Department for
Business, Energy
& Industrial Strategy

Building Energy Efficiency Survey: Storage sector, 2014–15

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Contents

Notes on statistical conventions

1. All estimates for energy consumption and greenhouse gas emissions are presented on an annual basis.
2. All results presented relate to 2014–15.
3. All estimates shown in all reports are point estimates and subject to uncertainty as they are based on survey findings. Confidence intervals are shown in Appendix A at sub-sector level for energy intensity for electrical and non-electrical uses.
4. Rounding conventions:
    - All energy values presented in this report are quoted in units of gigawatt-hours (GWh) and rounded to the nearest multiple of 10 with the exception of values below 10, which are presented as integers. For example, a quantity of 316 GWh would be presented in this report as 320 GWh;
    - All greenhouse gas emission values are quoted either in units of kilotonnes of carbon dioxide equivalent ($ktCO_2e$) rounded to the nearest multiple of 10 with the exception of values below 10, which are presented as integers, or in megatonnes of carbon dioxide equivalent ($MtCO_2e$) and rounded to one decimal place. For example, a quantity of 316 $ktCO_2e$ would be presented in this report as 320 $ktCO_2e$, or as 0.3 $MtCO_2e$;
    - All electrical and non-electrical energy intensity values (for example, tables C.5 and C.6) are quoted in units of kilowatt-hours per square meter GIA per year (kWh/m^2), rounded to the nearest integer;
    - All financial figures presented in tabular form in this report are quoted in thousands of pounds (£) and rounded to the nearest multiple of £100,000 unless stated otherwise. For example, a quantity of £65,340,000 would be presented in this report as 65,300 (in units of £ thousands);
    - All figures for total floor areas across the sector are quoted in units of millions of square meters and rounded to the nearest multiple of 1. For example, a floor area of 16,385,312 m^2 would be presented as 16 million m^2;
    - All percentage values are quoted to the nearest integer;
    - Abatement potential payback[1] estimates are shown to the nearest year.
5. Table conventions:
    - For data presented in tabular form, zero values are represented by a ‘dash’ symbol i.e. ‘-’;
    - For data presented in tabular form, the final row shows the total of all individual values. Where such a total is not applicable, a ‘double apostrophe’ symbol is presented i.e. ‘’.
6. All floor area figures are presented in units of Gross Internal Area (GIA). This is the floor area of a building measured to the internal face of the perimeter walls at each floor level. Further information can be found in “Code of measuring practice: definitions for rating purposes”, available at: www.gov.uk/government/publications/measuring-practice-for-voa-property-valuations/code-of-measuring-practice-definitions-for-rating-purposes.

[1] Payback is a measure of the time required for the cumulative savings associated with an energy saving measure to match the cost of installation. It is calculated by dividing the capital installation cost associated with a measure by the annual financial savings achieved based on energy cost reductions accounting for any annual operational costs.

Executive summary

Introduction

The Building Energy Efficiency Survey (BEES) was designed to meet the following research objectives:

- To update the Department's understanding of how energy is used, for a snap-shot in time, across the non-domestic building stock in more detail than is available at present;[2]
- To update the Department's understanding of how energy use can be abated across the non-domestic building stock in more detail than is available at present;
- To understand the barriers and enablers of energy abatement.

The first two objectives are addressed in this and other sector reports. The third objective is addressed in the BEES overarching report.

Overview of project method

The BEES study reports on the non-domestic building stock for England and Wales. Within this overall scope the stock is split into 10 sectors. These are in turn made up of 38 sub-sectors, each of which were analysed separately. This report provides the detailed study findings for the storage sector.

The study collected data through a large sample of telephone surveys (3,690) across all sectors. Each survey record is a premises which may represent a whole building or a part of a building. This information was obtained from a single organisation in a premises[3]. A smaller subset of site surveys (214) across all sectors were sampled from within the telephone survey sample. The telephone survey respondents were randomly selected from national level datasets for England and Wales.

The telephone surveys were used as the primary input into two models. One model calculated the records' energy use (the energy use model) and the other calculated the energy saving potential (the abatement model). The energy use model estimated the energy consumption of each premises record at an end use level. The abatement model determined the abatement potential of energy efficiency measures which could be applied to that premises, their capital cost and the amount of energy these measures could save.

The detailed findings from site surveys and a database of matched energy and activity data were used to calibrate the two models. The site surveys were also used to validate the telephone survey responses, and collect information on barriers and enablers from the site contacts.

Overall, the model calibration process has shown that at a sub-sector level the energy use consumption is reliable but that at a single record level the accuracy has a higher level of uncertainty.

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[2] The current non-domestic stock model (Pout, C (2000) NDEEM: the national non-domestic buildings energy and emissions model) is underpinned by field research conducted by Sheffield Hallam University in the 1990s.

[3] For all telephone surveys, the person responsible for managing energy on site was sought to complete the survey.

The overall project method had weaknesses in two key areas:

- Data inputs were obtained through telephone surveys, which were highly simplified. The telephone survey was designed to ensure it was easy to understand for non-energy experts so this meant questions could not be particularly technical and this further limited the sophistication of the input data to the model;
- The majority of the inputs were self-reported, which meant it was prone to a range of biases, such as differences in interpretation or understanding of a question by the respondent.

Following analysis of the data on the individual premises, the record results were weighted in order to produce results representative of all non-domestic buildings in England and Wales in each sector.

Storage sector overview

The storage sector consisted of cold stores, large distribution warehouses, stores and warehouses; for the purpose of this study, it did not include storage premises that were present in other building types. The storage sector had a total floor area of 140 million m^2 (18 per cent of the total non-domestic stock) across 178,700 premises (11 per cent of the total non-domestic stock). The storage sector's total energy consumption was 13,110 GWh. The sector's electrical energy consumption was 7,440 GWh (9 per cent of the total non-domestic stock) and non-electrical consumption was 5,670 GWh (7 per cent of total non-domestic stock).

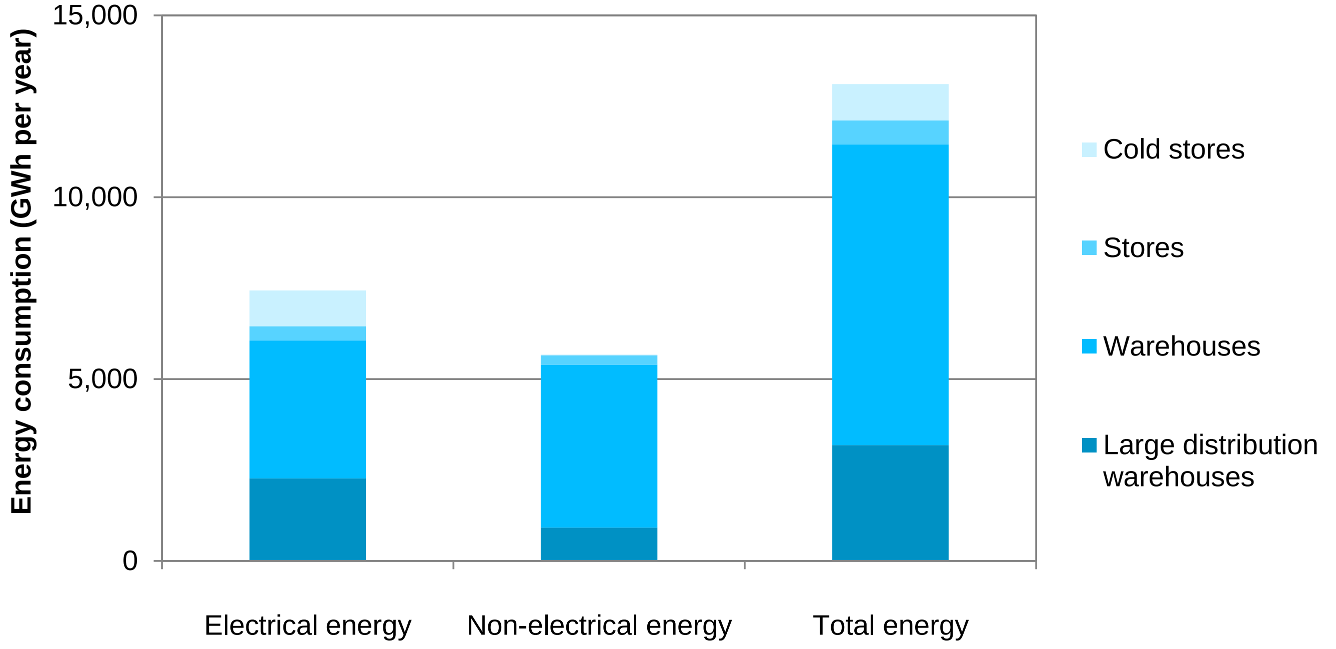
The findings in this report are based on data collected through 398 telephone surveys used in the energy use and abatement models and 18 site surveys in 2014–15.

Key findings

Energy consumption in the storage sector, 2014–15

- According to modelled data based on telephone survey responses, the sector consumed 13,080 GWh of energy. This included 7,440 GWh of electrical energy and 5,670 GWh of non-electrical energy per year (Figure 0.1).
- The largest energy consumer in this sector was warehouses with 8,270 GWh total energy consumption (63 per cent of sector total). Large distribution warehouses were the second largest consumers, with 3,180 GWh of total energy consumption (24 per cent of sector total).
- The difference in absolute consumption between the sub-sectors matched to some extent with their overall size. Warehouses was the largest sub-sector in terms of energy consumption, while also representing 72 per cent of the sector's overall floor area.
- Cold stores had the highest total median energy intensity (312 kWh/m^2), followed by large distribution warehouses (80 kWh/m^2).
- Cold stores typically displayed the highest median electrical energy intensity (310 kWh/m^2). The second most energy intensive sub-sector in terms of electrical energy was large distribution warehouses (47 kWh/m^2). Warehouses displayed the highest median non-electrical energy intensity of 27 kWh/m^2, followed by large distribution warehouses (16 kWh/m^2).
- The energy consumption of the storage sector was broken down into specific 'end uses'. The most significant end use was space heating (6,030 GWh, 46 per cent of total energy consumption), followed by internal lighting (2,580 GWh, 20 per cent of total).

Figure 0.1: Energy consumption by energy type and storage sub-sector, 2014–15



Source: Energy use model results for the sector covering England and Wales

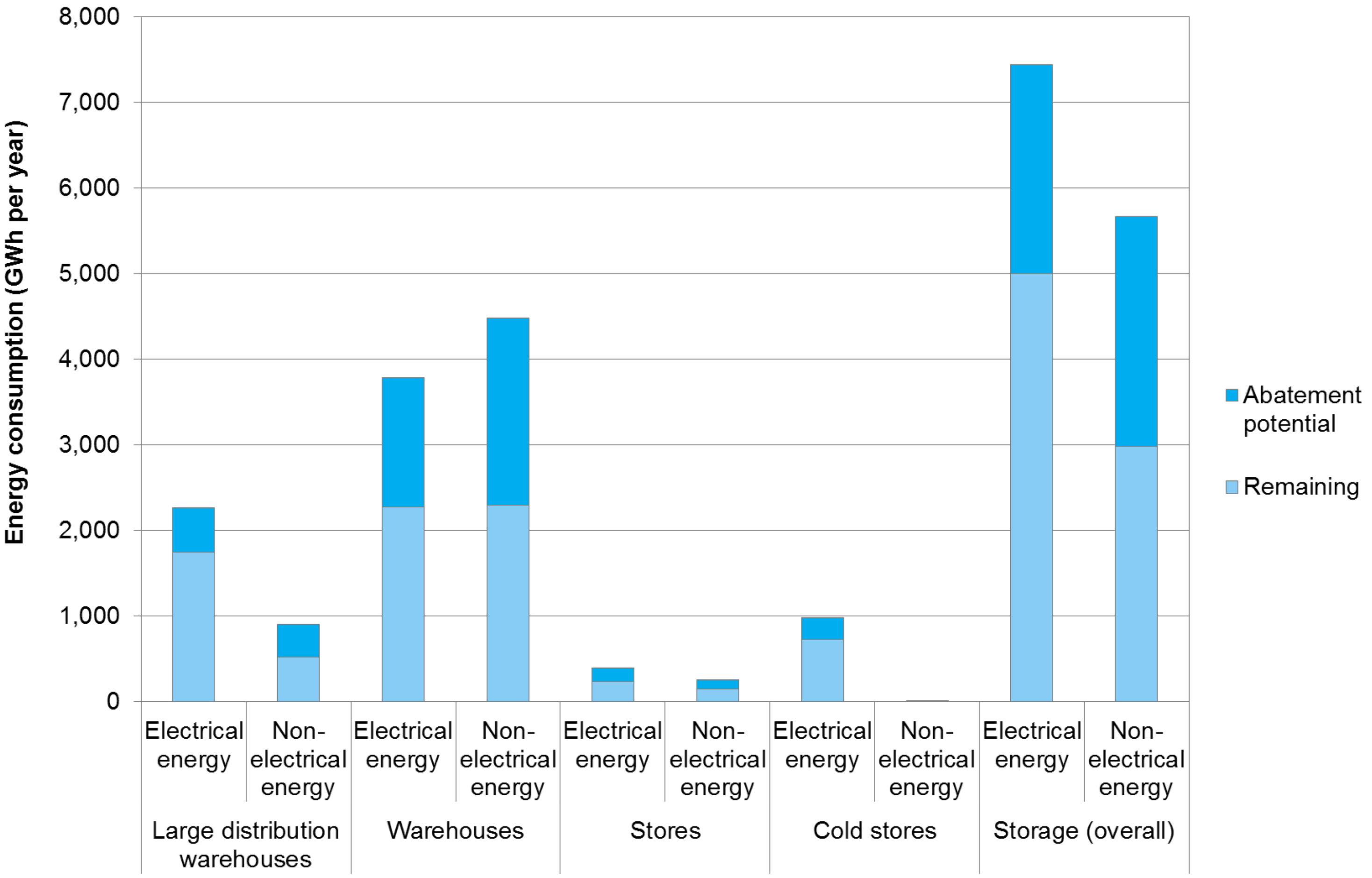
Abatement potential in the storage sector, 2014–15

- According to modelled data based on telephone survey responses, Figure 0.2 shows abatement potential for the sector, broken down by sub-sector and fuel type. This represents the total abatement potential that is technically available, which relates to the possible reductions in energy consumption following implementation of all applicable measures. The results include measures that are not cost-effective and the model applies a simple assessment of measure suitability. Building specific installation requirements that may impose additional costs are not accounted for.
- The total abatement potential in the storage sector was 5,120 GWh of total energy (39 per cent reduction on consumption). This was comprised of 2,430 GWh of electrical energy (a 33 per cent reduction on consumption) and 2,690 GWh of non-electrical energy (a 47 per cent reduction on consumption).
- This could be achieved at a capital cost of £2.48 billion. The socially cost effective potential was 1300 GWh of total energy consumption which consisted of 1,300 GWh of electrical consumption, with no socially cost effective abatement potential for non-electrical energy. Companies are more likely to be influenced by the payback period[4] for improvement: overall there were 900 GWh of total energy savings with a private payback period of 3 years or less (410 GWh of electrical energy abatement and 490 GWh of non-electrical energy abatement).
- The sub-sector with the largest relative and absolute abatement potential was warehouses, which could reduce consumption by 3690 GWh which spilts between with

[4] Payback is calculated by dividing the capital installation cost associated with a measure by the annual financial savings achieved based on energy cost reductions accounting for any annual operational costs.

1,510 GWh of electrical energy (40 per cent reduction on consumption) and 2,180 GWh of non-electrical energy (49 per cent reduction).

Figure 0.2: Abatement potential by energy type and storage sub-sector, 2014–15



Source: Abatement model results by sub-sector, England and Wales

Table 0.1 shows the abatement potential by measure type. Definitions of measure type are included in Appendix D. The largest group of savings for the storage sector – in terms of reductions in energy consumption – relate to the implementation of building instrumentation & control, lighting and carbon & energy management measures. The largest group of savings – in terms of the potential energy bill savings – relate to the implementation of lighting upgrades.

Table 0.1: Abatement potential in the storage sector by measure type, 2014–15

Measure type	Savings					
	Total annual energy bill saving (£ thousands)	Total annual greenhouse gas saving ($ktCO_2e$)	Total annual electrical energy savings (GWh)	Total annual non-electrical energy savings (GWh)	Total annual energy savings (GWh)	**Total capital cost of measure (£ thousands)**
Air conditioning and cooling	2,400	10	20	-	20	55,200
Building fabric	20,000	40	50	570	630	556,100
Building instrumentation and control	35,300	70	100	980	1,090	305,800
Building services distribution systems	6,800	30	70	-	70	177,200
Carbon and energy management	53,500	200	410	490	900	180,600
Hot water	1,800	5	6	50	50	44,100
Humidification	-	-	-	-	-	-
Lighting	128,900	540	1,300	-	1,300	582,500
Cooled storage	27,500	90	280	-	280	143,200
Small appliances	1,200	5	10	2	10	42,300
Space heating	20,600	40	60	580	640	265,300
Swimming pools	-	-	-	-	-	-
Ventilation	11,700	50	120	10	130	131,400
Total	**309,600**	**1,080**	**2,430**	**2,690**	**5,120**	**2,483,700**

Source: Abatement model results for the sector, England and Wales

1. Storage sector

This report relates to the storage sector (one of 10 sectors covered in the Building Energy Efficiency Survey (BEES)). This section provides definitions for the four storage sub-sectors (large distribution warehouses, warehouses, stores, and cold stores). It then sets the storage sector in the wider non-domestic stock context in terms of both the number of premises and floor area it represents.

Table 1.1 sets out the definitions for each of the sub-sectors reported in the storage sector.

Table 1.1: Table of storage sub-sector definitions[5]

Sub-sector	Definition
Large distribution warehouses	A warehouse of sufficient clear height and floor loading to accommodate racking systems designed to facilitate "just in time" and other goods distribution. The premises will be situated close to the motorway network (or occasionally to a mainline rail inter-connection) and will have excellent provision for loading and unloading goods with sufficient space for the easy movement of large articulated vehicles within the site and for trailer and container parking. Large distribution warehouses will usually have a floor area of greater than 5,000m^2.
Warehouses	Refers to unrefrigerated premises that are used for the temporary storage and redistribution of goods, manufactured products, merchandise or raw materials prior to their distribution for sale. Gross Floor Area should include all space within the premises including space designed to store non-perishable goods and merchandise, offices, lobbies, stairways, rest rooms, equipment storage areas, and lift shafts. This should not include exterior/outdoor loading bays or docks.
Stores	Refers to a premises used for bulk storage of items, which has minimal or transient staff occupancy. As distinct from a warehouse, factory, or distribution centre which have staff operating in the main space on a regular basis.
Cold stores	Refers to refrigerated premises that are used to store perishable goods or merchandise under refrigeration at temperatures below10 degrees Celsius . Gross Floor Area should include all space within the premises, which includes temperature-controlled areas, administrative offices, lobbies, stairways, restrooms, equipment storage areas, and lift shafts. This should not include exterior/outdoor loading bays or docks.

BEES focuses on energy use within buildings. In the storage sector, there are a number of activities where the majority of the area is associated with non-building uses. These are classified by the valuation office agency as ‘storage land’ and ‘storage depot’. They have been excluded from BEES. It should be noted however that these activities may include some floor space in buildings.

[5] These definitions were originally based on those used for US Energy Star scheme and then were adapted for the UK context.

