Department for
Business, Energy
& Industrial Strategy

Building Energy Efficiency Survey: Industrial 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 industrial 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.

[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.

Industrial sector overview

The industrial sector consisted of factories and workshops. The industrial sector had a total floor area of 175 million m^2 (22 per cent of the total non-domestic stock) across 252,800 premises (16 per cent of the total non-domestic stock).

The scope of the survey within the industrial sector excluded energy use from industrial processes: results only cover building energy consumption from buildings in the industrial sector. On this basis, the industrial sector's total energy consumption from buildings was 25,740 GWh. The sector's electrical energy consumption was 11,320 GWh (13 per cent of the total non-domestic stock) and non-electrical consumption was 14,410 GWh (19 per cent of total non-domestic stock). It was estimated within the BEES survey that building energy consumption was approximately one-quarter of the sector's total consumption.

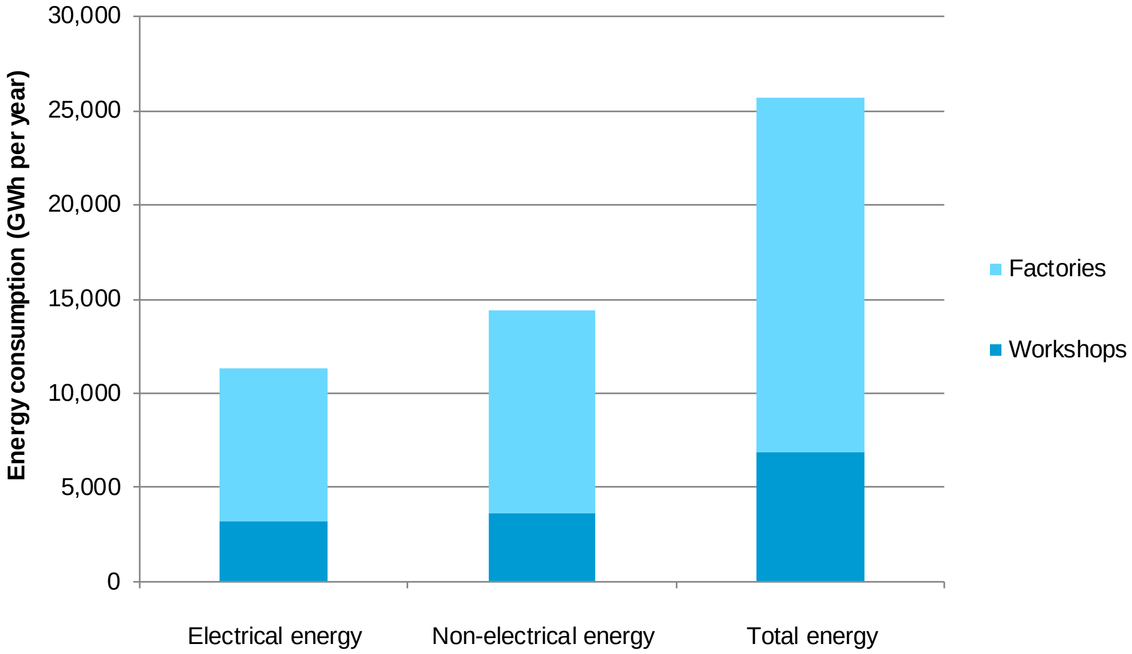
The findings in this report are based on data collected through 475 telephone surveys used in the energy use and abatement models and 15 site surveys in 2014–15.

Key findings

Energy consumption from buildings in the industrial sector, 2014–15

- According to modelled data based on telephone survey responses, buildings in the industrial sector consumed 25,740 GWh of energy. This included 11,320 GWh of electrical energy and 14,410 GWh of non-electrical energy per year (Figure 0.1).
- The largest energy consumer in this sector was factories, with 18,840 GWh total energy consumption (73 per cent of sector total). Workshops consumed 6,890 GWh of total energy (27 per cent of sector total).
- The difference in absolute consumption between the sub-sectors matched to some extent with their overall size. Factories were the largest sub-sector in terms of energy consumption, while also representing 61 per cent of the sector's overall floor area.
- Workshops had the largest median overall energy intensity (90 kWh/m^2), followed by factories (80 kWh/m^2).
- Workshops typically displayed the highest median electrical energy intensity (40 kWh/m^2). Workshops displayed a higher median non-electrical energy intensity than factories (50 kWh/m^2 and 40 kWh/m^2 respectively).
- The energy consumption of the industrial sector was broken down into specific 'end uses'. The most significant end use was space heating (14,620 GWh, 57 per cent total energy consumption), followed by internal lighting (6,830 GWh, 27 per cent of total energy).

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



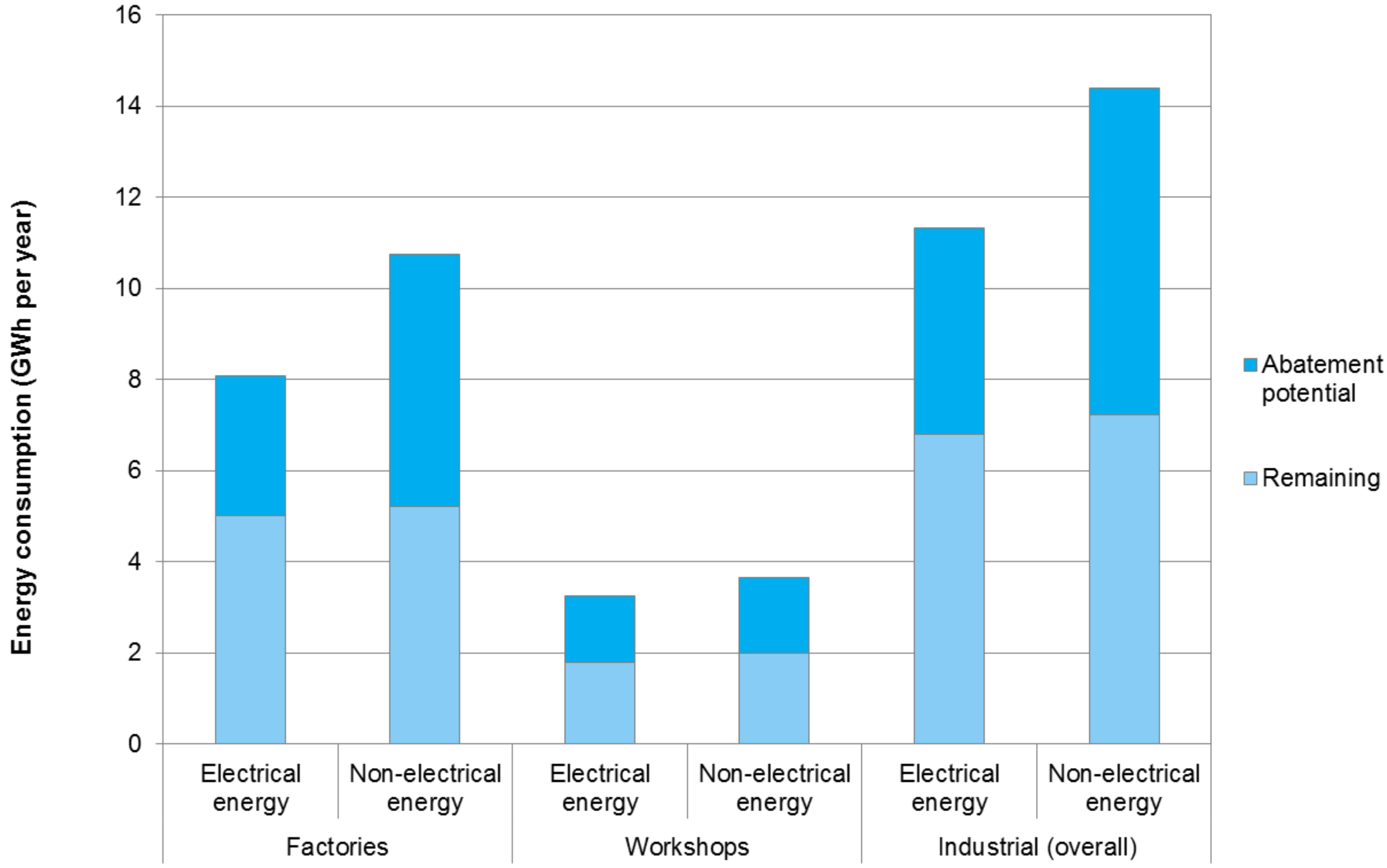
Source: Energy use model results for the sector covering England and Wales

Abatement potential for buildings in the industrial sector, 2014–15

- According to modelled data based on telephone survey responses, Figure 0.2 shows abatement potential for buildings in 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 for buildings in the industrial sector was 11,720 GWh of total energy (46 per cent reduction on consumption). This consisted of 4,520 GWh of electrical energy (a 40 per cent reduction on consumption) and 7,190 GWh of non-electrical energy (a 50 per cent reduction on consumption).
- This could be achieved at a capital cost of £4.6 billion. The total socially cost effective potential was 2,480 GWh, all of which was electrical energy consumption, with no cost effective potential for non-electrical energy. Companies are more likely to be influenced by the payback period[4] for improvement: overall there were 4,930 GWh of total energy savings with a private payback period of 3 years or less (3,380 GWh of electrical energy savings and 1,550 GWh of non-electrical energy savings).
- The sub-sector with the largest relative and absolute abatement potential was factories, with 3,070 GWh of electrical energy (38 per cent reduction on consumption) and 5,540 for non-electrical energy (51 per cent reduction on consumption).

