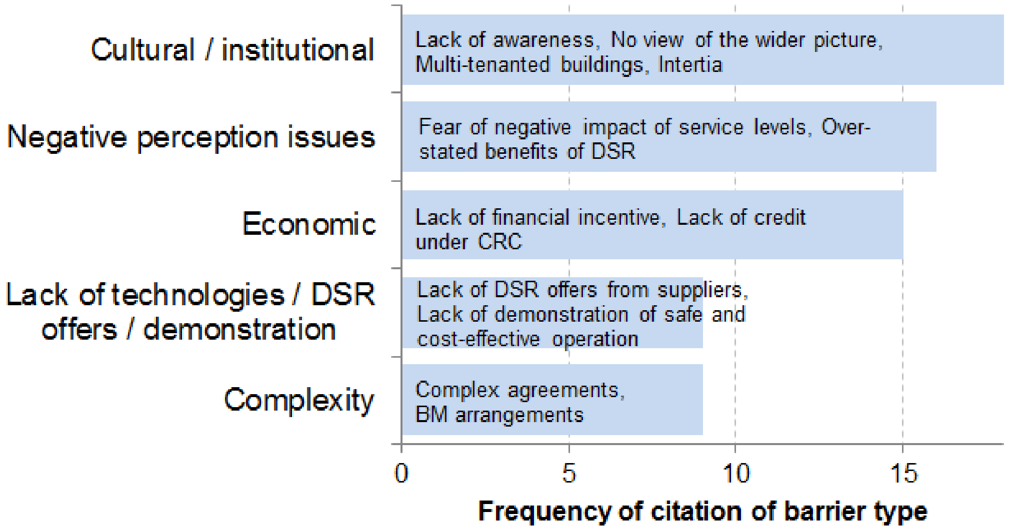

Figure 4: Overview of barriers cited during the telephone interviews

Although the barriers listed were wide-ranging, some common themes emerged, including:

- Since energy is not a focus of most of the organisations in this sector, DSR is not generally a priority. Some organisations are investing in energy efficiency measures (in particular low energy lighting), but for the majority DSR is not currently high on the agenda.[8]
- There was widespread concern that implementing DSR measures could lead to reduced levels of service or comfort for building occupiers (and feedback suggested that in general no impact on service levels would be accepted).
- Relatively low and / or uncertain financial incentives were also often cited as an important barrier.

A more detailed discussion of barriers to DSR, together with suggested enabling mechanisms, is provided in section 5.

1.5 Conclusions

In this study we have characterised the electricity demand profiles of a sample of non-domestic premises types and explored the potential for demand side response measures to reduce peak demands on the British electricity grid. A selection of the headline conclusions follows; a full set of conclusions is given in section 6.

- We estimate that non-domestic buildings (excluding industry) contribute approximately **15GW** (c.30%) to winter peak demands on Great Britain's national grid.
- The **retail**, **education** and **commercial offices** sectors contribute most to peak demands (over 50% from these top three), with a relatively even contribution from the remaining seven sub-sectors.

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[8] All of the consultees had some knowledge of DSR, but only two of the organisations that participated in the consultation are currently implementing DSR measures. Note that awareness levels of DSR amongst those consulted is not necessarily representative of the sector as a whole (as the sample is likely to be biased).

- This suggests that **engagement across all building types** will be required to fully exploit the DSR potential.
- Assessment of the technical potential suggests that DSR measures could reduce winter peak demands in Britain due to non-domestic buildings from **1–4.5GW** (or 0.6–2GW if no flexibility can be provided from lighting).
- Engagement with DSR in this sector is currently very low, due to a combination of barriers including lack of focus on energy issues, lack of awareness of DSR measures, concerns of negative impacts on service levels and an insufficient / unclear economic case for action.
- Consumers in this sector are **unlikely to accept any impact on service levels** to accommodate DSR measures. This is in contrast to energy intensive industry for example, where energy costs are often a factor in setting working practices.
- It is likely that a range of enabling mechanisms will be required to support greater uptake of DSR in non-domestic buildings. Measures are required to increase confidence in and awareness of DSR, to reduce complexity of DSR arrangements and to demonstrate the economic case.

2 Introduction

2.1 Context

Electricity is one of the key forms of energy delivery in the UK, representing nearly a fifth of total final energy consumption in 2010.[9] Demand for electricity is expected to increase in the future for various reasons[10], putting additional strain on the system. Traditionally, electricity supply in the UK has involved generation at power stations around the country, combined with high voltage transmission and (lower voltage) distribution networks to deliver the electricity to consumers, as shown in the following diagram.

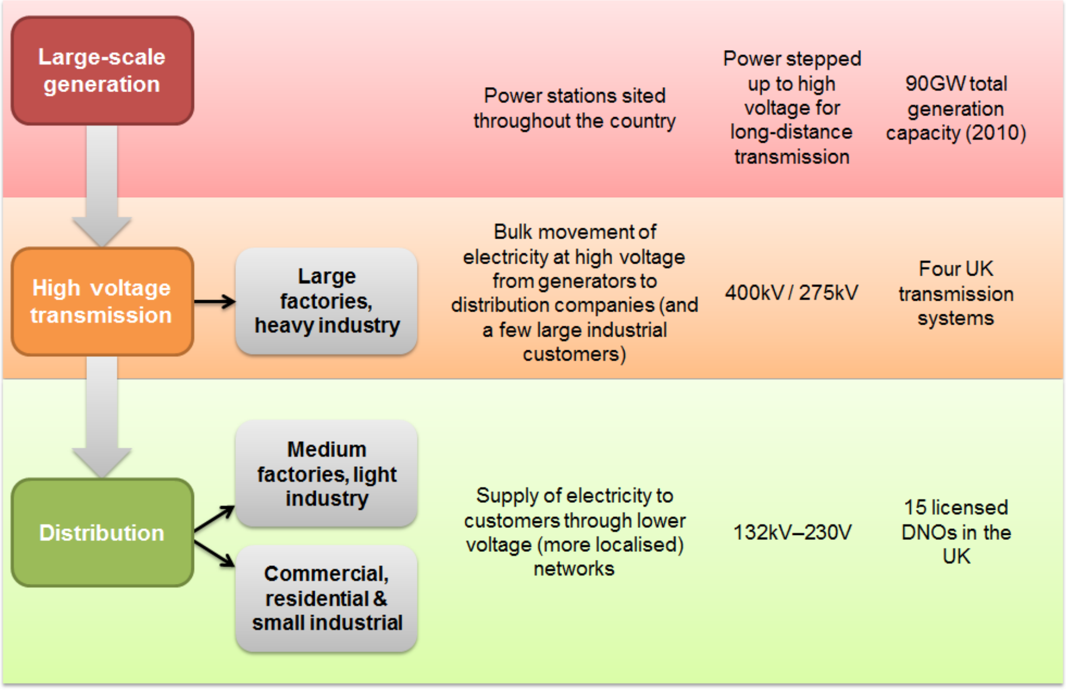

Figure 5: Overview of the UK's interconnected electricity system

In order to maintain secure supplies, the system must be sized to meet peak demands, which occur for relatively limited periods over the course of a year. This results in generating plant and transmission and distribution networks being under-utilised for much of the time. Demand side response is a method of reducing peaks in demand, by encouraging reduced consumption during peak periods or shifting consumption to other times when the overall demand on the grid is lower.[11]

The UK energy regulator Ofgem works to promote competitive gas and electricity markets to ensure secure, affordable and sustainable energy supplies for consumers. Ofgem is therefore interested in the potential role of demand side response in limiting peak electricity demand and improving the efficiency of the system. It is in this context that

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[9] Source: Digest of UK Energy Statistics, Chapter 1, Chart 1.4, p.15 (2011). According to DUKES, electricity accounted for 17.5% of the UK's final energy consumption in 2010, after petroleum (45.5%) and natural gas (33%).

[10] Demands are expected to growth due to population growth, and the forecast increased electrification of certain demands (such as heating and road transport) as part of efforts to reduce the UK's GHG emissions.

[11] Reducing the magnitude (and frequency) of peak demands offers a number of potential benefits, see section 2.3.2.

Ofgem commissioned Element Energy and De Montfort University to undertake this study into the potential for DSR in the commercial and public sector.

2.2 Aims and scope

This study's primary aims are to:

- Quantify the technical potential for demand side response in non-domestic buildings.[12]
- Assess the barriers to further uptake of demand side response and identify enabling mechanisms required for the potential to be realised.

The study is limited to considering electricity demands in the non-domestic building sector, excluding energy-intensive industrial processes. Further details of the building types included are given in section 3.1. In terms of geographical coverage, the focus of the modelling work is Great Britain only.

2.3 Overview of demand side response

2.3.1 Definition

There exist a number of definitions of demand side response (DSR) in the literature, and although they vary slightly, the overall meaning implied is broadly similar. For the purpose of this study we use DSR to refer to the change in electricity consumption patterns in response to a signal. Demand side response, which may be brought about by a suite of methods, results in more efficient use of the electricity system and along with energy efficiency measures can be used to reduce peak electricity demands. We summarise some of the mechanisms available in the figure below.

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[12] Given the range of potential benefits of DSR (see section 2.3.2), there are various ways of defining its *technical potential*. Many of these benefits are difficult or impossible to quantify, hence in this study we focus on assessing the potential for DSR to reduce peak demands on the national grid.

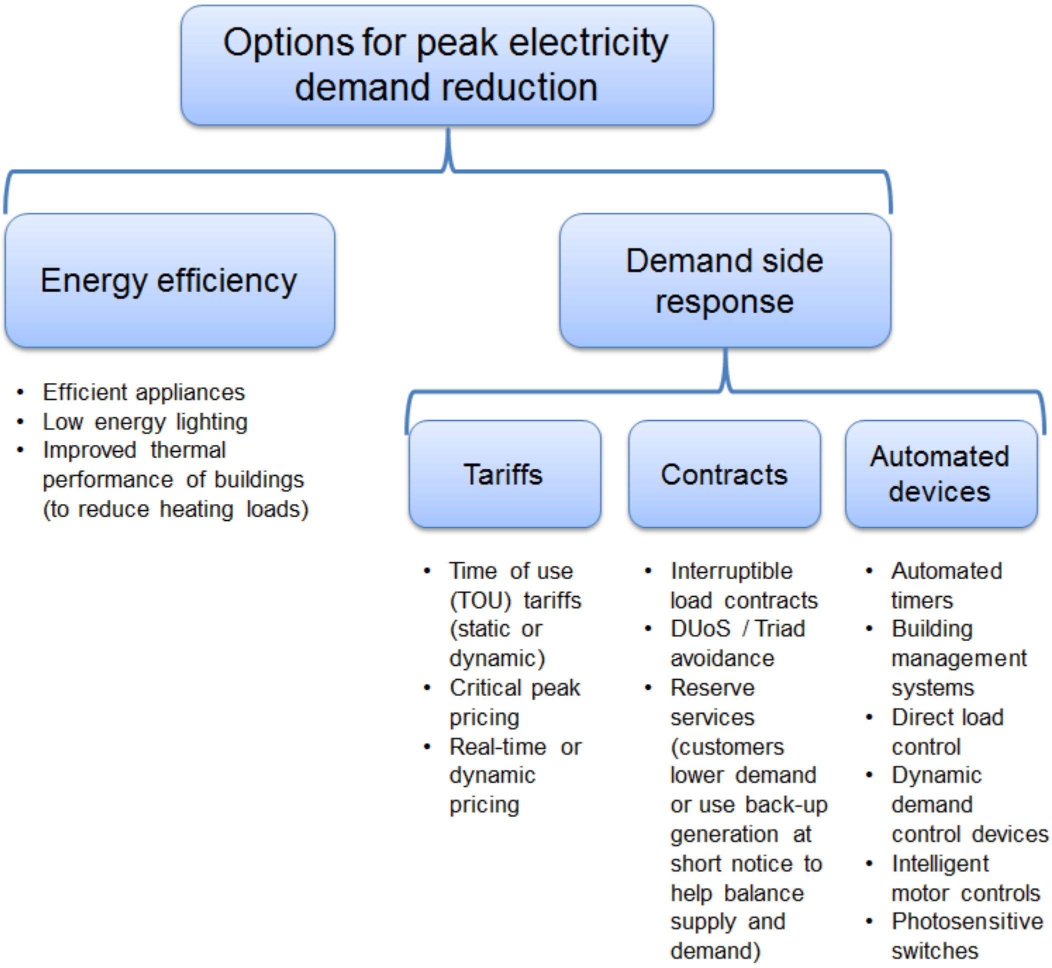

Figure 6: Examples of demand side response mechanisms

In the following sub-sections we explore some of the aspects of DSR in further detail.

2.3.2 Role of DSR in the electricity system

A comprehensive overview of the benefits and challenges associated with DSR is given in a paper by Strbac of Imperial College[13], which lists the following drivers for the introduction of DSR:

- The potential for more efficient use of (generation and transmission) assets and increased efficiency of electricity system operation.
- Recent developments in information and communication technology (ICT), which could facilitate the deployment of further DSR solutions.
- With ageing electricity infrastructure assets in the UK, the opportunity exists to integrate DSR technologies in the strategy for asset replacement.
- GHG emission reduction goals leading to a focus on distributed generation (e.g. CHP), and renewables (in particular wind power). DSR could play a useful enabling role for such technologies (see below).

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[13] *Demand side management: Benefits and challenges*, Goran Strbac, Imperial College (2008). Energy Policy 36 (2008) 4419–4426.

Although the uptake of DSR solutions has been relatively restricted in the UK to date (see section 2.3.4), they offer numerous potential benefits and could be an important aspect of the electricity system in future.

Benefits of DSR

The potential economic and environmental benefits resulting from increased uptake of demand side response measures include:[14]

- The potential to **reduce generation margin** – in order to guarantee adequate security of supply the total installed generation capacity must exceed peak demands (to guard against unexpected losses in generation (e.g. due to plant failure)). DSR could in theory provide long-term reserve, the potential being dictated by the how often shortfalls in supply occur, and the size and duration of any deficits. In practice this would mean persuading consumers to reduce demands in the event of a shortfall, rather than installing and maintaining back-up generation that would only be used infrequently. [15]
- **Improved transmission grid investment and operation efficiency** – under current arrangements, security of supply is maintained in part by running the system in a state to withstand possible outages, including ensuring access to spare generation capacity that can be dispatched at short notice. The penalty of adopting such an operating regime is that generation and network utilisation factors are low (i.e. inefficient in terms of asset utilisation). Higher utilisation could be achieved if overloads (that may occur in the event of a generator outage for example) could be avoided by reducing demands at critical locations.
- **Improving distribution network investment efficiency** – this includes a number of potential benefits[16], from increasing the amount of distributed generation that could be accommodated on an existing network, to managing the loads on transformers in urban areas (where space constraints may make capacity increases impractical).
- **Managing demand-supply balance in systems with intermittent renewables** – higher levels of generation from renewables such as wind power is likely to necessitate increased levels of reserve.[17] DSR can act as a form of standing

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[14] This summary of the benefits of DSR draws from the following sources: *Demand Side Response: A Discussion Paper*, Ofgem (2010); *A Scoping Study: Demand Side Measures on the UK Electrical System*, KEMA for the DTI (2005); and Strbac (2008).

[15] As noted in Strbac (2008), this potential role for DSR is likely to become increasingly important with further deployment of wind turbines. The characteristics of wind power mean that its potential to displace conventional plant in terms of peak output (GW) is rather more limited than its potential to provide energy (GWh). Therefore, opportunities will exist for alternative forms of reserve (which could be provided by DSR) in a high wind future.

[16] Strbac (2008) lists the benefits here as: "*(i) deferring new network investment, (ii) increasing the amount of distributed generation that can be connected to the existing distribution network infrastructure, (iii) relieving voltage-constrained power transfer problems, (iv) relieving congestion in distribution substations, (v) simplifying outage management and enhancing the quality and security of supply to critical-load customers, and (vi) providing corresponding carbon reduction*."

[17] Generation from renewables is expected to increase significantly over the coming decades. For example, the Committee on Climate Change suggests that the UK may need total installed wind generation capacity of around 27GW by 2020. *Meeting Carbon Budgets – Third Progress Report to Parliament*, The Committee on Climate Change, Chapter 2, p.76, (June 2011).

reserve, leading to improved system performance (e.g. offering loads when high wind output corresponds to periods of low demand).

- **Reduced costs of electricity generation and supply** – the efficiency improvements outlined above could reduce (or defer) investments required, hence allow lower cost electricity supply.
- **Increased uptake of energy efficiency measures** – as Figure 6 (above) suggests, DSR solutions are typically distinct from energy efficiency measures. However, participation in DSR activities can lead to increased awareness of energy issues, including a better understanding of energy usage patterns, and thus reductions in demand through energy efficiency.
- **Reduced GHG emissions from the power sector** – DSR can lead to environmental benefits by facilitating greater uptake of renewable generation (as discussed above) and by reducing the need for peaking plant, which is often a carbon-intensive form of generation.

Drawbacks of DSR

While DSR clearly offers a range of potential advantages, we should also be aware of the potential downsides, which include:

- **Added complexity** – this includes more complex contracts with suppliers and the need for additional hardware (e.g. frequency response, direct load control devices).
- **Privacy concerns** – certain forms of DSR require organisations to share data with a third party, which could be regarded as undesirable.
- **Upfront investment required** – some forms of DSR involve the installation of new equipment, which has an associated cost. Electricity suppliers may be unwilling to cover the expenditure given the ease with which customers can change suppliers, and many organisations may be reluctant to invest unless a clear (and short) payback period can be demonstrated.
- **Potential increase in total consumption** – in general, DSR is viewed as a technique for shifting when loads occur, with minimal impact on total consumption. The greatest opportunities for DSR are those loads with in-built inertia or storage as periods of load reduction can be preceded or followed by increased demand with no impact on the service provided to consumers. However, if DSR is offered through increased use of storage, then total energy consumed over a year would be directly related to the (in)efficiency of the energy store.
- **Interference with natural diversity of demand** – if measures such as direct load control are applied to a high proportion of similar loads (e.g. air conditioning in buildings), then while the total load may be reduced for a period, there is a risk of greater coincidence (lower diversity) immediately following the period of demand reduction. The simultaneous start-up of multiple systems following a load-shedding period could produce a peak in demand, which is an issue that requires careful management.
- **Potential for increased carbon emissions** – in some cases DSR measures could lead to increased carbon emissions. For example, if local diesel generators are run under STOR instead of traditional large-scale generation plant, the emissions per unit of electricity generated will typically be higher. However, as this will only be for short periods, the total increase in emissions is likely to be

insignificant compared to total generation emissions. Most energy demand measures will reduce emissions or have little effect.

2.3.3 Types of DSR

Figure 6 in section 2.3.1 introduced the main types of DSR mechanisms available. In this section we provide further details of the principal DSR solutions.

Tariffs

- **Time of use tariffs** – as the name suggests, TOU tariffs involve varying the price of electricity throughout the day (as opposed to consumers paying a flat rate for electricity). Pricing structures more closely reflect the varying costs of supply, i.e. with higher prices during peak periods. TOU tariffs may be *static*, with fixed prices in defined periods, or *dynamic*, allowing pricing structures to vary at short notice (e.g. in reaction to market events).
- **Critical peak pricing** – this is a form of dynamic tariff that allows suppliers to increase electricity prices at short notice (typically at peak periods).
- **Real-time or dynamic pricing** – such contracts allow electricity prices to be varied frequently (e.g. hourly), more accurately reflecting wholesale electricity costs. Typically price signals are provided to consumers in advance.