Storage sector in the context of the wider non domestic stock

The storage sector is a large segment of the non-domestic stock. It accounts for 11 per cent of the non-domestic stock in terms of premises count (178,700) and 18 per cent in terms of floor area (140 million m^2 GIA[6]).[7]

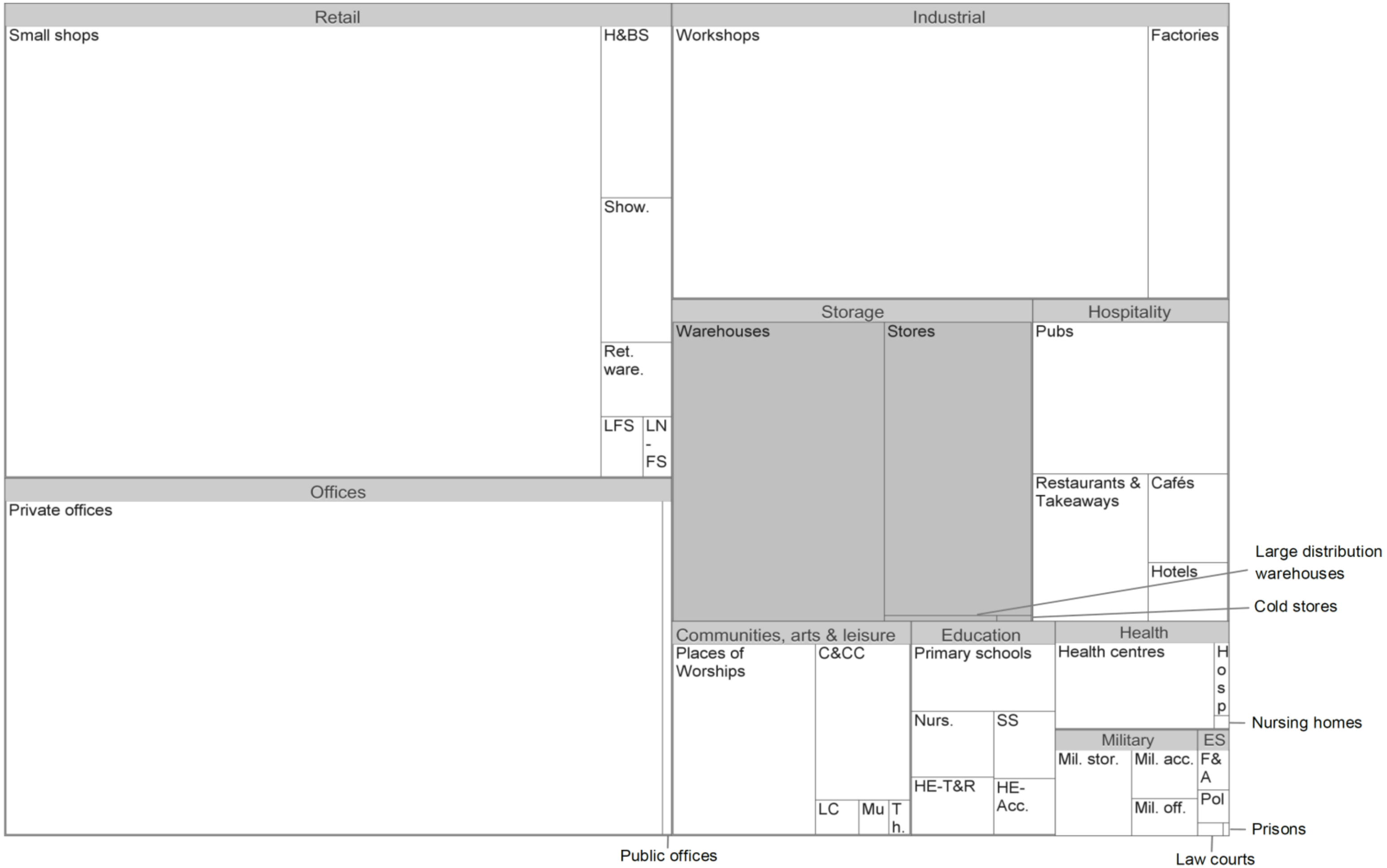
In terms of energy consumption the sector consumed13,110 GWh of total energy per year. This comprised 7,440 GWh of electrical energy and 5,670 GWh of non-electrical energy per year, this is equivalent to 8 per cent of the non-domestic total (9 per cent electrical and 7 per cent of non-electrical energy energy). This information is set out in Figure 1.1, Figure 1.2 and Figure 1.3.

[6] GIA stands for Gross Internal Area: the area of a building measured to the internal face of the perimeter walls at each floor level.

[7] The sources for these statistics can be found in the technical annex (and are referred to collectively as the Population table).

Figure 1.1: Premises frequency by sub-sector for the non-domestic stock, 2014–15

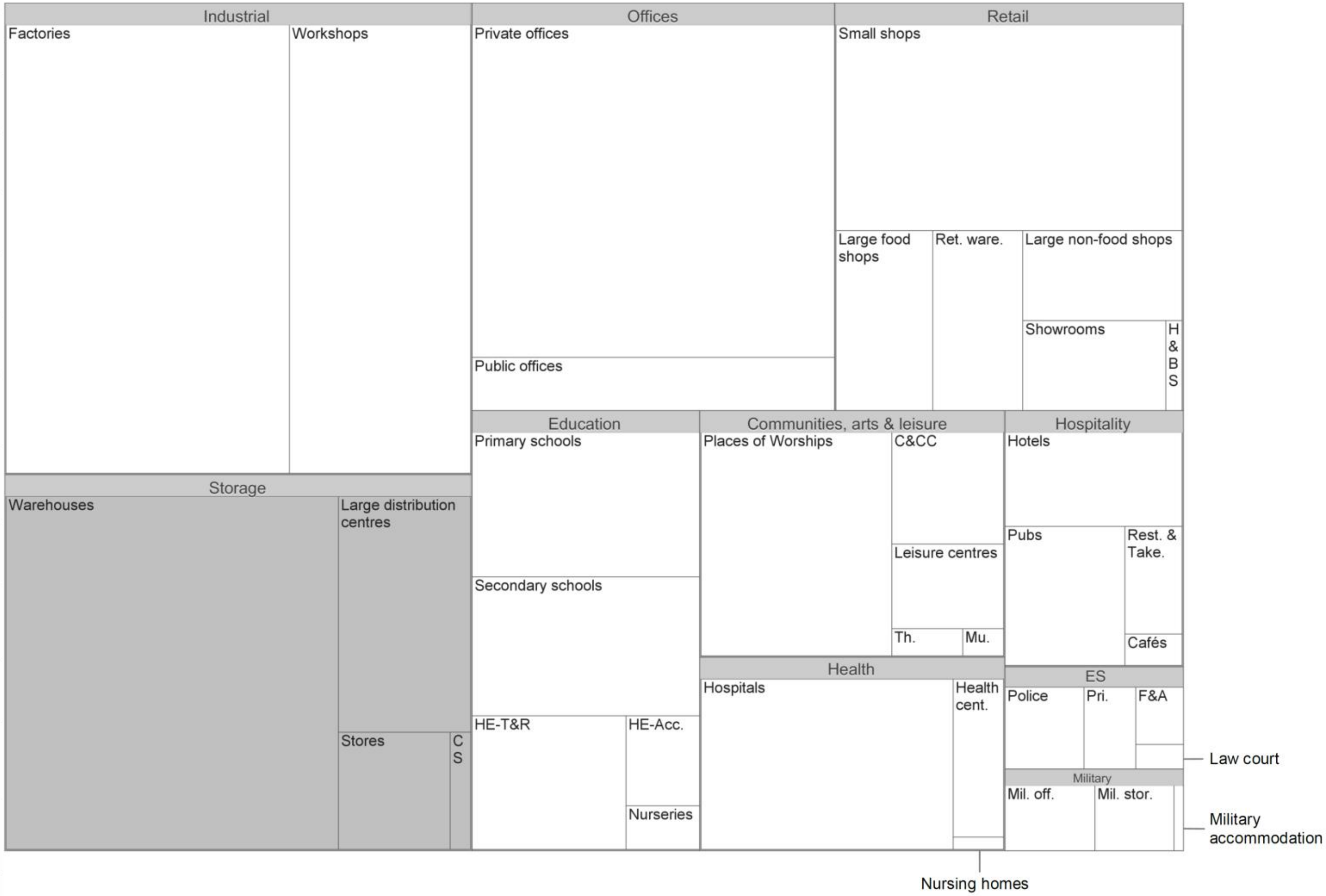
ID	Sub-sector
H&BS	Hairdressing & beauty salons
Show.	Showrooms
Ret. ware.	Retail warehouses
LFS	Large food shops
LN-FS	Large non-food shops
C&CC	Clubs & community centres
LC	Leisure centres
Mu.	Museums, Art galleries and Libraries
Th.	Theatres, cinemas and concert halls
Nurs.	Nurseries
SS	Secondary schools
HE-T&R	HE—Teaching and research
HE-Acc.	HE — Accommodation
Hosp.	Hospitals
Mil. stor.	Military storage
Mil. acc.	Military accommodation
Mil. off.	Military offices
F&A	Fire & ambulance stations
Pol.	Police stations



Source: Population table

Figure 1.2: Floor area by sub-sector for the non-domestic stock, 2014–15

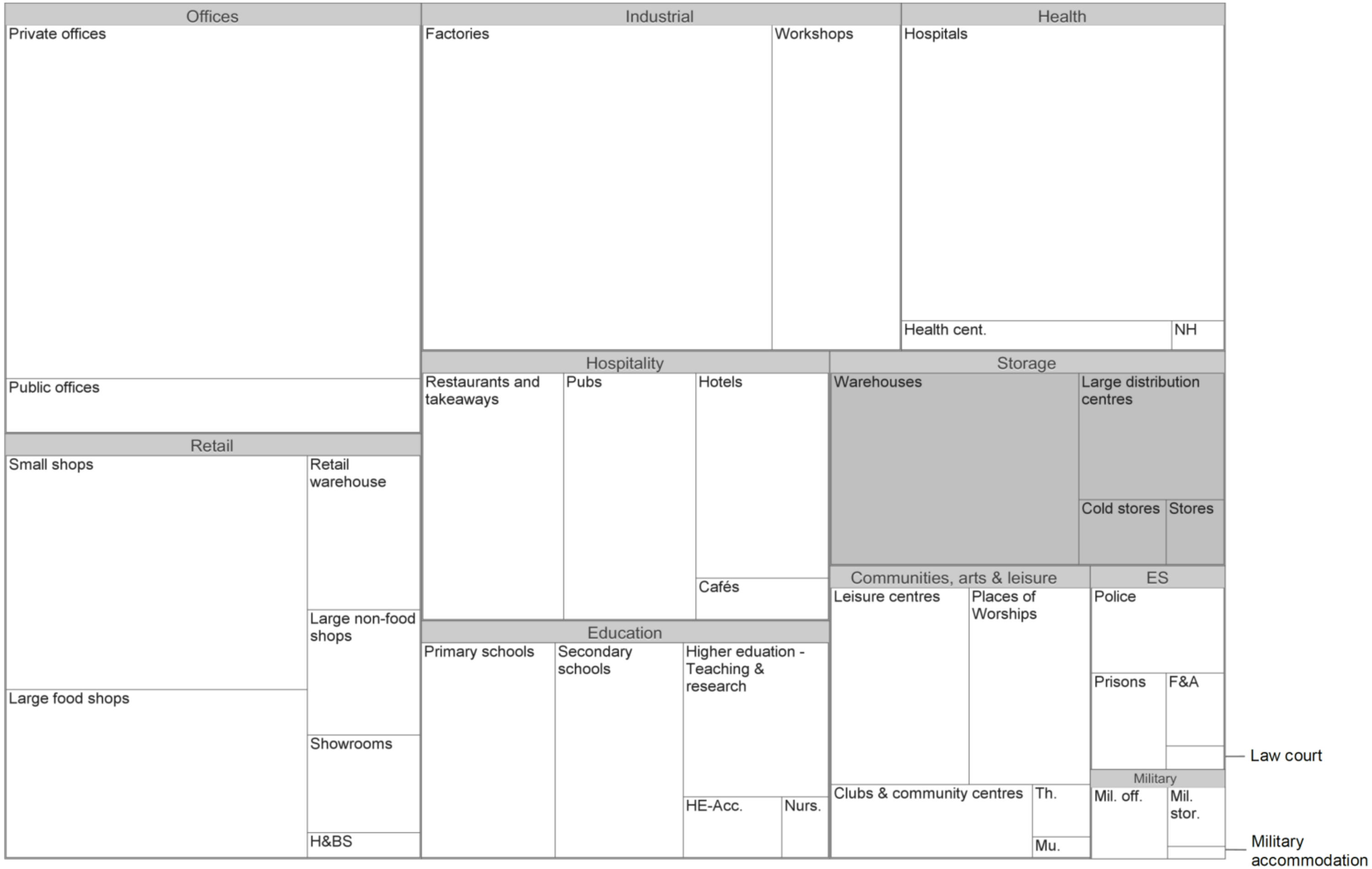
ID	Sub-sector
Ret. ware.	Retail warehouse
H&BS	Hairdressing & beauty salons
CS	Cold stores
HE-T&R	HE—Teaching and research
HE-Acc.	HE — Accommodation
C&CC	Clubs & community centres
LC	Leisure centres
Th.	Theatres, cinemas and concert halls
Mu.	Museums, Art galleries and Libraries
Health cent.	Health centre
Rest. & Take.	Restaurants & takeaways
Pri.	Prisons
F&A	Fire & ambulance stations
Mil. off.	Military office
Mil. Stor.	Military storage



Source: Population table

Figure 1.3: Energy consumption by sub-sector for the non-domestic stock, 2014–15

ID	Sub-sector
Health cent.	Health centre
NH	Nursing homes
H&BS	Hairdressing & beauty salons
HE-Acc.	HE — Accommodation
Nurs.	Nurseries
Th.	Theatres, cinemas and concert halls
Mu.	Museums, Art galleries and Libraries
F&A	Fire & ambulance stations
Mil. off.	Military office
Mil. Stor.	Military storage



Source: Energy use model results by sub-sector, England and Wales

General characteristics of the storage sector

The survey records relate to a single premises within buildings predominantly classified as storage activities. In some cases the premises will be the whole building, in other cases the premises will just relate to the area occupied by a single organisation within a building.

Storage premises varied greatly in size and complexity from small, rarely occupied commercial lockups to the largest distribution warehouses and cold stores in England and Wales. The use of space also varied considerably. Storage premises included single-site, small business premises incorporating office space, a service yard and storage for equipment and stock; whereas others were storage or distribution premises forming part of a much larger business. Larger and more complex distribution facilities were more likely to operate multiple shifts or 24 hours a day with conveyor systems, robot cranes and automated picking systems often found in these premises. A wide range of servicing arrangements were found in this sector, from low serviced unoccupied and unheated storage spaces to mechanically ventilated and air conditioned distribution centres with large numbers of staff. Staff offices, rest facilities and canteens, workshop or process areas and vehicle garages were common supporting activities.

Cold storage facilities were a distinct sub-sector within the storage sector; ranging from small-scale storage facilities to very large-scale national refrigerated distribution centres. These premises were typically dominated by the cold storage space itself, with ambient temperature storage, office accommodation, staff catering and rest facilities found in supporting areas. The following facilities were distinct in the storage sector (from all other categories of non-domestic premises in the BEES study): highly insulated, refrigerated throughout the year and very energy intensive. In these premises the spaces are designed to suit the product, not the human occupants.

Summary statistics for the storage sector

A number of standard characteristics for the storage sector are set out in Table 1.2, Figure 1.4 and Figure 1.5; from premises and organisation size through to peak operating hours and premises tenure. These key characteristics for the hospitality sector and how these vary across the hospitality sub-sectors themselves are described.

Analysis of BEES has primarily been done to give a fair representation of floor area within sub-groups. Floor area has a strong association with energy use.

Based on the floor area weighted records, premises in the storage sector broadly fit into three categories:

- Large cold store and large distribution warehouse facilities were typically built after 1991 and often had long hours of operation (greater than 16 hours per day). These premises consisted of single buildings or multiple building ‘campus’ sites; These tended to have a floor area greater than 5,000 m^2;
- Medium sized warehouses typically consisting of single building premises operating more standard hours (8 to 15 hours of operation per day) and a mixture of owned and leased premises; These tended to have a floor area greater than 1,000 m^2;
- Smaller stores were mainly managed by micro-sized organisations and smaller than 500 m^2 in floor area size.

In terms of organisation size, large distribution warehouses and cold stores tended to be operated by large organisations, most likely a reflection of the scale of their operations. In contrast stores were typically operated by micro or small-sized organisations (those employing

1-9 or 10-49 members of staff). The greatest variance in organisation sizes occurred in warehouses with premises across all organisational size groups.

The storage sector often occupied premises with a floor area of greater than 1,000 m^2, with all sub-sectors including premises greater than 10,000m^2. The only sub-sector which had a very different profile of floor area sizes was stores, which had a mixture of floor areas from less than 50 m^2 up to greater than 10,000 m^2. Cold stores had an almost exclusive make up of premises of 1,000 m^2 in floor area or greater (93 per cent), and large distribution warehouses premises were almost exclusively over 10,000m^2 in floor area (90 per cent).

With regards to tenure, overall there was an almost even split between leased and owned premises (46 per cent and 48 per cent, respectively). This same overall profile was present in stores and warehouses. In cold stores there was a greater prevalence of owner-occupied premises than leased (72 and 14 per cent, respectively), whereas large distribution warehouses bucked this with 51 per cent leasing the premises compared with 29 per cent who owned the premises. There was a large proportion of large distribution warehouses that reported ‘Do not know’ when asked about premises tenure (19 per cent).

Across the storage sector, 93 per cent of respondents reported that they considered ways to reduce energy use in their premises. The majority of cold stores (71 per cent) and large distribution warehouses (69 per cent) reported “actively seeking new ways to reduce energy use”. Stores and warehouses had an approximately even split between those “trying to reduce energy use where possible, but it’s not a priority” and “actively seeking new ways to reduce energy use”.

In terms of building age, almost half of stores were built between 1940 and 1985 (45 per cent). A large proportion of cold stores (26 per cent) were also built during this timeframe, although another 21 per cent of cold stores were built between 1991 and 2006. The sub-sector with the most modern buildings was large distribution warehouses, of which 64 per cent were built after 1991.

Of the overall storage floor area, 78 per cent was in premises for which the storage area took up the whole building. Typically, this profile was demonstrated across all sub-sectors, except for cold stores. The cold stores sub-sector had 61 per cent of premises occupying whole buildings, and 38 per cent occupying multiple-building ‘campus’ sites.

Across the storage sector, premises typically had peak operating hours of fewer than 15 hours per day (83 per cent). The warehouse and store sub-sectors demonstrated similar peak operating hour profiles (90 and 74 per cent, respectively). In contrast, large distribution warehouses and cold stores had peak operating hours across all categories, with both sub-sectors having premises operating up to 24 hours per day (18 and 43 per cent, respectively).

In terms of opening hours, there was a greater variation across the storage sector. 80 per cent of premises in the sector had opening hours of 15 hours or less and 26 per cent had opening hours from 16 to 24 hours per day. Warehouses and stores typically had opening hours of fewer than 15 hours (84 and 74 per cent, respectively), whilst 47 per cent of cold stores and 42 per cent of large distribution warehouse were open 24 hours per day.

Table 1.2: Range of building and premises characteristics by storage sub-sector by percentage of floor area, 2014–15

Column percentages

	Storage sub-sector				
	Large distribution warehouses (%)	Warehouses (%)	Stores (%)	Cold stores (%)	**Storage sector (%)**
Organisation size					
Micro (0-9)	-	9	50	8	11
Small (10-49)	1	23	10	11	18
Medium (50-249)	9	18	5	23	16
Large (250+)	89	49	33	58	56
Don’t know	-	1	2	-	1
Total floor area (m^2)					
Less than 50	-	-	2	-	0
50-99	-	0	7	-	1
100-249	-	2	24	-	4
250-499	0	7	23	2	7
500-999	0	18	13	5	14
1,000-4,999	2	36	6	31	27
5,000-9,999	8	7	8	18	7
10,000 or more	90	30	17	44	40
Tenure					
Owned	29	53	43	72	48
Leased	51	46	40	14	46
Don’t know	19	0	17	14	6
Energy management ambition[8]					
Active	69	38	41	71	45
Passive	29	54	42	29	48
None	2	8	17	0	8
Do not know	-	-	-	-	-
Age of building					
Pre-1900	-	2	15	-	3
1900-1939	5	4	11	14	5
1940-1985	14	40	45	26	35
1986-1990	10	12	7	21	11
1991-2006	46	22	14	15	26
2007 or later	18	5	2	4	7
Don’t know	7	15	7	20	13

[8] ‘Active’ relates to respondents who indicated that they “actively seek new ways to reduce energy use”; ‘Passive’ relates to respondents who indicated that they “try to reduce energy use where possible, but it’s not a priority”, ‘None’ relates to respondents who indicated that they “have not considered ways to reduce energy use”.

Table 1.2 continued.