[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.

Figure 0.2: Abatement potential for buildings by energy type and industrial 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 buildings in the industrial sector – in terms of reductions in energy consumption – relate to the implementation of building instrumentation & control measures, lighting, and carbon & energy management measures. The largest group of savings – in terms of the potential energy bill savings - related to the implementation of lighting upgrades.

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

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	13,200	40	130	-	130	177,300
Building fabric	55,900	350	110	1,760	1,870	1,454,500
Building instrumentation and control	76,300	490	160	2,360	2,520	520,300
Building services distribution systems	23,700	70	240	-	240	342,500
Carbon and energy management	128,500	580	900	1,550	2,450	350,500
Hot water	2,700	20	10	70	80	86,200
Humidification	-	-	-	-	-	-
Lighting	246,700	700	2,480	-	2,480	662,300
Cooled storage	700	2	7	-	7	35,500
Small appliances	2,200	7	20	5	30	73,400
Space heating	39,900	270	50	1,390	1,430	322,200
Swimming pools	-	-	-	-	-	-
Ventilation	42,700	140	420	60	470	542,200
Total	**632,600**	**2,650**	**4,520**	**7,190**	**11,710**	**4,566,700**

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

1. Industrial sector

This report relates to the industrial sector (one of 10 sectors covered in the Building Energy Efficiency Survey (BEES)). This section provides definitions for the two industrial sub-sectors (factories, and workshops). It then sets the industrial 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 industrial sector.

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

Sub-sector	Definition
Factories	Refers to buildings used for manufacturing or assembling goods. This may include heavy industry, large scale manufacturing, chemical, food, metals, minerals, brewing and other large scale production & processing activities. Typically a factory includes a main production area that has high-ceilings and contains heavy equipment used for assembly line production. Gross Floor Area should include all space within the building(s) at the plant, including production areas, offices, conference rooms, employee break rooms, storage areas, mechanical rooms, stairways, and lift shafts.
Workshops	Refers to smaller premises used for the manufacture or repair of goods and equipment. Gross Floor Area should include all internal spaces including workshop area, offices, toilets, corridors, stairways, lift shafts and common areas.

Definition of the scope of the BEES study in the industrial sector

The industrial sector was unique within the BEES study as energy from industrial processes was excluded from the scope. Results in this report therefore only cover energy consumption for energy use outside of industrial processes, such as building services.

In non-industrial spaces (e.g. offices, common parts, catering kitchens etc.) within the premises all energy use was in scope. In industrial spaces within the premises, only the energy required to condition the space for the occupants in the space was in scope. This included heating, hot water, space cooling (non-process), pumps, fans and controls associated with building services, and general lighting. Please refer to appendix E for further information on the definition of non-process and process loads and how these were handled in the project.

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

Industrial sector in the context of the wider non domestic stock

The industrial sector is a large segment of the non-domestic stock. It accounts for 16 per cent of the non-domestic stock in terms of premises count (252,800) and 22 per cent in terms of floor area (175 million m^2 GIA[6]).[7]

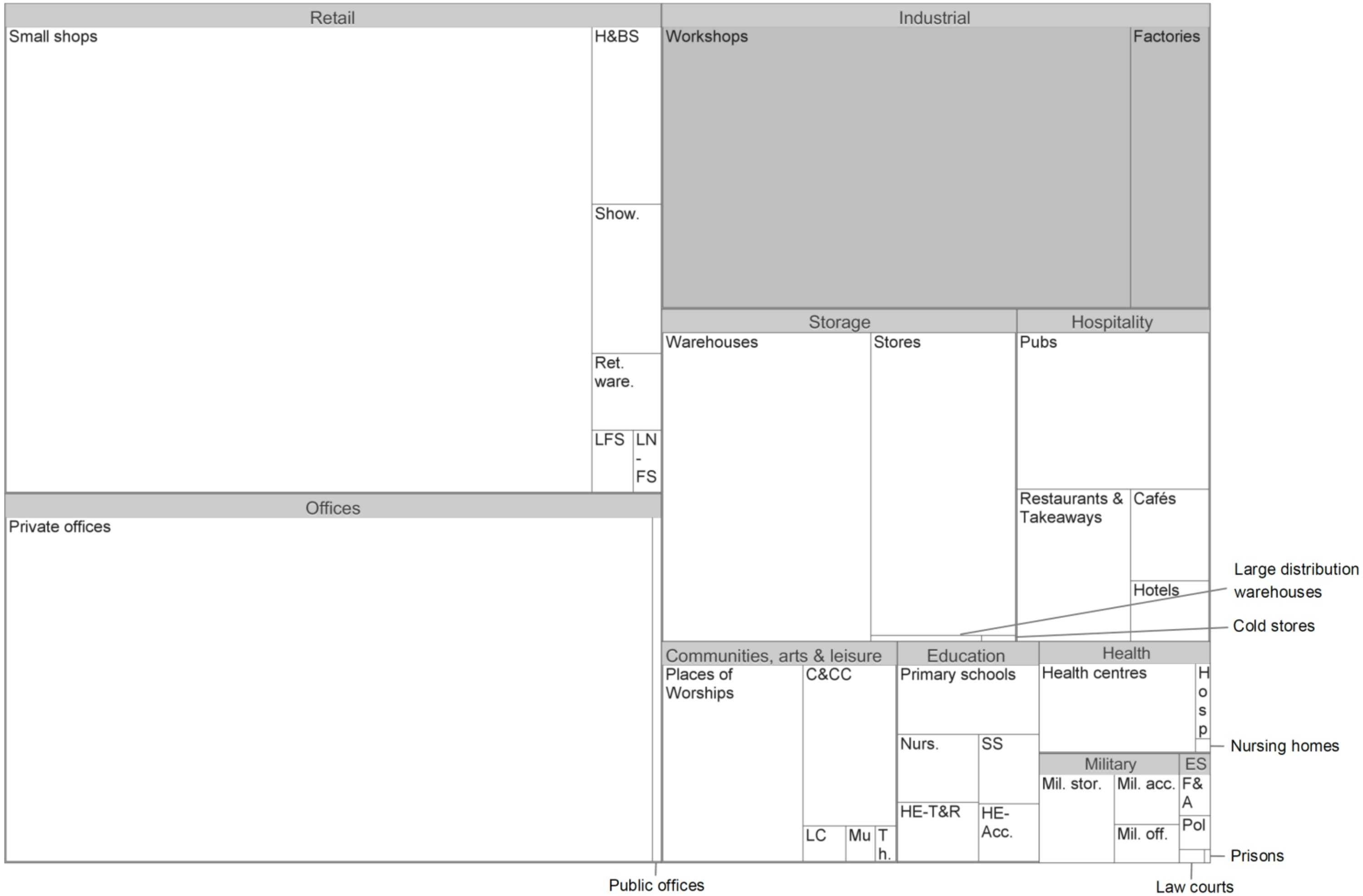
The total energy consumption of buildings in the industrial sector was 25,740 GWh. This comprised 11,320 GWh of electrical energy and 14,410 GWh of non-electrical energy per year, which is equivalent to 13 per cent and 19 per cent of non-domestic stock totals respectively. This information is set out 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