Contracts

- **Interruptible load contracts** – these contracts help to ensure system reliability by allowing suppliers to suspend supplies to certain customers (e.g. following an outage of a generation or network asset).[18] Such contracts are more common within the heavy industry sector (manufacturing, refining, mining etc.) but contracts for commercial customers also exist. For example, STOR agreements (see below) are a type of interruptible load contract as they involve suppliers asking consumers to reduce consumption at short notice.
- **Reserve services** – these services are required by National Grid to ensure security of supply in the event of unexpected demand increases or reduced generation. Reserve services can be either increased generation or demand reduction. Examples include fast reserve, fast start, demand management, short term operating reserve (STOR), and balancing mechanism (BM) start up.[19]
- **Triad management** – Triads are the three half hour periods of highest national system peak during a year. They are not know in advance, but can be forecast as they typically occur during late afternoon / early evening on cold winter week days. Charges for using the transmission network are distributed between electricity suppliers based on consumption during these periods. The suppliers in turn pass these *Triad charges* on to their customers. Triad management involves reducing consumption for around two hours during expected peak periods in order to minimise these charges.
- **Distribution use of system (DUoS) charge management** – DUoS charges are levied on consumers to cover the cost of using the distribution network. DUoS

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[18] Feedback from the consultation suggests that this type of contract has generally shifted from models where consumers' supplies are interrupted, towards *self-interruption* arrangements, i.e. where the consumer opts to reduce demands (in return for financial reward).

[19] For further details see: //www.nationalgrid.com/uk/Electricity/Balancing/services/balanceserv/reserve_serv /

charges for half-hourly metered customers may be comprised of several elements[20], some of which can be reduced by changing when power is consumed.

Automated devices

- **Building (energy) management systems** – a BMS (or BEMS) is a computer-based system that controls and monitors certain electrical and other energy-consuming equipment within a building (e.g. lighting, ventilation, security systems). Being computer-controlled, there is potential to program such systems to provide DSR services.
- **Direct load control** – involves installing devices on certain types of plant that enable the electricity supplier to (remotely) control consumption. This form of DSR is typically applied to loads that can be turned off or cycled for short periods without a noticeable loss of service (e.g. air conditioners, water heaters). Remote control of electric storage heaters is the most familiar example.
- **Dynamic demand control** – devices which can be used with any *time-flexible* electrical load (refrigeration, air conditioning, heating etc.). They can turn devices on and off in response to changes in the frequency of electricity supply.

2.3.4 DSR market status

Demand side response in the UK has to date been largely confined to energy intensive sectors such as heavy industry. The results of this study's consultation support the general consensus in the literature, i.e. that demand side response activity in the commercial sector is limited. There are various reasons behind this, which we explore in section 5.

The current status of DSR in the UK, and future outlook is presented in the IEA's Demand Side Management Programme annual report:

In the current GB market DSR is principally used to reduce demand in periods of system stress (e.g. sudden loss of generation or transmission failures). DSR actively participates in the Short-Term Operating Reserve (STOR), contributing 445 MW in 2010. Response to wholesale price is currently limited to large industrial consumers that have half hourly meters and are charged the wholesale electricity price. The introduction of Smart Meters could increase the opportunities for DSR, for example through greater use of time or price sensitive tariffs. To automatically respond to variable tariffs or wholesale prices, consumers would need equipment (to complement Smart Meters) that will reduce demand automatically by turning off non-essential electrical devices. This, in conjunction with the likely electrification of heat and transport which could significantly increase the amount of discretionary demand, could lead to greater participation of the demand side in the wholesale market.[21]

2.4 Methodology

The main aims of this study are to understand the potential for reducing peak electricity demands, and the associated barriers to further DSR uptake in the non-domestic sector.

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[20] E.g. capacity (or availability) charge (based on peak daily demand), charges for each unit of electricity consumed (which may vary by time of day), reactive power charges and fixed charges.

[21] From *Implementing Agreement on Demand-Side Management Technologies and Programmes*, International Energy Agency, 2011 Annual Report, p.40, (2012). www.ieadsm.org/Files/Exco%20File%20Library/Annual%20Reports/REV.Annual%20report_2011C_lag.pdf.

To meet the objectives the team conducted two main work streams. First, a consultation with energy consumers and other stakeholders in the relevant sub-sectors was held in order to gather information on the current levels of engagement with and barriers to DSR. In parallel, a data modelling exercise was undertaken in which demand profiles for a selection of building types were analysed. The data for the modelling came from a variety of sources, including some of the organisations that participated in the consultation. The overall methodology is summarised below.

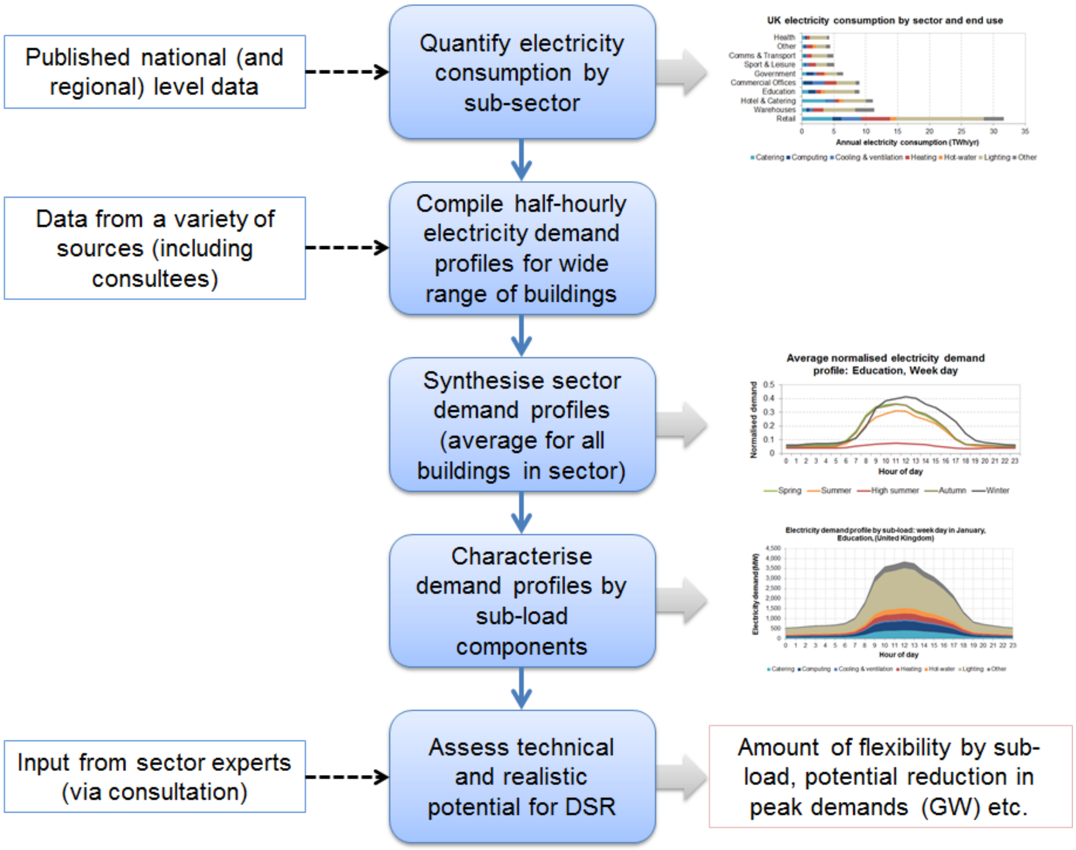

Figure 7: Overview of project methodology

Further details of the methodology are provided in the appendix, section 7.1.

3 Electricity use in non-domestic buildings

3.1 Characterising the non-domestic building stock

In this study we are principally concerned with electricity demands (in particular peak demands and the potential for shifting loads in time) in non-domestic buildings. Electricity consumption, including total annual demand and demand profiles, vary by building type according to the nature of activity and occupancy patterns, for example. Furthermore, the importance of different sub-loads also varies by building type, e.g. the relative amount of demand for lighting, heating, hot water etc. is very different in a leisure centre compared to a retail unit. We therefore classify buildings into different usage classes in order to build up a picture of demand profiles by sub-sector.

The term non-domestic buildings is used in this study to refer to a broad cross-section of commercial and public sector premises. It is important to note that the study does not include electricity consumption in the energy intensive industrial sector. The breakdown of non-domestic building types used in this study is consistent with that adopted as the basis for reporting energy consumption in the UK.[22] The non-domestic building stock is classified according to ten sub-sector types:

- Commercial offices
- Communications and transport
- Education
- Government
- Health
- Hotel and catering
- Other[23]
- Retail
- Sports and leisure
- Warehouses

This provides a manageable number of classifications whilst also giving sufficient coverage to allow differences in usage patterns (and hence electricity consumption) to be taken into account.

3.2 Annual electricity consumption in non-domestic buildings

The sub-sectors of interest for this study accounted for around a quarter of the total UK electricity demand in 2009.[24] Although this work is mainly concerned with peak (rather than annual) demands, the breakdown of demands within the non-domestic sector is a useful starting point in understanding the potential role of DSR. We present electricity demands by sub-sector and end use type below. This is required to estimate the contribution of each sub-sector (and sub-load) to peak demands (by combining annual demands with demand profiles, see section 3.3.2).

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[22] See *Digest of UK Energy Statistics*, available on the DECC website.

[23] “Other” buildings are those that do not fall into any of the other nine categories listed.

[24] *Digest of UK Energy Statistics 2010*, Chart 5.1, Chapter 5, p.118 (DECC). Total electricity demand across all sectors was around 380TWh/yr in 2009. Other major consumers were the domestic (32%) and industrial (26%) sectors.

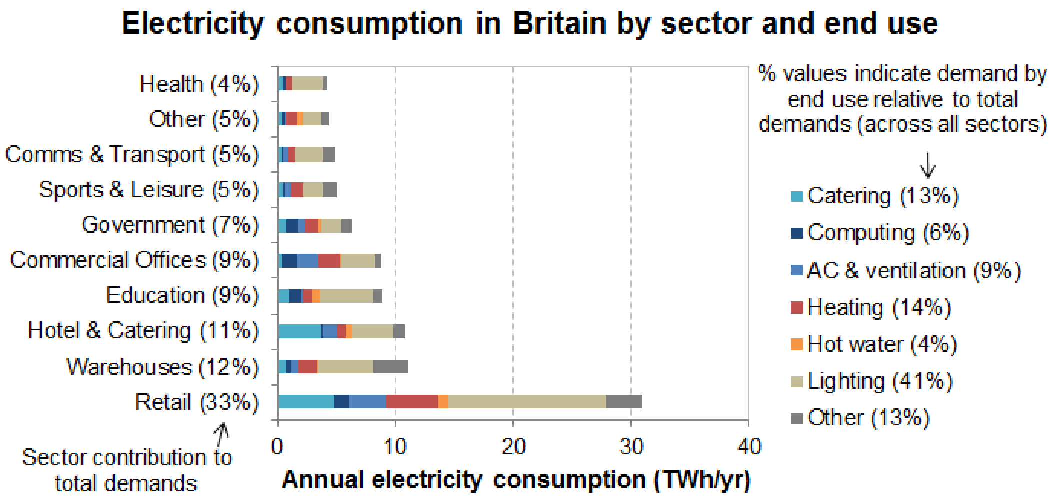

Figure 8: Annual electricity consumption in the UK by sub-sector and end use (2009)[25]

These data suggest that of the sub-sectors considered here retail (which includes high street shops, shopping centres, supermarkets, department stores etc.) is the largest consumer of electricity, representing a third of annual consumption in non-domestic buildings.[26] Consumption amongst the following four largest consumers (warehouses, hotel & catering, education, commercial offices) is relatively even. Assuming that contribution to peak demands is correlated to annual consumption of electricity (a reasonable assumption); this suggests that realising the full potential of DSR will require action across many of these sectors.

The graph above also shows the contribution of seven different sub-loads to annual demands by sub-sector. This is of interest since certain demands are better suited to DSR than others. Typically there is more opportunity to shift loads with in-built inertia or storage (e.g. heating, cooling, refrigeration) without causing a loss of service to consumers. The data above reveal that across these sub-sectors lighting is the dominant sub-load (c.40% of annual demands). Although lighting is not generally regarded as flexible,[27] reductions through energy efficiency measures are possible.[28] Demands that are generally accepted as being well suited to DSR (in particular cooling & ventilation, heating, hot water) represent over a quarter of total annual demands.

With an understanding of how annual demands are split by sub-sector and sub-load, the next step is to explore how consumption varies throughout the course of a year. We therefore present and analyse a selection of demand profiles in the following section.

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[25] Source*: Energy Consumption in the UK, Service sector data tables, 2011 update*, Table 5.6 (DECC). Note, we assume here that refrigeration (including freezers) is the principal sub-load in the category “Other” (for further details see appendix, section 7.2).

[26] Excluding medium to heavy industry.

[27] Most individuals contacted through the consultation believed that lighting is highly unlikely to be compatible with DSR. However, light switching and dimming can be part of DSR strategies, as evidenced by experience in the US, where demand side management measures are more widely implemented.

[28] Upgrading lighting to modern, energy efficient solutions can lead to substantial reductions in annual electricity consumption and offer a short payback period (as evidenced by one of this study’s consultees).

Key points

- The building classification used for this study is based on the system employed for reporting UK energy consumption statistics.
- Of the ten sub-sectors, retail is the single largest contributor to annual electricity demands, account for a third of the total in non-domestic buildings (excluding industry).
- There is relatively little difference in demands across most of the other sub-sector, which suggests the need for action across a range of building types to fully exploit the potential for DSR.
- Lighting is the major end use in this sector, accounting for 40% of annual electricity consumption. There is significant potential for reducing lighting loads via energy efficiency and a certain level of (technical) potential for lighting to play a role in DSR (see section 4).

3.3 Sub-sector demand profiles

3.3.1 Normalised profiles by sub-sector

Through a process of collecting, analysing and averaging half-hourly metered electricity consumption data in a range of buildings, normalised daily demand profiles for each sub-sector have been generated.[29] Normalised in this context means that demands in each hour of a given day (within each month) are expressed relative to the demand in the peak hour of the year. Example profiles for each sub-sector for a week day in December are given below.

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[29] For full details of the methodology see section 7.1.

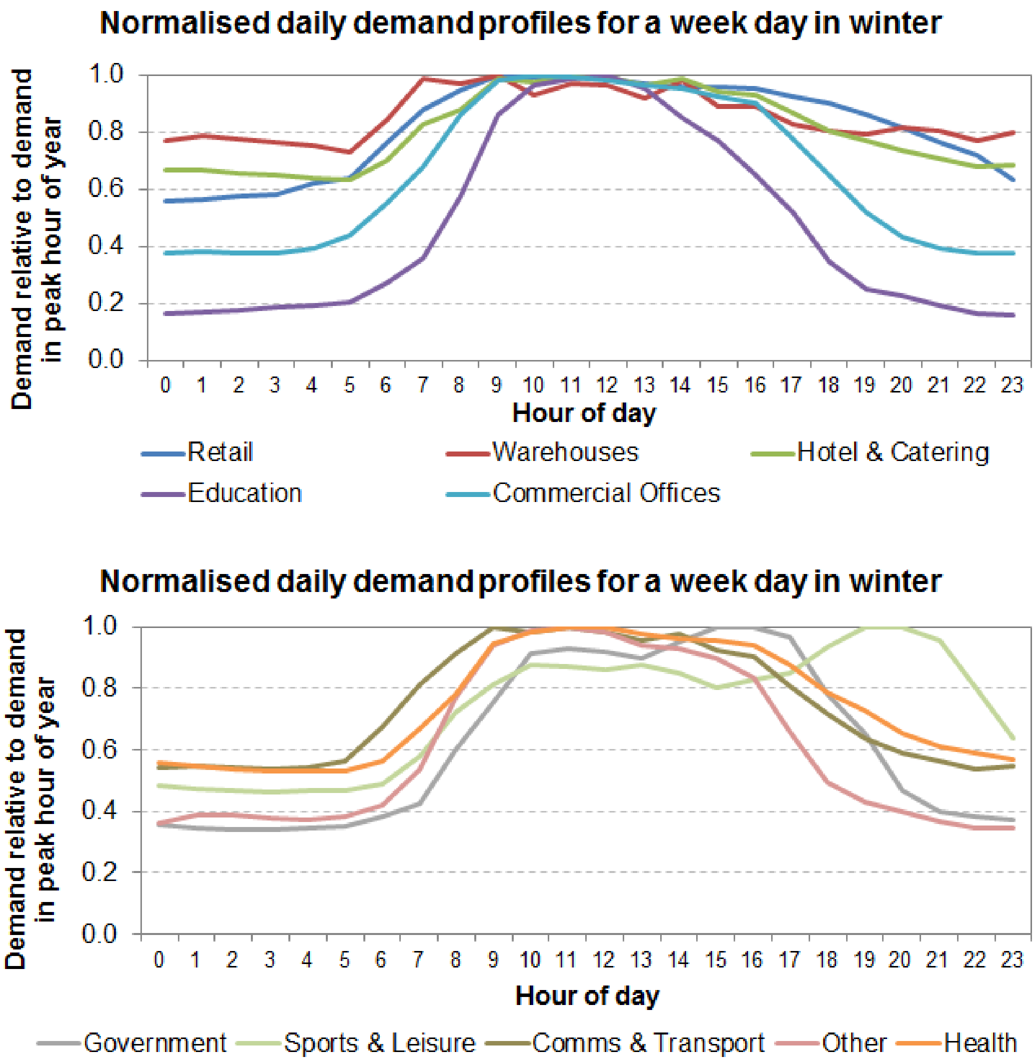

Figure 9: Average normalised demand profiles by sector for a winter week day

The different profile shapes reflect the diverse occupancy / usage patterns of buildings by sector. For example, a typical nine-to-five routine is evident for buildings in *Education*, in contrast to sub-sectors such as *Health* or *Warehouses*, where diurnal variations are lower.

Given that different loads offer different levels of flexibility (i.e. some are more suited to DSR than others), next we consider the composition (in terms of end-use) of these overall profiles by sub-sector.

3.3.2 Contribution of each end use to overall demands

Representative demand profiles (showing total electricity demand) for each sub-sector were derived from HHM consumption data for a sample of buildings. The HHM data show the buildings' total electricity demands, but do not include information on how the sub-loads (due to catering, cooling, heating etc.) vary over time.

As a first approximation, we base the profile of each sub-load on the overall profile (after accounting for any seasonal variation).[30] With a knowledge of annual demands by sub-

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[30] Ideally, we would have constructed the profiles of demand by sub-load based on sub-metered data for buildings by sector. However, sub-metered data (which indicate

load (see above), we can use these profiles to estimate diurnal variations in demands, and we present the resulting profile for the Education sub-sector as an example below.

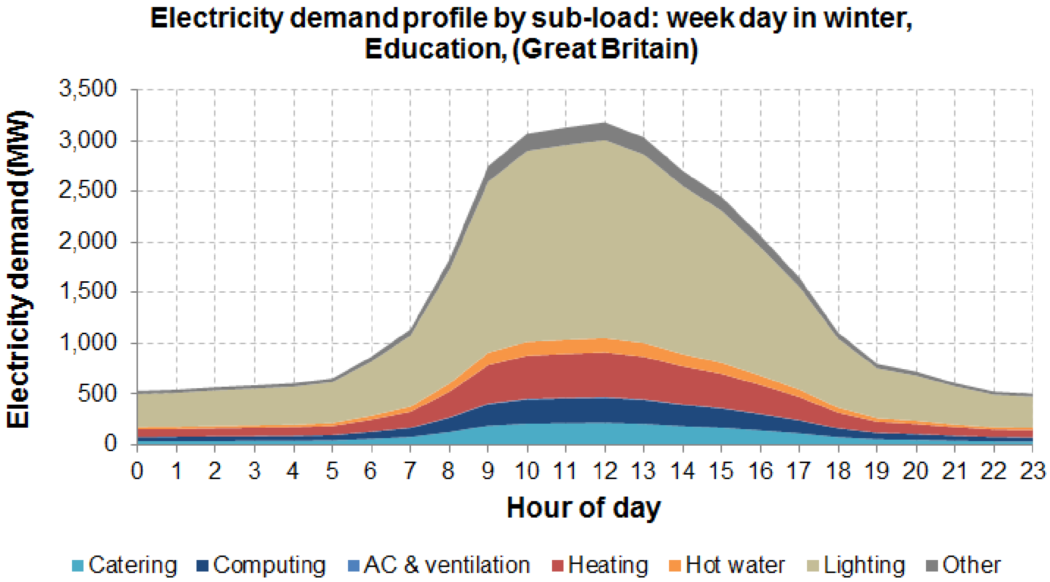

Figure 10: Daily demand profile by sub-load for a week day in winter (Education)

When interpreting such graphs, we should be mindful of the fact that these profiles represent all buildings across a sector. In the example above (Education), this includes schools, colleges, universities etc. Where available, we have made use of sub-metered data to more accurately represent the variation of each sub-load. For example, the graph below shows the profile for the retail sector according to:

a) Following the method outlined above (i.e. each sub-load's profile following the overall profile).
b) Using real-world sub-metered data to set the profiles for selected sub-loads.