	Storage sub-sector				
	Large distribution warehouses (%)	Warehouses (%)	Stores (%)	Cold stores (%)	**Storage sector (%)**
Building structure					
Part of building	6	8	10	0	8
Whole building	75	80	70	61	78
Multiple buildings	18	12	20	38	14
Peak operating hours[9]					
8 or less	25	42	29	36	37
9-15	40	48	45	13	46
16-23	17	8	17	8	10
24	18	1	2	43	5
Don't know	-	1	7	-	1
Opening hours[10]					
8 or less	12	27	17	18	23
9-15	25	57	56	27	50
16-23	21	3	0	8	7
24	42	12	19	47	19
Don't know	-	1	7	-	1
Unweighted base	*43*	*225*	*109*	*21*	*398*

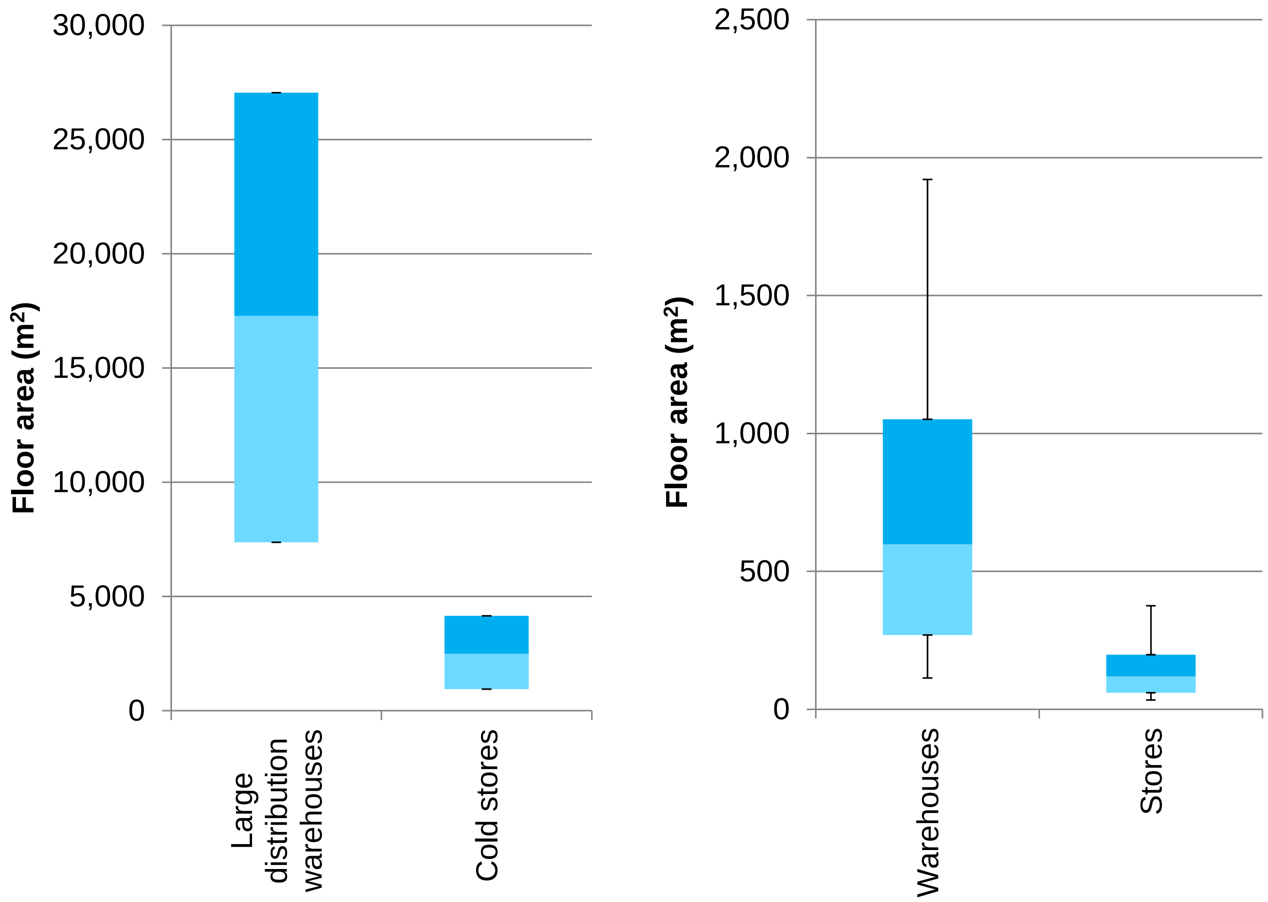
Source: Telephone survey or equivalent records for the sector, England and Wales

[9] Respondents were asked "How many hours in a typical working day is the premises reasonably fully occupied by your employees (at least 50% of staff present)?".

[10] This is defined as the total number of hours that the premises is at least partially occupied by staff (when at least 20 per cent of the maximum number of staff -on a typical working day- are present).

Figure 1.4 shows the distribution of premises sizes, in terms of floor area, by sub-sector. The plot shows that large distribution warehouses had the largest median floor area in the storage sector at 17,280 m^2, followed by cold stores (2,500 m^2), warehouses (600 m^2) and stores (120 m^2). The distribution of floor area sizes for large distribution warehouses was also much wider than other sub-sectors, with the central 50 per cent of records having floor areas between 7,380 m^2 and 27,050 m^2; compared with a range of 950 m^2 to 4,150m^2 in cold stores and 270 m^2 to 1,050 m^2 in warehouses.

Figure 1.4: Premises size by storage sub-sector, 2014–15

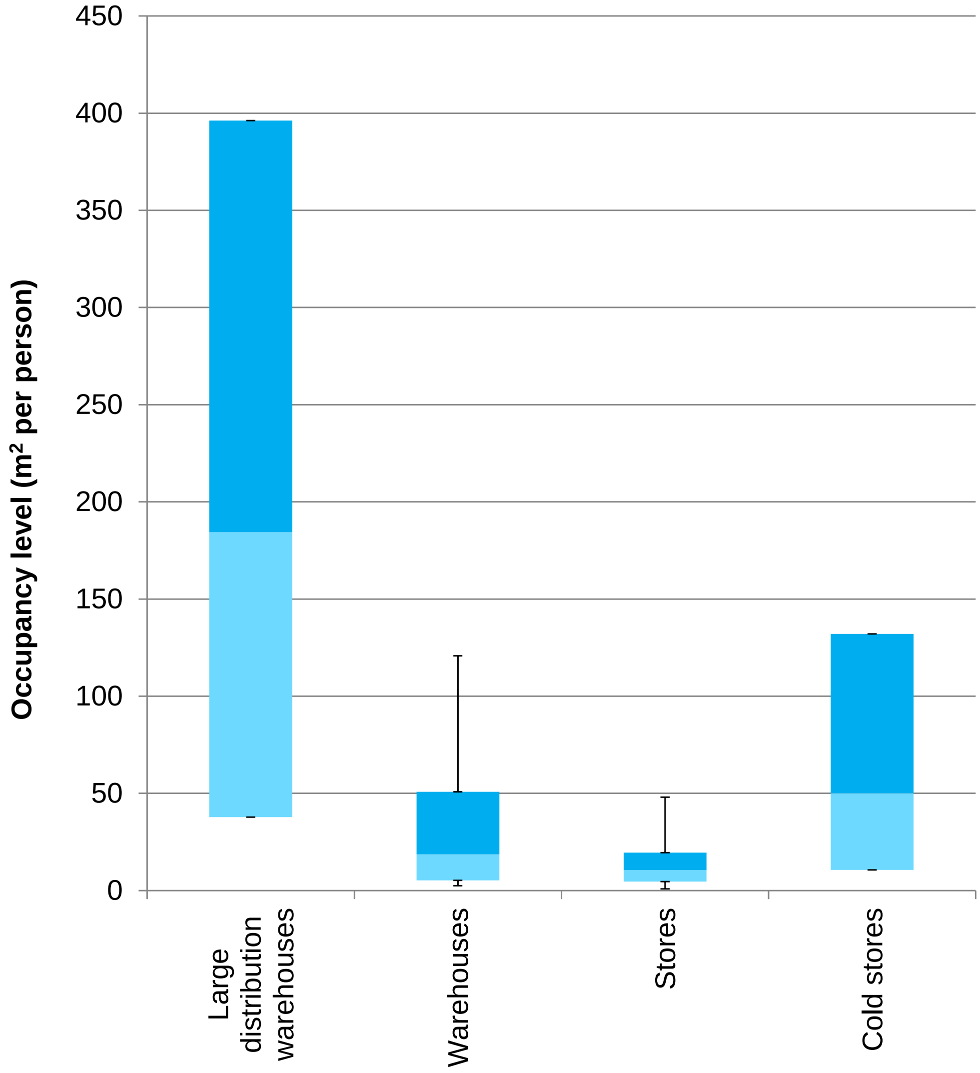


Note: In box and whisker plots, the blue columns, when combined, indicate the range of floor areas covered by the interquartile range of results (the middle 50 per cent of data points). The upper black bars extend to the 90th percentile, capturing a further 15 per cent of the total number of data points. The lower black bars span to the 10th percentile, also capturing 15 per cent of the total number of data points. Therefore within each sub-sector, 80 per cent of the total number of data points are displayed, with the outlying maxima and minima (10 per cent of data points each) excluded. For series with fewer than 50 data points, the black bars are excluded.

Source: Telephone survey or equivalent records for the sector, England and Wales

Figure 1.5 shows the distribution of occupancy level (the floor area per staff and visitor number) based on the number of staff and visitors present over a typical working day. Large distribution warehouses show the lowest median occupancy level of 180 m^2 per person.[11] This compares with a median of 50 m^2 per person in cold stores, 20 m^2 per person in warehouses and 10 m^2 per person in stores.

Figure 1.5: Occupancy density by storage sub-sector, 2014–15



Note: In box and whisker plots, the blue columns, when combined, indicate the range of floor areas covered by the interquartile range of results (the middle 50 per cent of data points). The upper black bars extend to the 90th percentile, capturing a further 15 per cent of the total number of data points. The lower black bars span to the 10th percentile, also capturing 15 per cent of the total number of data points. Therefore within each sub-sector, 80 per cent of the total number of data points are displayed, with the outlying maxima and minima (10 per cent of data points each) excluded. For series with fewer than 50 data points, the black bars are excluded.

Source: Telephone survey or equivalent records for the sector, England and Wales

[11] Commonly, in sectors where this metric is reported, staff density would be based on Net Lettable Floor Area (NLA). This is the area of a building that is let to tenants and excludes common areas e.g. walkways. A typical ratio from GIA to NLA is 0.7.

2. Methods

This section provides a summary of the Building Energy Efficiency Survey (BEES) methodology describing the research objectives of this study, the standard approach to data collection, data screening and data processing; as well as the methodological challenges for the storage sector.

Greater detail on the BEES methodology in relation to the storage sector is presented in Appendices A, B and C, which cover statistics on the methodological quality and an explanation of how the approach was tailored for the storage sector.

A detailed technical annex for BEES has also been published alongside this report, which provides detailed coverage on sampling approaches, the study method and the models used. This can be found at www.gov.uk.

Research objectives

The Building Energy Efficiency Survey (BEES) was designed to meet the following research objectives:

- To update the Department's understanding of how energy is used, for a snap-shot in time, across the non-domestic building stock in more detail than is available at present;[12]
- To update the Department's understanding of how energy use can be abated across the non-domestic building stock in more detail than is available at present;
- To understand the barriers and enablers of energy abatement.[13]

The first two objectives are addressed in this and other sectors reports. The third objective is addressed in the BEES overarching report.

Standard approach

A standard overall approach was designed to gather information on energy use in premises relying on telephone surveys and a limited number of site surveys. The non-domestic stock was broken down into 10 sectors and 38 sub-sectors.

The analysis for BEES is performed at sub-sector level with bespoke questionnaires and modelling assumptions used at this level.

The study has generated a database of 3,690 records. Each record may represent an entire building or a premises within a larger building. The findings in this report are based on data collected for the storage sector through 398 telephone surveys and 18 site surveys during 2015.

The records include data on energy usage, information on the building itself (fabric, age etc.) and the occupant's organisation.

The survey asked respondents about the energy used within or associated with premises e.g. sports floodlighting, external security and car park lighting. Energy use activities which were not within the scope of the study included storage process loads. It was not possible to capture all energy end uses that may be present on the premises.

The standard method is summarised in Figure 2.1 and set out in the bullet points below:

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[12] The current non-domestic stock model (Pout, C (2000) NDEEM: the national non-domestic buildings energy and emissions model) is underpinned by field research conducted by Sheffield Hallam University in the 1990s.

[13] The detail on the barriers and enablers of energy abatement are addressed in the overarching report.

1. **Sample design** - BEES has been sampled and grossed primarily based on data from the Non-domestic National Energy Efficiency Data-framework (ND-NEED). This dataset uses the Valuation Office Agency's (VOA) property rating list. Where a sector was out of scope of the VOA database, alternative data sources were used. This gives a base record of address, floor area, building type, and energy use[14]. Using the Experian references in ND-NEED it was possible to add a contact telephone number. Analysis shows that the scope of BEES includes 89 per cent of premises floor area in England & Wales. The number of surveys per sub-sector was determined based on their overall size with a minimum of 50 surveys sought where possible. Overall 1 per cent of floor area has been surveyed based on the sub-sectors in scope.
2. **Data collection** – A sub-sector tailored telephone survey, supplemented with data from a more detailed site survey in a subset of cases, was used to gather the information required to model the energy end uses within these premises.
    - The telephone survey involved a single stage and took around 25 minutes to complete. It gathered basic information on the premises, its servicing and usage. It also included sub-sector specific key questions to gather further data on the most significant energy end uses. These questions were designed with input from expert interviewers and, if necessary, trial site surveys at the design stage of the research programme. The survey was conducted with the person responsible for energy management, building management or another suitable manager.
    - A limited number of site surveys were undertaken on the telephone survey sample. The candidates were selected based on a range of characteristics such as energy intensity, location and floor area size. The site surveys gathered detailed information on the energy end use consumption, activities (extent and intensity), abatement potential and the barriers and facilitators to implementing energy efficiency measures in the premises. The outputs were used to test the energy use and abatement models. Data collected on site was also used to correct and overwrite findings from the initial telephone survey. The data on barriers was collected via semi-structured face to face interviews.
3. **Data cleansing** - Prior to modelling, the data were cleansed firstly through record exclusion. Records were screened for outliers, then they were reviewed for quality. The outlier analysis was based on typical operating metrics, such as occupancy level (the number of square metres per person in a premises). Where extreme values were identified the record would be removed. The quality assurance process identified the proportion of questions for which a response was required to model energy use. Any records which failed to meet the minimum data quality thresholds, measured by the percentage of 'don't know' responses were excluded. Exclusion of these records was deemed necessary on the grounds that a significant prevalence of 'Don't know' responses was considered indicative of a respondent who lacked engagement or had a poor understanding of their premises' core services and equipment. Within the health sector, a total of 192 telephone survey or equivalent records were collected – following the record exclusion process a total of 166 records were retained for analysis. In this sector the share of records excluded was moderately low (14 per cent of total), as many of the records in the available sample yielded a low proportion of 'Don't know' responses, considered to indicate poor record reliability, while others did not have a reliable matched floor area.
4. Secondly, record amendment was conducted on the remaining data. The remaining

[14] The BEES sector and sub-sector classifications were based on a bespoke classification developed from VOA data of Special Category Code (SCAT) and Property Description.

records were reviewed and in some cases data amended to overcome isolated yet important instances of ‘Don’t know’. These amendments were applied to the telephone survey dataset. Where telephone survey records contained a ‘Don’t know’, the response was estimated where possible based on the most likely response based on what was typical for the premises, or was proxied based on other question responses[15].

5. **Data processing** – Two models were used to process the cleaned telephone survey outputs. The **energy use model** was used to estimate the energy use in each premises, and the **abatement model** was used to estimate the cost and abatement potential of different abatement measures if they were to be installed in that premises. These models are outlined below, for more details see the technical annex. It should be noted that all processed outputs relate to the time when the original data was collected.[16]
    - The energy use model used an energy calculator to estimate a premises energy consumption, split by end use and fuel type, based on the cleaned telephone survey responses. A calibration process was carried out for each sub-sector to map telephone survey responses to different values of parameters in the energy calculator. This calibration was based on alternative data sources, previous knowledge of the sub-sector and the site surveys. The energy use mode did not take dynamic effects or building geometry into account, given the nature of the telephone survey data.
    - The abatement model used the cleaned telephone survey outputs and a set of relatively simplistic measure applicability rules to assess whether or not different abatement measures were applicable to a particular premises. The effect of applicable measures was estimated by changing relevant parameters in the energy calculator and recalculating the energy consumption of the premises.
6. **Weighting** – All the data generated was weighted upwards to represent the sub-sector population, based on the likelihood the premises was selected and on the overall share of floor area in the achieved sample.

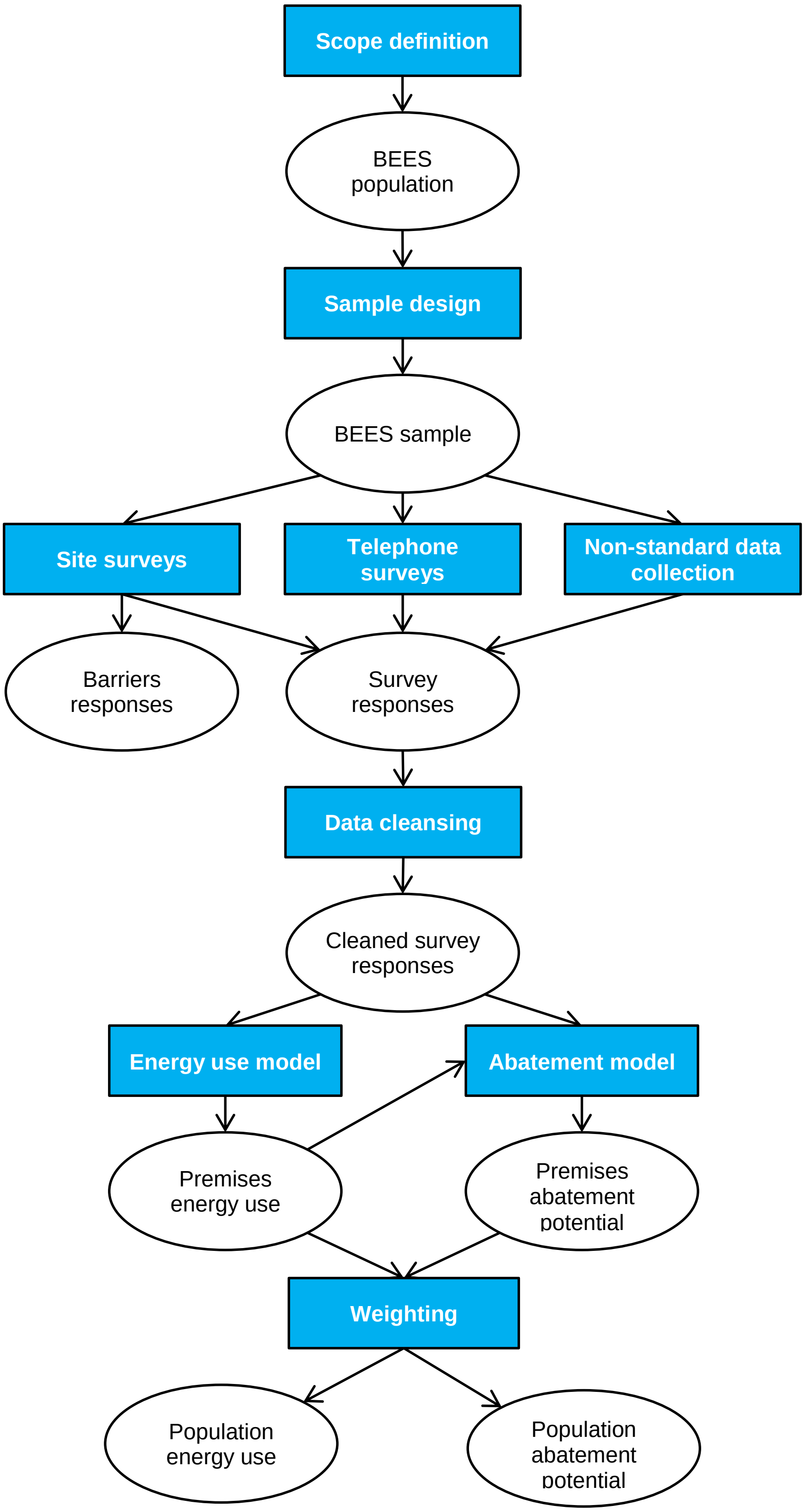
This approach was then tailored by sector. The impact of the change to the methodology within the storage sector is covered in “Methodology challenges in the storage sector”, which follows in this section, and in more detail in Appendix B.

All estimates shown in this report are point estimates and subject to uncertainty as they are based on survey findings. Confidence intervals are shown in Appendix A at sub-sector level for energy intensity for electrical and non-electrical uses.

[15] For example, in one sub-sector a small number of respondents gave a ‘Don’t know’ response to the question “Do you use electricity to heat tap water and/or showers and if so how much?”. The vast majority of responses to within the sub-sector were ‘None’, so this was used as a proxy as it was deemed to be suitably representative of the sample. The energy consumption for these sites was also checked in each instance for any evidence that water was heated with non-electrical fuel.

[16] Data collection for the Building Energy Efficiency Survey in its entirety occurred over 18 months from late 2013 to mid-2015.

Figure 2.1: Methodology flowchart



Methodology challenges in the storage sector

For storage sub-sectors there were a number of deviations required from the 'standard' BEES methodology in order to address the limitations of available datas and to overcome modelling challenges. A summary of further specific issues encountered is set out below and a full description is included in Appendix B.