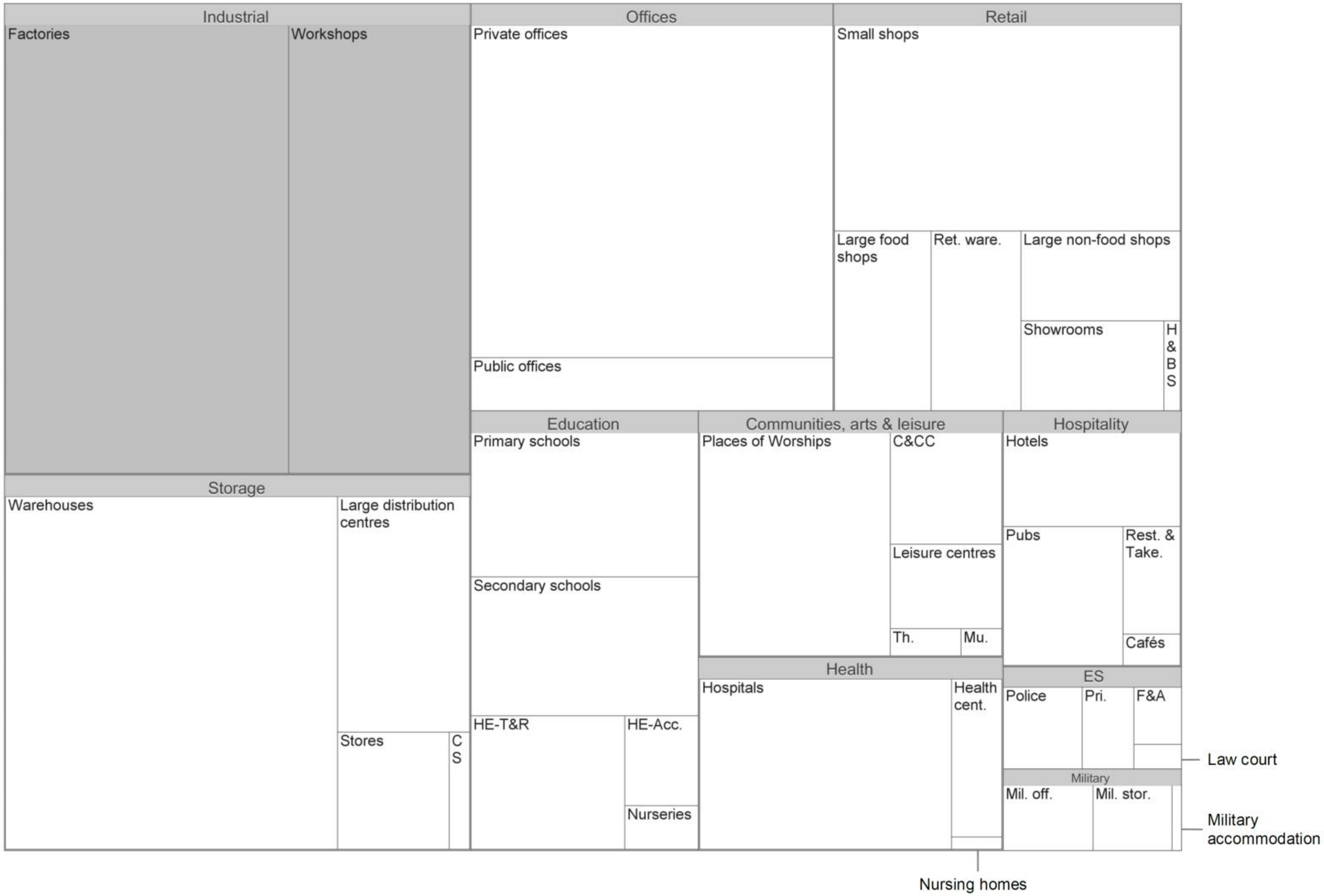
ID	Sub-sector
H&BS	Hairdressing & beauty salons
Show.	Showrooms
Ret. ware.	Retail warehouses
LFS	Large food shops
LN-FS	Large non-food shops
C&CC	Clubs & community centres
LC	Leisure centres
Mu.	Museums, Art galleries and Libraries
Th.	Theatres, cinemas and concert halls
Nurs.	Nurseries
SS	Secondary 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

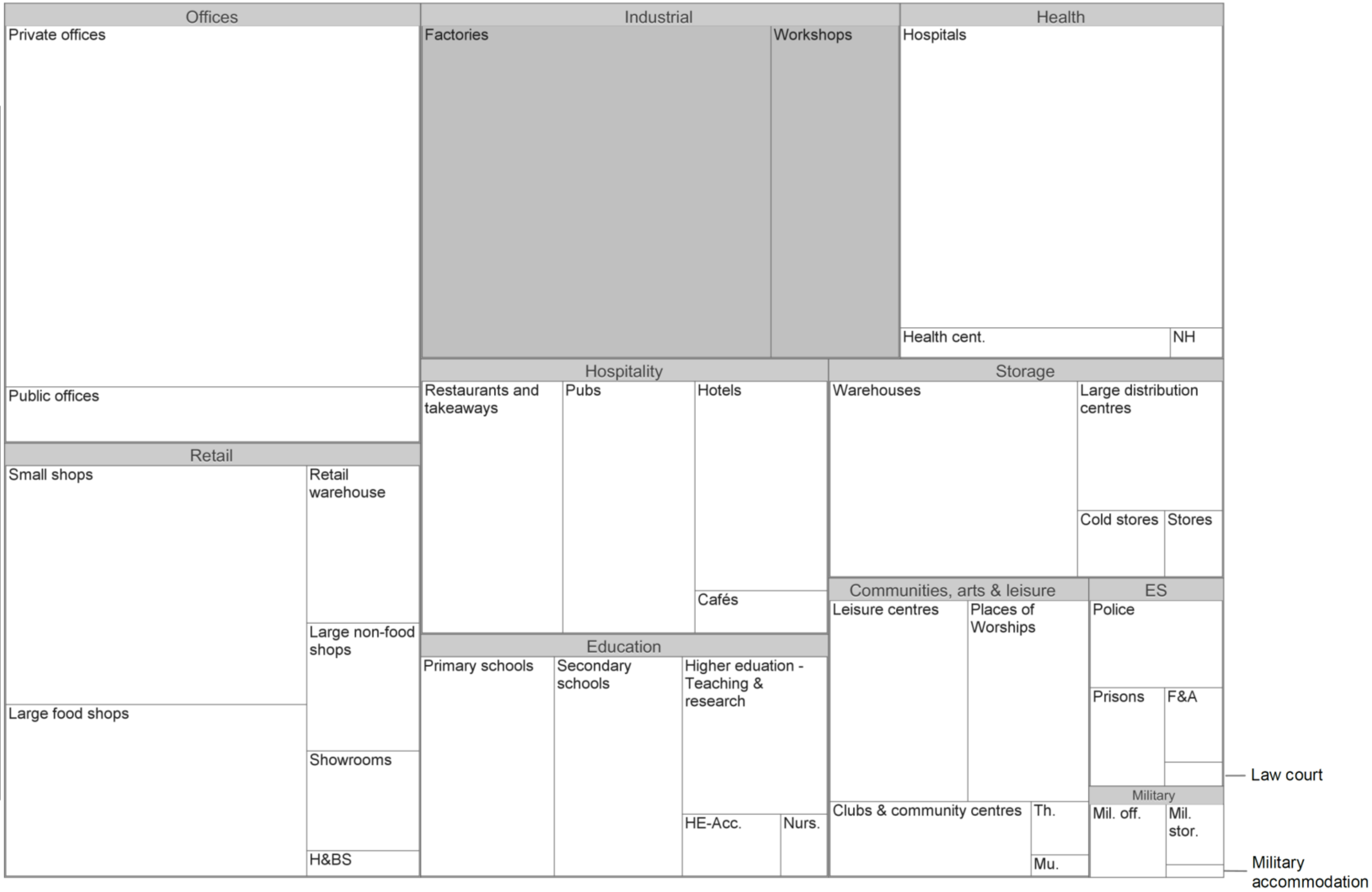
ID	Sub-sector
Ret. ware.	Retail warehouse
H&BS	Hairdressing & beauty salons
CS	Cold stores
HE-T&R	HE—Teaching and research
HE-Acc.	HE — Accommodation
C&CC	Clubs & community centres
LC	Leisure centres
Th.	Theatres, cinemas and concert halls
Mu.	Museums, Art galleries and Libraries
Health cent.	Health 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 industrial sector

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

Industrial premises varied greatly in size and complexity from small workshops with occasional use to some of the largest industrial sites in England and Wales. There are a limited number of exceptionally large industrial facilities which are not included in the Valuation Office Agency dataset, which was used to sample premises for the BEES analysis.