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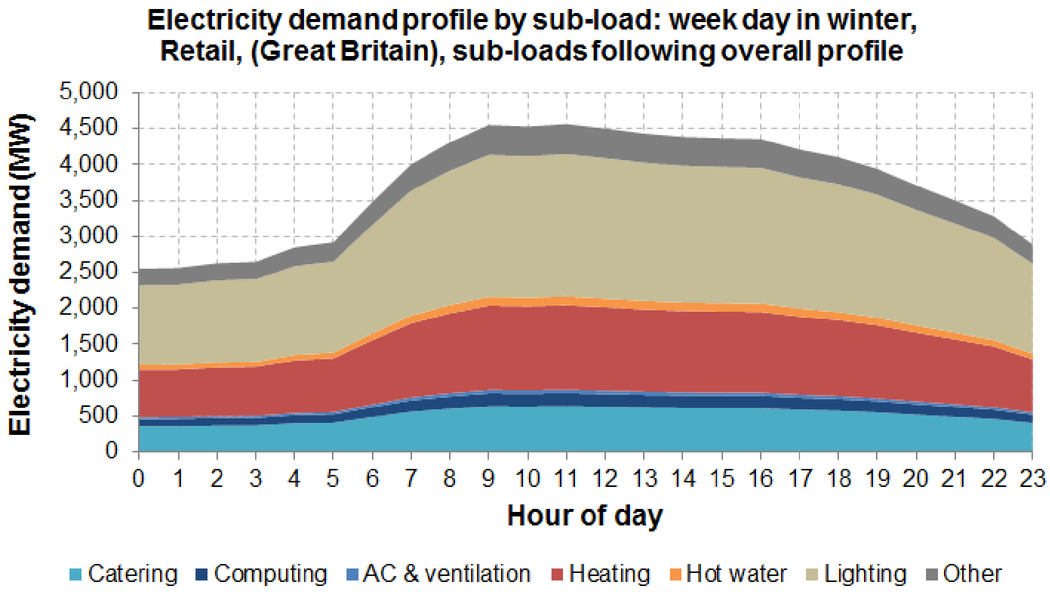
consumption by load type) are not widely recorded and the amount available for this analysis was limited.



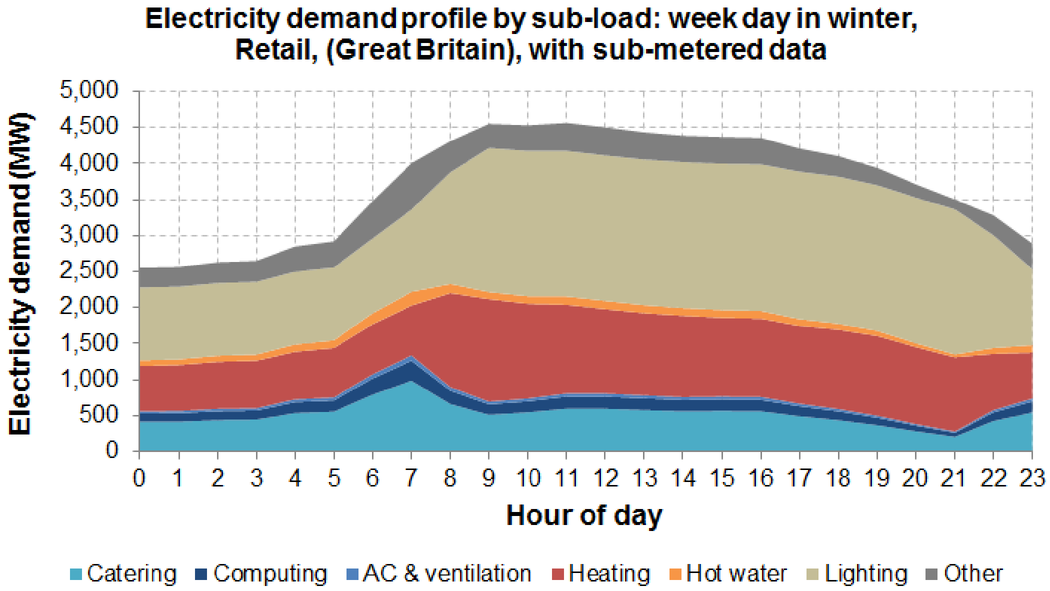


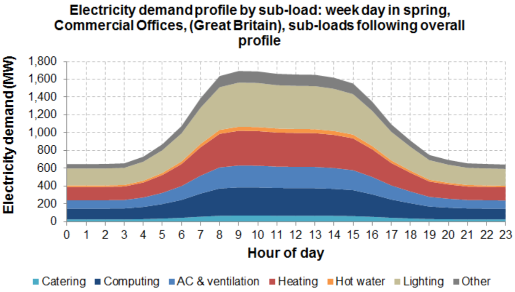
Figure 11: Daily demand profile by sub-load with each demand following overall profile (top graph) and modified taking account of sub-metered heating and lighting loads (bottom graph)

As mentioned above, we first approximate the profiles of each sub-load by assuming that each follows the profile shape of the total load (which comes from the measured HHM data). We refine this (lower graph of Figure 11) by over-writing the profiles for up to two sub-loads based on measured sub-metered data (where available). The profiles of the remaining sub-loads are then calculated with the constraints of maintaining (i) the overall profiles shape (i.e. the sum of all the sub-loads) and (ii) consumption by sub-load (the area under the curve).

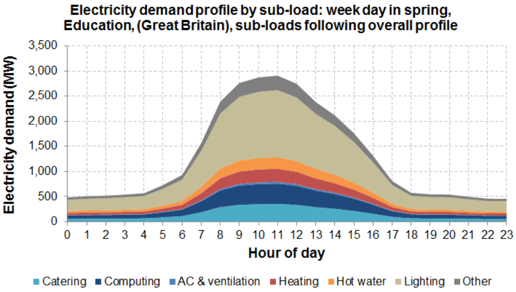
Following this method for the example above leads to a small change in sub-load profile shapes, mainly early in the morning. This is a result of the lighting and heating loads remaining lower for longer according to the sub-metered data. The overall similarity between the two graphs above provides confidence in the initial assumption that sub-loads broadly follow overall profile shapes at the aggregated (sub-sector) level.

Given the paucity of sub-metered data, the sub-load profiles are assumed to follow the overall profile (by sub-sector) in the majority of cases. A selection of profiles for a week day in spring (April) is given in the figure below.

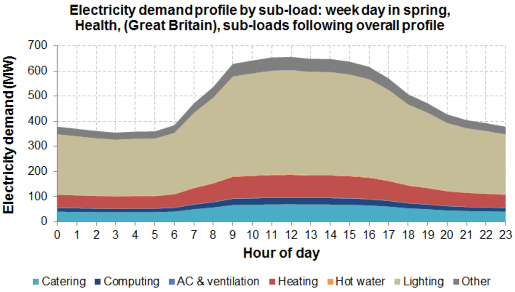
Commercial offices



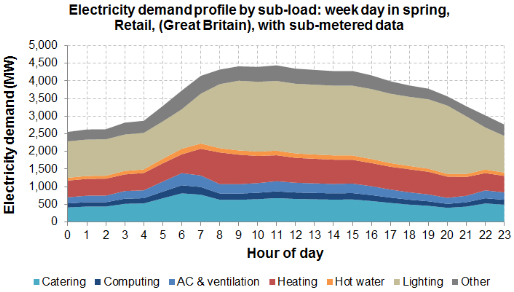
Education



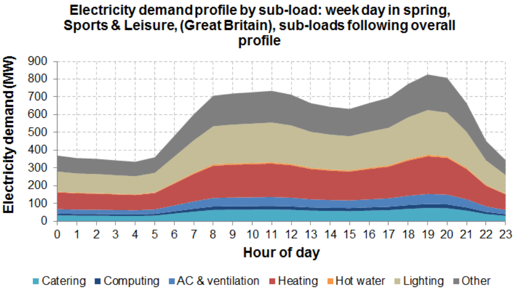
Health



Retail



Sports and leisure



Warehouses

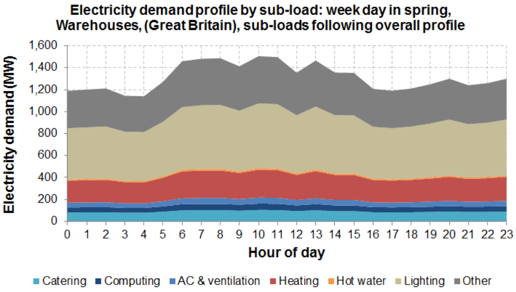


Figure 12: Daily demand profile by sub-load for a selection of sub-sectors (week day in spring)

In addition to revealing the overall load profile shape, these plots provide an estimate of the relative size of each sub-load during each hour of the day. This is of interest from a DSR perspective since certain loads are likely to be more flexible than others. We return to this point in section 4.

The profiles above correspond to demands for a week day in a given season. Daily electricity demand profiles also vary by day of week (in particular week day versus weekend day) and by season (as a result of changing weather patterns for example). We capture this variation in the modelling and explore the extent of daily and seasonal variation below.

3.3.3 Daily and seasonal variation

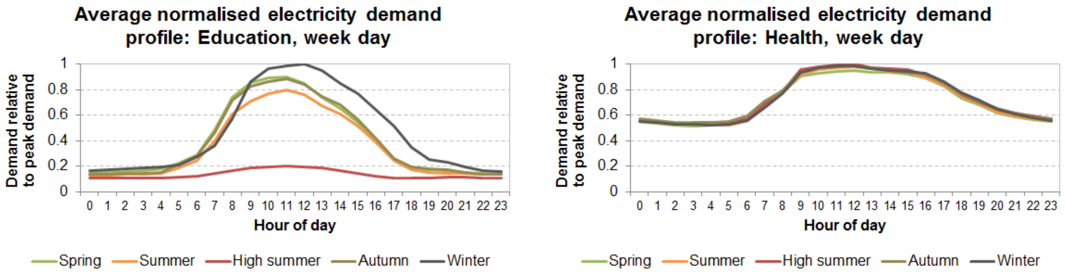
Variation in overall demand profile

Since the HHM electricity consumption data for each building covered a period of at least one year, we are able to capture daily and seasonal variations in demand profiles. For the purpose of considering electricity demands the year is split into five seasons, based on definitions used in electricity industry profiling:

- **Spring** – a period of around eight weeks beginning from the clock change in the last weekend of March.
- **Summer** – a ten week period following spring (covering the latter part of May, June and early July).
- **High summer** – the six week period prior to the last weekend in August.
- **Autumn** – period from the last weekend in August to the clock change in the last weekend in October (i.e. covering September and October).
- **Winter** – defined as the period in which GMT is adopted (i.e. this covers roughly November to March (inclusive)).

The variation in normalised demand profiles across these seasons for a selection of sub-sectors is shown below.

Education **Health**



Retail **Sports and leisure**

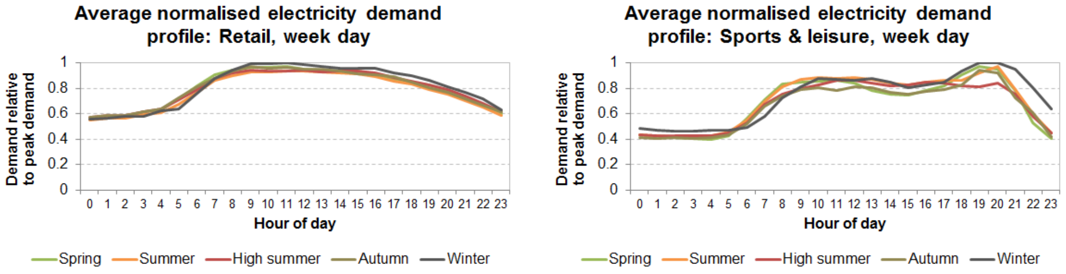


Figure 13: Seasonal variation in demand profiles for a selection of sub-sectors (week day)

The electricity consumption data collected for this study suggest that for most non-domestic building types the seasonal variation in demands is minimal.[31] Having said that,

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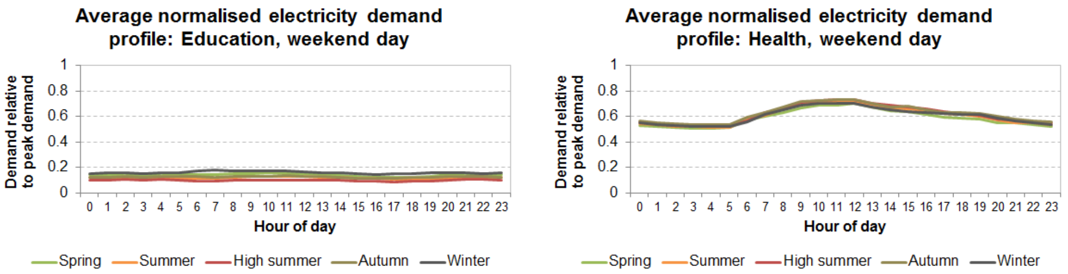
[31] Higher electricity demands may be expected in winter due to higher lighting loads (a result of shorter daylight hours) and increased heating demands. However, many of the sub-sectors considered show little seasonal variation in overall electricity demands. This may be a result of heating representing a relatively low fraction of total demands (7–22%), and increased air conditioning loads in summer offsetting any reductions in heating.

we can see from the above that the seasonal variation is pronounced in the Education sub-sector, which shows markedly lower demands in high summer (i.e. August), which is to be expected given the academic calendar.

Seasonal variation for weekend days is shown below (Figure 14). Comparison of these graphs against those for week days (above) also reveals the differences in consumption patterns throughout the week.

Education **Health**



Retail **Sports and leisure**

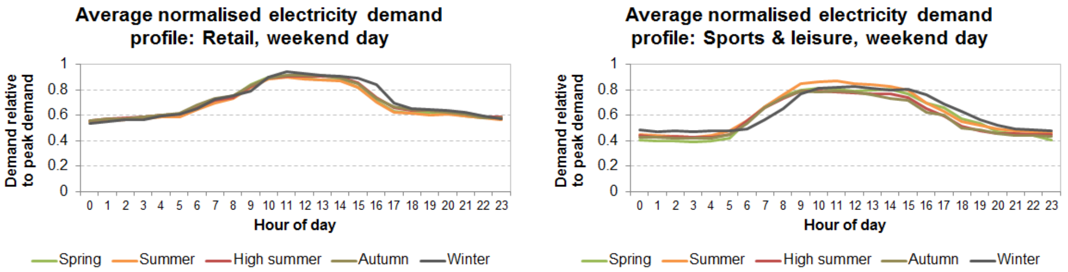


Figure 14: Seasonal variation in demand profiles for a selection of sub-sectors (weekend day)

Figure 13 and Figure 14 together reveal that in some sectors (such as retail), demands are relatively constant throughout the week, whilst in others (e.g. Education), there is a clear difference between week days and weekends. This is consistent with expectations given typical occupancy patterns of buildings within these sub-sectors.

Weekly / seasonal variations in demand limit the firm power available for DSR[32], which is a complicating factor for month-ahead contracting (typically required in the balancing market). By covering a diverse portfolio of sites, aggregators are able to circumvent this issue to some extent.

Seasonal variation by sub-load

The sub-load data presented in section 3.3.2 compares the profiles across different sub-sectors within a given season. Our analysis also accounts for seasonal variations (to reflect, for example, the fact that the majority of heating loads are in the winter, while

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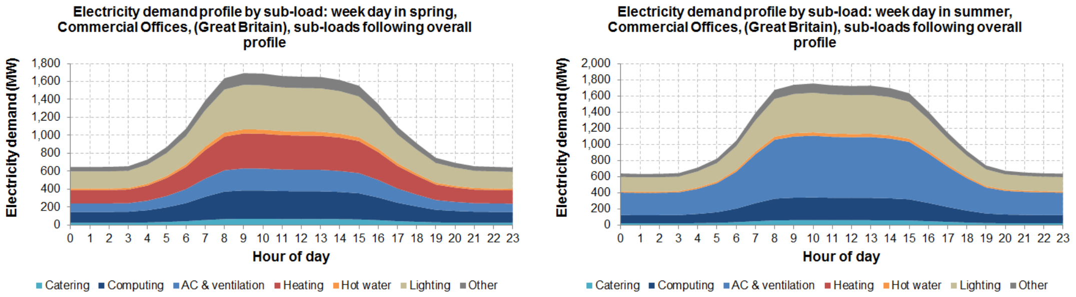
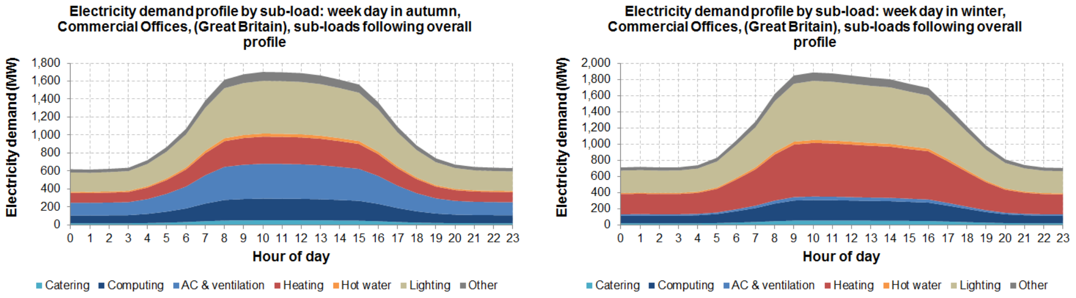
[32] The need for balancing services such as STOR varies by season, day of week and time of day. To reflect this, National Grid defines six seasons, with working days (which include Saturdays) and non working days (Sundays and Bank Holidays) and defined periods in which services are required (see section 4.3.5).

cooling loads tend to be greater in the summer). The following figure demonstrates this seasonal variation for *Commercial offices*.[33]



Spring

Summer



Autumn

Winter

Figure 15: Seasonal variation in sub-loads – Commercial offices

Seasonal variations are particularly pronounced for buildings in which heating and / or cooling loads represent a high proportion of total demands. Given that such loads are potentially well suited to DSR measures (due to the associated storage / inertia), it is important to capture these seasonal variations when assessing the potential for DSR measures (see section 4).

Key points

- Through a process of collecting and analysing HHM electricity consumption data we have generated typical demand profiles for each sub-sector. The profiles reflect the different usage and occupancy patterns that characterise the building types within each sub-sector.
- The profiles capture diurnal, weekly and seasonal variation in demands and allow us to estimate the contribution of each sub-sector, and each sub-load, to peak demands.

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[33] In Figure 15 the seasons spring, summer, autumn and winter correspond to the months of April, July, October and January respectively.

3.4 Aggregated demand profiles

In the previous sections we investigated the consumption profiles by sub-sector (and sub-load). Summing demands across sub-sectors allows us to estimate the total load profile of the non-domestic sector. The following graph shows the total peak demands by season (for a typical week day).