- **Data collection** No site surveys could be recruited for cold stores; this limited the richness of information available for calibrating energy use models, and prevented further verification of the telephone survey data quality.
- **Data processing** Estimation of the energy used for refrigerating cold storage areas was challenging, especially due to the limitations encountered in data collection in terms of sample sizes achieved and the number of site surveys completed in cold stores. A benchmark-based model was developed using data from research conducted by the European Commission and the Californian Energy Commision[17],in order to generate plausible estimates. This means the results in cold stores were less based on primary evidence gathered than in other sub-sectors.
- **Data processing** Heating systems in storage premises were highly mixed, with multiple systems, unheated spaces, varied set points and controls and air leakage to outside very common. The energy model was unable to take account of sufficient variables to achieve a good correlation with matched energy data. As a result the space heating consumption is presented with low confidence, which in this sector accounts for 46 per cent of total consumption.

[17] CEC, 2008, Energy Benchmarking of Warehouses for Frozen Foods available at: http://ucce.ucdavis.edu/files/datastore/234-1194.pdf and EU, 2009, Improving cold storage equipment in Europe available at: https://ec.europa.eu/energy/intelligent/projects/sites/iee-projects/files/projects/documents/ice-e_ice_e_publishable_report_en.pdf

3. Energy consumption

This section presents a series of summary charts and tables detailing the results of the energy use modelling undertaken during the analysis of the storage sector.

Energy consumption and greenhouse gas emissions in the storage sector

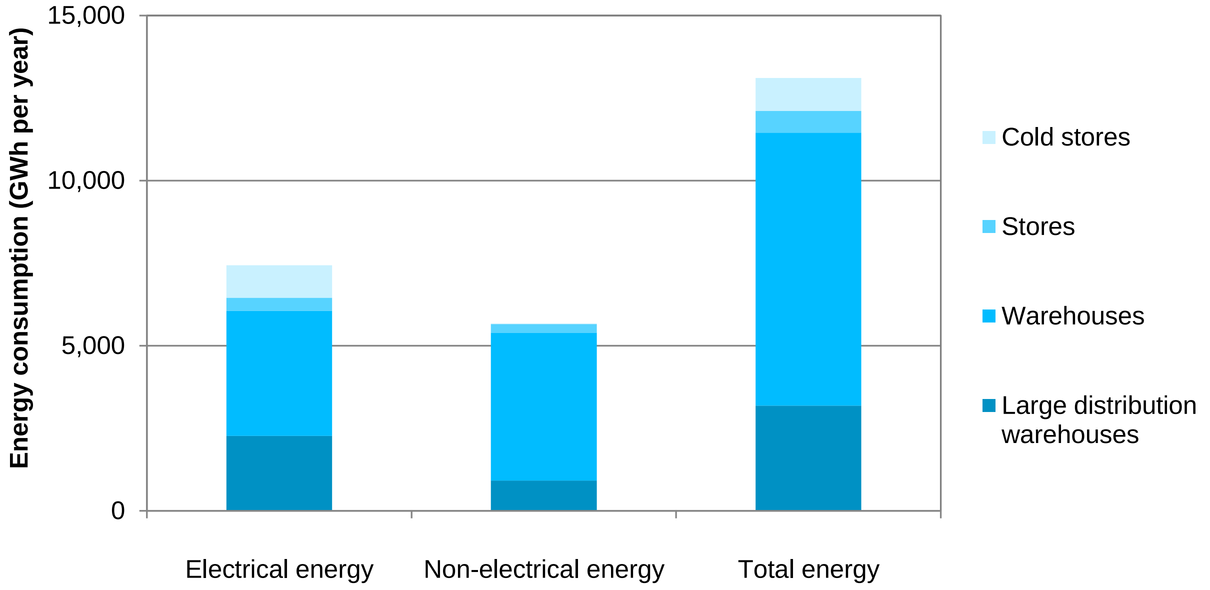
The total energy consumption, electrical and non-electrical energy consumption of the storage sector is presented in Figure 3.1, broken down by the four storage sub-sectors (large distribution warehouses, warehouses, stores and cold stores).

The storage sector consumed 13,110 GWh of energy. This consisted of 7,440 GWh of electrical energy and 5,670 GWh of non-electrical energy per year (Figure 3.1).

The energy consumer in this sector was warehouses with a consumption of 8,270 GWh of energy (63 per cent of total). This was split between 3,790 GWh of electrical energy (51 per cent of sector total) and 4,480 GWh of non-electrical energy (79 per cent of sector total). This was partly due to this sub-sector being the largest in the storage sector (100 million m^2 compared with 27 million m^2 for large distribution warehouses and 11 million m^2 for stores).

Large distribution warehouses were the second largest consumers in the sector, with a consumption of 3,180 GWh of energy (24 per cent of total). This consisted of 2,270 GWh of electrical energy consumption (31 per cent of sector total) and 910 GWh of non-electrical energy consumption (16 per cent of sector total). Stores were the smallest consumers in the sector with a consumption of 660 GWh (5 per cent of total), which was split into 400 GWh of electrical energy (5 per cent of sector total) and 260 GWh of non-electrical energy (5 per cent of sector total).

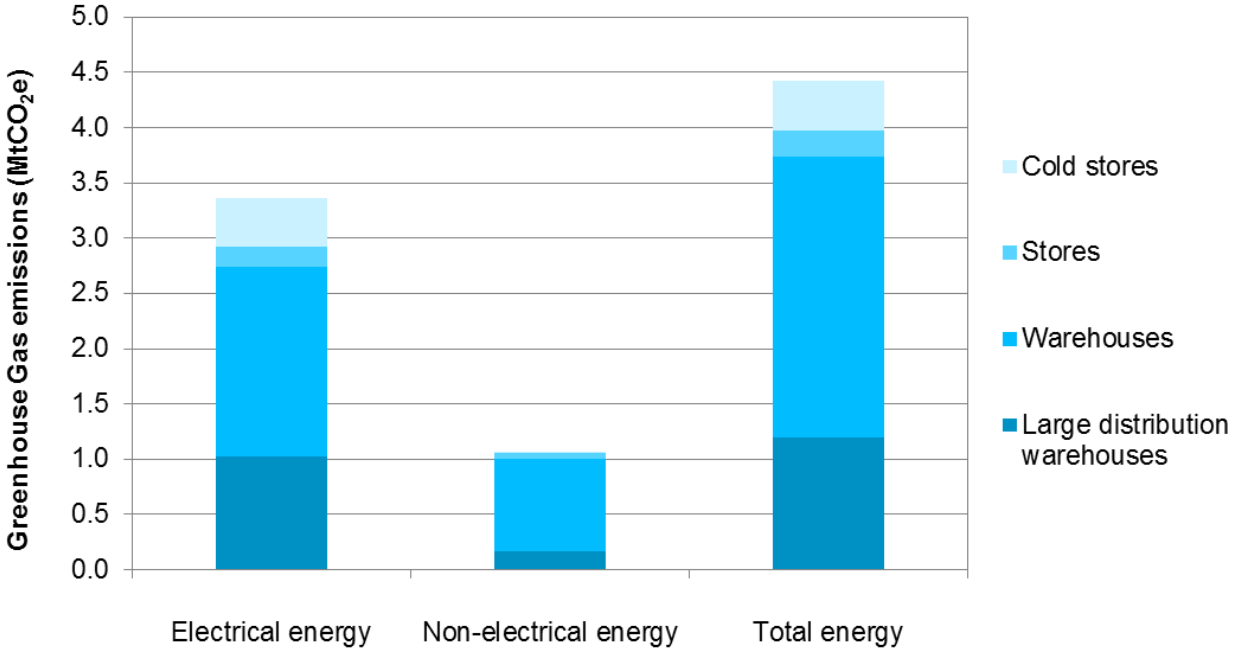
Figure 3.1: Electrical and non-electrical energy consumption by energy type and storage sub-sector, 2014–15



Source: Energy use model results for the sector, England and Wales

The greenhouse gas emissions for the storage sector are presented in Figure 3.2.[18] The total greenhouse gas emissions from the storage sector were deemed to be 4.4 $MtCO_2e$ per year. The annual emissions from electrical energy consumption were 3.4 $MtCO_2e$ and those from non-electrical energy consumption were 1.1 $MtCO_2e$.

Figure 3.2: Greenhouse gas emissions by energy type and by storage sub-sector, 2014–15



Source: Energy use model results by sub-sector, England and Wales

Energy consumption by end use

The distribution of energy consumption by end use is presented in Figure 3.3 and Table 3.1.[19]

The energy use model defines 23 separate energy end uses in its analysis. These are derived by modelling the telephone survey inputs and calibrated using site survey data. For the purposes of presentation in Figure 3.3 the 23 uses have been simplified to six categories, covering key building services end uses (heating, hot water, lighting, fans, cooling & humidification and other) and one custom category relevant to the sector (cooled storage). The simplified classification is shown against the more detailed classification results in Table 3.1.

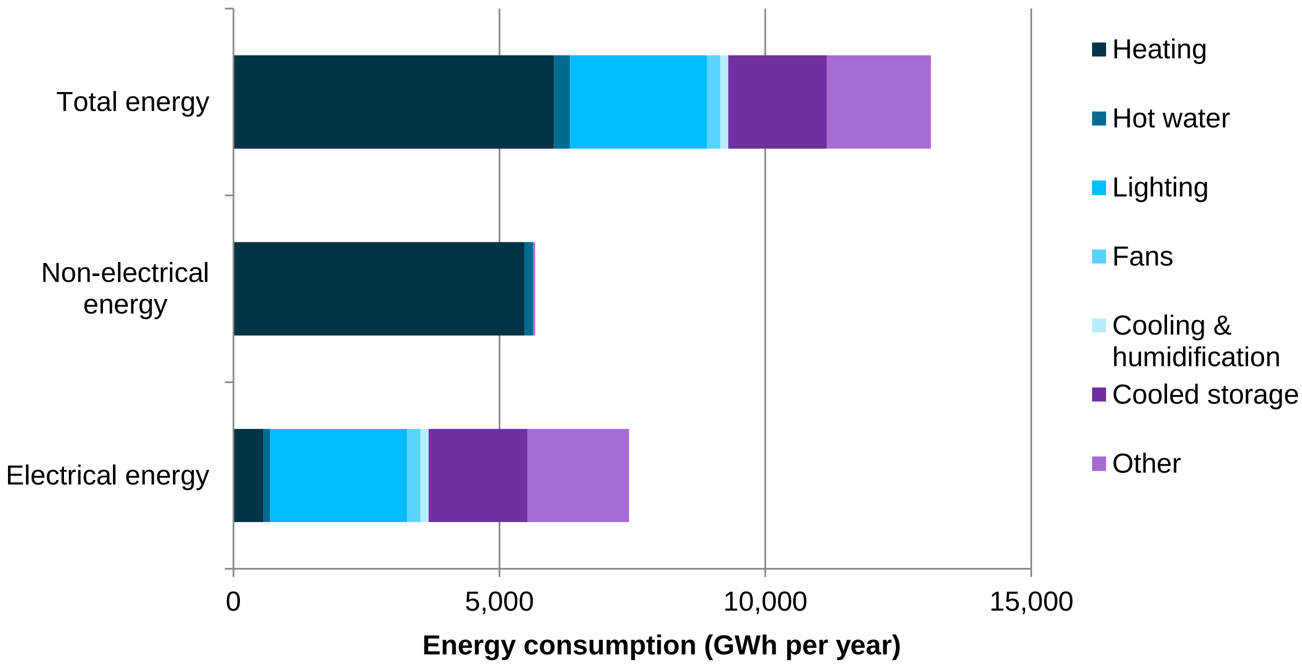
Further detail can be found in Appendix C on the 23 end uses and how these are re-categorised to seven categories.

[18] Greenhouse gas emissions were estimated using energy consumption figures from the energy use model and grid average electricity and fuel emission factors from IAG guidance on valuing greenhouse gas emissions published by DECC, updated on 10 December 2015. See https://www.gov.uk/government/publications/valuation-of-energy-use-and-greenhouse-gas-emissions-for-appraisal for further information.

[19] In the context of the BEES study, small power represents office equipment (comprising computers, printers and ancillary desktop equipment). Other plug-in loads are disaggregated into entertainment equipment, catering, pool/leisure equipment etc.

The total energy consumption for the storage sector was 13,110 GWh. The most significant end use was space heating (6,030 GWh, 46 per cent of total energy consumption), followed by internal lighting (2,580 GWh, 20 per cent of total). The most common end uses of electrical energy were internal lighting at 2,580 GWh (35 per cent of total), followed by small power (1,850 GWh, 25 per cent) within the other category. The next major end uses included space heating (560 GWh, 8 per cent) and cooled storage (390 GWh, 5 per cent). The most significant non-electrical energy end uses were space heating at 5,470 GWh (96 per cent) followed by hot water (170 GWh, 3 per cent). Non-electrical energy consumption for heating was much higher than electrical energy consumption (5,470 GWh compared with 560 GWh).

Figure 3.3: Energy consumption by simplified end use breakdown for the storage sector, 2014–15



Source: Energy use model results for the sector, England and Wales

Table 3.1: Energy consumption by energy type and energy end use for the storage sector, 2014–15

Energy end use category (Simplified)	BEES end use category[20]	Electrical energy consumption (GWh/year)	Non-electrical energy consumption (GWh/year)	Total energy consumption (GWh/year)
Heating	Space heating	560	5,470	6,030
Hot water	Hot water	120	170	290
Cooling & humidification	Space cooling	150	-	150
Fans	Fans	250	-	250
Lighting	Lighting - internal	2,580	-	2,580
Cooled storage	Cooled storage	390	-	390
Other	Catering	60	40	90
	Small power	1,850	-	1,850
	Pumps	60	-	60
	Controls	40	-	40
	Lighting - external	330	-	330
	ICT equipment	270	-	270
	Vertical transport	10	-	10
	Entertainment equipment	20	-	20
	Pool/leisure	-	-	-
	Other	760	-	760
Total		**7,440**	**5,670**	**13,110**
Unweighted base		*398*	*278*	*398*

Source: Energy use model results by sub-sector, England and Wales

Storage sector energy intensity distributions

Energy intensity (energy use per m^2 floor area) enables activities across sectors to be compared, and is used for benchmarking in the building services industry.[21] Figure 3.4, figure 3.5 and Figure 3.6 presents the distribution of energy intensity for all modelled records in each sub-sector within the storage sector, in terms of total energy intensity, electrical energy intensity and non-electrical energy intensity respectively.[22] In this report all intensity figures (excluding box plots) have been calculated using the total sector or sub-sector floor area regardless of whether they have a particular energy source or end-use.

Figure 3.4 shows that cold stores had the highest total median energy intensity (312 kWh/m^2), followed by large distribution warehouses (81 kWh/m^2). Figure 3.5 and Figure 3.6 shows that

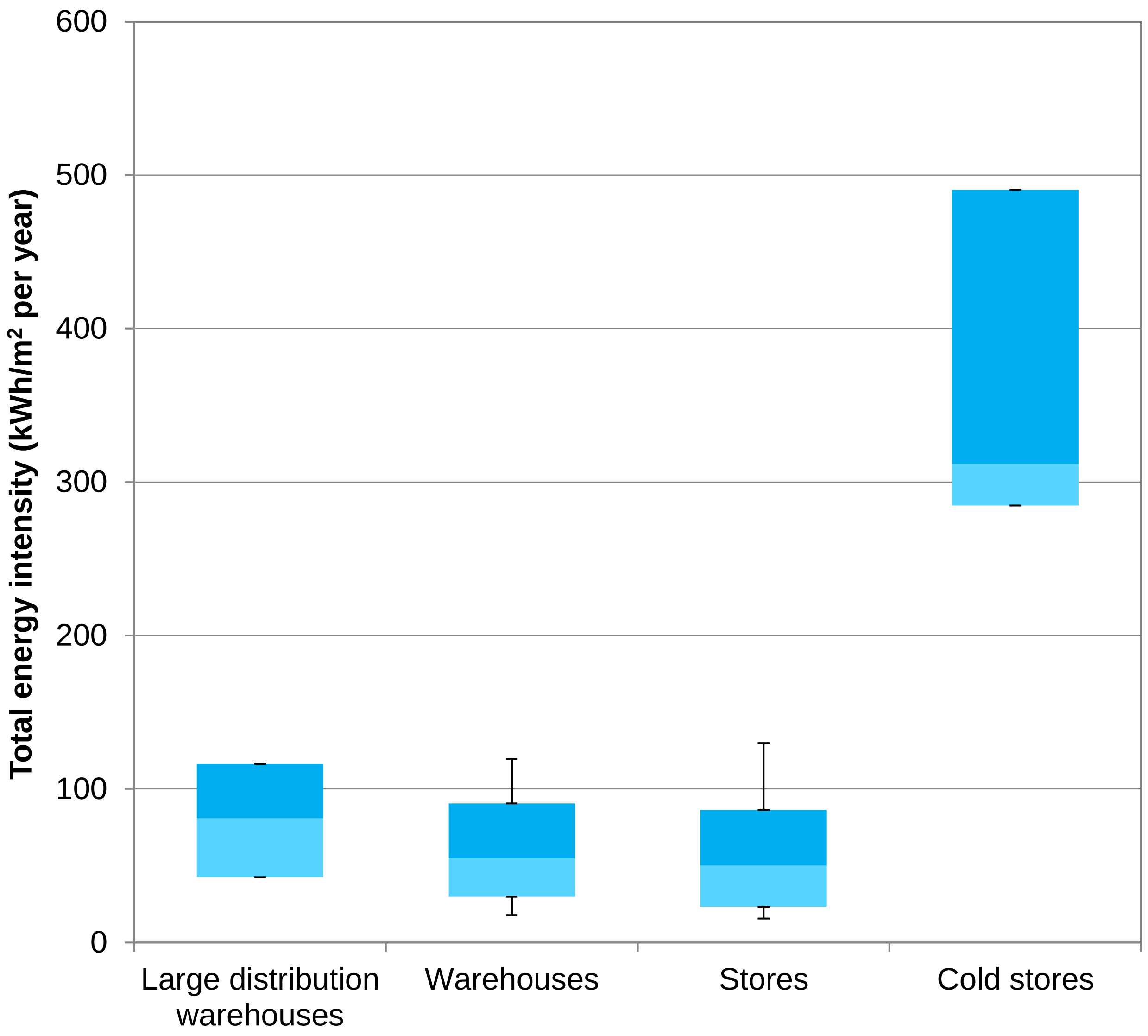
[20] The end uses are defined in Appendix C.

[21] As employed in CIBSE TM46 Energy Benchmarks (available at: http://www.cibse.org/knowledge/cibse-tm/tm46-energy-benchmarks), and others.

[22] Please note mean energy intensities are calculated by summing the total consumption associated with an end use and dividing it by the sub-sectors total floor area. The energy intensities for non-electrical uses are therefore based on the total population and do not make an allowance for where the main heating fuel is electricity.

cold stores typically displayed the highest median electrical energy intensity (310 kWh/m^2). The second most energy intensive sub-sector in terms of electrical energy was large distribution warehouses (47 kWh/m^2). Warehouses displayed the highest median non-electrical energy intensity of 27 kWh/m^2, followed by large distribution warehouses (16 kWh/m^2).