Usage of space was dominated by industrial activities in both sub-sectors. Smaller buildings (e.g. workshops) showed a higher proportion of non-industrial activities (mainly office and storage space) than larger buildings in the factories sub-sector. Outdoor areas such as vehicle yards, outdoor storage and process areas were also common in workshops.

In terms of complexity, the servicing arrangements in most industrial buildings were relatively simple. Extensive mechanical ventilation and cooling were rare in process areas unless these were dedicated to part of the industrial process. Most premises were heated, but heating consumption was often offset by heat released from equipment used in industrial processes. Where significant office space was present it was common for a separate heating and/or cooling system to be present for these areas which usually required closer control of temperature than the industrial spaces.

Energy intensive activities and equipment were relatively rare in non-industrial spaces in the industrial sector. Where activity was energy intensive server rooms and staff catering were the main uses.

Summary statistics for the industrial sector

A number of standard characteristics for the industrial 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 industrial sector and how these vary across the industrial 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 industrial sector had some clear similarities, and some clear differences:

- Workshops tended to occupy whole buildings, with a relatively even split between owned and leased premises. Typically workshops had peak operating hours for fewer than 15 hours a day, and were mainly occupied by small and micro organisations;
- Factories also occupied whole buildings in most cases (66 per cent), however 26 per cent occupied multiple buildings. They tended to be larger (64 per cent were 10,000 m^2 or larger), with opening and peak operating hours ranging from fewer than 8 hours, to 24 hours.

In broad terms factories tended to be occupied by large organisations whilst workshops were occupied by small organisations. 54 per cent of floor area in factories is occupied by large organisations. In contrast 74 per cent of workshops are occupied by either micro or small organisations.

Factories typically occupied premises with a floor area greater than 1,000m^2, (88 per cent), with the majority of premises having a floor area of 10,000 m^2 or more (66 per cent). Workshops had a greater variance in floor area, with 60 per cent below 1,000m^2.

Workshops demonstrated a split between owned and leased premises (44 and 56 per cent, respectively). Many of the factories however, were owned (69 per cent). Typically, factories and workshops occupied a whole building (66 and 82 per cent, respectively).

Overall in the industrial sector 90 per cent had considered energy use. However, 57 per cent of respondents in factories described themselves as “Actively seeking new ways to reduce energy use”, whereas 67 per cent of workshops respondents admitted “trying to reduce energy where possible, but it was not a priority”.

In terms of building age, 62 per cent of the industrial sector premises were built between 1940 and 1990. The majority of factories and workshops were built in this period (57 and 51 per cent respectively) with very few premises being constructed prior to this year banding.

The peak operating hours for each sub-sector broadly corresponded to opening hours. Factories had a larger variation than workshops with opening hours, and peak operating hours, across all bandings. 46 per cent of factories were open, and at peak operation, for 24 hours a day. The majority of workshops had peak operating hours, of fewer than 15 hours per day (99 per cent).

Table 1.2: Range of building and premises characteristics by industrial sub-sector by per centage of floor area, 2014–15

Column per centages

	Industrial sub-sector		
	Factories (%)	Workshops (%)	**Industrial sector (%)**
Organisation size[8]			
Micro (0-9)	9	37	20
Small (10-49)	13	37	22
Medium (50-249)	24	17	22
Large (250+)	54	8	36
Don't know	-	1	0
Total floor area (m^2)			
Less than 50	-	1	0
50-99	0	4	2
100-249	1	16	7
250-499	3	23	11
500-999	7	15	10
1,000-4,999	18	11	16
5,000-9,999	4	2	3
10,000 or more	66	27	51
Tenure			
Owned	69	44	59
Leased	31	56	41
Don't know	-	0	0
Energy management ambition[9]			
Active	57	15	41
Passive	39	65	49
None	4	20	10
Don't know	-	-	-
Age of building			
Pre-1900	1	4	2
1900-1939	4	5	4
1940-1985	57	51	55
1986-1990	8	8	8
1991-2006	18	8	14
2007 or later	6	1	4
Don't know	5	22	12

[8] 'Large' relates to organisations employing 250+ staff, with further categories defined as: Medium (50-249), Small (10-49), Micro (1-9).

[9] '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.

	Industrial sub-sector		
	Factories (%)	Workshops (%)	**Industrial sector (%)**
Building structure			
Part of building	8	11	9
Whole building	66	82	73
Multiple buildings	26	6	17
Peak operating hours[10]			
8 or less	17	30	22
9-15	27	69	43
16-23	11	1	7
24	46	0	28
Don't know	-	0	0
Opening hours[11]			
8 or less	10	19	14
9-15	30	64	43
16-23	4	16	8
24	56	1	35
Don't know	-	0	0
Unweighted base	*106*	*369*	*475*

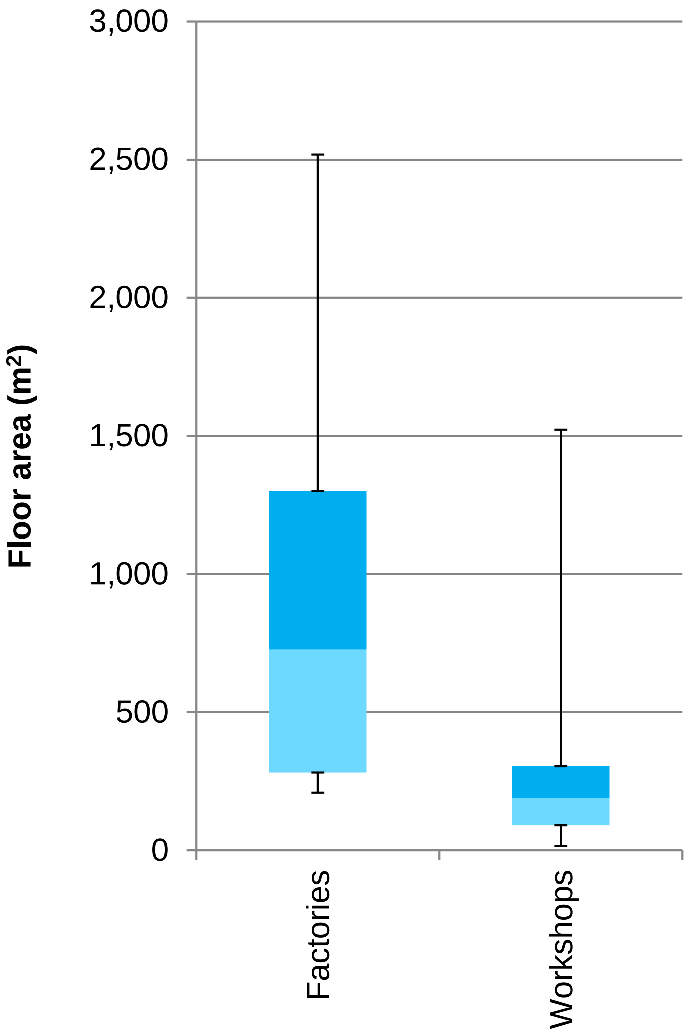
Source: Telephone survey or equivalent records for the sector, England and Wales

[10] 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)?".

[11] 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 factories had the largest median floor area in the industrial sector at 730 m^2, however there are a limited number of exceptionally large industrial facilities which are not included in the Valuation Office Agency dataset, which was used to sample industrial premises. Workshops had a median floor area of 190 m^2. The distribution of floor area sizes for factories was also much wider than for workshops. The central 50 per cent of records for factories had floor areas between 280 m^2 and 1,300 m^2 compared with a range of 90 m^2 to 300 m^2 in workshops.