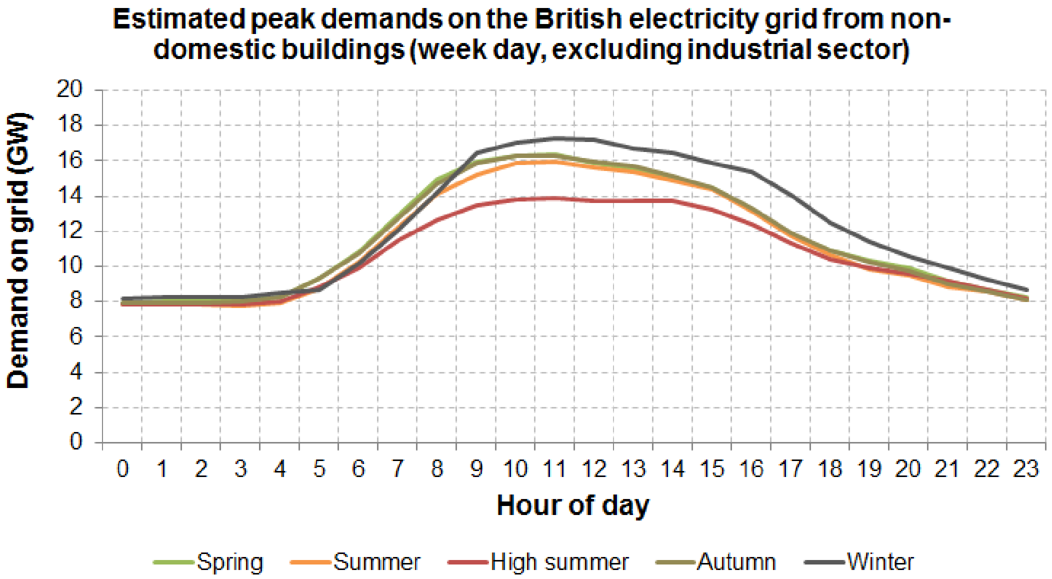

Figure 16: Peak demands on GB electricity grid by season due to non-domestic buildings

According to this estimate, the winter peak demand due to non-domestic buildings (excluding the industrial sector) is around 17.5GW. We can see from this graph that the peak for this sector occurs at around 11am on a week day, whereas overall peak demands on the grid are typically from around 4–6pm (see for example Figure 20 in section 4.3.4). Even so, these sub-sectors together account for around 30% of national peak demands.

The methodology employed allows us to estimate the contribution of each sub-sector to overall demand, which provides an indication of the main contributors to peak demands by time of day (see below).

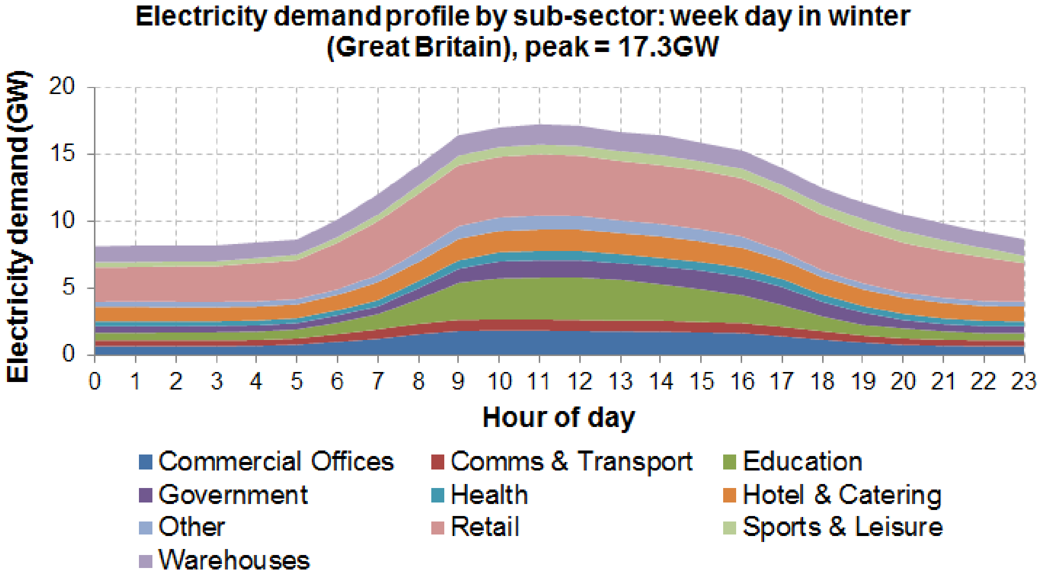

Figure 17: Electricity demand profile of non-domestic buildings for a winter week day

This graph reveals that the three sub-sectors that contribute most to peak demands are *Retail*, *Education* and *Commercial Offices*. The difference between the top three contributors to peak demand compared to the three largest annual consumers is due to the differing load profiles by sub-sector. Figure 8 in section 3.2 shows that the top three sub-sectors in term of annual electricity demands are retail, warehouses and hotel & catering. However, given the flatter overall load profile shapes of the latter two of these sub-sectors, they come further down the list in terms of adding to peak demands.

We can see from the above that (with the exception of retail and education) each of the sub-sectors contributes a similar amount towards peak demands. This supports the need for action across the full range of non-domestic building types if the full potential of DSR is to be realised.

An alternative way of breaking down the total demand profile is to consider the contribution of each sub-load (end use) across all sub-sectors, as shown in the figure below.

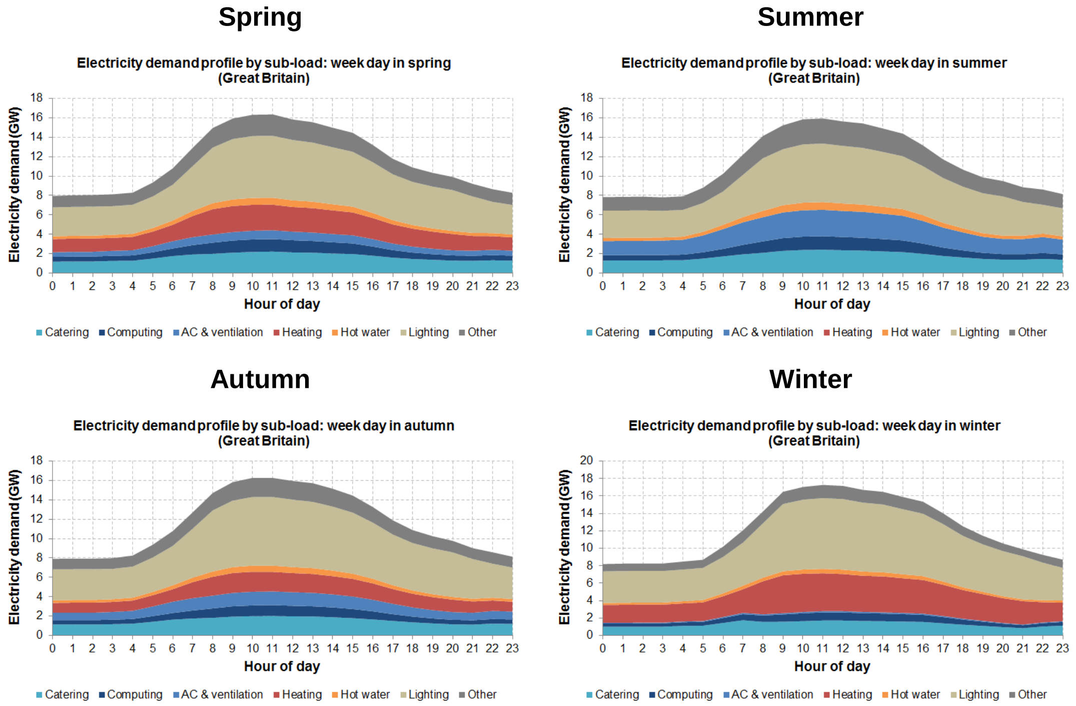

Figure 18: Seasonal variation in sub-loads (all sub-sectors)

It is clear from the above that some sub-loads are relatively constant throughout the year (e.g. catering, computing, hot water), whilst others (notably heating and cooling) show distinct seasonal variation. In terms of contribution to the winter peak, lighting and heating appear to be two major elements. Cooling loads are typically higher in summer and although this sub-load is not the most significant contributor to peak loads at the national level, cooling loads can cause issues on local distribution networks (e.g. in dense urban areas with high concentrations of office buildings).

Key points

- Peak demands due to non-domestic buildings are around 17.5GW and occur at around 11am on a winter week day.
- Non-domestic buildings contribute around 15GW to national peak demands (from all sectors, which occur during late afternoon on winter week days), around 30% of the total.
- The *Retail*, *Education* and *Commercial Offices* sub-sectors are the top three contributors to peak demands, with a relatively even split between the remaining building types. Exploiting the full potential for DSR will require participation from buildings across all sub-sectors.

4 Potential for demand side response in non-domestic buildings

4.1 Overview

In this section we investigate the potential for DSR to change load patterns, based on the analysis of electricity profiles by sub-sector presented in the previous section. Our starting point is to consider the various end uses and DSR measures available. Based on the characteristics of different DSR solutions we can assess the candidate sub-loads for reduction / shifting from peak periods.

4.1.1 Suitability for demand side response by end use

Demand side response measures aim to alter when electricity is consumed with minimal impact on levels of service provided to the consumer. The amount of flexibility to reduce demands in peak periods clearly varies by end use. For example, immersion heaters can be scheduled to run in periods either side of a peak window with no noticeable impact on hot water availability (given a sufficiently large thermal store). On the other hand, the level of flexibility of computing loads for example is rather lower as significant reductions in demand could only be achieved by changing working patterns. Summaries of the characteristics and potential flexibility each of the main sub-loads are given below.

Catering

Major electricity consuming equipment in this category includes ovens, electric hob, grills, microwaves, extraction fans etc. There is limited flexibility in when these demands occur without changing operating patterns.

Computing

Reductions through energy efficiency are possible (turning off unneeded equipment), but the potential for shifting loads in time without impacting business operations is very limited.

Space cooling & ventilation

Loads can typically be interrupted for up to 30 minutes at a time with no significant impact on the environment in the building.[34] This period depends on various factors including system type, building characteristics, ambient temperature and desired internal temperature range. Adequate fresh air supplies must be maintained for health and safety reasons.

Heating

Electric heating usually involves warm air systems, which suggests that while there may be potential to reduced loads for short periods (<15 minutes), extended demand reduction is not likely to be possible without an impact on temperatures (although some variation may be acceptable).

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[34] One (retail sector) organisation with extensive experience of active load management reported through the consultation that HVAC systems are routinely turned down / off for up to 60 minutes with no noticeable impact on comfort levels (at times of non-extreme ambient temperatures).

Hot water

Electric heating of water potentially offers high levels of flexibility. The period for which immersion heaters could be switched off depends on size of hot water tank (and effectiveness of insulation), and demand for hot water. There is no flexibility for instantaneous hot water systems, with the exception of non-critical applications (e.g. washrooms).

Lighting

In addition to energy efficiency improvements available through upgrading lighting solutions, there may be some potential for reducing lighting loads during peak periods through dimming and switching off non-essential lights. Although few consultees suggested lighting as a potential target for DSR measures[35], this load should not be ignored given its overall contribution to peak demands.

With enabling technology such as dimmable lighting and advanced controls (linked to building management systems), there may in future be some potential to reduce lighting loads at peak times.[36] Clearly the extent to which lights could be switched off or dimmed will vary by premises and will be dictated by issues such as type of lighting, the nature of activity and individuals' personal preferences. As the eye responds to light levels in a very non-linear way, the perceived reduction in illuminance will generally be much less than the actual lighting power reduction.

In assessing the technical potential (in terms of demand flexibility) for DSR below, we disregard the existing barriers, and assume that technical solutions could be implemented, even if their uptake today is low (see section 7.3).

The extent to which lighting loads could be reduced through dimming depends to some extent on what form of lighting is in place. For example, with the right controls installed, fluorescent lighting can be programmed to dim steadily (e.g. ramping down to say 50% power consumption).[37] Such reduction can be achieved in an imperceptible manner over a period of a few minutes and may be desirable in areas of buildings where occupancy is intermittent. Coupled with motion detectors to instantaneously switch back to full output, this type of solution can provide significant reductions in energy use with no negative impact on service levels. However, this type of system would require significant levels of investment (controls linked to every light fitting), and would provide limited potential for DSR since timing of reductions will be unpredictable.

---

[35] Having said this, a number of organisations are striving to reduce overall lighting loads (i.e. a permanent reduction via lower energy lighting, rather than reduced lighting levels are certain times). The installation of low energy lighting was identified as one of the most cost-effective energy efficiency measures available.

[36] E.g. lighting loads were included in some of the sites in an automated demand response trial in California. See *Automated Demand Response Technology Demonstration for Small and Medium Commercial Buildings*, Page et al. (July 2011).

[37] Note that to be dimmable, fluorescent lights require high frequency ballast. The ballast is a piece of electronic circuitry that provides the starting and operating conditions required. Dimmers are devices designed to vary voltage and hence power supplied to lamps. While simple variable voltage devices can be used to dim traditional (incandescent) lights, more specialised equipment is needed for other lighting such as fluorescent, solid state (including LEDs) and mercury vapour lighting.

Refrigeration

Loads in retail refrigeration can be interrupted for 15 minutes at a time quite readily. According to feedback from one organisation with experience in this area 30 minutes is possible in theory (but would be considered extreme). Cold stores and freezers offer further flexibility as they can be "charged up" (super-cooled) and then switched off for 30–60 minutes, possibly more if not opened.

Key points

- Demand side response is a broad term covering a range of measures, with different characteristics in terms of response time required and load reduction duration.
- Not all electricity end uses are suitable for providing response via DSR. For example, there is little scope to reduce computing or catering loads during peak periods (without a significant impact on business operations or working practices).
- The loads most suitable for DSR include space cooling, ventilation, heating, hot water (with storage), refrigeration and lighting.

4.2 Overall DSR potential

Drawing on evidence from this study's consultation and published literature, we have identified some flexibility in certain sub-loads. Given the difficulties in precisely quantifying the level of flexibility, we consider three scenarios to indicate the possible range, each being defined by the amount of potential reduction of selected sub-loads in the peak period. The scenarios are:

- ***Conservative*** – includes cautious assumptions regarding the level of demand flexibility, this scenario represents our lower estimate of the technical potential.
- ***Moderate*** – the moderate scenario is an intermediate case, with reasonably ambitious flexibility assumptions.
- ***Stretch*** – represents an optimistic case, where high levels of flexibility may be possible. This scenario is consistent with high levels of awareness of energy issues and acceptance of a certain level of impact on service levels in buildings.

The table below summarises the assumptions on level of flexibility by sub-load for each scenario, which are based on our understanding of DSR potential acquired via discussions with DSR providers and organisations with practical experience of DSR implementation.

Table 2: Overall DSR potential – scenarios[38]

Scenario	Flexibility in peak periods by sub-load (across all sub-sectors)			
	Hot water	Lighting	HVAC	Other
Conservative	25%	10%	10%	10%
Moderate	50%	20%	20%	20%
Stretch	75%	40%	30%	30%

Note: zero flexibility assumed for catering or computing sub-loads.

For the peak hour (5pm on a winter week day), the sub-sectors considered in this study contribute around 15GW to peak demands. With the assumptions set out above we have calculated the amount of flexible load (based on the load profiles presented in section 3), and tabulated the results below.

Table 3: Flexibility of electricity demands in non-domestic buildings under three scenarios of DSR potential

Sub-sector	Estimated load flexibility during peak hour by scenario (winter week day, Great Britain) (GW)		
	Conservative	Moderate	Stretch
Retail	0.4	0.7	1.3
Education	0.2	0.3	0.6
Commercial offices	0.1	0.3	0.4
Other sub-sectors	0.6	1.2	2.1
Total	**1.2**	**2.5**	**4.4**

As shown in Table 3, the top three sub-sectors (retail, education and commercial offices) account for over half of the total flexible electricity demand at the peak hour. Based on the scenarios presented above for the degree of flexibility of the main flexible sub-loads, a total potential demand reduction from non-domestic buildings from around 1.2 to 4.5 GW has been estimated.

In light of the feedback from the consultation regarding flexibility of lighting (i.e. the widespread attitude that the potential to reduce lighting loads during peak periods is very limited), we have calculated the DSR potential under the three scenarios outlined above with an assumption of zero flexibility in lighting load. The results are given below.

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[38] The figures in this table indicate the assumed level of flexibility (used to calculate the potential for peak demand reduction). For context, we may consider HVAC loads, which are believed to offer flexibility in that systems may be turned off for short periods with no perceptible impact on air quality or temperature (see section 4.1.1). For example, if supplies to HVAC systems could be interrupted for 15 minutes at a time, and the whole stock of systems were available, in theory a 25% reduction in loads could be maintained.

Table 4: Flexibility of electricity demands in non-domestic buildings – lighting sensitivity

	Estimated load flexibility during peak hour by scenario (winter week day, Great Britain) (GW)		
	Conservative	**Moderate**	**Stretch**
All non-domestic sub-sectors – including lighting	1.2	2.5	4.4
All non-domestic sub-sectors – excluding lighting	0.6	1.2	1.8

These results suggest that if lighting loads play no part in providing load reduction during peak periods, the technical potential for DSR reduces by 50–60%. This is consistent with expectations given the contribution of lighting to peak demands (e.g. see Figure 18, section 3.4). Note also that any potential for DSR via the reduction of lighting loads is likely to reduce with increasing uptake of energy efficient lighting.

Exactly how the technical potential for DSR may be delivered is subject to considerable uncertainty, but we investigate below how the various DSR measures could contribute. In practice the future mix of DSR solutions will depend on how the market evolves, including DSR offers developed and the response of consumers in this sector.

Key points

- The total technical potential for peak demand reduction via DSR measures in non-domestic buildings is estimated to be from around 1–4.5GW (or 0.6–2GW if no flexibility can be provided from lighting).
- The top three sub-sectors that could provide flexibility at peak times are retail, education and commercial offices.

4.3 Demand side response measures

The table below summarises the characteristics of some of the main types of DSR in terms of *response time* (i.e. notice period required for demands to be reduced), *duration* (period for which the load reduction must be maintained), and suitable sub-loads.

Table 5: DSR measures and characteristics

Type of DSR measure	Response time	Duration	Suitable sub-loads[39]
Direct load control	Minimal	Variable	HVAC, refrigeration, hot water
DUoS charge avoidance	Fixed	3 hours	Hot water, lighting, HVAC
Frequency response	2 seconds	30 minutes	Refrigeration (fridges), HVAC, lighting, hot water
Time of use tariffs, CPP, real-time pricing	Variable (known for static TOU, not for dynamic tariffs, day ahead for CPP)	3 hours	Hot water, lighting, HVAC, refrigeration (freezers / cold storage)
STOR	Up to 4 hours[40]	2 hours	Hot water, freezers, lighting, HVAC (and back-up generation)
Triad avoidance	Day ahead	2 hours	Hot water, refrigeration, lighting, HVAC

We discuss each measure in further detail below, including a quantitative assessment of the potential impact on demands where possible.

4.3.1 Direct load control

The installation of remotely controlled devices on plant such as HVAC systems allows utility companies to directly control certain loads, providing the opportunity to switch loads off during peak periods or increase demands at times of high generation. In return for making loads available for direct load control, consumers are given financial compensation by suppliers. Direct load control can help grid balancing and reduce peaks and troughs in demand by controlling non-critical loads for short periods without negatively impacting levels of service. However, this type of DSR requires the installation of equipment on consumers' appliances, together with adequate communications systems (the most common being radio signals and power line carrier systems). While there have been a number of trials of direct load control in other countries (e.g. the US), interest in this form of DSR has been low in the UK to date. The reasons for this include a lack of offers from

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[39] Suitable sub-loads in the sector of interest for this study – i.e. non-domestic buildings excluding industry.