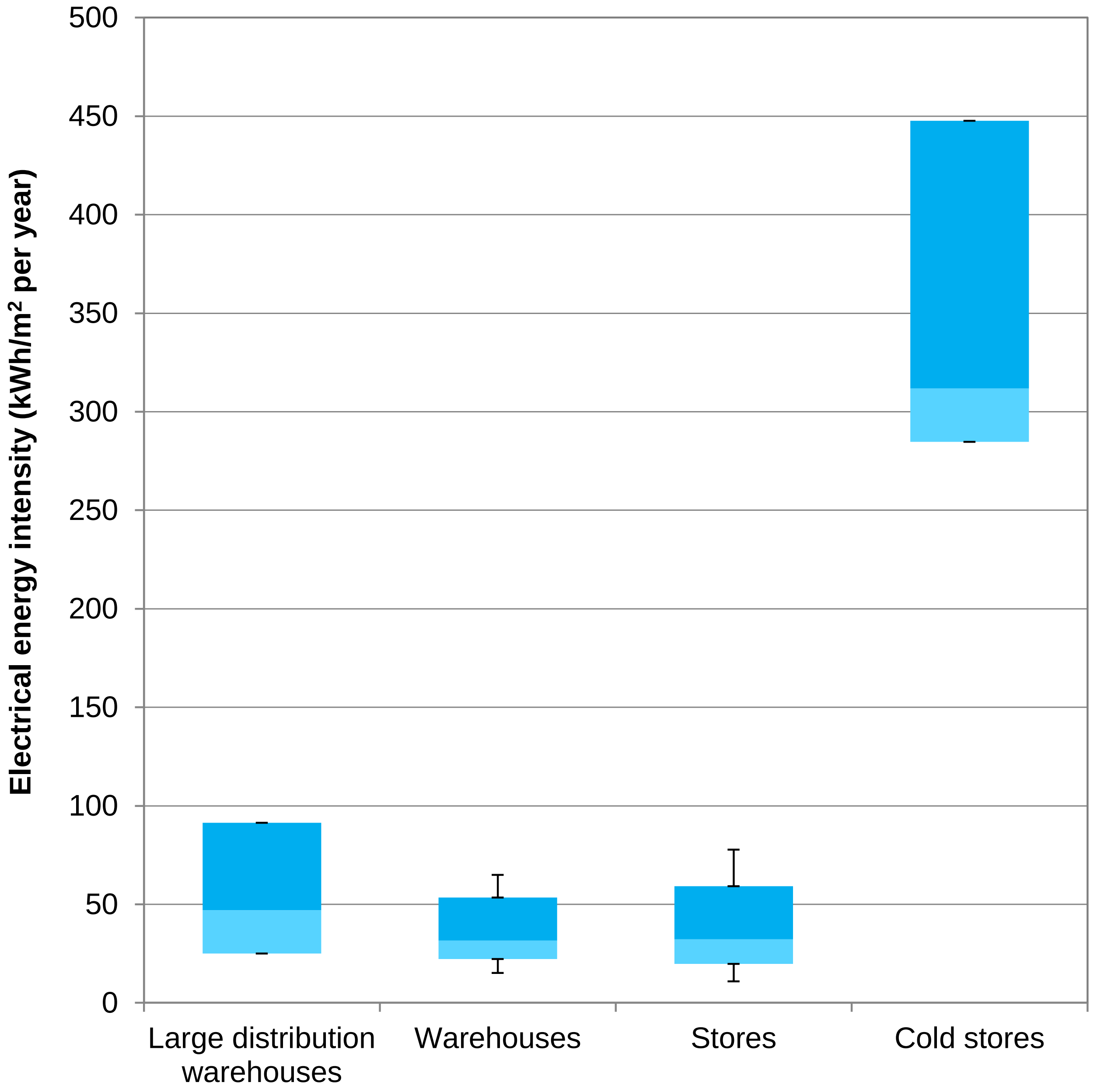
Figure 3.4: Distribution of total energy intensity by storage sub-sector, 2014–15



Note: In box and whisker plots, the blue columns, when combined, indicate the range of floor areas covered by the interquartile range of results (the middle 50 per cent of data points). The upper black bars extend to the 90th percentile, capturing a further 15 per cent of the total number of data points. The lower black bars span to the 10th percentile, also capturing 15 per cent of the total number of data points. Therefore within each sub-sector, 80 per cent of the total number of data points are displayed, with the outlying maxima and minima (10 per cent of data points each) excluded. For series with fewer than 50 data points, the black bars are excluded.

Source: Energy use model results by sub-sector, England and Wales

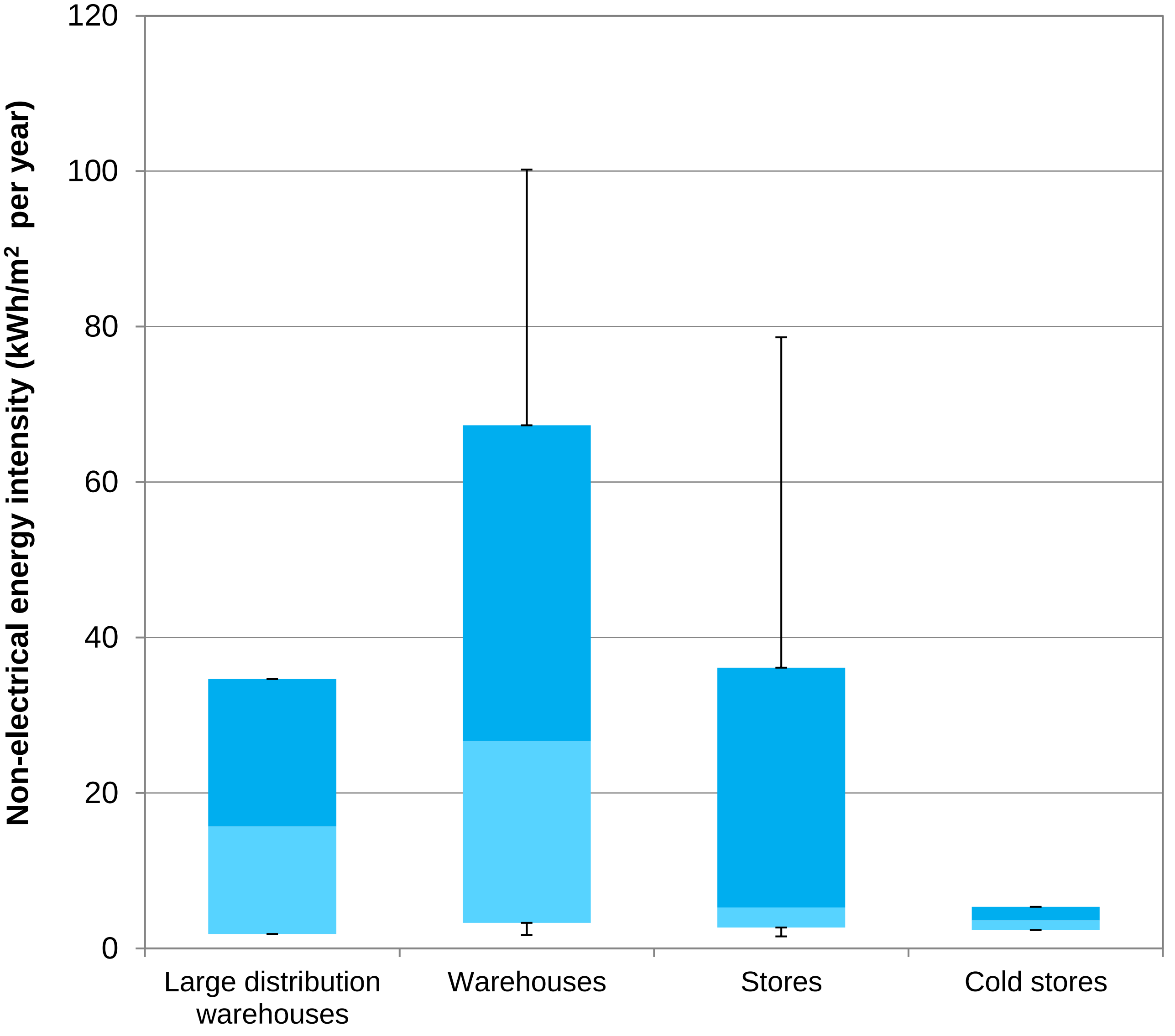
Figure 3.5: Distribution of electrical energy intensity by storage sub-sector, 2014–15



Note: In box and whisker plots, the blue columns, when combined, indicate the range of floor areas covered by the interquartile range of results (the middle 50 per cent of data points). The upper black bars extend to the 90th percentile, capturing a further 15 per cent of the total number of data points. The lower black bars span to the 10th percentile, also capturing 15 per cent of the total number of data points. Therefore within each sub-sector, 80 per cent of the total number of data points are displayed, with the outlying maxima and minima (10 per cent of data points each) excluded. For series with fewer than 50 data points, the black bars are excluded.

Source: Energy use model results by sub-sector, England and Wales

Figure 3.6: Distribution of non-electrical energy intensity by storage sub-sector, 2014–15



Note: In box and whisker plots, the blue columns, when combined, indicate the range of floor areas covered by the interquartile range of results (the middle 50 per cent of data points). The upper black bars extend to the 90th percentile, capturing a further 15 per cent of the total number of data points. The lower black bars span to the 10th percentile, also capturing 15 per cent of the total number of data points. Therefore within each sub-sector, 80 per cent of the total number of data points are displayed, with the outlying maxima and minima (10 per cent of data points each) excluded. For series with fewer than 50 data points, the black bars are excluded.

Source: Energy use model results by sub-sector, England and Wales

Storage sub-sector energy end use breakdowns

Figure 3.7 shows the mean modelled energy intensity by end use for each of the sub-sectors in the storage sector. Further data is provided in Appendix C where energy consumption and energy intensity are provided separately for electrical and non-electrical energy end use breakdowns by sub-sector.

Heating was the dominant end use within the storage sector (46 per cent of total energy consumption). Heating intensity was highest in warehouses and large distribution warehouses. Premises in these sub-sectors tended to be occupied by staff during operational hours, and a higher proportion of the storage area was reported to be heated than in stores, where unheated storage areas were more common. Hot water intensity was low in all sub-sectors, which was linked to low occupancy levels in these premises.

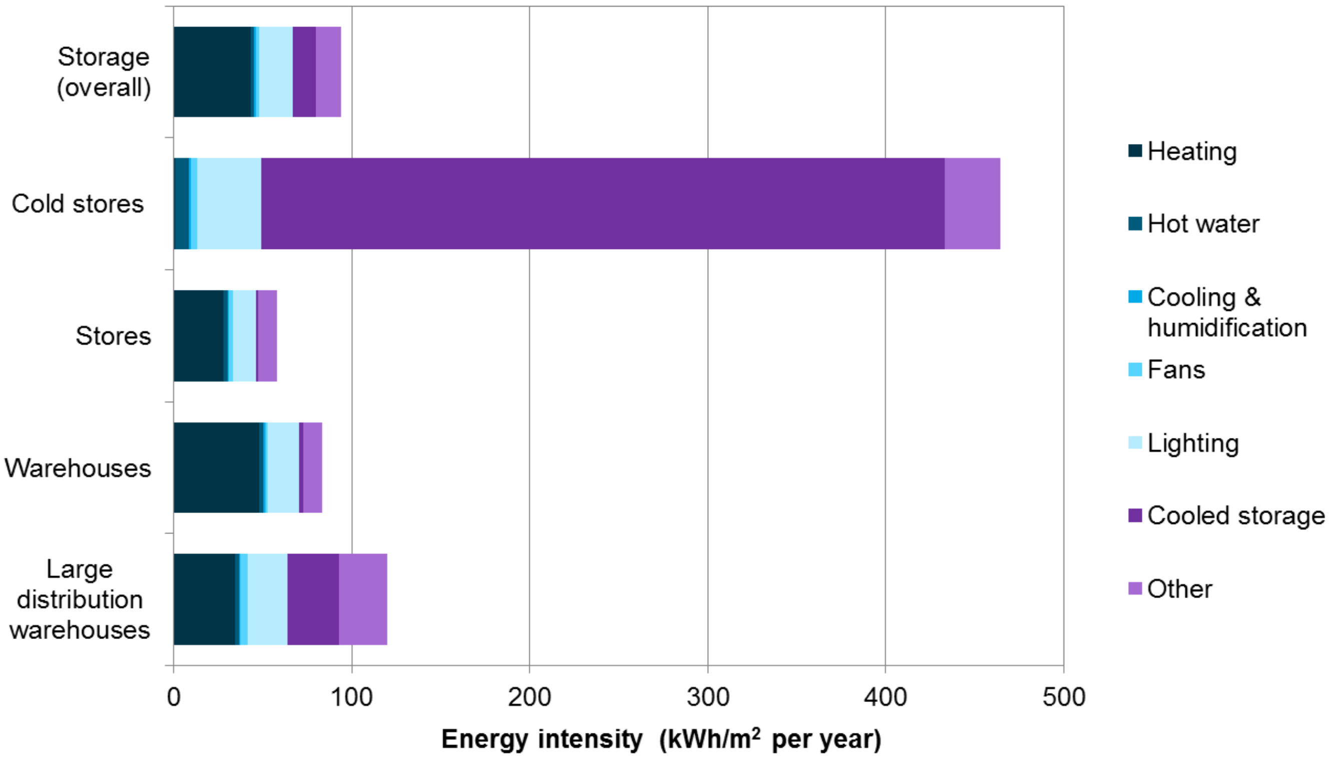
Lighting consumption was also significant in the storage sector (20 per cent of total consumption). Lighting intensity was lowest in stores where unoccupied spaces were more common, and lighting was more likely to be switched off during working hours. In contrast, in warehouses and large distribution warehouses it was noted that lighting was commonly left on during working hours even in spaces that were only occasionally visited by staff. Large distribution warehouses had slightly longer operational hours than warehouses, and this contributed to a slightly higher lighting intensity.

Energy consumption for fans and cooling & humidification was minimal in all sub-sectors. In the majority of cases this was only found in areas with high occupancy such as offices or meeting rooms, or special areas such as server rooms.

Energy consumption from manual handling and automation equipment (e.g. forklifts, robot cranes, conveyor belts) was the main contributor to the “other” category. This was particularly prevalent in large distribution warehouses, which had the highest energy intensity for “other” end uses, and automated stock handling was common in this sub-sector. Staff catering was also reported in a number of cases, especially in larger premises.

Cold stores were distinct from the other sub-sectors in this sector, as the majority of their floor area was dedicated to refrigerated storage with minimal supporting areas such as offices reported in the telephone survey. As a result, cooled storage energy consumption dominated the energy end use breakdown in this sub-sector, followed by lighting. It should be noted that due to a small sample size and lack of site surveys, data for cold stores is presented with low confidence. Cold storage areas were also present in premises in the other storage sub-sectors, particularly large distribution warehouses.

Figure 3.7: Mean energy intensity simplified end use breakdowns by storage sub-sector, 2014–15



Source: Energy use model results by sub-sector, England and Wales

4. Abatement potential

In this section, abatement potential[23] for the storage sector is considered. Abatement potential is calculated on a sub-sector and sector level.

Abatement method

In order to determine the abatement potential for each premises record, the abatement model identified appropriate abatement measures based on the responses from the telephone survey, and then calculated the energy saved by the measure compared with existing equipment based on the energy end use energy consumption calculated in the energy use model. Appendix D provides more detail on the main groupings of abatement measures, and the technical annex sets out a detailed explanation of the abatement model. The abatement model calculates 95 individual measures, but these have been grouped into larger categories, within each group of measures there will be some measures that are more cost-effective than others for the sector and sub-sectors. Some cost effective measures will therefore be hidden within groups that are not considered cost effective as a whole.

The abatement potential was calculated on the basis of replacing current equipment with a more efficient alternative, regardless of the age or efficiency of this current equipment. This captured the entire technical potential available. It did not take into account the likelihood of equipment being replaced as part of a planned replacement cycle or whether take-up would be limited due to barriers or site-specific factors.

The costs were based on standardised absolute installation costs[24], while the benefits were only based on the incremental reduction in energy consumption[25]. Replacement of systems which were not at the end of their life were therefore included, but will be more expensive, as the impact on energy consumption is likely to be smaller for new equipment, while the full capital costs are taken into account. This means that a measure may be cost-effective if the system is replaced at the end of its life, especially as at the end of life the cost of the more energy efficient alternative would be compared to replacement with a less efficient alternative - but, the same measure may not be cost-effective if the system is replaced earlier in its life. Replacing measures at the end of life will be less costly for organisations, but it would take longer for the full potential to be realised. While the costs include an allowance for installation costs and hassle costs, this may not include all the wider disruption costs that may be faced by organisations upgrading equipment; for example it does not factor in the costs of relocating staff if it is not possible for staff to work on site while work is underway. The extent to which organisations face these costs will depend on whether upgrades are scheduled as part of a wider refurbishment.

To account for the impact of interactions between measures - for example if more efficient lights are installed the impact of using better lighting controls is smaller - the abatement measures in each premises were ordered by their return on investment. This way the impact of installing

[23] Abatement potential refers to the potential to improve the energy efficiency of the premises in a given sub-sector.

[24] The total cost consists of the capital cost, installation cost and annual operational costs. These costs were based on the costs of existing installations in non-domestic buildings.

[25] Supplementary guidance to the HM Treasury Green Book on Appraisal and Evaluation in Central Government: https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/483278/Valuation_of_energy_use_and_greenhouse_gas_emissions_for_appraisal.pdf

cheaper measures was taken into account first before calculating the impact of more expensive measures.

The calculated costs and energy savings were weighted to represent the whole sub-sector and storage sector throughout England and Wales.

Total technical abatement potential for storage sector

The abatement potential for each sub-sector where it is available is shown in Table 4.1 and Figure 4.1. The total abatement potential was between 25 and 45 per cent of total energy[26]. Each sub-sector can achieve between 23 to 40 per cent savings in electrical energy consumption and 42 to 49 per cent savings in non-electrical energy consumption. This could be achieved at an overall capital expenditure of £2.48 billion.

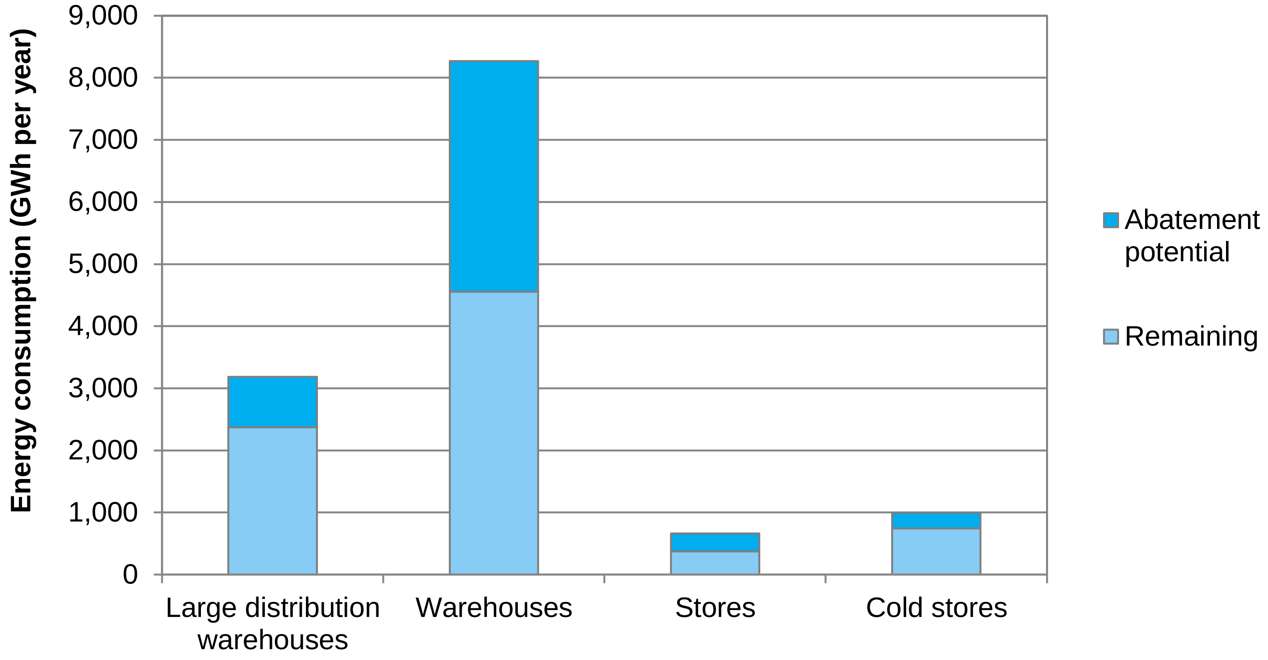
Table 4.1: Abatement potential by storage sub-sector, 2014–15

		Baseline		Abatement potential		
Sub-sector	**Capital Expenditure required to deliver abatement potential (£ thousands)**	Annual electrical energy consumption (GWh)	Annual non-electrical energy consumption (GWh)	Annual electrical energy savings (GWh)	Annual non-electrical energy savings (GWh)	Overall reduction (per cent)
Large distribution warehouses	280,400	2,270	910	520	390	28
Warehouses	1,690,700	3,790	4,480	1,510	2,180	45
Stores	390,300	400	260	160	110	41
Cold stores	122,400	980	10	250	7	25
Total	**2,483,700**	**7,440**	**5,670**	**2,430**	**2,690**	**39**

Source: Abatement model results for the sector by sub-sector, England and Wales

[26] All costs, energy and carbon savings are based on 2015 values and sourced from Interdepartmental Analysts' Group reference tables available at https://www.gov.uk/government/publications/valuation-of-energy-use-and-greenhouse-gas-emissions-for-appraisal. The costs presented are nominal.