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

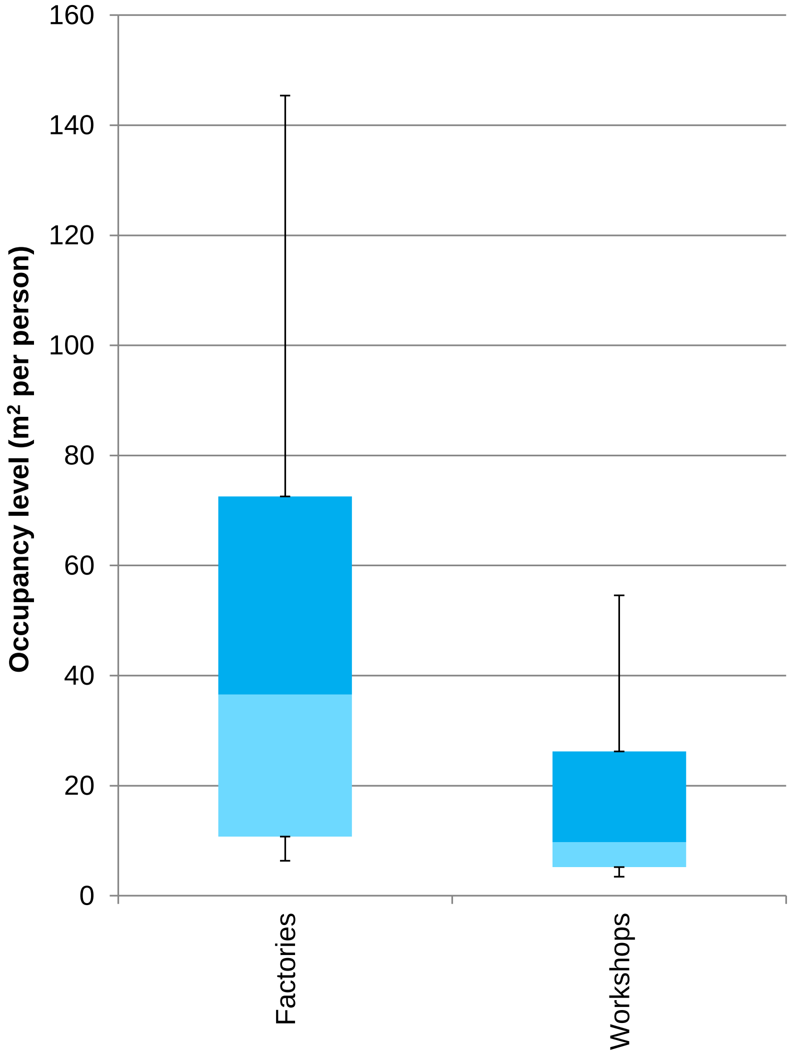


Note: In box and whisker plots, the blue columns, when combined, indicate the range of floor areas covered by the interquartile range of results (the middle 50 per cent of data points). The upper black bars extend to the 90th per centile, capturing a further 15 per cent of the total number of data points. The lower black bars span to the 10th per centile, 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.

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

Figure 1.5 shows the distribution of occupancy levels (the floor area per staff and visitor number) based on the number of staff and visitors present over a typical working day. Factories showed the lowest median occupancy level of 37 m^2 per person.[12] This compared with a median of 10 m^2 per person in workshops.

Figure 1.5: Occupancy level by industrial 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 per centile, capturing a further 15 per cent of the total number of data points. The lower black bars span to the 10th per centile, 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.

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

[12] 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 industrial sector.

Greater detail on the BEES methodology in relation to the industrial 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 industrial 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;[13]
- 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.[14]

The first two objectives are addressed in this and other sector 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 was performed at sub-sector level with bespoke questionnaires and modelling assumptions used at this level.

The factories sub-sector was originally two distinct sub-sectors, factories and large industrials, for the two different building types – these were amalgamated retrospectively due to poor response rates in large industrials. The underlying analysis however is based on different questionnaires and modelling assumptions.

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 industrial sector through 475 telephone surveys and 15 site surveys during 2015.

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

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[13] 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.

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

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 industrial 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:

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[15]. 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

[15] 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.

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 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[16].
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.[17]
    - 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.

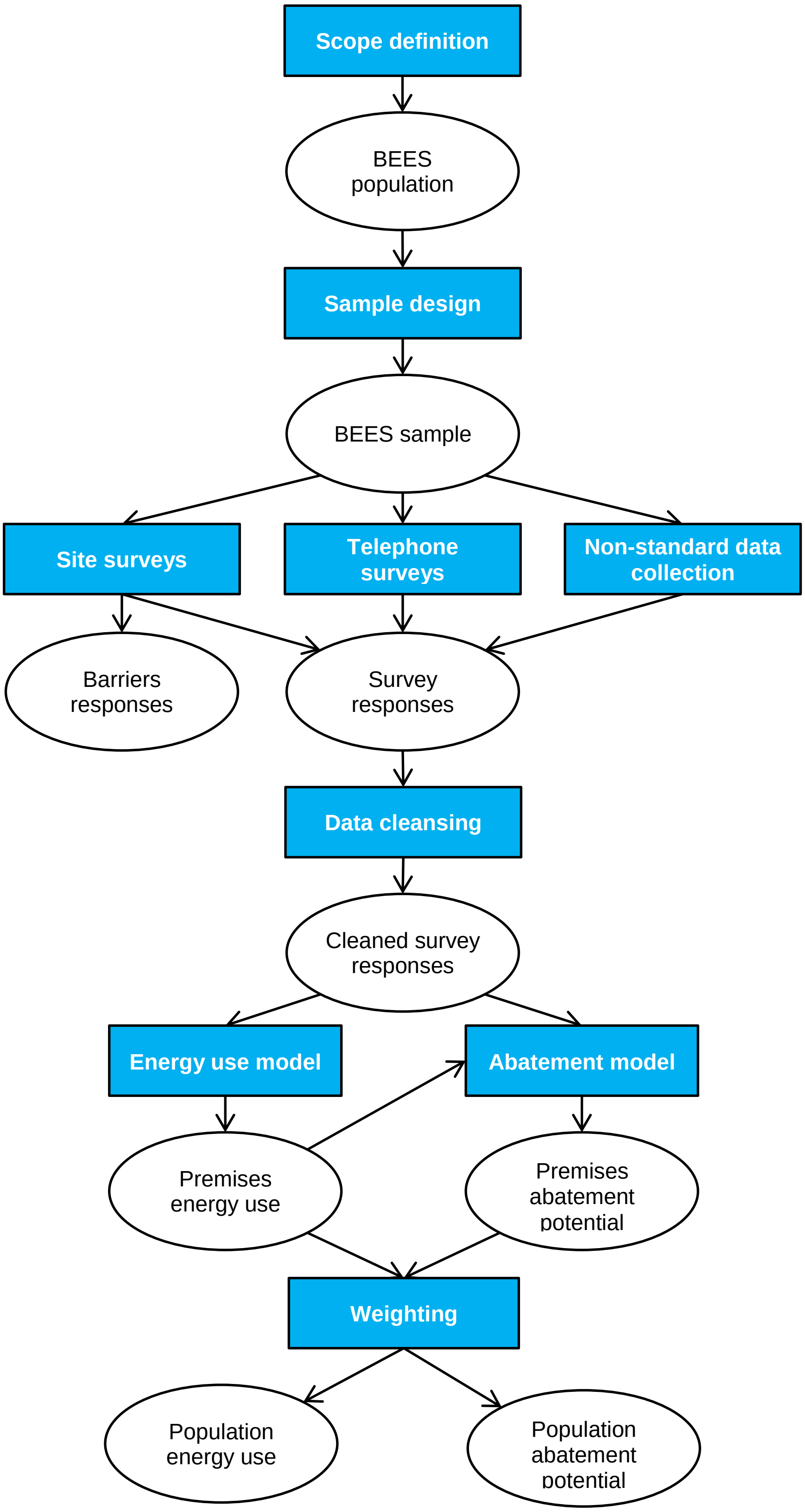
This approach was then tailored by sector. The impact of the change to the methodology within the industrial sector is covered in “Methodology challenges in the industrial sector”, which follows in this section, and in more detail in Appendix B.

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.

[16] 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.

[17] 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 industrial sector

For industrial sub-sectors a customised approach was required in certain cases due to limitations of available datasets and specific issues encountered within sub-sectors. A major difficulty in the sector was modelling the non-process load as accurately as possible. The energy use records were produced by modelling each premises as if it were simply a warehouse i.e. no process load was present. Further information from the telephone survey on how the process load in the premises interacted with the standard building services load was used to adjust the building services loads were then increased or reduced accordingly.