[40] Four hours is the upper limit, referred to in National Grid's demand side information leaflet: www.nationalgrid.com/NR/rdonlyres/306C5B80-3AF1-480A-AA74-A480D7399634/28078/Demand_side_leaflet.pdf.
In practice response times for STOR are often considerably lower (of the order of tens of minutes). Different levels of responsiveness can be reflected in contractual terms.

suppliers, lack of clear financial incentive to participate, concerns over interruption to services, and issues relating to the installation of new equipment on existing plant.[41]

4.3.2 Distribution use of system charge avoidance

Electricity suppliers pay distribution network operators (DNOs) for the service they provide in taking power from the transmission system and supplying it to end users (the charge covers the cost of installing and maintaining distribution networks). As explained in section 2.3.3, DUoS charges may be passed on by suppliers via an additional element on consumers' bills.[42] DUoS charge avoidance strategies involve reducing a site's peak demand (to minimise capacity charges) and / or reducing consumption during peak periods when unit charges are higher. For example, it may be possible at some premises to reduce HVAC loads, dim lights in certain areas etc.

Since the use-of-system charge is only a relatively small component of the electricity tariff, the price signal available through varying this charge is unlikely to be effective for delivering DSR. To have an impact on consumption, it is likely to be necessary for suppliers to combine the use-of-systems price signal with a variable energy tariff that reflects the higher marginal cost of generation at times of peak demand. The effectiveness of use-of-system pricing is also dependent on the supplier passing the price signal through to consumers. This is likely to be the case at present, where peak network demand and peak generation costs tend to coincide. In a future where there is high penetration of wind generation on the grid, however, suppliers may design time of use tariffs to encourage demand to follow wind generation, which may not be consistent with the DNOs' desire to shift load away from network peaks.

4.3.3 Frequency response

Imbalances between electricity generation and demand result in changes to the frequency of electricity supply (which is nominally 50Hz in the UK). If demand exceeds supply (as a result of inaccurate forecasts or a generation disruption event for example) frequency will drop (a result of a slight slowdown of generators). The converse is also true. One way that National Grid manages this issue is by calling on generators to operate in frequency-response mode, which involves providing spare capacity by running at reduced (and continually varied) output. This mode of operation is inefficient for generators, which must therefore be compensated for providing this service.[43]

An alternative solution to this challenge is for the response to be provided on the demand (rather than the generation) side and in DSR terminology this is referred to as frequency response or dynamic demand control.[44] The most suitable loads for automated frequency response are refrigeration (including freezers), air conditioning and (non-instantaneous) water heating.

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[41] For example, allocating responsibility for ongoing maintenance of equipment, ensuring all engineers who may come across them understand what the devices are for etc.

[42] DUoS charges are typically around 12% of a HHM consumers' total electricity bill, according to: *Distribution Use of System (DUoS) charges for half-hourly metered customers*, E.ON, Central Networks, p.5.

[43] In 2011 National Grid spent £138m on frequency response. Source: balancing service summary reports: www.nationalgrid.com/uk/Electricity/Balancing/Summary/.

[44] Unlike some other forms of DSR, the main motivation for implementing frequency response is to balance supply and demand (rather than to achieve reductions in peak demands).

National Grid estimates the requirement for frequency response to be around 1.7GW (this is the primary and secondary response requirement, which is used to react to the grid frequency falling below 50 Hz, i.e. by reducing demand). National Grid estimates a smaller response requirement of around 350MW to cope with high frequency conditions, i.e. by increasing demand.[45] We can put this response requirement into context by considering the peak demand profile and its breakdown by sub-load.

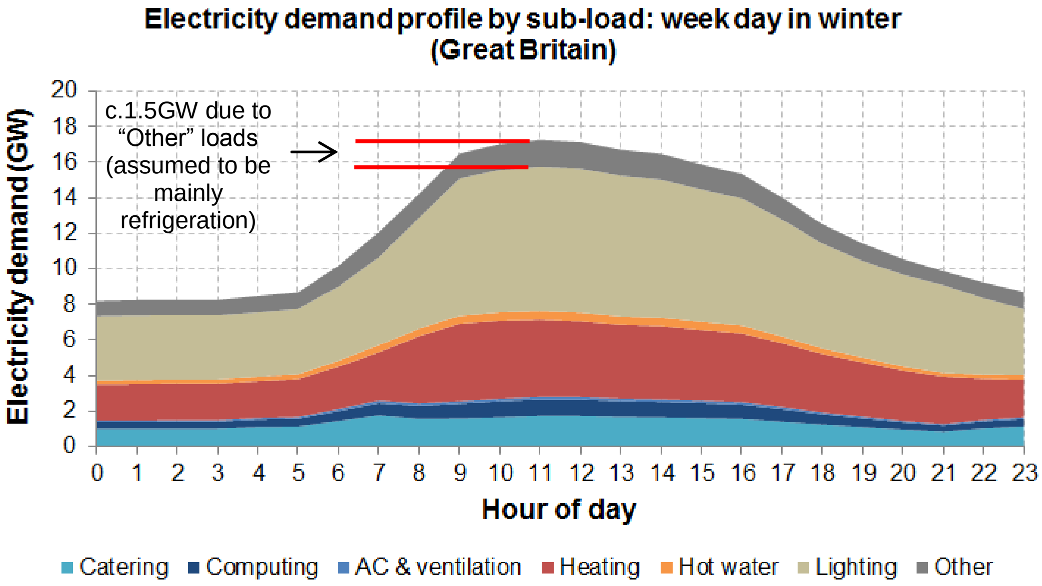

Figure 19: GB grid demand profile for non-domestic buildings (winter week day)

The overall peak in the demand profile for the sectors assessed is 17.3GW, of which 1.5GW is due to the 'Other' category (largely refrigeration). This suggests that a large part of the National Grid requirement for frequency response could be provided by commercial refrigeration loads. This is consistent with the view of one of the consultees, who believed frequency response requirements could be met by commercial refrigeration, HVAC and data-centre AC, with refrigeration providing the largest share.

Key points

- The technical potential exists for sub-loads in non-domestic buildings to provide a large part of National Grid's requirement for frequency response.
- The end uses most suitable for this form of DSR include refrigeration and HVAC systems.

4.3.4 Time of use tariffs

Static / dynamic TOU tariffs

The concept of time of use tariffs is familiar to UK consumers through, for example, Economy 7 tariffs for householders that encourage a shift of demands to off-peak periods by offering lower unit prices overnight.[46] The electricity supply contracts of many of the

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[45] *Future Balancing Services Requirements: Response*, National Grid. www.nationalgrid.com/uk/Electricity/Balancing/services/frequencyresponse.

[46] Such tariffs are best suited to dwellings in which heating and / or hot water demands are met with electricity.

organisations consulted for this study include a day-night element (i.e. different prices are charged for electricity consumed during the night), but generally not any finer resolution. Given the need to provide a clear financial incentive for organisations to change their patterns of consumption, TOU tariffs may be an important part of future DSR offers.

As an example, we have estimated the amount of flexible demand (in the sub-sectors of interest for this study) for a three hour period around the time of peak loads on the grid. As the graph below shows, the peak period is typically from around 4–7pm.

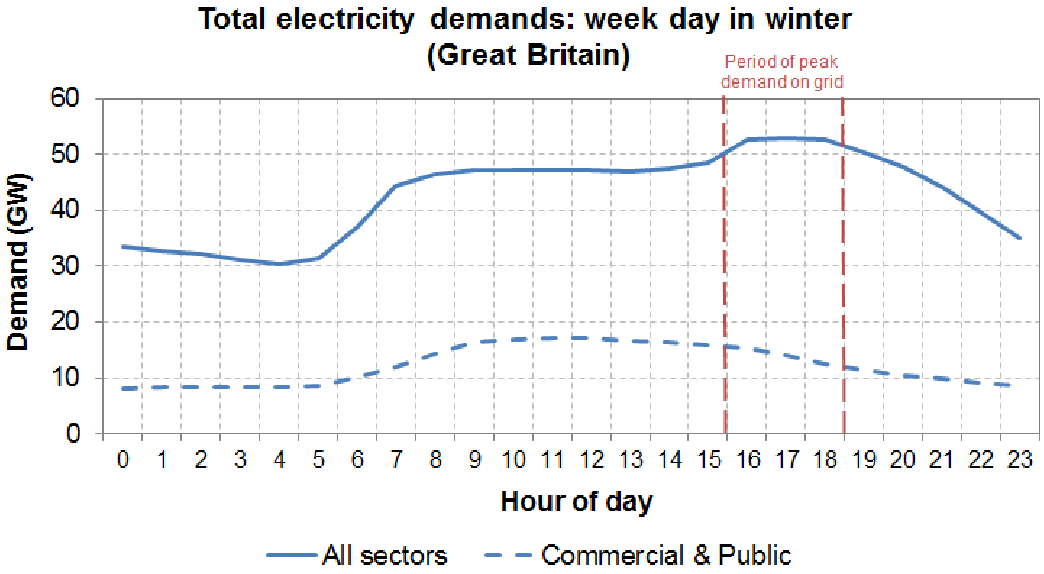

Figure 20: Demand on British national grid for a week day in winter[47]

Precise calculation of the potential for demand reduction in non-domestic buildings in this period is not feasible[48]; instead we use a range of indicative scenarios to indicate possible flexibility:

- **Low** – includes conservative assumptions on the amount of flexibility and represents a future with little attitude change towards DSR (i.e. DSR measures continued to be viewed with scepticism by most consumers in the non-domestic sector).
- **Medium** – an intermediate scenario with relatively optimistic assumptions relating to the technical potential for reducing loads in peak times in response to price signals.
- **High** – the high scenario includes upper estimates of the technical potential for DSR (in terms of load flexibility) and is consistent with a future with a high imperative for DSR (e.g. consumers may accept some reduction to service levels if the alternative is lack of security of supply).

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[47] All sectors demand data from Initial Demand Outturn figures based on National Grid operational generation metering (14/12/11). www.nationalgrid.com/uk/Electricity/Data/Demand+Data/. Commercial & Public profile from this study's modelling.

[48] The technical potential depends on various factors, including subjective decisions / personal preferences (e.g. to what extent lighting may be switched off / dimmed without unacceptable impacts, for how long may HVAC systems be turned off whilst maintaining adequate comfort levels), which cannot be quantified.

As stated in Table 5 (section 4.1 above), the main sub-loads of interest for DSR through TOU tariffs are HVAC systems, hot water and lighting. The table below sets out our assumptions regarding the proportion of these sub-loads that could be flexible (i.e. able to contribute to peak reduction without unacceptable impacts on service levels) given a sufficiently strong price signal during peak periods.

Table 6: TOU tariff demand flexibility – assumptions[49]

Scenario	Proportion of load at national level that is flexible		
	Hot water	Lighting	HVAC
Low	25%	10%	10%
Medium	50%	20%	20%
High	75%	40%	30%

We have included lighting on the assumption that some non-critical lighting could be turned off and other lighting loads reduced through dimmers (a required enabling technology, see section 7.3) at peak periods without an unacceptably high impact on building occupiers. Similarly, there is likely to be some potential to reduce heating output for a period given a sufficient price incentive. The overall load profiles resulting from these scenarios are presented graphically below.

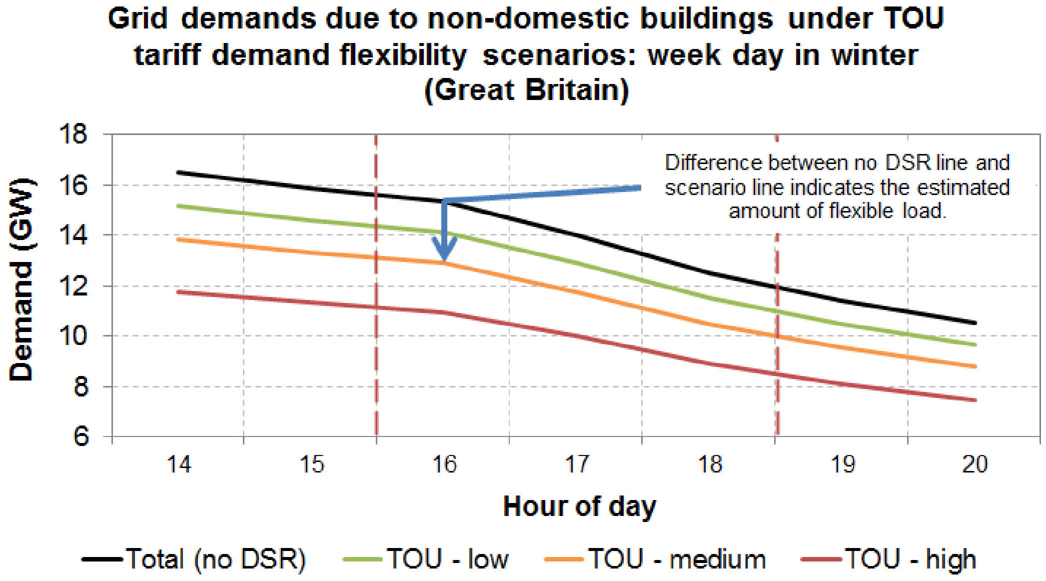

Figure 21: Estimated demand flexibility – TOU scenarios

Based on these scenarios, the estimated amount of flexible load in the peak hour (5–6pm) is from 1.1GW (low scenario) to 4GW (high scenario) (equivalent to 8–28% of demand). As mentioned above, there is a high degree of uncertainty associated with these figures, which represent estimates of the technical potential for demand reduction in non-domestic premises. Given the relatively high contribution of lighting to overall demands, these levels of reduction rely on exploiting the (potential) flexibility of this sub-load. Note that the

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[49] Flexibility assumptions represent the technical potential and are based on the view developed through conversations with a range of stakeholders in this sector (including building energy managers and DSR providers).

convergence in low, medium and high scenarios towards the end of the peak period occurs due to the lighting load (as a proportion of total load) reducing from around 6pm.

Key points

- Based on the assumption that there may be some flexibility in hot water, HVAC and lighting loads, we estimate that TOU tariffs could lead to 1.1–4GW of demand reduction during the peak hour.
- The magnitude of this technical potential remains relatively uncertain. It is clear however, that accessing the potential will require not just implementation of appropriate technologies, but also actions to overcome the various barriers that currently exist (see section 5).

Critical peak pricing and real-time pricing

Critical peak pricing (CPP) is a form of TOU tariff in which a pre-designated peak price is imposed for consumption during periods specified by the electricity supplier as a critical peak. The critical peak tariff is generally much higher than the non-peak tariff, a multiple of four or five times would be typical, but will only be applied for a limited number of days / hours per year. Consumers will typically receive day-ahead notification that the critical peak tariff will be applied on the following day. The critical peak pricing tariff will often be super-imposed on a static time of use price structure, but could also be used in combination with a flat-rate.

There is very limited experience of use of critical peak pricing in the UK. The most widespread use of a CPP tariff has been in France in the residential sector, following the introduction of the Tempo tariff by EDF in 1996. In this tariff design, the year is divided into three types of days, named after the colours of the French flag, with each day divided into peak pricing periods. The blue days are the most numerous (300 per year) and the least expensive; a higher tariff is applied on 43 days of the year designated as white and the highest tariffs are imposed on red days, which are the remaining 22 days of the year. The ratio of tariffs between the most expensive periods, i.e. peak period on red days, and least expensive, off-peak period on blue days, is around fifteen-to-one. The Tempo tariff has been highly effective at reducing consumption on peak days.

Real-time pricing (RTP) contracts offer an electricity rate that varies on an hourly basis reflecting fluctuations in the price of electricity on the wholesale market. Customers are either informed of pricing on an hour-ahead basis or they are informed a day ahead of the rate structure to be applied on the following day.

Again there is little experience of use of RTP in the UK, although it has been employed effectively by several US utilities. Commonly a two-part RTP tariff is applied. Customers are billed for *baseline* use at a standard rate and pay (or receive credits) for energy used in excess of (or below) the baseline at the hourly rate. RTP has been an effective tool for delivering demand side response among large industrial and commercial customers. To realise the benefits of an RTP structure, customers need to understand their electricity consumption patterns in substantial detail and need to be aware of their flexibility to curtail or defer discretionary usage.

Studies on the impact of price-based demand side response schemes often report the effectiveness of the tariff in terms of the *price elasticity* of electricity demand. Price elasticity is a measure of the rate at which consumption of a good (e.g. electricity) changes as its price changes by one percent. So for example, if a consumer’s electricity consumption has a price elasticity of -0.2, then a 100% increase in electricity tariff (i.e. a doubling) results in a 20% reduction in consumption. The price elasticity of electricity demand observed in a number of studies of demand side response programmes are shown in the table below.

Table 7: Impact of time of use based demand side response programmes on peak period electricity consumption[50], [51]

Type of DSR	Enabling technology	Target market	Region	Demand response impact	Comment
CPP	None	Small I&C (<200 kW)	California	Peak period electricity consumption reduced by 6% to 9%	
CPP	Smart thermostat	Small I&C (<200 kW)	California	Elasticity of substitution[1] of -0.02	A total reduction of peak period demand of 14% was observed; largely attributed to the enabling technology.
RTP	None	Large Commercial	Georgia	Elasticity of substitution from 0 to -0.53 (ave. -0.21)	Total peak period reduction of 17%.
RTP	None	Large Industrial	Georgia	Elasticity of substitution from 0 to -0.31 (ave. -0.18)	Total peak period reduction of 17%.
RTP	None	Pulp & Paper manufacturing	England & Wales, East US	Elasticity of substitution of -0.15	
RTP	Self-generation	Pulp & Paper manufacturing	England & Wales, East US	Elasticity of substitution of -0.3	
RTP	None	Large commercial (>2MW)	New York	0	
RTP	None	Large government (>2MW)	New York	-0.3	
RTP	None	Large Industry (>2MW)	New York	-0.11	

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[50] *Benefits of Demand Response in Electricity Markets and Recommendations for achieving them*, US Department of Energy, (February 2006).
[51] *Primer on Demand-side Management*, The World Bank, (February 2005).

RTP	None	Med./Large I&C (>100kW)	UK (Midlands Electric)	-0.01 to -0.27	Population of about 500 customers, most with peak demand (>1MW).
RTP	None	Large I&C (>1MW)	North & South Carolina (Duke Power)	-0.01 to -0.38	Population of about 50 customers, some with long experience of RTP.

[1] Elasticity of substitution measures the rate at which customers substitute peak electricity consumption for off-peak consumption in response to a change in the ratio of peak to off-peak prices.

The results tabulated above indicate a wide range in responsiveness of commercial and industrial customers to price-based demand side programmes. At the upper bound, an elasticity of -0.53 indicates a high degree of response (this is an elasticity of substitution, so means that the customers increase the ratio of off-peak to peak usage by around 50% in response to a doubling of the peak to off-peak price multiple). Many of the studies reported elasticities in the range of -0.1 to -0.3 (a 10–30% reduction in peak period demand for a doubling of the peak period price). The response tends to be higher in the larger customers, potentially because they have better knowledge of their consumption and a greater incentive to respond to energy price signals.

A number of the studies have assessed the impact of enabling technologies, such as smart thermostats or load control switches that automate the response to price signals. This requires smart devices that are able to receive signals regarding the pricing structure, for example via radio signals or via communication with a smart metering system. These studies have found that enabling technologies have significantly increased the response to CPP and RTP tariffs. Many of these programmes (mainly in the US) have used smart thermostats to control air conditioning loads in commercial buildings. Automated response to price signals has also been shown to be effective in trials in refrigerated warehouses, where refrigeration loads (as well as office HVAC loads) are controlled according to a pre-set hierarchy, triggered by signals from the utility. Load reductions of 25% to 35% were recorded without loss of productivity.[52]

Key points

- There is currently very limited experience of critical peak pricing and real time pricing in the UK.
- Trials from elsewhere (mainly in the US) suggest that a wide range of responses to price signals may be expected amongst non-domestic consumers.
- Smart technologies (that automate the response to price signals) can significantly increase the response to CPP / RTP tariffs.