Figure 4.1: Abatement potential by storage sub-sector, 2014–15

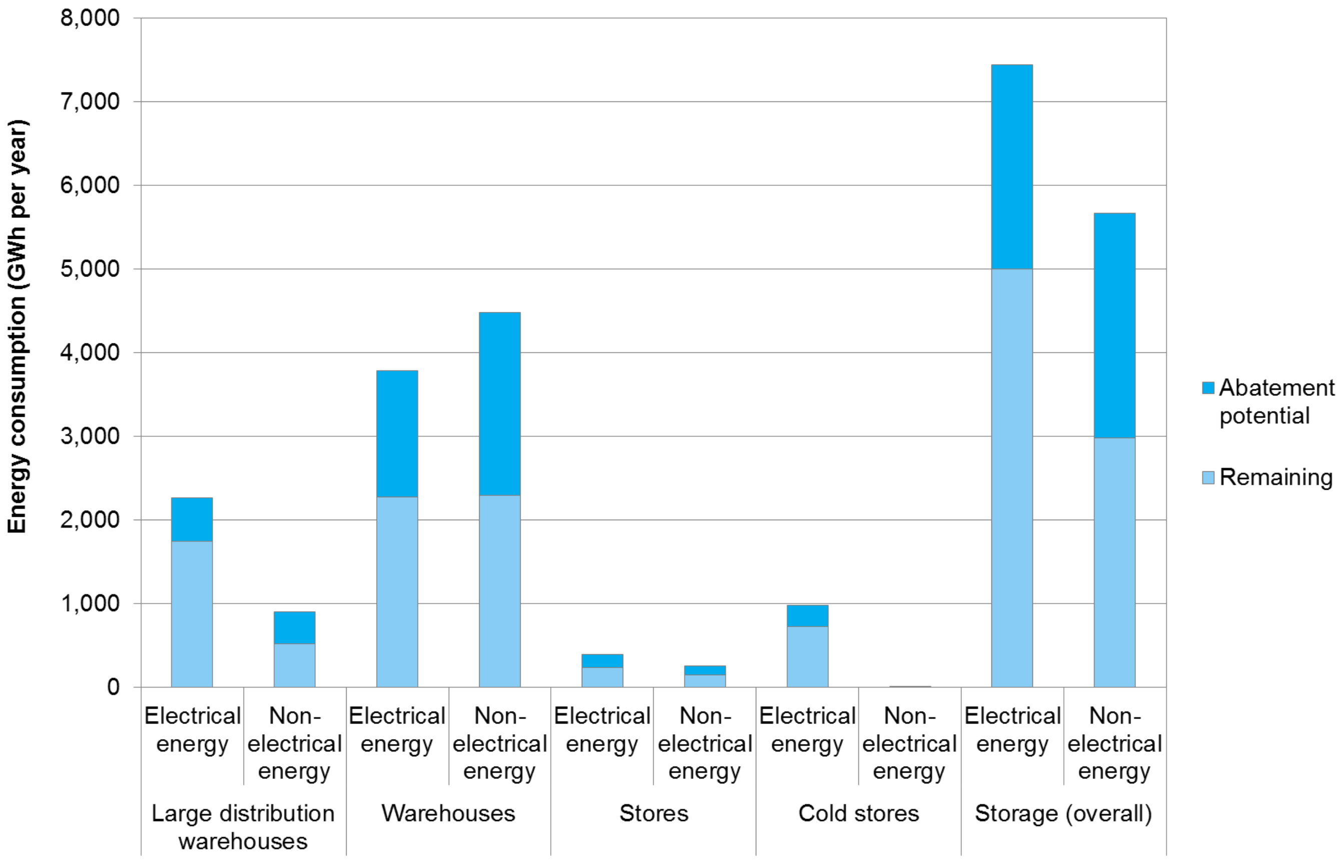


Source: Abatement model results by sub-sector, England and Wales

Figure 4.2 shows that the total technical abatement potential in 2014–15 varied by sub-sector: Warehouses had the largest absolute and proportional scope for reduction (45 per cent of total energy consumption). This compared with 28 per cent in stores and 25 per cent in both large distribution warehouses and cold stores.

The results were separated into electrical and non-electrical energy. On a percentage basis there was significantly more abatement potential associated from savings in non-electrical energy use. This is likely due to the high prevalence of non-electrical energy being used as a fuel for space heating and building instrumentation and controls, and the associated savings from related abatement measures. Further detail of the abatement potential for each sub-sector is provided in Appendix D.

Figure 4.2: Abatement potential by energy type and storage sub-sector, 2014–15



Source: Abatement model results by sub-sector, England and Wales

Marginal Abatement Cost Curve

As well as the total abatement potential and the costs of delivery, it is important to understand the overall cost-effectiveness of measures. Using the abatement model it was possible to assess the costs and benefits of measures from the point of view of society as a whole, by following Government guidance on the valuation of energy use and emissions.[27] This takes into account the capital expenditure, operational expenditure, social cost of energy, air quality impacts, and value of emissions, all discounted at the social discount rate. While this includes the main categories of costs, it was not possible to include the costs and benefits of all impacts on occupants: for example some measures may provide a potentially better occupant experience through improved illumination, or a potentially worse occupant experience through lack of control over light switches.

A measure is socially cost effective if the total social benefits outweigh the total social costs of the measure across the lifetime of the measure. This is a static measure of cost effectiveness based on current expected costs and benefits - for example this does not take into account potential reductions in capital costs that could result from more of that technology being installed. To enable groups of measures to be compared, a metric of social-cost effectiveness was calculated: Net Present Value of costs and benefits (NPV) divided by total energy savings over the lifetime of the measures in the group and plotted on a Marginal Abatement Cost Curve (MACC), which shows the level of abatement opportunity available and the costs associated with this opportunity if they were all implemented in 2014–15. The MACC in Figure 4.3.

graphically represents each group of abatement opportunities as a block. The width of the block represents the total amount of abatement the measure can deliver in GWh and the height represents the cost-effectiveness. Because the measure groups are ranked by cost-effectiveness, the most cost-effective (delivering abatement at the least-cost per GWh) will be found on the left of the diagram. Moving to the right, measure groups become subsequently more costly.

As the MACC assesses cost from a societal perspective, we have supplemented this by providing the simple private payback periods for each measure group to help show how attractive these measures might be for individual organisations on the basis of how long it takes to recoup the costs of measures undertaken from the energy savings generated. Note that the payback period reflects the gross bill savings of the measure alone, rather than the bill savings that would be achieved by the measure if all other measures were installed.

The total abatement potential of the socially cost effective measure groups was 1,300 GWh, all of which was electrical energy consumption. This represents the energy savings that could be achieved through measures where the benefits outweigh the costs to society. The total abatement potential relating only to measure groups with a private payback of 3 years or less was 900 GWh, of which 410 GWh was electrical energy consumption and 490 GWh non-electrical energy consumption. Within each group of measures there will be some measures that are more cost-effective than others for each sub-sector. Some cost effective measures will therefore be hidden within groups that are not considered cost effective as a whole. Similarly the aggregation of measure groups from the sub-sector level to the sector level may hide

[27] Supplementary guidance to the HM Treasury Green Book on Appraisal and Evaluation in Central Government: https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/483278/Valuation_of_energy_use_and_greenhouse_gas_emissions_for_appraisal.pdf

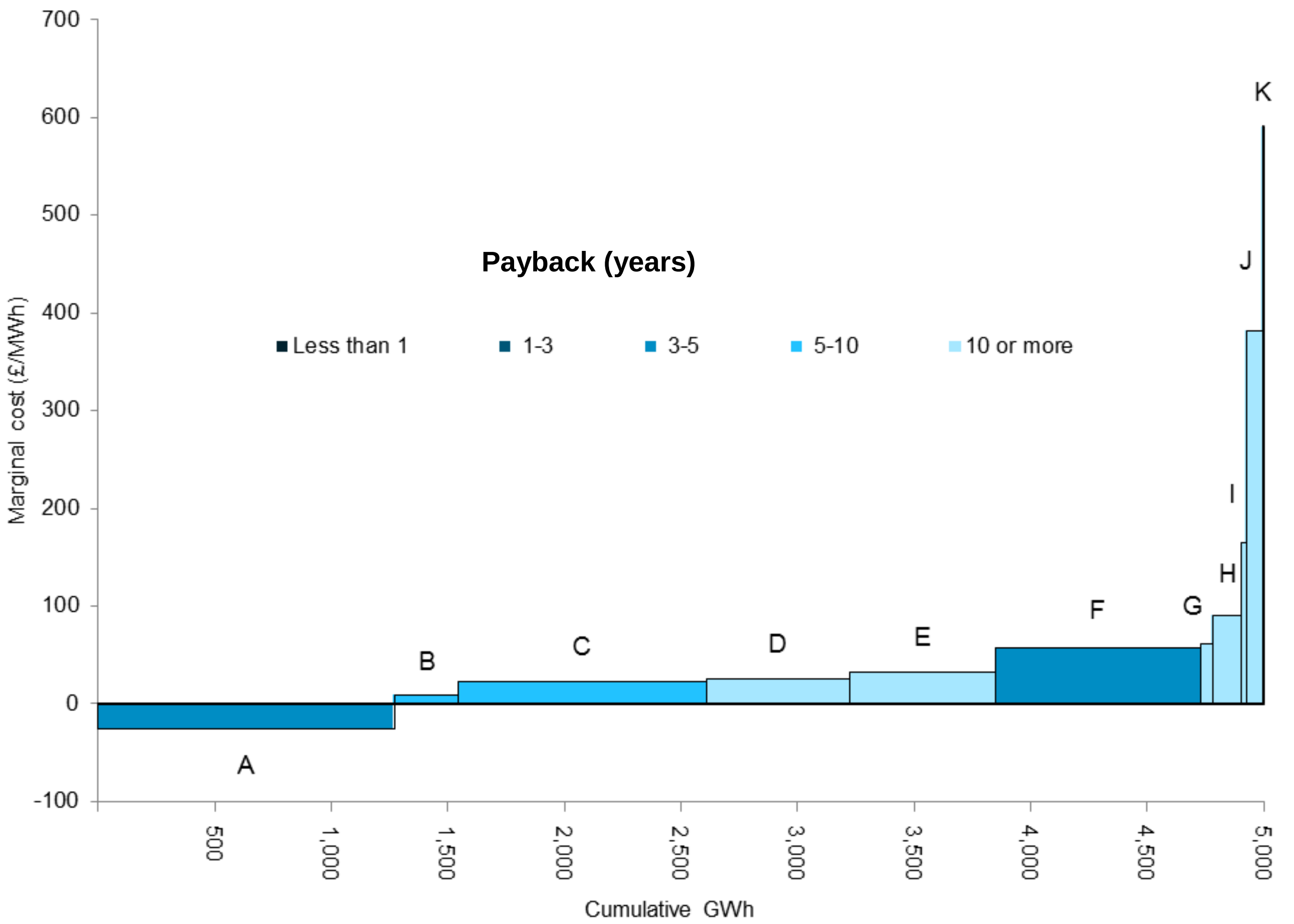
measure groups that are cost effective in a particular sub-sector, but not for the sector as a whole.

Only the lighting measure group was socially cost-effective when measure groups were considered at the sector level. If implemented, this measure group provides more financial benefits to society than costs. The lighting measure group also had relatively low payback periods, suggesting it may be more likely to get taken up, but recognising that take-up will also depend on the extent to which there are barriers.

These modelled findings corresponded broadly with opportunities identified in the site surveys. Typically site surveys identified potential savings associated with carbon and energy management, space heating and lighting upgrades and building instrumentation and controls. In terms of carbon and energy management measures it was found that on some premises the lights were often left on in unoccupied spaces and computers were left on, or in standby mode, when not in use. Furthermore, gas-fired air heaters were sometimes in operation close to shutter doors that were fully open and occupants had access to local heating control panels which led to excessive heating / cooling. In several premises lighting upgrades to LEDs were identified. Many of the surveyed premises were currently fitted with inefficient lighting, such as T8 fluorescent lamps and HID high bay lighting – both more inefficient lamp types when compared to LEDs. The heating systems were also often reasonably old and there was scope for additional optimum start/stop controls on the boilers.

In some cases site surveys identified additional potential to that calculated in the modelled output for a record. Typically this would be the case where an exceptional characteristic had been identified on-site, which related to information, which had not been gathered in the telephone survey. An example of this was to have thermostats located in draughty corridors or large spaces. These were not necessarily reflective of temperatures in the majority of the premises area and therefore likely to result in overheating.

Figure 4.3: Marginal abatement cost curve by measure type, 2014–15



Note: the marginal abatement cost is calculated based on the social cost effectiveness, while the payback period is calculated from a private cost effectiveness perspective.

A Lighting [MAC: £-26 per MWh. GWh: 1,300]

B Cooled storage [MAC: £9 per MWh. GWh: 280]

C Building instrumentation and control [MAC: £23 per MWh. GWh: 1,090]

D Building fabric [MAC: £26 per MWh. GWh: 630]

E Space heating [MAC: £32 per MWh. GWh: 640]

F Carbon and energy management [MAC: £57 per MWh. GWh: 900]

G Hot water [MAC: £61 per MWh. GWh: 50]

H Ventilation [MAC: £91 per MWh. GWh: 130]

I Air conditioning and cooling [MAC: £165 per MWh. GWh: 20]

J Building services distribution systems [MAC: £382 per MWh. GWh: 70]

K Small appliances [MAC: £590 per MWh. GWh: 10]

Source: Abatement model results for the sector, England and Wales

Table 4.2 shows the abatement potential by measure type. The most significant available savings – in terms of a reduction in overall energy consumption and annual energy bill savings – were associated with building instrumentation and control measures, lighting and carbon and energy management measures.

Table 4.2: Abatement potential by measure type, 2014–15[28]

Measure type	Savings					**Total capital cost of measure (£ thousands)**
	Total annual energy bill saving (£ thousands)	Total annual greenhouse gas saving ($ktCO_2e$)	Total annual electrical energy savings (GWh)	Total annual non-electrical energy savings (GWh)	Total annual energy savings (GWh)	
Air conditioning and cooling	2,400	10	20	-	20	55,200
Building fabric	20,000	40	50	570	630	556,100
Building instrumentation and control	35,300	70	100	980	1,090	305,800
Building services distribution systems	6,800	30	70	-	70	177,200
Carbon and energy management	53,500	200	410	490	900	180,600
Hot water	1,800	5	6	50	50	44,100
Humidification	-	-	-	-	-	-
Lighting	128,900	540	1,300	-	1,300	582,500
Cooled storage	27,500	90	280	-	280	143,200
Small appliances	1,200	5	10	2	10	42,300
Space heating	20,600	40	60	580	640	265,300
Swimming pools	-	-	-	-	-	-
Ventilation	11,700	50	120	10	130	131,400
Total	**309,600**	**1,080**	**2,430**	**2,690**	**5,120**	**2,483,700**

Source: Abatement model results for the sector, England and Wales

[28] Annual greenhouse gas emissions were estimated using the energy savings from the abatement model and the long run marginal electricity and fuel emission factors from IAG guidance on valuing greenhouse gas emissions published by DECC, updated on 10 December 2015 (see https://www.gov.uk/government/publications/valuation-of-energy-use-and-greenhouse-gas-emissions-for-appraisal for further information). Measures were assumed to be installed in 2015 and the annual emissions savings averaged over the lifetime of the measure.

Appendix A: Sampling statistics

This appendix provides summary quality statistics for the sample. The confidence intervals by sector for electrical energy intensity and non-electrical energy intensity by sub-sector are provided, and the the telephone survey response rates by sub-sector.

Confidence intervals

Table A.1: Confidence intervals for electrical energy intensity

	Mean (kWh/m^2)	Confidence interval (kWh/m^2)
Cold stores	457	± 63
Large distribution warehouses	85	± 31
Warehouses	38	± 6
Stores	35	± 12
Storage	**53**	**± 13**

Table A.2: Confidence intervals for non- electrical energy intensity

	Mean (kWh/m^2)	Confidence interval (kWh/m^2)
Cold stores	7	± 8
Large distribution warehouses	34	± 15
Warehouses	45	± 11
Stores	23	± 19
Storage	**41**	**± 9**

Response rates

Table A.3: Telephone survey response rates for the storage sector

	Warehouse (%)	Store (%)	Large distribution warehouse (%)	Cold store (%)
Completed interview	10	10	7	7
Still live[29]	27	44	33	27
Screening failure/other non-response[30]	24	20	30	32
Refusal	26	17	12	14
Invalid contact details	13	9	19	20

[29] This refers to sites which were prepared as part of the sample, but were not required. As such they may have been contacted to take part in a telephone survey but neither refused nor accepted (e.g. non answer, answer-phone, tried to make appointment).

[30] This refers to sites which were deemed out of quota during the sampling process, and also includes sites which did not pass the initial screening – this may have been due to a mismatch of sub-sector type between the sampling register and the response given during a telephone interview.

Appendix B: Storage method challenges and data collection

This appendix provides detail of any non-standard methodology used for the storage sector.

Storage sector methodology challenges

In the case of the storage sector it was not possible to adopt the standard approach to data collection described in the methodology section for all sub-sectors. The reasons are outlined in Table B.1.

Table B.1: Storage sector approach challenges

Stage	Challenge	Response	Impact
Design	Valuation office SCAT.PD definition of Stores included a broad range of activities, a number of which were not anticipated at the time of survey design. Examples included catalogue retail premises, builder's merchants, premises where non-storage activities (e.g. offices) were more prevalent than storage activities, and premises which included industrial process activities. The diversity of the subsector was confirmed by site survey findings The telephone survey did not include significant questioning on non-storage activities, seeking only to identify their share of building area.	A review of the Thompson codes in the Experian data was undertaken for the records in this subsector to identify sites which were likely to be fundamentally unsuitable for modelling using the telephone survey responses collected in the study. A number of records were excluded from analysis as a result of this. Furthermore, one site was re-categorised as a workshop after a site survey revealed that it was a vehicle repair business. No further action was taken outside the standard method.	Low-Medium. This issue has two impacts on the BEES results: BEES energy modelling did not attempt to account for industrial/manufacturing process energy uses (these are out of scope). Shortfalls in predicted energy consumption compared to matched energy data was observed in subsectors where an overlap with industrial activities was apparent. This shortfall made calibration more challenging and reduced confidence in end use energy estimates for the subsector. The exclusion of records falling outside the scope of our modelling capacity leaves an element of the subsector unrepresented in the BEES study. This may be partially offset by storage premises appearing in the workshop sub-sector but it was not possible to determine this in any conclusive manner.

Stage	Challenge	Response	Impact
Data collection and processing	No site surveys could be recruited in the cold stores sub-sector, and the availability of matched energy data for the records included in the telephone survey was very limited. In addition, accurate estimation of cold stores energy consumption for refrigerating the storage space is complex, requiring detailed technical insight into the refrigeration system. This was not considered realistic to collect over a telephone survey.	The energy modelling approach was developed based on established benchmark data, and no calibration process could be undertaken.	The lack of calibration against site survey results reduces confidence in the energy consumption and end use estimates for this subsector, however the total energy consumption figures are considered to be acceptable.
Data processing	Within the storage sector there was a diverse set of approaches to heating of storage space with many variables affecting the heating consumption. This makes heating consumption very difficult to predict, especially in large premises where multiple systems and activities are often present. These issues included (but are not limited to): multiple heating systems, door openings and air infiltration, heated volume, set point temperature, building form and insulation, type of heating systems, operational hours and controls).	The energy model was limited to estimating heating consumption based on the primary heating system and the area of the building this served. While reasonable adjustments could be made for many of the factors affecting heating demand, certain issues such as type of door openings and multiple heating systems could not be accounted for.	High variability was noted when comparing model results with matched energy data. While the overall average heating consumption for the modelled results is considered plausible, individual estimates are noted to be unreliable. This reduces confidence in the range of energy intensities predicted by the model and consequently the estimated abatement potential for heating measures.

Telephone survey and site survey data collection

Table B.2 shows that 398 telephone survey or equivalent records and 18 site surveys were completed in total.

Table B.2: Summary of data collection statistics, 2014–15

	Telephone survey						Site surveys	
Sub-sector	Target sample quota	Number of telephone surveys completed	Number of telephone survey equivalent records completed	Total telephone survey or equivalent records completed	Number. of telephone survey records retained post-screening[31]	Average interview length (mins.)	Target sample size	Site surveys completed
Large distribution warehouses	50	46	4	50	43	28	9	5
Warehouses	355	242	1	243	225	23	9	9
Stores	217	118	1	119	109	23	9	4
Cold stores	30	21	0	21	21	23	3	0
Storage sector	**652**	**427**	**6**	**433**	**398**	**23**	**30**	**18**

Source: Telephone survey or equivalent records, England and Wales

[31] See section 2 on Methods for details of the procedure for record screening on the grounds of data quality.

Appendix C: End use definitions and energy intensity end use breakdowns

This appendix provides definitions on the energy end uses and the energy intensity by end use category across each sub-sector within the storage sector. This is split out between electrical energy and non-electrical energy use.

Energy end use definitions

The definitions for the adapted CIBSE energy end uses are set out in Table C.1.