This approach had a number of difficulties. A summary of further specific issues encountered is set out below and a full description is included in Appendix B:

- **Data collection** Site survey recruitment in the industrial sub-sectors was challenging. Direct contact with industrial organisations was undertaken in order to increase the number of candidates, with multiple sites provided by single organisations. This may have introduced a bias compared to random sampling and affected the representativeness of responses on energy management practices and barriers and facilitators to energy effieicny. .
- **Data collection** Originally, factories and large industrials (>20,000 m^2) were to be treated as separate sub-sectors, but as a result of the poor response rates in large industrials, they were merged for reporting purposes which did not affect the overall robustness but reduced the granularity of results.
- **Data processing** The exclusion of process loads from energy modelling in the BEES study precluded the direct use of matched energy data. There was therefore no source to calibrate the accuracy of the energy use calculations for the premises. In other sub-sectors the energy use record aligned with the matched energy data for the premises but this was not the case in industrial premises. This reduced confidence in the model calibration processes.
- **Data processing** It was common in many premises for the process load to interact with the standard building services, possibly resulting in a reduced need for heating or requiring additional lighting in key spaces. The telephone survey gathered information on these interactions but it was limited in the level of detail that it could gather, due to the simplified nature of a telephone survey, and also restricted to the respondent's perception of how these end uses interact. As such, confidence levels in heating, cooling and fans end use energy estimates were low in the industrial sector.
- **Data processing** In many of the site surveys it was observed that users had much wider comfort level bandings than compared to users in other sectors – the tolerance for temperatures that would be usually too high or too low in other environments was accepted. The energy modelling will therefore be less accurate, as typical comfort conditions are assumed.
- **Data processing** It was observed in the site surveys that standard uses would often be carried out in environments that were not purpose built for the activity. For example, an office activity might be conducted in a refurbished area within a warehouse. This meant that some of the typical assumptions that apply to such

spaces may not have been as applicable, reducing the reliability of estimates of energy uses for these end-uses.

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 industrial sector.

Scope of industrial sector consumption

The scope of the survey within the industrial sector excluded energy use from industrial processes. Results only cover building energy consumption from premises in the industrial sector. Within the survey, respondents were asked to provide an estimate of the share of their electrical and non-electrical consumption that was used for industrial process activity. Overall 20 per cent of electrical energy and 35 per cent of non-electrical energy was used for building energy uses. Please refer to appendix E for further information on the definition of non-process and process loads and how these were handled in the project.

Table 3.1: Share of energy consumption used for industrial processes in the industrial sector, 2014–15[18]

	Factories	Workshops	Industrial sector
Electrical process share	83%	67%	**80%**
Non-electrical process share	62%	71%	**65%**
TOTAL process share	**75%**	**69%**	**74%**
Unweighted base	*102*	*338*	***440***

Source: Telephone survey or equivalent records for the sector and Energy use model results for the sector, England and Wales

Energy consumption and greenhouse gas emissions from premises in the industrial sector

The electrical and non-electrical energy consumption of premises in the industrial sector is presented in Figure 3.1, broken down by the two industrial sub-sectors (factories and workshops).

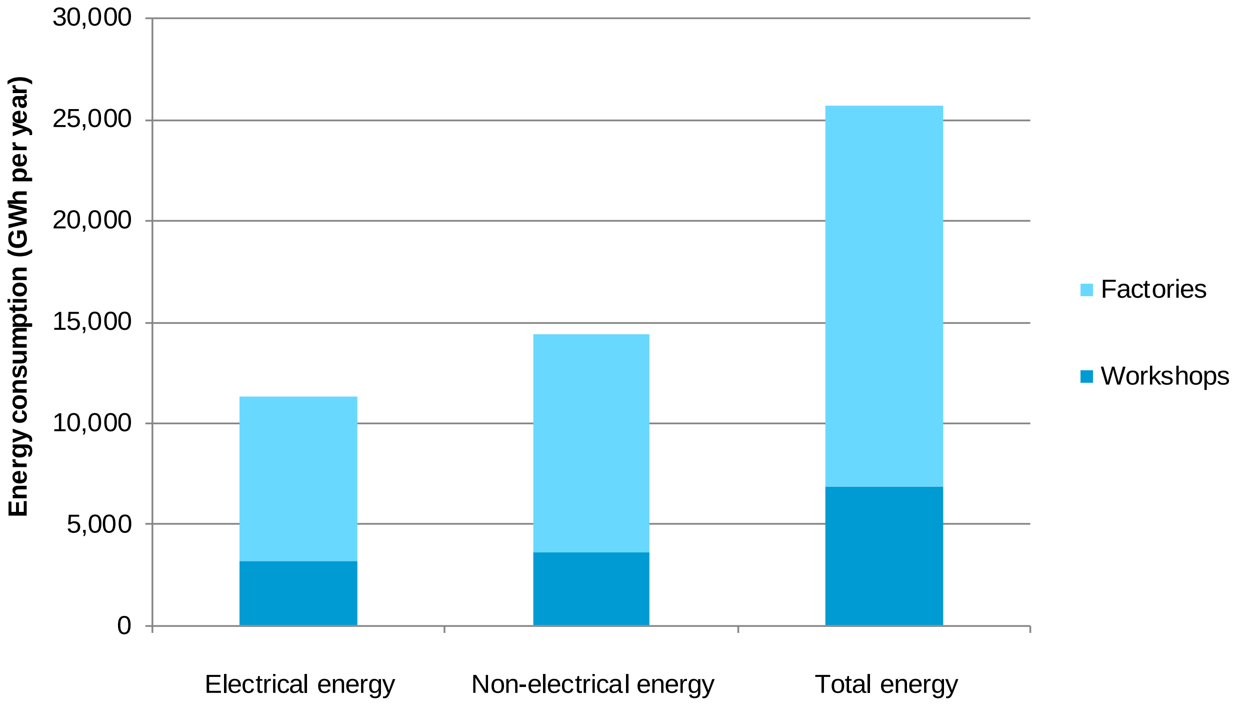
The premises in the industrial sector consumed 25,740 GWh of energy. This consisted of 11,320 GWh of electrical energy and 14,410 GWh of non-electrical energy per year (Figure 3.1).

The largest energy consumer in the sector was factories, with a consumption of 18,840 GWh of total energy (73 per cent of total). This consisted of 8,080 GWh of electrical energy (71 per cent of sector total) and 10,760 GWh of non-electrical energy (75 per cent of sector total). This was partly due to this sub-sector being the largest in the industrial sector (107 million m^2 compared with 68 million m^2 for workshops).

Workshops consumed 6,890 GWh of total energy (27 per cent of total). This comprised 3,240 GWh of electrical energy consumption (29 per cent of sector total) and 3,650 GWh of non-electrical energy consumption (25 per cent of sector total).

[18] The questions to estimate the share of industrial processes were not answered in 7 per cent of telephone surveys hence lower unweighted bases are shown in this table.