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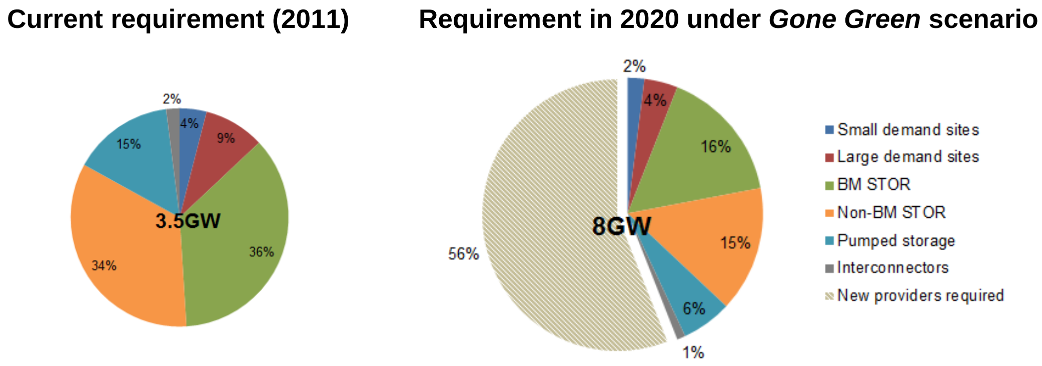
[52] *Demand Response Opportunities in Industrial Refrigerated Warehouses in California*, Berkeley National Laboratory, (July 2011).

4.3.5 Short term operating reserve

Introduction

In its 2009 consultation on operating transmission networks, National Grid stated that it "*procures a wide range of Balancing Services from various sources. These can be generation or demand sites, BM (Balancing Mechanism) or Non–BM providers, as long as technical and commercial service requirements are met.*"[53] The figure below shows the forecast change in STOR requirement from what is currently required to levels needed in 2020 (this forecast is the requirement for STOR under the National Grid's *Gone Green* scenario. This scenario presents a view of the electricity system in 2020 under the assumption that Government's current climate change targets have been met).[54]


Current requirement (2011)

Requirement in 2020 under *Gone Green* scenario

Figure 22: National Grid STOR requirements[55]

As this figure illustrates, a significant increase in the need for balancing services to provide reserve is anticipated over the coming years. From a DSR perspective we distinguish between two main types of STOR: back-up generation and demand reduction (both of which are seen by the grid as a reduction in demands).

Back-up generation

It is not uncommon for commercial premises to have some form of back-up generation on site (typically diesel generators or, on very large sites, open cycle gas turbines) to supply power for critical loads in the event of an interruption to grid supplies. For example, hospitals, police headquarters, data centres, banks, large commercial offices and utility companies (including water companies) will usually have some form of emergency power generation.[56] In many cases the on-site generators are only used if main power supplies fail (as opposed to CHP plants for example, which tend to have high annual run hours).

According to statistics published by DECC, the installed generation capacity of major power producers[57] in Britain in 2010 was 80.7GW.[58] DECC also records the capacity of

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[53] *Operating the Electricity Transmission Networks in 2020, Initial Consultation*, p.58, National Grid (June 2009).

[54] *'Gone Green' a Scenario for 2020*, National Grid Briefing, National Grid, (December 2008). www.nationalgrid.com/NR/rdonlyres/554D4B87-75E2-4AC7-B222-6B40836249B5/32656/ScenarioNarrative.pdf

[55] Figure reproduced from *Operating the Electricity Transmission Networks in 2020, Initial Consultation*, Figure 21, p.58, National Grid (June 2009).

[56] Back-up generation is a strict requirement for a property to be considered suitable for certain types of use (e.g. as a data centre where a high level of redundancy is needed).

[57] Major power producers include all companies whose prime purpose is the generation of electricity.

[58] Total transmission entry capacity basis. Source: DUKES, Table 5.8.

"Other generators", i.e. *companies who produce electricity as part of their manufacturing or other commercial activities, but whose main business is not electricity generation*.[59] National statistics suggest that just over 3GW of generation capacity exists within commercial companies (as of the end of 2010).[60]

However, the total installed capacity of back-up generation (i.e. emergency power supplies that do not regularly supply power to the grid) is estimated to be significantly higher. Although no firm figures are available, the total capacity of diesel generation installed in the UK has been estimated at around 20GW.[61] This is of a similar order of magnitude to another estimation provided through this study's consultation, which was that up to 30GW of such capacity may exist. We should however be mindful of the fact that much of this back-up plant is rarely used and therefore not necessarily (currently) a reliable source of power. Indeed, further feedback from the consultation suggested that a "very high proportion" of the UK's back-up generation is unreliable. Clearly this reliability issue is a barrier to back-up generation participating in DSR. However, it is not insurmountable and in fact reliability considerations provide an incentive for organisations to ensure generators are well maintained.[62]

Under normal circumstances using back-up capacity is not an economically competitive form of generation; it is generally only called upon in emergencies when price rises can cover the costs of generation. The average contracted utilisation payment for STOR paid by National Grid in 2011 was around £225/MWh.[63] (this is in addition to an availability payment of around £22,000 per MW of firm reserve). Compared with a typical price seen by commercial consumers of around £100/MWh (10p/kWh), we can see that this is an expensive form of generation.

With an increasing level of intermittent generation on the grid (e.g. solar PV, wind power), the need for flexible generation is expected to increase, and given the right price signals, a greater proportion of the existing back-up generation could provide useful services to the grid. Third party aggregators have a role to play in exploiting this potential by managing generation operations and integration with the system operator. This includes aggregating multiple generating units that in isolation would not meet National Grid's technical criteria for participating in STOR.

Demand reduction

An alternative means of reducing loads on the grid (other than running back-up generators) is to curtail demands during peak periods. National Grid defines STOR availability windows, which are periods in which it may call upon STOR to provide the flexibility to deal with demands exceeding available supply.[64] The number and timing of

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www.decc.gov.uk/en/content/cms/statistics/energy_stats/source/electricity/electricity.aspx.

[59] DUKES 2011, Chapter 5, paragraph 5.66, p.130.

[60] DUKES, Table 5.9.

[61] Estimation by EA Technology, as quoted in *Demanding Times for Energy in the UK*, RWE npower, p.24.

[62] Diesel generators should be run regularly (at least monthly, preferably weekly) to check reliability. Problems arising as a result of infrequent operation include flat batteries, contaminated fuel, and failures of the cooling system.

[63] Source: Monthly Balancing Services Summary reports: www.nationalgrid.com/uk/Electricity/Balancing/Summary/.

[64] There are two forms of STOR arrangement: *Committed* and *Flexible*. Committed service providers offer availability in all of the STOR windows (and National Grid commits to buy the services offered). Flexible providers do not have to offer services in all availability windows. For further details see:

these windows varies by season, but they are typically around 7am–1pm and 4pm–9pm, as shown in the figure below.

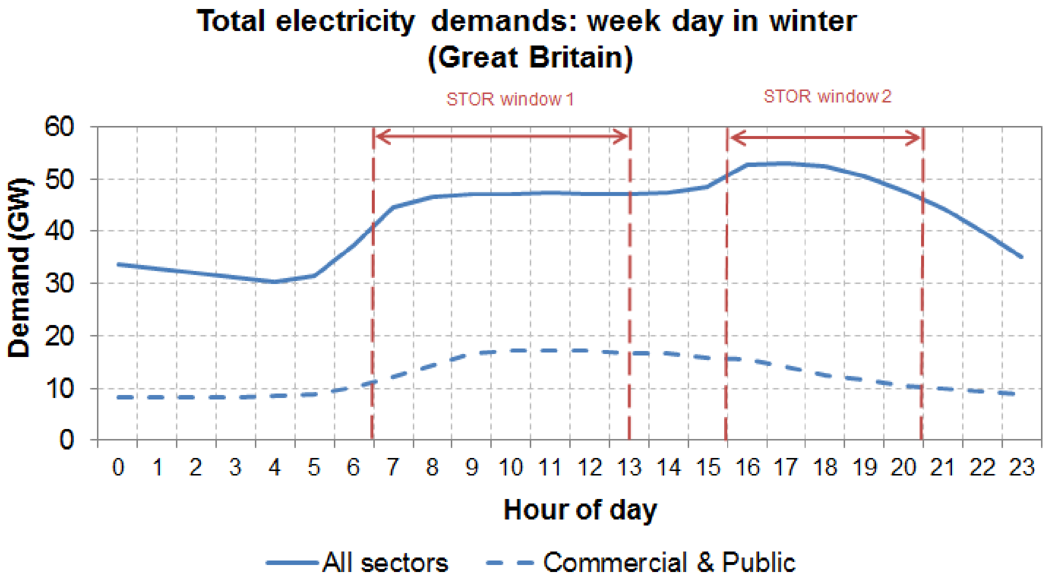

Figure 23: Typical STOR availability windows for a winter week day

National Grid requires STOR participants to offer at least 3MW of generation or steady demand reduction on request.[65] Many organisations in the commercial sector do not have this level of flexible load and therefore require the services of an aggregator to participate in the STOR market.

Given the requirement to reduce demands for two hours, the most likely candidate loads for reduction during STOR windows are from water heaters, freezers and lighting. Air-conditioning and air handling loads could also be candidates for STOR. Although it may be difficult to provide the maximum duration of response at the individual building level without compromising occupant comfort, aggregators could play a role here by managing loads across numerous sites. In order to indicate the technical potential of DSR from STOR, we assume that the flexible portion of these sub-loads is:

- Hot water – 50%
- Freezers – 50%
- Lighting – 20%
- HVAC – 20%

As mentioned above, quantifying the potential for reducing demands via DSR with a high degree of certainty is not feasible. Nonetheless, investigating the potential flexibility of loads based on a set of reasonably conservative assumptions gives an idea of the approximate size of the potential.

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www.nationalgrid.com/uk/Electricity/Balancing/services/balanceserv/reserve_serv/stor/.

[65] Participants are permitted to provide the service by aggregation across multiple sites.

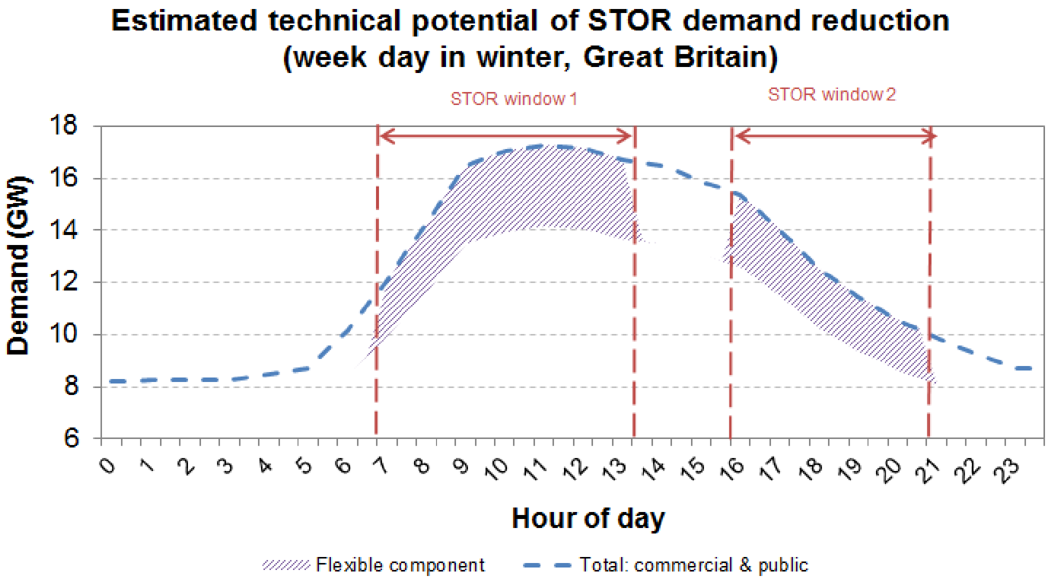

Figure 24: Indication of amount of flexible load in STOR availability windows assuming some flexibility in hot water, freezers and lighting

The shaded area of Figure 24 shows the amount of flexible load, calculated from the assumptions set out above and the estimated contribution of each sub-load to peak demands (see for example Figure 18 section 3.4). In the case of loads such as immersion heaters and freezers, we would expect load reduction during the STOR windows to be accompanied by an increase in demands immediately before / after the period (on the basis that total energy consumed does not change with DSR).[66] The same is not true for lighting in that consumers are unlikely to demand additional lighting before or after a period in which some lights are dimmed or switched off.

Based on the relatively conservative assumptions of the flexibility of hot water, lighting, HVAC and freezer loads set out above; we find that there could be potential to reduce peak loads in the non-domestic sector by nearly 20% (c. 3GW) through STOR demand reduction.

Key points

- Short term operating reserve in non-domestic buildings offers the potential (both through back-up generation and demand reduction) to significantly contribute to the National Grid's requirement for STOR (which could more than double by 2020).
- Under a scenario with assumed flexibility in hot water, HVAC, freezer and lighting loads, we estimate the technical potential for demand reduction during STOR windows to be up to 3GW.

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[66] We have not attempted to show a modified profile shape taking this into account.

4.3.6 Triad avoidance

Triad avoidance is a common technique for reducing electricity bills in the non-domestic sector.[67] Many large energy consumers receive Triad warnings, i.e. alerts of when a Triad is expected, which act as a signal to reduce electricity consumption for a period of around two hours. The Triad warning system currently helps to limit the winter peaks in demand on the grid, yet further reductions could be achieved through greater participation of commercial consumers.

Given that demand reduction must be maintained for a period of around two hours, the most likely suitable sub-loads for this form of DSR include hot water, refrigeration (in particular freezers) and lighting (similar to STOR). Compared to STOR arrangements, under which consumers must be available to provide demand reduction at least three times a week, Triad periods occur relatively infrequently. By definition, there are three Triads per year (each separated by at least ten days), although large energy consumers may receive around 10–20 Triad warnings each winter. Since Triads occur infrequently, there may be greater potential to reduce non-essential loads during these periods (compared to potential demand reductions under STOR for example), however quantifying this potential with any degree of accuracy in not feasible based on available data.

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[67] For example, six out of nine industrial consumers interviewed as part of the GB Electricity Demand study reported that undertake Triad management. *GB Electricity Demand – realising the resource, Interim report paper 3*, Sustainability First, Table 5, p.22 (2012).

5 Barriers to uptake of demand side response measures

5.1 Consultation

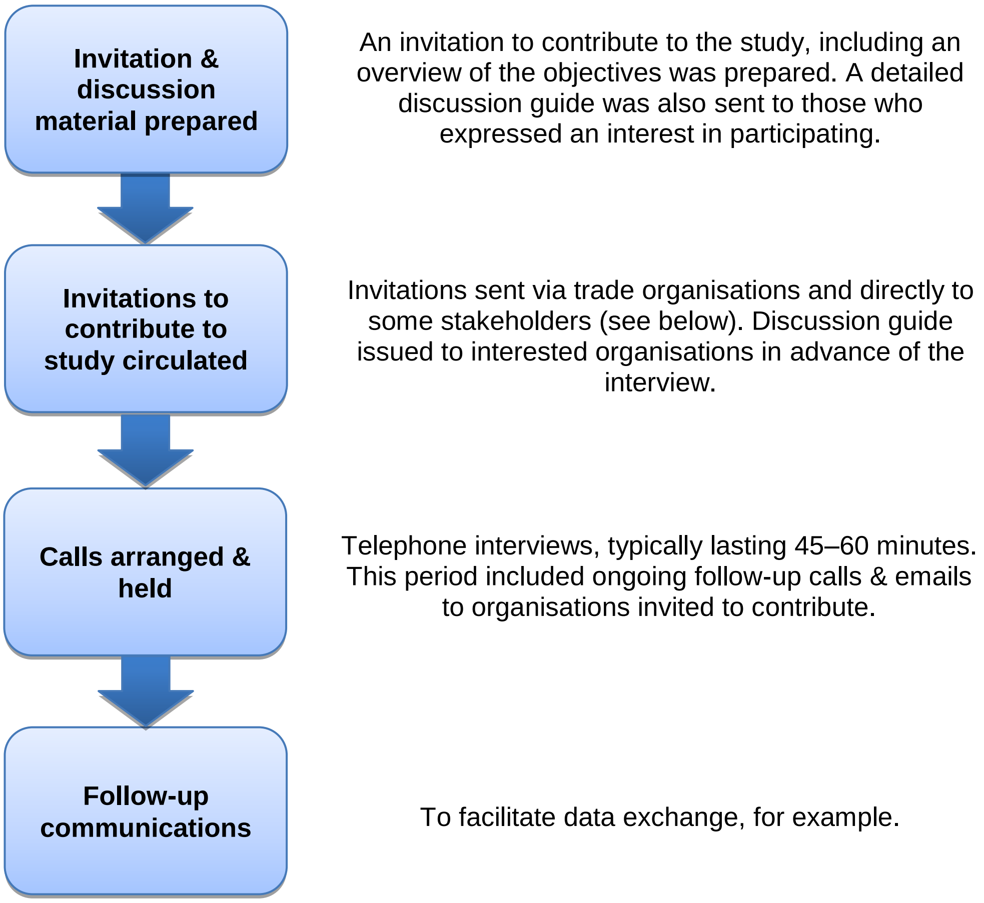
The consultation with industry stakeholders formed a central part of this study's evidence-gathering exercise. The consultation served two main purposes, namely to:

1) Supplement existing data sets of electricity demand profiles (held by the project team) with further real-world data from a range of non-domestic building types.
2) Understand the existing levels of engagement with DSR, the potential for greater uptake, the barriers restricting expansion of DSR and potential enabling mechanisms.

This section provides an overview of the consultation process, with key results in terms of barriers and enabling mechanisms summarised in sections 5.2 and 5.3.

5.1.1 Process

The consultation process followed is summarised in the diagram below.



An invitation to contribute to the study, including an overview of the objectives was prepared. A detailed discussion guide was also sent to those who expressed an interest in participating.

Invitations sent via trade organisations and directly to some stakeholders (see below). Discussion guide issued to interested organisations in advance of the interview.

Telephone interviews, typically lasting 45–60 minutes. This period included ongoing follow-up calls & emails to organisations invited to contribute.

To facilitate data exchange, for example.

Through the consultation we aimed to speak to a wide range of organisations in the non-domestic sector, including companies with a specific interest in demand side response. Invitations were sent to contacts via various routes:

- By drawing on the team's existing contact databases and direct enquiries to specific organisations.
- Emails / website posts / newsletter items via trade associations.
- Stakeholders recommended by interviewees during the consultation.

The following trade associations assisted with circulating the invitation to participate in the consultation to relevant members:

- The Facilities Management Association.
- British Institute of Facilities Management.
- British Council of Offices.
- British Council of Shopping Centres.
- British Property Federation.
- UK Green Building Council.
- Major Energy Users' Council.

Via these routes, hundreds of organisations were invited to participate in the consultation, which led to 16 telephone interviews taking place during March and April 2012.

5.1.2 Sub-sector coverage

By conducting telephone interviews with a range of organisations, from facilities management companies, to demand aggregators, to major retailers, we achieved coverage across all of the main sub-sectors of interest, as shown below.