Table C.1: Definitions for energy end uses

End use category		Description
1	**Space heating**	Energy consumption for space heating (including via ventilation), excluding hot water heating, process heating and unusual end-uses such as swimming pool heating and frost protection of ramps. Includes electricity input to heat pumps directly associated with space heating should be included.
2	**Hot water**	Energy used for hot water (e.g. hand washing and drying, showers, manual dish washing in kitchenettes) including electrical consumption of any heat recovery systems, but not pumps and controls. Excludes water heating associated with central catering.
3	**Space cooling**	Energy consumption for chillers, cooling towers, and air-cooled condensers for comfort cooling purposes, including the condenser and cooling tower fans, sump heaters and ancillaries except pumps. Excludes dedicated computer and telecommunication cooling systems. Includes local coolers and apportioned cooling load of reversible heat pumps.
4	**Fans**	Ventilation fans, including recirculation fans and mechanical plant room fans, excluding condenser and cooling tower fans
5	**Pumps**	All pumps excluding those specific to unusual end uses such as swimming pools. Includes pumps used for central heating, hot water, and boiler ancillaries such as burner fans, flue boost or dilution fans and gas pressure boosters, chilled water and condenser water, cold water booster pumps and sump pumps.
6	**Controls**	Controls for mechanical and electrical services, building energy management systems, security and alarm systems.
7	**Humidification**	All humidification plant used to provide humidification for general building services including ventilation and air conditioning but excluding special energy uses such as swimming pool de-humidification.
8	**Lighting – internal**	All general internal lighting including task lights and emergency lights.

End use category		Description
9	**Lighting – external**	All external lighting associated with the premises, including for dedicated car parks and street lighting for dedicated access routes
10	**Lighting – display**	All display lighting including retail/artwork display or demonstration lighting, decorative lighting in lobbies etc.
11	**Small power equipment**	Office equipment uses within the general premises space comprising computer workstations, printers, and desk based telecommunications equipment. Also includes electronic point of sale equipment.
12	**ICT equipment**	All servers, central computers, telecommunications equipment, transmitters, etc. Typically but not always found in a dedicated room. Includes dedicated computer and telecommunication cooling systems. Excludes control equipment.
13	**Vertical transport**	All vertical transport devices including lifts, escalators, travellators and any other powered means of vertical passenger transport associated with the premises. Includes dedicated vertical transport controls.
14	**Catering - central**	Kitchen (or café) catering preparation and servery equipment including dishwashers, and water heating associated with catering. Excludes restaurant lighting, ventilation and air conditioning.
15	**Catering - distributed**	Energy use for food and drink preparation in kitchenettes, rest rooms, etc. including kettles, coffee making machines, microwaves, fridges and hot water boilers for drink making; also all food and drink vending machines for premises occupants, including those located in café and restaurant areas.
16	**Cooled storage**	All energy uses for devices or facilities providing commercial cold food storage e.g. chilled cabinets, freezers, cold rooms. It includes lighting in display cabinets and trace heating in display cabinet doors.
17	**Entertainment lighting**	Stage or performance lighting.
18	**Entertainment equipment**	Audio-visual equipment, gaming machines, etc. Includes projectors, TV screens, sound systems in all premises types
19	**Laundry**	Fabric washing and drying machines
20	**Medical equipment**	Energy used for medical equipment or health services in hospitals, doctor's surgeries, dentists, vet centres, etc. Excludes equipment in laboratories.
21	**Laboratory equipment**	Energy used for equipment in laboratories.
22	**Pool/leisure**	All energy use associated with pool and sport leisure facilities within the premises. This should include heating, lighting, pumps, ventilation, humidification, and dedicated controls, alarms etc.
23	**Other**	Any other energy uses which fall outside categories 1 to 21, which are "normal" - i.e. are typical for the specific building type.

Source: Adapted from Upgrade of CIBSE TM22 from 2006 to 2012 version by Verco, March 2012

The energy end uses have been grouped for the purpose of presentation in the report. The groupings are set out in Table C.2.

Table C.2: Energy end use categories (detailed to reduced number) by energy type

Energy type	Detailed end use category	Reduced end use category
Electrical	Space heating	Heating
	Hot water	Hot water
	Space cooling	Cooling & humidification
	Fans	Fans
	Lighting - internal	Lighting
	Central catering	Other
	Distributed catering	Other
	Small power	Other
	Pumps	Other
	Controls	Other
	Lighting - display	Other
	Lighting - external	Other
	Vertical transport	Other
	Cooled storage	Cooled storage
	Entertainment equipment	Other
	Pool/leisure	Other
	Laundry	Other
	ICT equipment	Other
	Lab equipment	Other
	Other - normal	Other
Non-electrical	Space heating	Heating
	Hot water	Hot water
	Catering	Other
	Pool/leisure	Other

Note: The following sources were used to inform end use categories and how to simplify them: Definition of energy end uses in "Draft International Standard ISO/DIS 12655: Energy performance of buildings – Presentation of real energy use of buildings, 2011" (available at https://www.iso.org/obp/ui/#iso:std:iso:12655:ed-1:v1:en:term:3.6.5); and "Carbon Buzz reduced energy end uses, 2016" (available at http://www.carbonbuzz.org/index.jsp).

Tables C.3 and C.4 show energy consumption by end use for each storage sub-sector and for the sector combined. Tables C.5 and C.6 show energy intensity by end use for each storage sub-sector and for the sector combined.

Table C.3: Electrical energy consumption by energy end use category and storage sub-sector, 2014–15

Simplified end use category	BEES energy end use category	Electrical energy consumption (GWh per year)				
		Large distribution warehouses	Warehouses	Stores	Cold stores	**Storage (overall)**
Heating	Space heating	70	420	70	2	560
Hot water	Hot water	30	90	10	2	120
Cooling & humidification	Space cooling	10	130	10	3	150
Fans	Fans	110	110	20	10	250
Lighting	Lighting - internal	590	1,760	150	80	2,580
Cooled storage	Cooled storage	780	230	20	830	1,850
Other	Central catering	20	3	-	-	20
	Distributed catering	10	20	10	-	30
	Small power	4	310	40	40	390
	Pumps	2	50	4	-	60
	Controls	10	30	4	1	40
	Lighting - display	-	-	-	-	-
	Lighting - external	240	60	20	20	330
	Vertical transport	1	10	1	-	10
	Entertainment equipment	10	10	3	-	20
	Pool/leisure	-	-	-	-	-
	Laundry	-	-	-	-	-
	ICT equipment	60	200	10	1	270
	Lab equipment	-	50	20	-	80
	Other	330	320	20	10	680
Total		**2,270**	**3,790**	**400**	**980**	**7,440**
Unweighted base		*43*	*225*	*109*	*21*	*398*

Source: Energy use model results by sub-sector, England and Wales

Table C.4: Non-electrical energy consumption by energy end use category and storage sub-sector, 2014–15

Simplified end use category	**BEES energy end use category**	**Non-electrical energy consumption (GWh per year)**				
		Large distribution warehouses	Warehouses	Stores	Cold stores	**Storage (overall)**
Space heating	Heating	850	4,370	250	-	5,470
Hot water	Hot water	30	110	10	10	170
Other	Central catering	30	5	-	-	40
	Pool/leisure	-	-	-	-	-
Total		**910**	**4,480**	**260**	**10**	**5,670**
Unweighted base		*35*	*168*	*65*	*11*	*279*

Source: Energy use model results by sub-sector, England and Wales

Table C.5: Electrical energy intensity by energy end use category and storage sub-sector, 2014–15

Simplified end use category	BEES energy end use category	Electrical energy intensity (kWh/m^2 per year)				
		Large distribution warehouses	Warehouses	Stores	Cold stores	**Storage sector**
Heating	Space heating	3	4	6	1	4
Hot water	Hot water	1	1	1	1	1
Cooling & humidification	Space cooling	0	1	1	1	1
Fans	Fans	4	1	2	4	2
Lighting	Lighting - internal	20	20	10	40	20
Cooled storage	Cooled storage	30	2	1	380	10
Other	Central catering	1	0	0	-	0
	Distributed catering	0	0	1	-	0
	Small power	0	3	3	20	3
	Pumps	0	1	0	0	0
	Controls	0	0	0	0	0
	Lighting - display	-	-	-	-	-
	Lighting - external	9	1	1	8	2
	Vertical transport	0	0	0	-	0
	Entertainment equipment	0	0	0	-	0
	Pool/leisure	-	-	-	-	-
	Laundry	-	-	-	-	-
	ICT equipment	2	2	1	0	2
	Lab equipment	-	1	2	-	1
	Other	12	3	2	5	5
Total		**90**	**40**	**40**	**460**	**50**
Unweighted base		*43*	*225*	*109*	*21*	*398*

Source: Energy use model results by sub-sector, England and Wales

Table C.6: Non-electrical energy intensity by energy end use category and storage sub-sector, 2014–15

Simplified end use category	**BEES energy end use category**	**Non-electrical energy intensity (kWh/m^2 per year)**				
		Large distribution warehouses	Warehouses	Stores	Cold stores	**Storage sector**
Space heating	Heating	30	40	20	0	49
Hot water	Hot water	1	1	1	7	1
Catering	Central catering	1	0	0	-	0
Other	Pool/leisure	-	-	-	-	-
Total		**30**	**50**	**20**	**7**	**40**
Unweighted base		*43*	*225*	*109*	*21*	*398*

Source: Energy use model results by sub-section, England and Wales

Appendix D: Abatement potential

The definitions for each measure type are included in this appendix as well as the abatement potential for each storage sub-sector. For each sub-sector a table on abatement potential by measure type is provided as well as a marginal abatement cost curve.

Measure type definitions

The measure type definitions are included in Table D.1. The research team determined these definitions based on their experience as energy specialists. The full list of abatement model measures, and their mapping into relevant measure groups, is also shown.

Table D.1: Measure type definitions

Measure type	Definition	Measure name
Air conditioning and cooling	Measures associated with air conditioning and cooling plant	Cooling time controls Cooling re-commissioning Cooling temperature control Cooling plant upgrade (0-8 years old) Cooling plant upgrade (8-15 years old) Cooling plant upgrade (more than 15 years old) Free cooling Cooling zone controls
Building fabric	Measures associated with the external building fabric	Flexible plastic curtains on loading bays High speed shutter doors to loading bays Interlocks between heating systems and loading bay or vehicle access doors Replace glazing Cavity wall insulation Loft insulation Clean windows Ground insulation Insulation maintenance Internal/external wall insulation Reflective coatings for windows Blinds Flat roof insulation Draught proofing Double glazing
Building instrumentation and control	Measures associated with improving the controls and monitoring on standard building services	BMS installation BMS re-commissioning BMS maintenance Energy meters for kitchen facilities Energy meters for lifts and escalators Heating zone controls Time controls on the heating system Weather compensator controls on heating Time control on hot water system Lift maintenance

Building services distribution systems	Measures associated with improving the efficiency of the building's distribution systems	Voltage optimisation
Carbon and energy management	Measures associated with organisational policy, users of the building and the capacity of the core delivery teams	Awareness campaign targeted at HVAC (heating, ventilation and air conditioning) HVAC maintenance Improve sub-metering Procurement Energy management Awareness campaign targeted at catering usage Awareness campaign targeted at lift usage 'Low hanging fruit' energy awareness campaign Cooled storage procurement Catering equipment procurement Keeping external doors shut (retail) Reduced use of air curtains (retail) 'Intensive' energy awareness campaign Minimise simultaneous operation of heating and cooling systems
Cooled storage	Measures which improve the efficiency of the refrigeration plant	Optimise refrigeration controls Relocate catering equipment Replace central catering refrigeration equipment Replace cooled storage refrigeration equipment
Hot water	Measures associated with improving the efficiency of hot water used for domestic services; such as hot tap water	Replacement of central generation of hot water with point of use Domestic hot water maintenance Hot water efficiency measures (low flow taps, showers & baths)
Humidification	Measures associated with the systems regulating building humidity	Humidification control maintenance
Lighting	Measures associated with lighting improvements	Automatic controls on lighting Localised lighting controls CFL to LED lighting retrofit T12 to LED lighting retrofit T5 to LED lighting retrofit T8 to LED lighting retrofit T8 to T5 lighting retrofit Lighting maintenance T12 to T5 lighting retrofit External lighting – HID to LED External lighting control Dsiplay lighting controls

Small applicances	Measures associated with small power usage, such as computer upgrades	Replace catering equipment Automated shutdown for ICT usage Computer upgrade LCD flat screens Server virtualisation Thin clients Doors on fridges (retail)
Space heating	Measures that improve the efficiency of heating the building	Replace heating boiler plant with high efficiency type (0-8 years old) Replace heating boiler plant with high efficiency type (8-15 years old) Replace heating boiler plant with high efficiency type (15 years old or more) Boiler maintenance Holiday season plant shutdown Optimise heat zoning Thermostatic radiator valve (TRV) Pipe work insulation
Swimming pools	Measures that improve the efficiency of energy used for swimming pools	Energy meters for the pool complex Swimming pool covers Draught proofing of pool Pool maintenance
Ventilation	Measures that improve the efficiency of the ventilation systems	Optimising ventilation time controls Optimising ventilation zoning Variable speed drives Ventilation plant upgrade (0-8 years old) Ventilation plant upgrade (8-15 years old) Ventilation plant upgrade (15 years old or more) Motor replacement Motor controls Motor resizing

Note: The following sources were used to inform end use categories and how to simplify them: Definition of energy end uses in “Draft International Standard ISO/DIS 12655: Energy performance of buildings — Presentation of real energy use of buildings, 2011” (available at https://www.iso.org/obp/ui/#iso:std:iso:12655:ed-1:v1:en:term:3.6.5); and “Carbon Buzz reduced energy end uses, 2016” (available at http://www.carbonbuzz.org/index.jsp).

Large distribution warehouses

In large distribution warehouses there was an annual abatement potential of 520 GWh of electrical energy and 390 GWh of non-electrical energy (equivalent to 230 $ktCO_2e$ combined). This equates to a 23 per cent and 42 per cent reduction on energy consumption respectively. The capital cost to achieve this is £280m. The annual savings delivered would be £61m[32]. These figures are grouped according to measure type in Table D.2. The total abatement potential of the socially cost effective measure groups was 620 GWh, of which 440 GWh was electrical energy consumption and 180 GWh was non-electrical energy consumption. This represents the energy savings that could be achieved through measures where the benefits outweigh the costs to society. The total abatement potential relating only to measure groups with a private payback of 3 years or less was 250 GWh, of which 170 GWh was electrical energy consumption and 90 GWh non-electrical energy consumption. Within each group of measures there will be some measures that are more cost-effective than others for each sub-sector. Some cost effective measures will therefore be hidden within groups that are not considered cost effective as a whole (Figure D.1).

Table D.2: Abatement opportunity data for large distribution warehouses, 2014–15

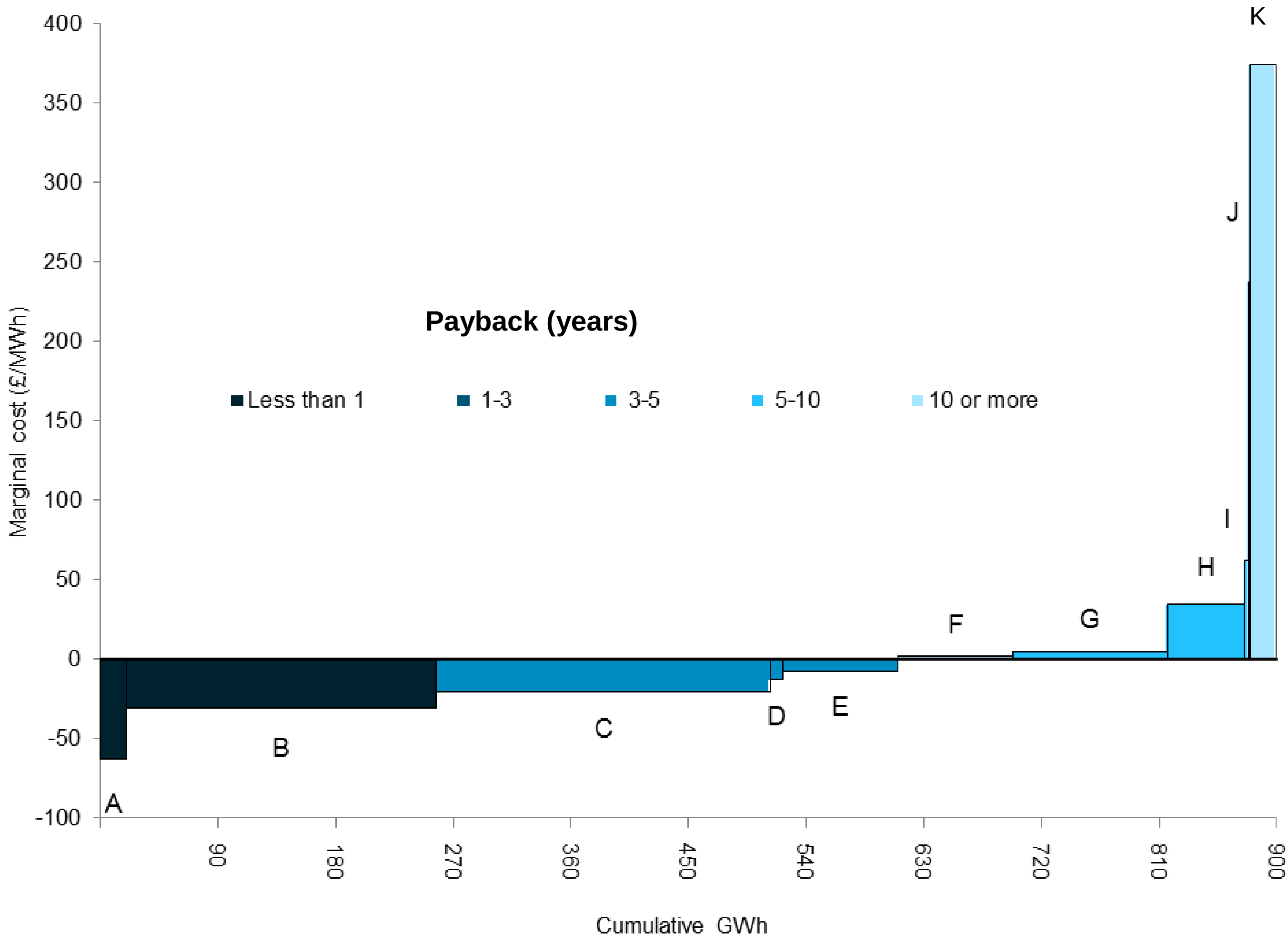
	Savings						
Measure type	Total annual energy bill saving (£ thousands)	Total annual greenhouse gas saving ($ktCO_2e$)	Total annual electrical energy savings (GWh)	Total annual non-electrical energy savings (GWh)	Total annual energy savings (GWh)	**Total capital cost of measure (£ thousands)**	Payback period (years)[33]
Air conditioning and cooling	300	1	3	-	3	2,500	10
Building fabric	2,500	20	2	90	90	45,900	12
Building instrumentation and control	3,800	20	10	110	120	26,000	5
Building services distribution systems	1,700	5	20	-	20	41,400	15
Carbon and energy management	16,900	60	150	90	240	6,300	0
Hot water	400	2	2	10	10	1,800	4
Humidification	-	-	-	-	-	-	-
Lighting	26,000	70	260	-	260	108,800	4
Cooled storage	1,700	6	20	-	20	0	0
Small appliances	100	0	1	0	1	1,300	13
Space heating	2,800	20	7	80	90	9,600	3
Swimming pools	-	-	-	-	-	-	-
Ventilation	5,100	20	50	7	60	36,800	
Total	**61,300**	**230**	**520**	**390**	**910**	**280,400**	‘’

Source: Abatement model results for sub-sector, England and Wales

[32] Annual savings relates to the financial savings associated solely with the reduced energy consumption.

[33] Payback relates to the duration of time after which the capital costs of a measure are recouped through the accumulated bill savings the measure delivers. Note that the payback period reflects the gross bill savings of the measure alone, rather than the bill savings that would be achieved by the measure if all other measures were installed.

Figure D.1: Marginal abatement cost curve for large distribution warehouses, 2014–15



Note: the marginal abatement cost is calculated based on the social cost effectiveness, while the payback period is calculated from a private perspective.

A Cooled storage [MAC: £-63 per MWh. GWh: 20]
B Carbon and energy management [MAC: £-31 per MWh. GWh: 240]
C Lighting [MAC: £-20 per MWh. GWh: 260]
D Hot water [MAC: £-13 per MWh. GWh: 10]
E Space heating [MAC: £-8 per MWh. GWh: 90]
F Building fabric [MAC: £1 per MWh. GWh: 90]
G Building instrumentation and control [MAC: £5 per MWh. GWh: 120]
H Ventilation [MAC: £35 per MWh. GWh: 60]
I Air conditioning and cooling [MAC: £62 per MWh. GWh: 3]
J Small appliances [MAC: £237 per MWh. GWh: 1]
K Building services distribution systems [MAC: £374 per MWh. GWh: 20]

Source: Abatement model results for sub-sector, England and Wales

Warehouses

In warehouses there was an annual abatement potential of 1,510 GWh of electrical energy and 2,180 GWh of non-electrical energy (equivalent to 720 $ktCO_2e$ combined). This equates to a 40 per cent and 49 per cent reduction on energy consumption respectively. The capital cost to achieve this is £1.7bn. The annual savings delivered would be £205m[34]. These figures are grouped according to measure type in Table D.3. The total abatement potential of the socially cost effective measure groups was 940 GWh, all of which was electrical energy. This represents the energy savings that could be achieved through measures where the benefits outweigh the costs to society. There was no abatement potential relating to measure groups with a private payback of 3 years or less. Within each group of measures there will be some measures that are more cost-effective than others for each sub-sector. Some cost effective measures will therefore be hidden within groups that are not considered cost effective as a whole (Figure D.2).