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

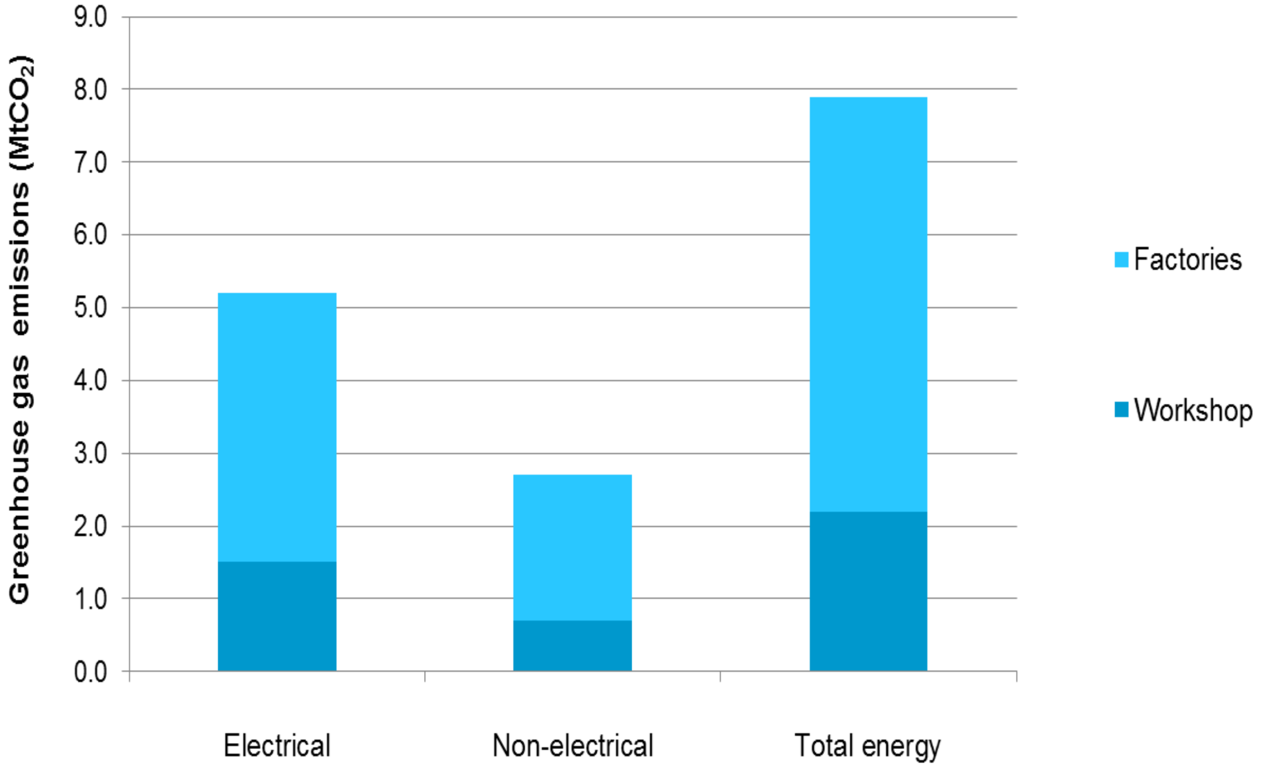


Source: Energy use model results for the sector, England and Wales

The greenhouse gas emissions for premises in the industrial sector are presented in Figure 3.2.[19] The total greenhouse gas emissions from premises in the industrial sector were deemed to be 7.8 $MtCO_2e$ per year. The annual emissions from electrical energy consumption were 5.1 $MtCO_2e$ and those from non-electrical energy consumption were 2.7 $MtCO_2e$.

[19] 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.

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



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

Energy consumption by end use from premises in the industrial sector

The total energy consumption by end use is presented in Figure 3.3 and Table 3.2.[20]

The energy use model defines 23 separate building energy end uses in its analysis. These were 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 (small power). The simplified classification is shown against the more detailed classification results in Table 3.2.

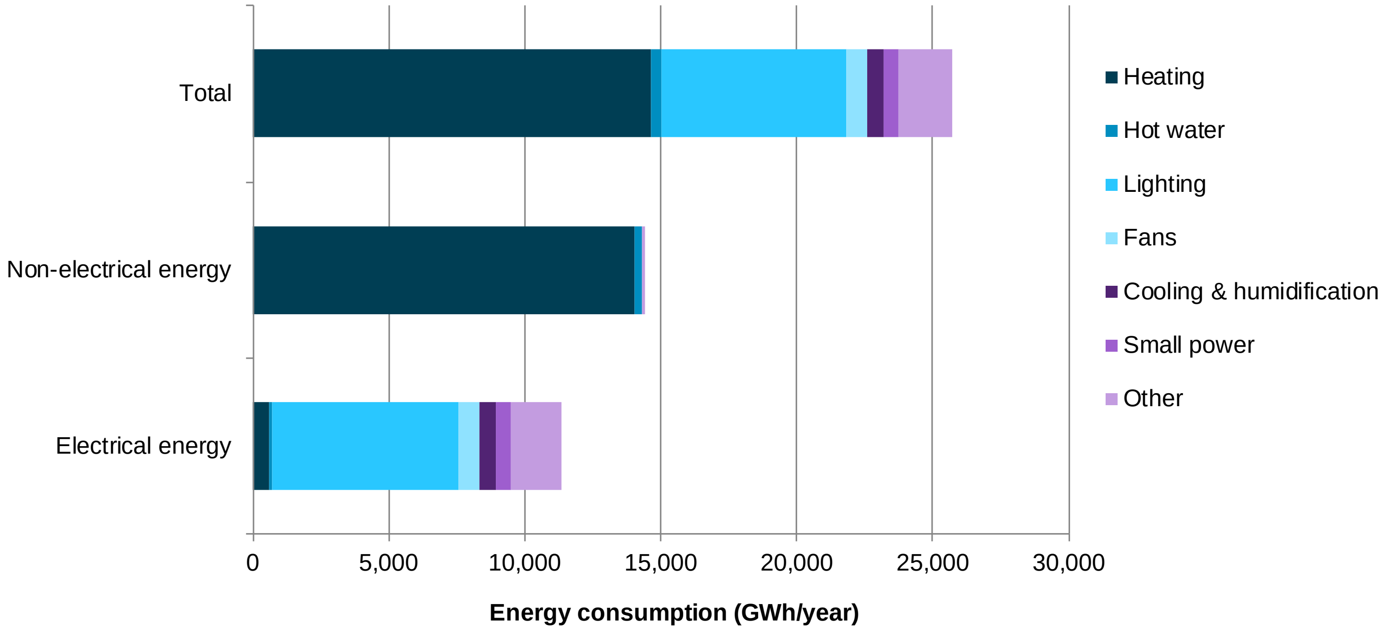
Further detail can be found in Appendix C on the 23 end uses and how these are re-categorised to the categories used in this sector report.

The total energy consumption for premises in the industrial sector was 25,470 GWh. The most significant end use was space heating (14,620 GWh, 57 per cent total energy consumption), followed by internal lighting (6,830 GWh, 27 per cent of total energy consumption). The most

[20] 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.

common end uses of electrical energy were internal lighting at 6,830 GWh (60 per cent of total), followed by external lighting (910 GWh, 8 per cent). The next major electrical end uses included fans (780 GWh, 7 per cent), space cooling (610 GWh, 5 per cent) and space heating (570 GWh, 5 per cent). The most significant non-electrical energy end uses were space heating at 14,050 GWh (98 per cent of total) followed by hot water (240 GWh, 2 per cent). Non-electrical energy consumption for heating was much higher than electrical energy consumption (14,050 GWh compared with 570 GWh).

Figure 3.3: Energy consumption by simplified end use breakdown for premises in the industrial sector, 2014–15 (industrial process energy use not included)



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

Table 3.2: Energy consumption by energy type and energy end use for premises in the industrial sector, 2014–15

Energy end use category (Simplified)	BEES end use category[21]	Electrical energy consumption (GWh/year)	Non-electrical energy consumption (GWh/year)	Total energy consumption (GWh/year)
Heating	Space heating	570	14,050	14,620
Hot water	Hot water	140	240	380
Lighting	Lighting - internal	6,830	-	6,830
Fans	Fans	780	-	780
Cooling & humidification	Space cooling	610	-	610
Small power	Small power	530	-	530
Other	Medical equipment	-	-	-
	Pumps	220	-	220
	Catering	180	120	310
	Cooled storage	20	-	20
	Controls	70	-	70
	Lighting - external	910	-	910
	Vertical transport	5	-	5
	Lighting - display	0	-	0
	Entertainment equipment	50	-	50
	Pool/leisure	-	-	-
	ICT equipment	270	-	270
	Laundry	4	-	4
	Other	130	-	130
Total		**11,320**	**14,410**	**25,740**
Unweighted base		*475*	*372*	*475*

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

Industrial 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.[22] Note the floor area relates to the total premises area even though a number of these end uses might only have been included when they related to non-industrial process areas e.g. offices. Figure 3.4 to Figure 3.6 present the distribution of energy intensity for all modelled records in each sub-sector within the industrial sector, in terms of total energy intensity, electrical energy intensity and non-electrical energy intensity respectively.[23] In this report all intensity figures (excluding box plots)

[21] The end uses are defined in Appendix D.

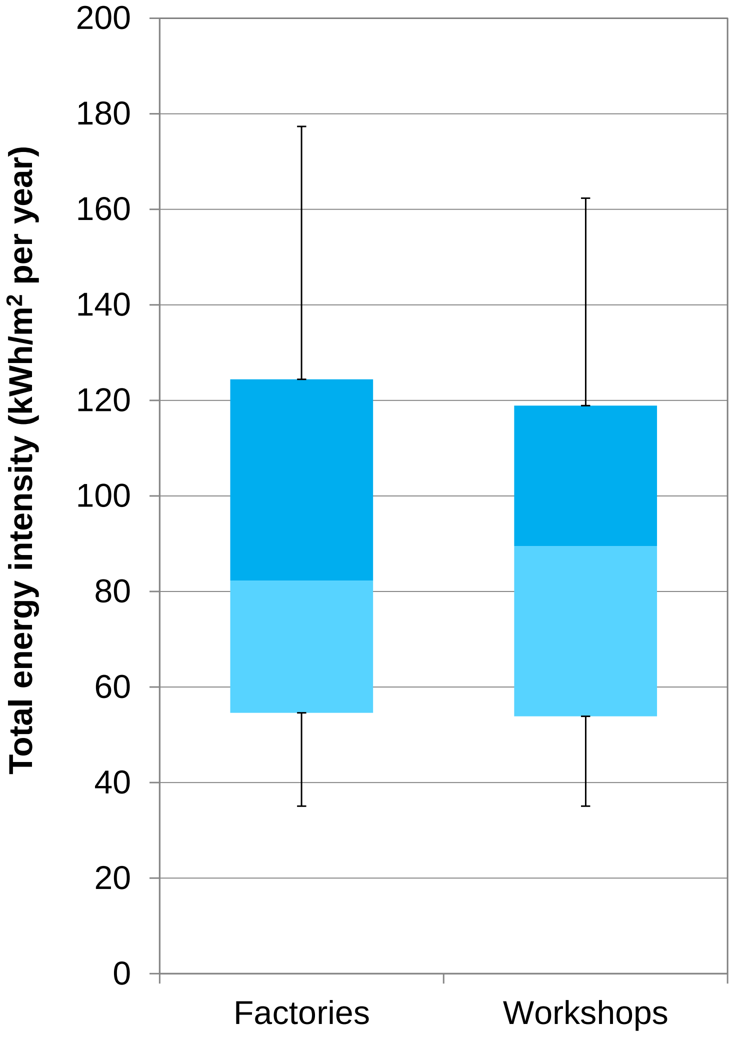
[22] As employed in CIBSE TM46 Energy Benchmarks (available at: http://www.cibse.org/knowledge/cibse-tm/tm46-energy-benchmarks), and others.