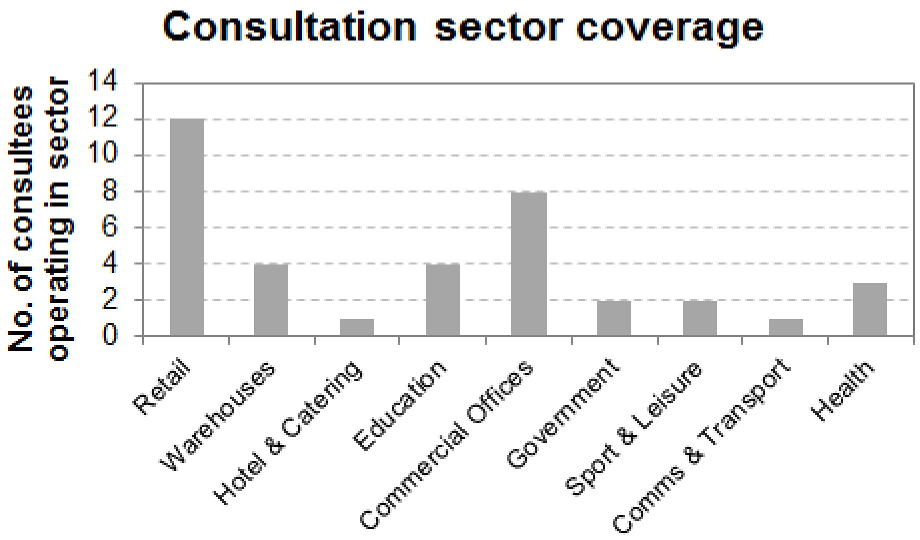


Figure 25: Summary of sub-sector coverage achieved through the consultation[68]

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[68] Note that the sum of number of consultees operating in each sector across all sub-sectors exceeds the total number of interviews held since some organisations have activities spanning several areas.

5.2 Barriers

5.2.1 Overview

As mentioned in section 2.3.4 above, the uptake of DSR measures in the commercial sector has been limited to date. One of the principal aims of the consultation was to explore perceptions of DSR and gather views from experts in the sector on the key barriers acting to restrict further engagement with DSR solutions. In this section we summarise the feedback received, and consider potential enabling mechanisms in section 5.3.

During the interviews, consultees were asked to describe the barriers preventing uptake of DSR. Given the openness of the question, a wide range of responses was received. In the diagram below we have categorised the barriers according to type and plotted the number of times barriers within each category were mentioned across all interviews.

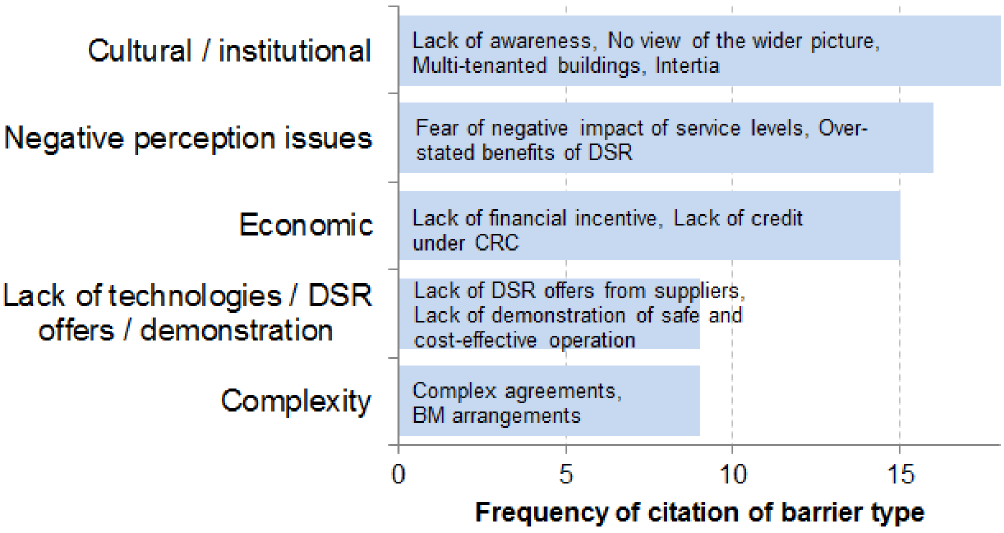

Figure 26: Overview of barriers cited by consultees during the telephone interviews

A barrier repeatedly mentioned in the interviews was the fact that since energy is not the core business of most organisations in the commercial sector, initiatives such as DSR are a low priority. Low and / or uncertain financial incentives were also often cited as important barriers. The summary results presented above suggest that a range of barriers will have to be addressed for further adoption of DSR measures in non-domestic buildings. We describe some of the key barriers in more detail in the following sections, and conclude by setting out some potential enabling mechanisms that could help overcome these hurdles.

> *"We have a lot to do to improve energy efficiency; DSR is further down the curve."*
>
> ***Head of Sustainability***, Property Company

5.2.2 Perception and awareness

Although the consultation showed reasonably high levels of awareness of DSR amongst the interviewees, we note that this is not necessarily representative of the non-domestic sector as a whole.[69] Indeed, one technology provider suggested that in their experience awareness and understanding of DSR in this sector is low and that this is a significant barrier to uptake.[70] Even if awareness of DSR is raised, a number of stakeholders mentioned that such activities are simply not a priority for most organisations (as energy management is not usually a core business activity).[71]

> *"DSR uptake in this sector is exceptionally low...TOU tariffs as rare as hens' teeth."*
>
> ***Energy Markets Director***, Energy Procurement Company

> *"Trials are needed but no one wants to be a guinea pig."*
>
> ***Energy Manager***, Local Authority

One of the key barriers, mentioned by nearly all interviewees, is the concern that DSR measures could lead to reduced levels of service or comfort. There appeared to be a consensus that there is no scope for interrupting core business functions in the sub-sectors in question, which suggests that the potential for DSR will only be delivered if zero reduction in service levels can be guaranteed.[72]

5.2.3 Economic barriers

According to one interviewee, the main reasons organisations implement DSR solutions are:

1) Additional revenue.
2) Reliability benefits for standby generation.
3) Interest in improving efficiency of electricity system and reducing emissions.

---

[69] Given the way that consultees were recruited (i.e. via an open invitation), it is unsurprising that those who spared the time to be interviewed had at least some knowledge of DSR.

[70] This was supported by feedback from another consultee, who believed that about half of energy managers in the commercial sector may be aware of DSR, but that of these, most would not understand the topic in detail (and would not know where / how to use DSR).

[71] For example, one consultee pointed out that implementing frequency response to provide a grid-balancing service is solving a problem that organisations do not have. Sufficient compensation is therefore required to overcome this barrier.

[72] There was a high level of scepticism amongst many of those interviewed that DSR measures can be implemented with no loss of service. It was also suggested that building energy managers and facilities managers tend to be highly risk averse, particularly regarding business critical equipment. Further trials are required to demonstrate risk-free operation of DSR measures (see section 5.3).

Organisations require a financial incentive to change their patterns of electricity consumption and / or provide services to the grid. However, many organisations consulted suggested that the lack of an economic case for implementing DSR measures is a significant barrier. Issues include uncertain benefits and the relative smallness of potential savings / revenue. For some organisations energy spend is a relatively low overhead and small electricity bill savings are therefore unlikely to warrant the time required to engage with DSR. Even for organisations in which energy bills represent a significant expenditure, the scale of the potential revenue from DSR (at current electricity prices) is often insufficient to justify action. Having said this, some of the feedback received indicated that organisations in certain sub-sectors (e.g. supermarkets, data centres) are becoming increasingly concerned about the rising cost of energy and exploring mitigation actions. A view expressed by some of the organisations that have engaged in DSR is that evaluating electricity costs or potential savings from DSR against turnover or total overheads is not a useful comparison; more appropriate is to compare the savings / income to net profit. The economic case for acting may then appear significantly more enticing.

> *"It all comes down to economics and levels of service. Tenants are unlikely to be interested at current electricity prices and will not accept any disruption to services."*
>
> ***Portfolio Energy Manager***, Property Company

To put the economic incentive into context, consider the potential annual revenues available from provision of 3MW (the minimum requirement) of STOR on a committed contract:

- Availability revenue: £66k/yr.
- Utilisation revenue: £35k to £55k/yr (based on 50 to 80 1hr utilisation periods per year).

This total potential revenue is based on 100% availability in STOR windows and may be divided between a pool of organisations aggregated together in order to deliver 3MW of firm reserve.

5.2.4 Complexity and market arrangements

Depending on the type of DSR solution, contractual agreements can be relatively complex and therefore represent a barrier. In particular, providing reserve services to the grid through short term operating reserve (STOR) requires the provider to understand often complex agreements[73] and technical standards such as G59 permits.[74] Other specific barriers relating to STOR and the balancing market include:

- Contract length in the balancing market dictates that providers must predict the load available a month in advance. Such predictions are difficult when the flexibility of load on plant such as AHUs or chillers is highly weather dependent (the STOR year is divided into six seasons – market participants must know the

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[73] STOR contracts are designed by National Grid and according to one source, they are difficult to understand and do not clearly demonstrate the benefits. Non energy intensive users are unlikely to want / be able to interpret a 160 page contract (hence there is currently a role for aggregators and DSR providers).

[74] This is an engineering recommendation that allows generators to run in parallel to the electricity distribution networks (from the Energy Networks Association).

reserve a site can deliver each season, workday and weekend, morning and afternoon).

- The short-term (1 hour ahead) balancing market can only be accessed by parties to the grid code, which requires at least 50 MW of connected load. In the US, where the demand side response market is much more developed, participation in the market is subject to much lower thresholds.
- STOR arrangements are quite rigid, for example STOR includes service windows, typically 7am–1:30pm and 4pm–9pm on weekdays. This can present a difficulty for organisations to engage in committed contracts (which require reserve to be made available in all the National Grid windows). Aggregators can overcome this difficulty to a certain extent, however, aggregators have also remarked on the challenges of aggregating participants together to be able to provide response across these windows (e.g. be able to provide the same level of response at 9pm to 10pm as is available in the middle of the day).

5.2.5 Other barriers

Other issues that hamper the further development of the market for DSR include:

- **Lack of certification of STOR and frequency response under the CRC Energy Efficiency Scheme** – since many of the target organisations for these measures fall under the CRC, the fact that CO_2 reductions delivered by STOR and frequency response are not credited is a barrier to their uptake. Any carbon saving from these measures is delivered at the level of the electricity system as a whole rather than at the individual site.

> *The lack of any kind of carbon accreditation for many kinds of DSR is a significant barrier.*
>
> ***Market Analyst,***
> DSR solutions provider

- **Multi-tenanted buildings** – arrangements for electricity supply can be more complex in multi-tenanted buildings and achieving adequate engagement with tenants (regarding energy issues) is significantly more challenging.
- **Technology** – some organisations currently deploying DSR measures believe that a lack of technology to exploit the full DSR potential is a critical barrier.
- **Lack of view of the broader picture** – according to some stakeholders consulted, most organisations are not aware of the wider picture and do not see compelling reasons for implementing DSR measures.
- **Lack of awareness of electricity consumption** – traditionally short-time step electricity metering and metering of sub-loads has not been common for large parts of the sector. This has led to a lack of knowledge within organisations and among energy managers of which loads could offer flexibility.
- **Organisational accounting arrangements** – some organisations do not include energy costs on their profit and loss statements (e.g. some businesses with multiple premises purchase energy centrally and individual sites do not pay their own energy bills). Similarly, in some circumstances councils pay the energy bills for public buildings (e.g. hospitals, schools), and the building occupiers (energy consumers) are isolated from these costs. In these situations there is little or no financial incentive for consumers to modify their behaviour to save energy or reduce consumption at peak times.

- **Condition of plant** – a number of consultees remarked that plant is often not maintained to a high standard and therefore may not provide a reliable response. This is the case for both onsite generation plant and equipment that might be used to provide demand reduction. For this reason, refrigeration is considered a good load for demand response as the equipment tends to be kept in good condition (as maintaining refrigeration is business critical). Air handling units and chiller plant on the other hand is often poorly maintained.

5.3 Enabling mechanisms

Having assessed the potential for DSR (section 4), and explored the existing barriers to uptake (section 5.2), we now consider the measures that may be required to unlock the potential. The enabling mechanisms summarised in Table 8 below are based on feedback collated through the consultation.

Table 8: DSR enabling mechanisms

	Enabler	Barriers addressed
Confidence-building & education	Guarantees of no negative impact on services as a result of implementing DSR.	- Perceived negative impact of DSR. - Concern that DSR measures could lead to reduced levels of service or comfort. - Low awareness of DSR. - Lack of prioritisation of DSR activities.
	A mechanism by which another party would be responsible for consequential damages arising from any negative impacts resulting from DSR.	
	Certification of DSR equipment to demonstrate that it meets set criteria.	
	Trials in different building types to demonstrate: 1) No negative impacts on levels of service. 2) Economic benefit (ideally < 2 year payback).	
	Trials and publication of successful case studies to demonstrate safety and cost-effectiveness of DSR solutions (including automated devices).	
	Education (of energy managers in particular) to provide greater knowledge of flexible loads and awareness of DSR.	
	Information targeted at decision-makers at relatively high levels[75] within organisations, promoting the benefits of engaging with DSR for the organisation and the wider benefits (economic, environmental, security of supply etc.).	
	Collaboration (e.g. between major retailers) whereby companies agree to work together to reduce demands. The CSR / reputational benefits could be appealing.	
	Improved energy metering has been a significant factor in enabling many organisations to improve energy efficiency. Better metering will also help to enable demand side response by improving awareness of the loads that could be available for DSR and the extent of flexibility they offer.	
Economic incentives	Consider how environmental benefits of DSR delivered at the wider system level could be credited to participating organisations, e.g. under the CRC.	- Lack of an economic case for implementing DSR measures.
	Mechanism(s) to ensure a share of the revenues from DSR goes towards creating a budget for energy efficiency could provide incentive for facilities managers to engage.	
Reduced complexity	Tailor DSR offers to the target audience – i.e. far more streamlined and simple.	- Overly complex DSR agreements.
	Engaging with DSR would be simpler if tariffs were the same in all buildings, such that DSR contracts could be tendered for across a suite of buildings or the portfolio as a whole.	
	Improve market access by relaxing the constraints on becoming a party to the grid code (enabling demand side participants to operate in the 1 hour-ahead balancing market).	

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[75] The decision-makers include asset managers (in landlord organisations) and senior management of tenant organisations. Energy managers generally have little incentive to recommend DSR to commercial decision-makers, which suggests that DSR must be promoted at a higher level.

An alternative source of suggested DSR enabling mechanisms comes from an ongoing study into the potential for DSR in Great Britain.[76] The third interim report from this study investigates DSR potential in the industrial sector and although industrial consumers fall outside of the scope of the current work, it is instructive to consider the enabling mechanisms identified. These were:[77]

- **Increased financial incentive / adequate compensation** – industrial consumers who provide DSR by interrupting production require adequate compensation for potential lost revenue.
- **Technical upgrades** – installation of new technology can facilitate more rapid response or greater automation. Industrial organisations are prepared to invest given sufficient returns.
- **Greater flexibility in DSR schemes' requirements** – e.g. reduced periods between committing to provide DSR and delivering demand reductions, and the opportunity to opt in and out of DSR at short notice.
- **Greater compatibility and coordination between DSR schemes** – e.g. to ensure that flexibility offered via STOR that is not used may still provide a useful service via an alternative mechanism.
- **Increased price information and visibility** – a lack of transparency of potential DSR revenues leads to difficulties for organisations evaluating the economic case for participating in DSR and is an obstacle to further DSR uptake.

Although the mechanisms by which DSR may be offered differ by sector (e.g. large industrial energy consumers might change working patterns in response to price signals whereas commercial organisations are unlikely to consider such measures), we can see that there are parallels between enablers identified for DSR in the industrial sector and DSR in commercial / public sector organisations.

The results of this study's consultation suggest that a suite of enabling mechanisms is likely to be required to facilitate increased uptake of DSR; financial incentives alone will not be sufficient to stimulate the market. All energy users consulted expressed the concern of DSR potentially leading to negative impacts on level of service, which highlights the need for further trials and appropriate guarantees with DSR offers. Given (i) sufficient confidence that business operations will not be disrupted and (ii) an adequate financial incentive; organisations may be more receptive to DSR offers provided that they are suitably tailored and not overly complex. There is a risk that DSR measures could be interpreted by consumers as an opportunity for suppliers to increase profits and some may be put off by a lack of knowledge and fear of (seemingly) complex arrangements. One suggestion arising from the consultation was to promote DSR solutions as (or alongside) energy efficiency measures, since there is currently much interest in this field.

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[76] *GB Electricity Demand Project*, Sustainability First, for a multi-partner consortium. See http://www.sustainabilityfirst.org.uk/gbelec.html.

[77] Source: *What Demand Side Services Could Customers Offer in 2010? Industry Electricity Demand*, Sustainability First, p.24–25, (March 2012). The authors conducted interviews with nine industrial companies that exhibited a "*wide variety of levels of participation in DSR schemes"*, p.21.

6 Conclusions

Electricity demand profiles and contribution to peak loads

- Through a process of analysing and aggregating sub-sector demand profiles, we estimate that non-domestic buildings (excluding industry) contribute approximately **15GW** to peak demands on Great Britain's national grid.
- The peak demand on the national grid typically occurs at around 5pm on a winter weekday and **demands from non-domestic buildings represent about 30% of the total** across all sectors.
- The aggregate demand profile for non-domestic buildings is relatively flat during the working day, with peak demands occurring at around 10am, followed by a gradual decline of around 10% by 4pm.
- **The retail sector** is the single largest contributor to peak loads across non-domestic buildings (excluding industry), accounting for around a quarter of peak demands. The next most significant sub-sectors are **education** (18%) and **commercial offices** (11%). Each of the other seven sub-sectors contributes 5–10% to peak demands.
- This suggests that the retail, education and commercial office sectors should be prioritised for DSR measures. However, **further engagement across all building types** will be required to fully exploit the DSR potential.
- At the national level **lighting** and **heating** are the two sub-loads that contribute most to peak demands. Both annual and peak electricity demands due to lighting may be reduced over the coming years through the installation of low energy lighting with advanced controls.[78]
- Even with energy efficiency improvements, lighting is likely to remain a major source of electricity consumption in non-domestic buildings. The majority of consultees currently see minimal potential for reducing peak lighting loads through DSR measures (due to the perceived impact on operations). However, lighting has been included in DSR trials in areas where such programmes are more advanced (e.g. California), which suggests that reductions are possible whilst still delivering adequate service levels (e.g. via intelligent integrated lighting controls). This is an area that that warrants further research.

Potential for demand side response to reduce peak demands

By considering the characteristics of various DSR measures and the distinct sub-loads we have estimated the technical potential for DSR in Great Britain. The key conclusions are as follows:

- The total technical potential for peak demand reduction via DSR measures in non-domestic buildings is estimated to be from around 1–4.5GW (or 0.6–2GW if no flexibility can be provided from lighting). The three sub-sectors that may contribute most to delivering this potential are retail, education and commercial offices.
- A large part of the National Grid requirement for frequency response could be provided by commercial refrigeration loads.

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[78] A number of the organisations contacted as part of this study's consultation mentioned the attractive payback periods offered by energy efficient lighting and were in the process of upgrading their buildings' lighting.

- Time of use tariffs are currently rare in the non-domestic sector, but more granular pricing could provide strong signals to reduce demands during peak periods. Through developing a range of indicative TOU strategies (including lighting, HVAC and hot water loads), we estimate that there could be between 1–4GW of peak demand reduction.
- Short term operating reserve (STOR) could be provided either by employing existing generation assets or through load reduction. Although no official statistics exist, estimates of the total installed capacity of back-up (mainly diesel) generation suggest that there could be around 20GW or more of such capacity installed in the UK. However, there is considerable uncertainty regarding the amount of well-maintained, reliable back-up generation that could provide useful STOR services. Nevertheless, removal of some of the barriers (see below) could unlock this significant resource and contribute towards National Grid's increasing need for STOR.[79]
- On the demand reduction side, one scenario including flexibility in lighting, hot water and refrigeration loads estimates around 3GW (c.20%) of demand flexibility at the national level.
- Increased deployment of DSR measures offers a number of wider benefits to the electricity system, including increased efficiency of asset utilisation, supporting greater penetration of renewables on the grid, releasing headroom on distribution networks to facilitate further uptake of distributed generation on congested local networks, reduction of the required generator margin and costs of calling on traditional reserve (including the associated environmental benefits).[80]

Current levels of DSR uptake in non-domestic buildings

- Although there was a reasonable level of awareness of DSR amongst the organisations consulted[81], uptake of DSR measures in non-domestic buildings (excluding the industrial sector) remains very low.[82]
- The main reasons for the low levels of engagement with DSR include[83]:
    - Perception of low (and / or uncertain) financial incentives.
    - Lack of simple DSR offers appropriate to the target audience (i.e. organisations for whom energy is not a core part of business operations).
    - Concerns over detrimental impact on service levels.
- Consumers in this sector are unlikely to accept any impact on service levels to accommodate DSR measures; nor is there scope to reduce peak demands by changing working hours. This is in contrast to energy intensive industry for example, where energy costs are often a factor in setting working practices.
- UK consumers have to date enjoyed relatively high levels of security of electricity supply, which partly explains the low levels of DSR activity. For example,

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[79] National Grid's STOR (positive reserve) requirements are forecast to rise from 4.5GW in 2010/11 to 7.5GW by the middle of the next decade (*Gone Green* scenario). *Future Balancing Services Requirements: Reserve*, National Grid, p.2.