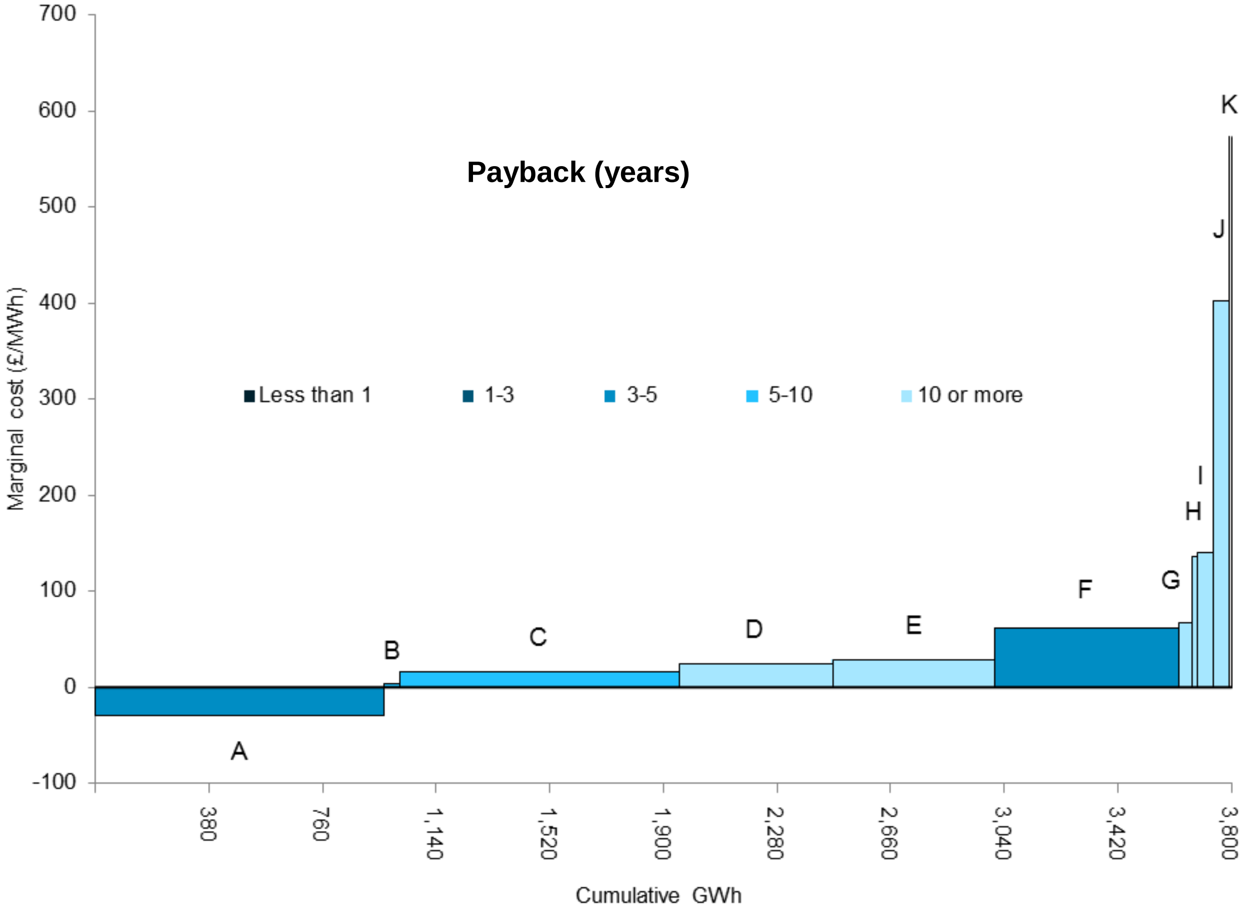
Table D.3: Abatement opportunity data for warehouses, 2014–15

	Savings						
Measure type	Total annual energy bill saving (£ thousands)	Total annual greenhouse gas saving ($ktCO_2e$)	Total annual electrical energy savings (GWh)	Total annual non-electrical energy savings (GWh)	Total annual energy savings (GWh)	**Total capital cost of measure (£ thousands)**	Payback period (years)[35]
Air conditioning and cooling	2,000	9	20	-	20	40,600	29
Building fabric	15,800	20	40	460	500	411,400	16
Building instrumentation and control	29,000	40	80	830	910	206,400	6
Building services distribution systems	4,500	20	50	-	50	124,600	16
Carbon and energy management	31,800	110	220	380	600	125,500	3
Hot water	1,200	2	4	30	40	30,100	22
Humidification	-	-	-	-	-	-	-
Lighting	93,300	440	940	-	940	416,800	4
Cooled storage	4,900	20	50	-	50	27,500	6
Small appliances	900	4	8	1	10	30,600	27
Space heating	16,800	20	50	480	530	201,800	11
Swimming pools	-	-	-	-	-	-	-
Ventilation	5,200	30	50	3	50	75,500	11
Total	**205,300**	**720**	**1,510**	**2,180**	**3,690**	**1,690,700**	‘’

[34] Annual savings relates to the financial savings associated solely with the reduced energy consumption.

[35] Payback relates to the duration of time after which the capital costs of a measure are recouped through the accumulated bill savings the measure delivers. Note that the payback period reflects the gross bill savings of the measure alone, rather than the bill savings that would be achieved by the measure if all other measures were installed.

Figure D.2: Marginal abatement cost curve for warehouses, 2014–15



Note: the marginal abatement cost is calculated based on the social cost effectiveness, while the payback period is calculated from a private perspective.

A Lighting [MAC: £-29 per MWh. GWh: 940]
B Cooled storage [MAC: £4 per MWh. GWh: 50]

C Building instrumentation and control [MAC: £16 per MWh. GWh: 910]

D Building fabric [MAC: £24 per MWh. GWh: 500]

E Space heating [MAC: £28 per MWh. GWh: 530]

F Carbon and Energy Management [MAC: £62 per MWh. GWh: 600]

G Hot water [MAC: £67 per MWh. GWh: 40]

H Air conditioning and cooling [MAC: £136 per MWh. GWh: 20]

I Ventilation [MAC: £140 per MWh. GWh: 50]

J Building services distribution systems [MAC: £403 per MWh. GWh: 50]

K Small appliances [MAC: £573 per MWh. GWh: 10]

Source: Abatement model results for sub-sector, England and Wales

Stores

In stores there was an annual abatement potential of 160 GWh of electrical energy and 110 GWh of non-electrical energy (equivalent to 70 $ktCO_2e$ combined). This equates to a 39 per cent and 43 per cent reduction on energy consumption respectively. The capital cost to achieve this is £390m. The annual savings delivered would be £18m[36]. These figures are grouped according to measure type in Table D.4. There was no abatement potential from socially cost effective measure. This represents the energy savings that could be achieved through measures where the benefits outweigh the costs to society. There was also no abatement potential relating to measure groups with a private payback of 3 years or less. Within each group of measures there will be some measures that are more cost-effective than others for each sub-sector. Some cost effective measures will therefore be hidden within groups that are not considered cost effective as a whole (Figure D.3).

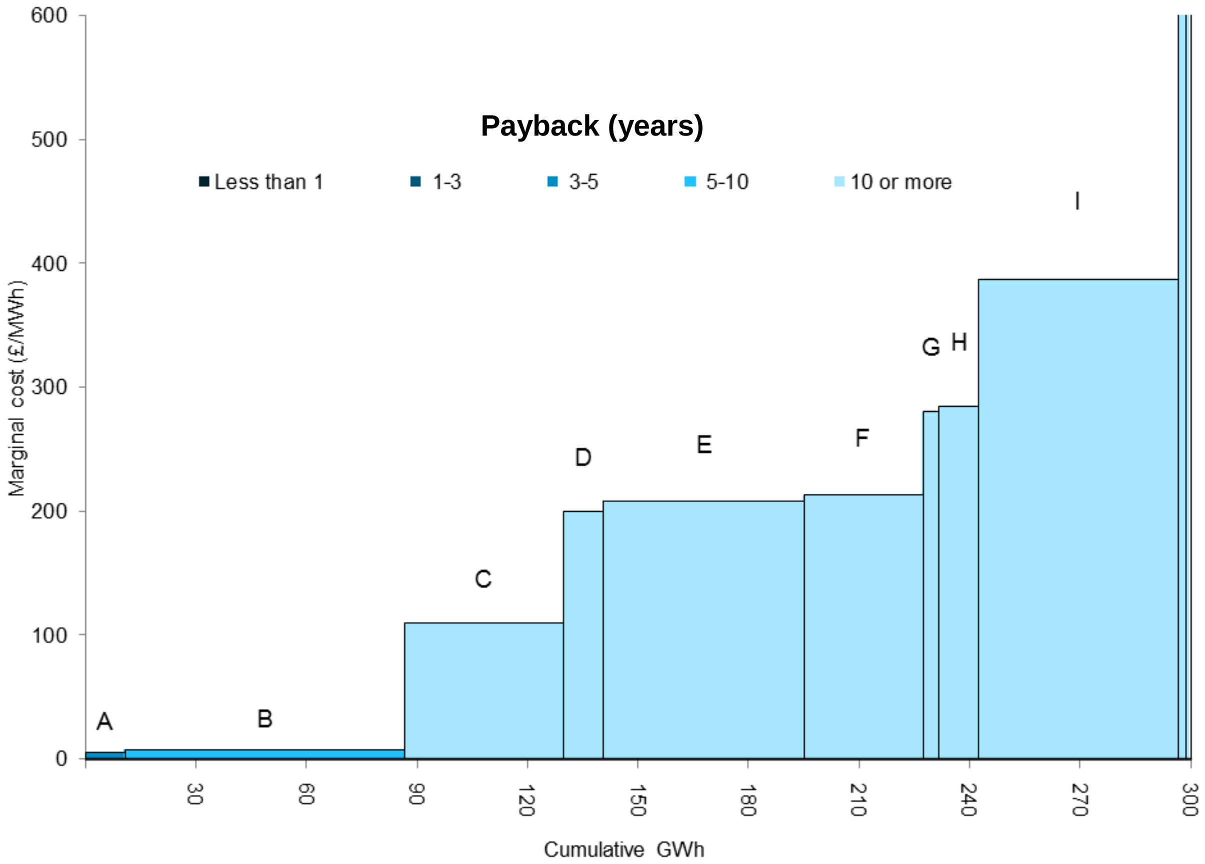
Table D.4: Abatement opportunity data for stores, 2014–15

	Savings						
Measure type	Total annual energy bill saving (£ thousands)	Total annual greenhouse gas saving ($ktCO_2e$)	Total annual electrical energy savings (GWh)	Total annual non-electrical energy savings (GWh)	Total annual energy savings (GWh)	**Total capital cost of measure (£ thousands)**	Payback period (years)[37]
Air conditioning and cooling	100	0	1	-	1	11,600	171
Building fabric	1,700	7	10	30	40	98,400	45
Building instrumentation and control	2,200	10	10	40	50	72,500	26
Building services distribution systems	500	2	5	-	5	10,600	14
Carbon and energy management	3,200	10	30	30	50	46,300	11
Hot water	100	1	0	4	4	11,600	79
Humidification	-	-	-	-	-	-	-
Lighting	7,400	20	70	-	70	53,900	7
Cooled storage	1,000	3	10	-	10	4,800	4
Small appliances	200	1	2	0	2	10,400	36
Space heating	1,000	5	5	20	30	53,500	41
Swimming pools	-	-	-	-	-	-	-
Ventilation	1,000	3	10	0	10	16,700	11
Total	**18,500**	**70**	**160**	**110**	**270**	**390,300**	‘’

[36] Annual savings relates to the financial savings associated solely with the reduced energy consumption.

[37] Payback relates to the duration of time after which the capital costs of a measure are recouped through the accumulated bill savings the measure delivers. Note that the payback period reflects the gross bill savings of the measure alone, rather than the bill savings that would be achieved by the measure if all other measures were installed.

Figure D.3: Marginal abatement cost curve for stores, 2014–15



Note: the marginal abatement cost is calculated based on the social cost effectiveness, while the payback period is calculated from a private perspective. Note also that series 'J' and 'K' are not visible as the y-axis as been capped at £600/MWh for presentation purposes .

A Cooled storage [MAC: £5 per MWh. GWh: 10]
B Lighting [MAC: £8 per MWh. GWh: 70]
C Building fabric [MAC: £109 per MWh. GWh: 40]
D Ventilation [MAC: £199 per MWh. GWh: 10]
E Building instrumentation and control [MAC: £208 per MWh. GWh: 50]
F Space heating [MAC: £213 per MWh. GWh: 30]
G Hot water [MAC: £280 per MWh. GWh: 4]
H Building services distribution systems [MAC: £284 per MWh. GWh: 10]
I Carbon and energy management [MAC: £387 per MWh. GWh: 50]
J Small appliances [MAC: £797 per MWh. GWh: 2]
K Air conditioning and cooling [MAC: £1,985 per MWh. GWh: 1]

Source: Abatement model results for sub-sector, England and Wales

Cold stores

In cold stores there was an annual abatement potential of 250 GWh of electrical energy and 10 GWh of non-electrical energy (equivalent to 70 $ktCO_2e$ combined). This equates to a 25 per cent and 47 per cent reduction on energy consumption respectively. The capital cost to achieve this is £122m. The annual savings delivered would be £25m[38]. These figures are grouped according to measure type in Table **Error! Reference source not found.**D.5. The total abatement potential of the socially cost effective measure groups was 30 GWh, 20GWh of which was electrical energy consumption. This represents the energy savings that could be achieved through measures where the benefits outweigh the costs to society. The total abatement potential relating only to measure groups with a private payback of 3 years or less was 40 GWh, all of which was electrical energy consumption. Within each group of measures there will be some measures that are more cost-effective than others for each sub-sector. Some cost effective measures will therefore be hidden within groups that are not considered cost effective as a whole (Figure D.4).

Table D.5: Abatement opportunity data for cold stores, 2014–15

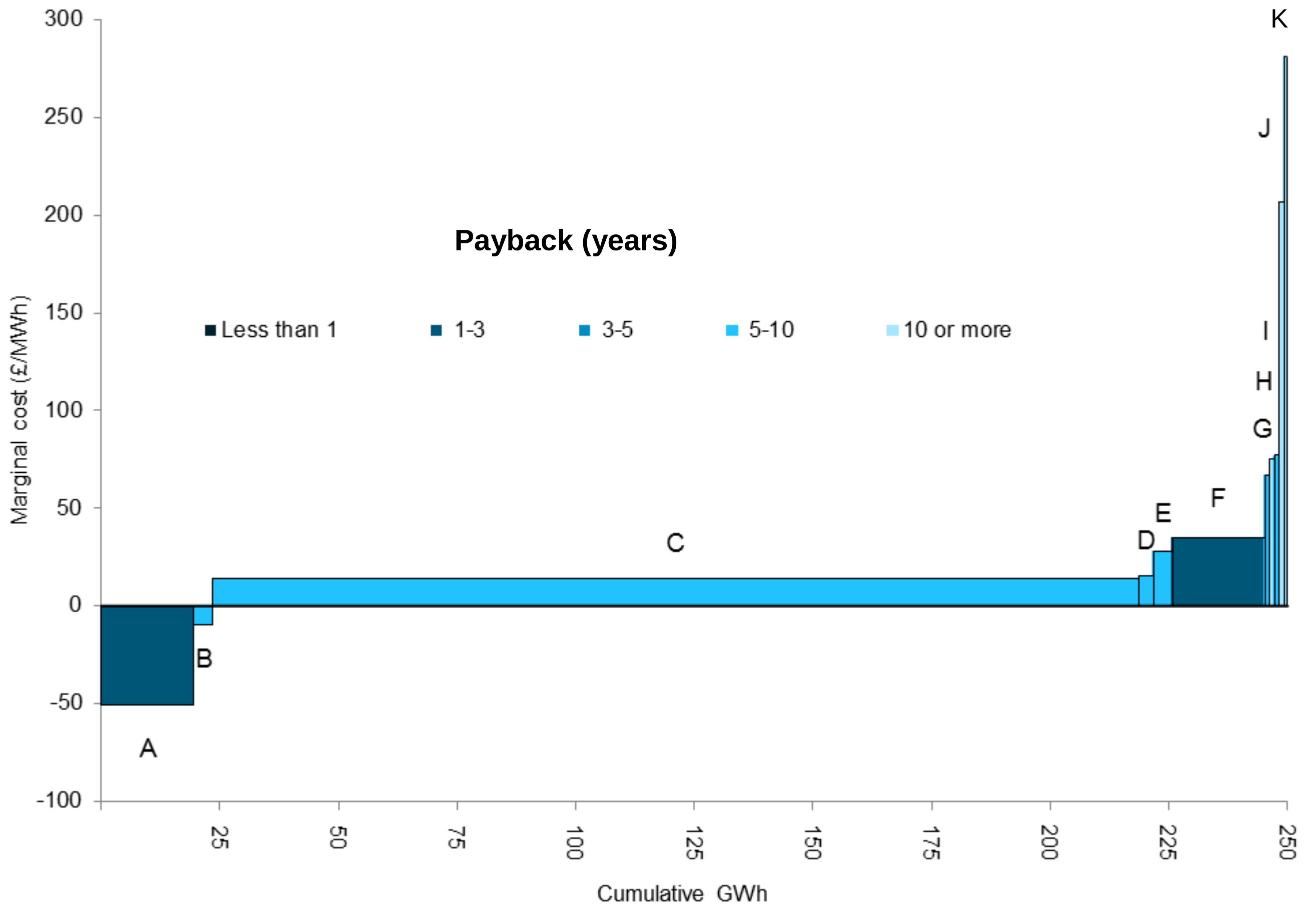
	Savings						
Measure type	Total annual energy bill saving (£ thousands)	Total annual greenhouse gas saving ($ktCO_2e$)	Total annual electrical energy savings (GWh)	Total annual non-electrical energy savings (GWh)	Total annual energy savings (GWh)	**Total capital cost of measure (£ thousands)**	**Payback period (years)**[39]
Air conditioning and cooling	100	0	1	-	1	600	7
Building fabric	0	0	0	0	0	400	17
Building instrumentation and control	100	1	1	3	3	900	7
Building services distribution systems	100	0	1	-	1	700	7
Carbon and energy management	1,600	5	20	0	20	2,400	1
Hot water	100	1	0	4	4	600	5
Humidification	-	-	-	-	-	-	-
Lighting	2,200	6	20	-	20	3,000	1
Cooled storage	19,900	60	200	-	200	110,900	5
Small appliances	0	0	0	0	0	0	20
Space heating	0	0	0	0	0	400	23
Swimming pools	-	-	-	-	-	-	-
Ventilation	400	1	4	-	4	2,400	4
Total	**24,600**	**70**	**250**	**10**	**250**	**122,400**	‘’

Source: Abatement model results for sub-sector, England and Wales

[38] Annual savings relates to the financial savings associated solely with the reduced energy consumption.

[39] Payback relates to the duration of time after which the capital costs of a measure are recouped through the accumulated bill savings the measure delivers. Note that the payback period reflects the gross bill savings of the measure alone, rather than the bill savings that would be achieved by the measure if all other measures were installed.

Figure D.4: Marginal abatement cost curve for cold stores, 2014–15



Note: the marginal abatement cost is calculated based on the social cost effectiveness, while the payback period is calculated from a private perspective.

A Lighting [MAC: £-51 per MWh. GWh: 20]
B Hot water [MAC: £-10 per MWh. GWh: 4]
C Cooled storage [MAC: £14 per MWh. GWh: 200]
D Building instrumentation and control [MAC: £15 per MWh. GWh: 3]
E Ventilation [MAC: £28 per MWh. GWh: 4]
F Carbon and energy management [MAC: £35 per MWh. GWh: 20]
G Air conditioning and cooling [MAC: £67 per MWh. GWh: <1]
H Building fabric [MAC: £75 per MWh. GWh: <1]
I Building services distribution systems [MAC: £77 per MWh. GWh: 1]
J Space heating [MAC: £207 per MWh. GWh: <1]
K Small appliances [MAC: £281 per MWh. GWh: <1]

Source: Abatement model results for sub-sector, England and Wales

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