[80] Despite the fact that there are difficulties in quantifying many of these wider benefits, they should not be ignored when considering the potential value of DSR.

[81] We note however that the pool of interviewees does not represent an unbiased sample.

[82] One consulteee from an organisation with clients across this sector described the current uptake of DSR in non-domestic buildings as "exceptionally low".

[83] We discuss barriers to DSR in more detail below and in section 5.

participation in DSR programmes is far higher in California, where the energy crisis of 2000/01 provided a strong incentive to manage consumption more carefully.

- Based on feedback from the organisations consulted, reserve services (back-up generation) represent the most common type of DSR in this sector.
- The majority of organisations consulted have not been offered DSR measures by their energy suppliers. However, many had been approached by one or more of a number of aggregators that are active in the UK. We also found some evidence that energy suppliers and DNOs are beginning to develop DSR offers.

Barriers to DSR in non-domestic buildings and potential enabling mechanisms

- The principal barrier restricting further uptake of demand side response measures in the non-domestic sector is the (perceived) **risk of reduced service levels**. This barrier was mentioned in some form by the majority of the organisations consulted. There was a consensus that firm **guarantees** of no impact on levels of service would be required for significant further uptake of DSR measures. A number of interviewees suggested that further **trials** and **case studies** (across the various sub-sectors) would be a useful means of improving confidence.
- Even with assurances that DSR will not negatively impact business operations, uptake could be restricted by a **lack of awareness** of or priority for such measures.[84] Given that energy is not a core aspect of most organisations' businesses, implementing DSR solutions is rarely a priority in the commercial / public sector. The most promising solution to this issue appears to be the concept of promoting DSR measures, including the wider picture of why DSR is necessary, amongst senior decision-makers in organisations. An alternative (or complementary) option is to market DSR as an energy efficiency measure to capitalise on the high levels of interest in this area.
- A lack of a sufficiently attractive (or clear) **economic case** was another barrier frequently mentioned during the consultation interviews. While some organisations are actively seeking ways to reduce energy bills (e.g. supermarkets, data centres), energy spend is low on the list of priorities for the majority of consumers.
- The **complexity** of implementing certain DSR measures (e.g. STOR) is a further barrier for organisations for which energy is not a central part of business operations. Further uptake of DSR will require the development of simplified DSR offers tailored to the target organisations.
- Further development of **automated technology** to deliver demand reductions during peak periods or to provide frequency response is also required. This technology would link with building energy management systems to ensure demand response does not impact on occupant comfort levels. Automated technology could also complement the rollout of smart meters in the small commercial sector, to improve the effectiveness of pricing signals.
- Many organisations in this sector participate in the CRC Energy Efficiency Scheme. DSR measures can provide CO_2 savings (albeit at the national level rather than individual site level); however **DSR is not certified under the CRC**. A

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[84] Most organisations appear to prioritise energy efficiency programmes over DSR measures. Demand side management is often viewed as an activity for the future ("further down the curve").

number of organisations consulted suggested that this is a barrier to further uptake of DSR.

- A **certification process** for certain DSR measures could be used to validate the claims of companies offering the products. Feedback from the consultation suggests that this could lead to increased confidence and thus facilitate higher uptake.
- The rollout of DSR measures will require communication with multiple stakeholders. For example, the landlords consulted for this study would never consider implementing any measures that could impact service levels without first engaging with their tenants. In this context, **multi-tenanted buildings** was cited as a specific barrier, affecting the commercial office and retail sectors in particular.

7 Appendix

7.1 Detailed methodology: generating average demand profiles

7.1.1 Overview

The process of generating electricity demand profiles by sub-sector is carried out in several stages. First the raw data for each building are converted into a 365-day dataset of whole-building electricity consumption. These data are then split by seasons, weekdays and Saturday and Sunday, and processed to produce average profiles for each sub-sector for each season and day type.

7.1.2 Data preparation

The data are stored in a mySQL database. The database is searched for keywords in the site name field to produce a list of sites for each category. Each site identifier is then used to query the database for all electricity datasets linked to the given site.

For each site the database is queried to gather data for each electricity meter. Each dataset is then processed using a simple data cleaning algorithm and interpolated to hourly resolution. Hourly resolution was chosen because some of the datasets, though recorded at half hourly intervals, include missing records and aggregating to hourly consumption helps mitigate the effect of interpolation.

The result is then trimmed to only include the period covered by all datasets for the site (to avoid missing data for any individual meter). The most recent reading is identified and the data are further trimmed, removing any data prior to exactly 365 days before this reading was recorded. If the remaining data set does not include the required 8,760 hourly readings then it is rejected. Note that to maximise the number of datasets available, the particular year of data was allowed to vary between data sets, though often the same year is used for all.

At this point the data are plotted as a simple time series to provide a ‘sanity check’ so that problematic datasets can be identified and removed. Figure 27 shows four examples of the data produced at this stage in the analysis.

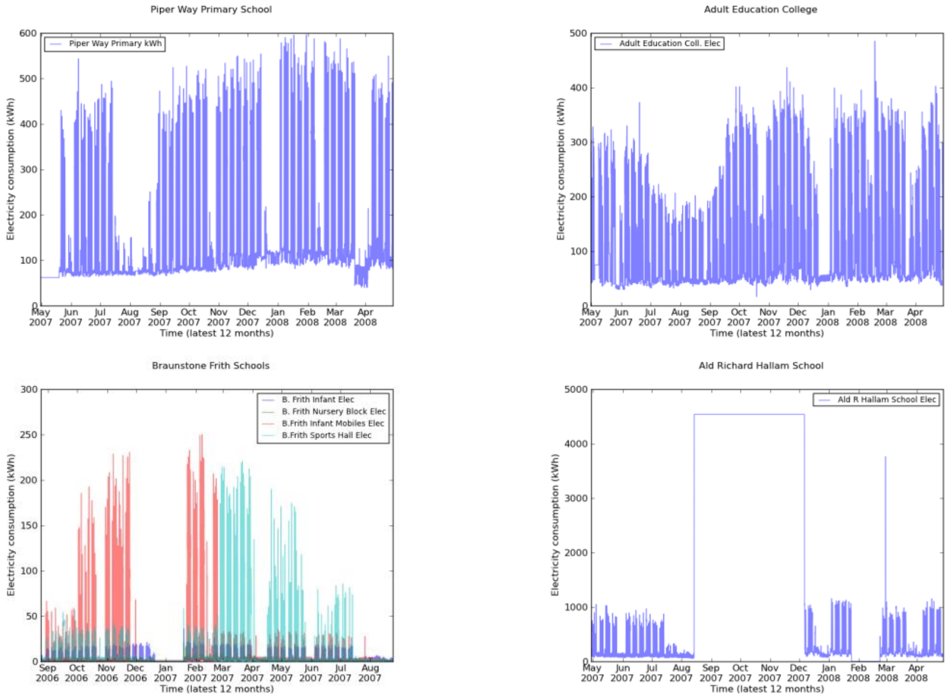

Figure 27: Examples of raw data for four schools

All of the examples above are schools and only one includes multiple datasets. Clearly there is a major problem with the site labelled ‘Ald R Hallam’. At this stage it is rejected.

For sites where there are more than one dataset, the labels for the individual meters are checked manually to ensure there is no sub-metering that will lead to double counting. All the datasets are then added together to provide the site total consumption time series.

To avoid the situation where larger sites are dominating the shape of the final profile, the totalled data for each individual site are normalised by dividing each value by the total annual consumption for the site (and multiplied by 1,000 to give kWh/MWh annual). The total annual consumption is calculated and the time series is divided by this total. The data are then ready for use.

7.1.3 Modelling

A simple approach to generating building profiles was employed. The normalised year of hourly data is split into five seasons, following the electricity industry convention for profile modelling, as follows:

- **Spring** – a period of around eight weeks from the last weekend of March.
- **Summer** – a ten week period following spring (latter May, June and early July).
- **High summer** – the six week period prior to the last weekend in August.
- **Autumn** – period from the last weekend in August to the last weekend in October.
- **Winter** – November to late March.

Then, within each season, data are divided into three day types: weekday (Monday–Friday), Saturday and Sunday. Finally, for each season / day type combination, split into 168 subsets, each subset containing data for only one of the 168 hourly periods in a week (i.e. Sunday at 00:00 through to Saturday at 23:00). The median of each subset of data, for each site, is calculated and recorded. For example, for spring (say 8 weeks), there will be eight values at hour *n* for Saturday, eight for Sunday and 8 x 5 = 40 for Monday-Friday. Median values of these sets are selected for each hour.

The median is used as it produces a robust profile which minimises the effect of outliers. Figure 28 shows four examples of profiles using the median in this way. The figures also show the 10th, 25th, 75th and 90th percentiles giving an indication of the variation in the underlying data. The figure includes the example that was rejected above and it can be seen that even with a large amount of corrupted data the profile is comparable with other schools.

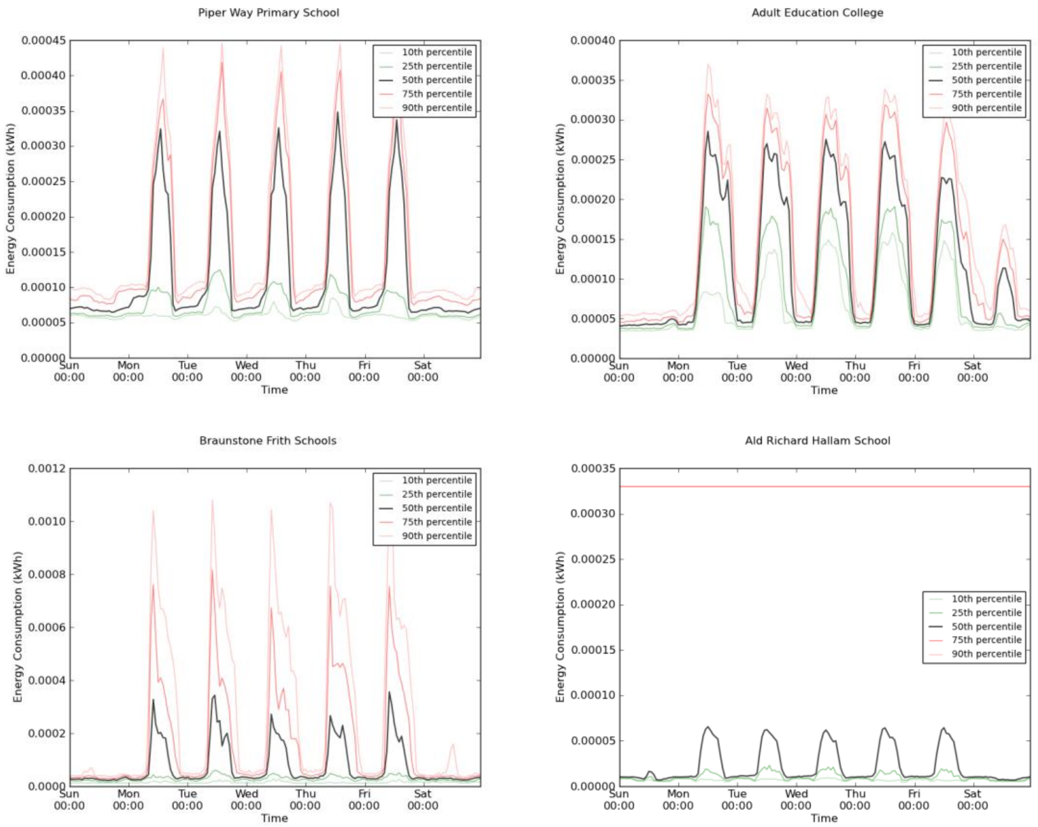

Figure 28: Profiles from four schools

7.1.4 Merging

The final step is to merge all the individual building profiles into one profile (for each day / season combination) for each sub-sector category. This is done by taking the average of the available profiles. That is, for each of the 168 data points the average is calculated and recorded. Figure 29 shows the results plotted as thick dark lines alongside the thin, pale lines of each individual building's profile.

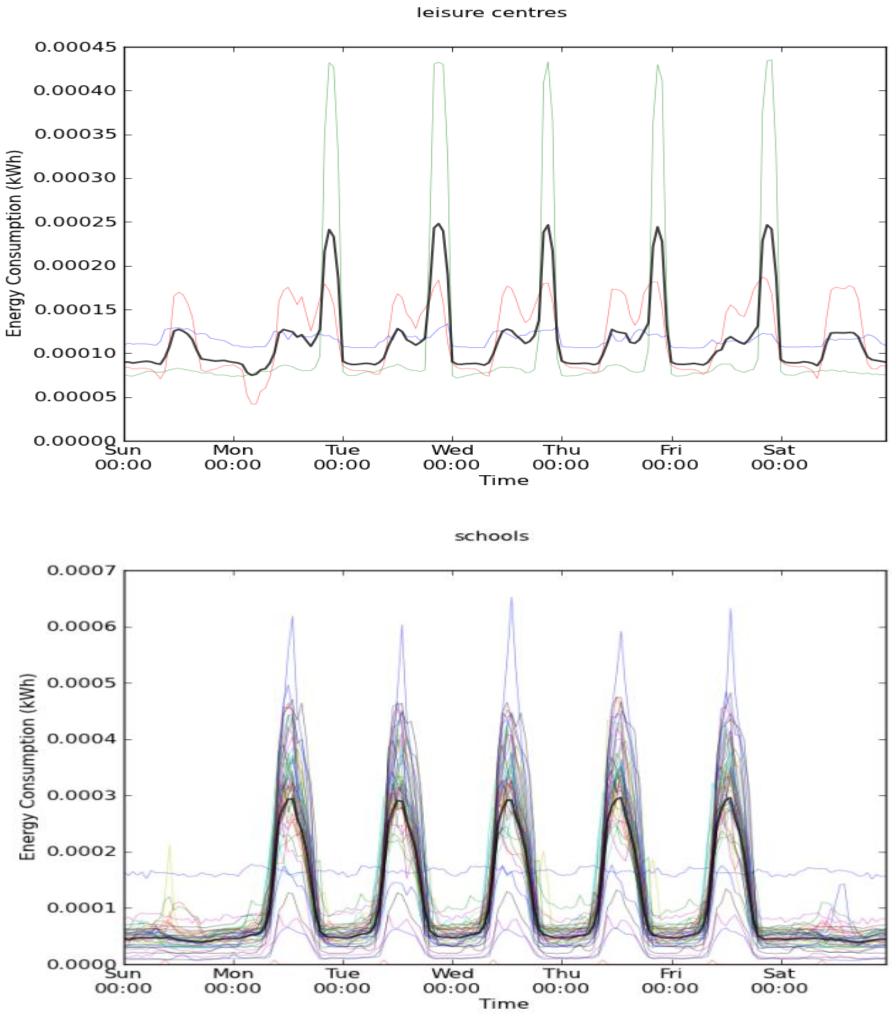

Figure 29: Final category profiles for two example categories

7.1.5 Number of data sets by sub-sector

The numbers of HHM data sets from which sub-sector average profiles were derived are given in the table below.

Table 9: Number of buildings' data sets behind average sub-sector demand profiles[85]

Sector	No. of data sets from which average demand profile is generated
Commercial offices	42
Education	76
Government	48
Health	3
Retail	39
Sports and leisure	8
Warehouses	10
Hotel and catering	-
Communications and transport	-
Other	N/A[86]

7.2 Characterising the "Other" sub-load category

Estimated electricity consumption by end use data for the service sector include the following categories:[87]

- Catering
- Computing
- Cooling and ventilation
- Heating
- Hot water
- Lighting
- Other

The category "Other" covers all end uses that do not fall under any of the other six. Given the high suitability of refrigeration loads for DSR measures, we have estimated the contribution of such loads to the "Other" category. A Defra-funded study into energy efficient refrigeration technologies provides an estimate of refrigeration energy consumption in the UK (commercial sector).[88] Summing the estimates for *retail display*, *kitchen refrigeration* and *generic cold storage*, this paper suggests total electricity demand for these uses is around 10.7TWh/yr. The data presented in Figure 8, section 3.2 show total electricity consumption in the "Other" category (across all sub-sectors) of 12.5TWh/yr. According to this estimate, refrigeration load therefore represents around 85% of demands in the "Other" category.

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[85] No complete half hourly metered data sets were available for either the *Communications and transport* or *Hotel and catering* sub-sectors. In the absence of empirical data, we estimated the profiles for these buildings based on data for other sub-sectors.

[86] The profile for "Other" buildings (which includes any service sector building types that do not fall into any of the other nine categories) was based on Elexon profile data for commercial buildings.

[87] Statistics published by DECC

[88] *Energy use in food refrigeration: Calculations, assumptions and data sources*, Food Refrigeration and Process Engineering Research Centre for Defra (2006).

7.3 Demand side response enablers to access the technical potential

7.3.1 Technologies

The assessment of the technical potential for DSR is based on the assumption that the existing barriers are removed.[89] For example, in section 4.3.3 we estimate the contribution of refrigeration equipment to total peak loads and compare the figure against National Grid's requirement for frequency response. Clearly, refrigeration equipment could only play a useful role in DSR if it were fitted with appropriate technology (i.e. dynamic demand control devices). Similarly, we include dimmable lighting in our assessment of technical potential for certain DSR measures, the implicit assumption here being that lighting is potentially dimmable and fitted with automated controls.

Exploiting the technical potential would require the deployment of a range of enablers (in addition to the enabling mechanisms outlined in section 5.3), including, for example:

- Dynamic demand controls.
- Dimmable lighting.
- Smart thermostats / load switchers.
- Control strategies linked to / integrated with building management systems.
- Advanced communications systems.

The UK Government has committed to the rollout of smart meters in all of the UK's homes and small businesses by 2019 (with implementation expected from 2014).[90] Smart meters provide real time consumption and pricing information, and two-way communication, and are therefore expected to be an important enabler of DSR.

7.3.2 Capacity Market

The UK Government set out the need for a capacity mechanism in its Electricity Market Reform White Paper[91] and introduced options for a mechanism, needed to provide *resource adequacy* (an element of security of supply).[92] DECC has since published a technical update to the White Paper that confirms the decision to implement a capacity mechanism in the form of a Capacity Market, *a mechanism which will contract for the required volume of capacity needed to deliver security of supply*.[93]

DSR is mentioned as one of the options (alongside traditional generation, storage and interconnection) that could help ensure security of supply and the capacity mechanism has been designed to encourage such measures. Further details are available at: www.decc.gov.uk/en/content/cms/legislation/white_papers/emr_wp_2011/tech_update/tech_update.aspx.

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[89] The alternative would be to attempt to estimate the technical potential accounting for existing barriers. However, such an approach would be problematic in terms of identifying and quantifying impacts of barriers; and would give a low estimate of technical potential.

[90] See www.decc.gov.uk/en/content/cms/tackling/smart_meters/smart_meters.aspx.

[91] *Planning our electric future: a White Paper for secure, affordable and low-carbon electricity*, Chapter 3, DECC (July 2011).

[92] Resource adequacy is defined as ensuring there is *sufficient reliable and diverse capacity to meet demand*.

[93] *Planning our electric future: technical update*, p.4, DECC, (December 2011).