[23] 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.

have been calculated using the total sector or sub-sector floor area regardless or whether they have a particular energy source or end-use.

Figure 3.4 shows that workshops had the largest median overall energy intensity (90 kWh/m^2), followed by factories (82 kWh/m^2). Figure 3.5 and Figure 3.6 show that workshops typically displayed the highest median electrical energy intensity (44 kWh/m^2). Workshops displayed a higher median non-electrical energy intensity than factories (45 kWh/m^2 and 40 kWh/m^2 respectively).

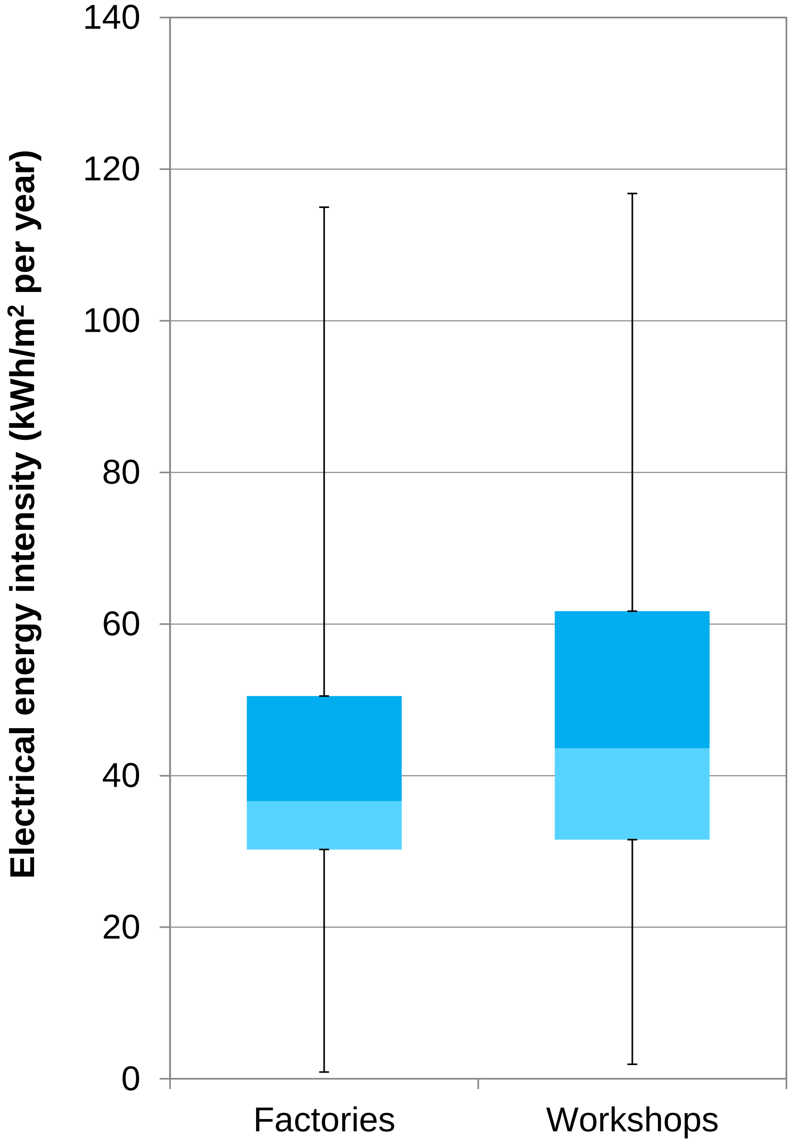
Figure 3.4: Distribution of total energy intensity by industrial sub-sector, 2014–15



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 per centile, capturing a further 15 per cent of the total number of data points. The lower black bars span to the 10th per centile, 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.

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

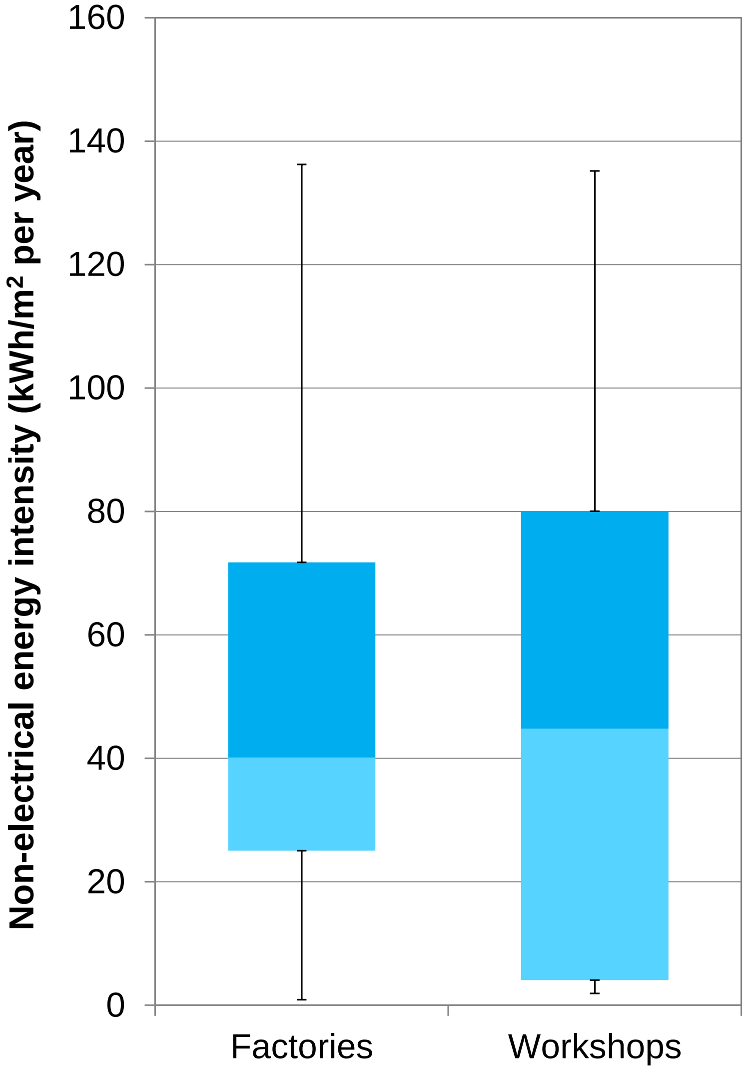
Figure 3.5: Distribution of electrical energy intensity by industrial sub-sector, 2014–15



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 per centile, capturing a further 15 per cent of the total number of data points. The lower black bars span to the 10th per centile, 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.

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

Figure 3.6: Distribution of non-electrical energy intensity by industrial 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 per centile, capturing a further 15 per cent of the total number of data points. The lower black bars span to the 10th per centile, 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.

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

Industrial sub-sector energy end use breakdowns

Figure 3.7 shows the mean modelled energy intensity by end use for both of the sub-sectors in the industrial sector. Note the floor area relates to the total premises area, including industrial process areas in which building energy consumption is minimal or non-existant. As process energy is excluded in these results, the total energy intensity appears lower than in reality. Further data is provided in Appendix C where energy consumption and energy intensity is provided separately for electrical and non-electrical energy end use breakdowns by sub-sector.

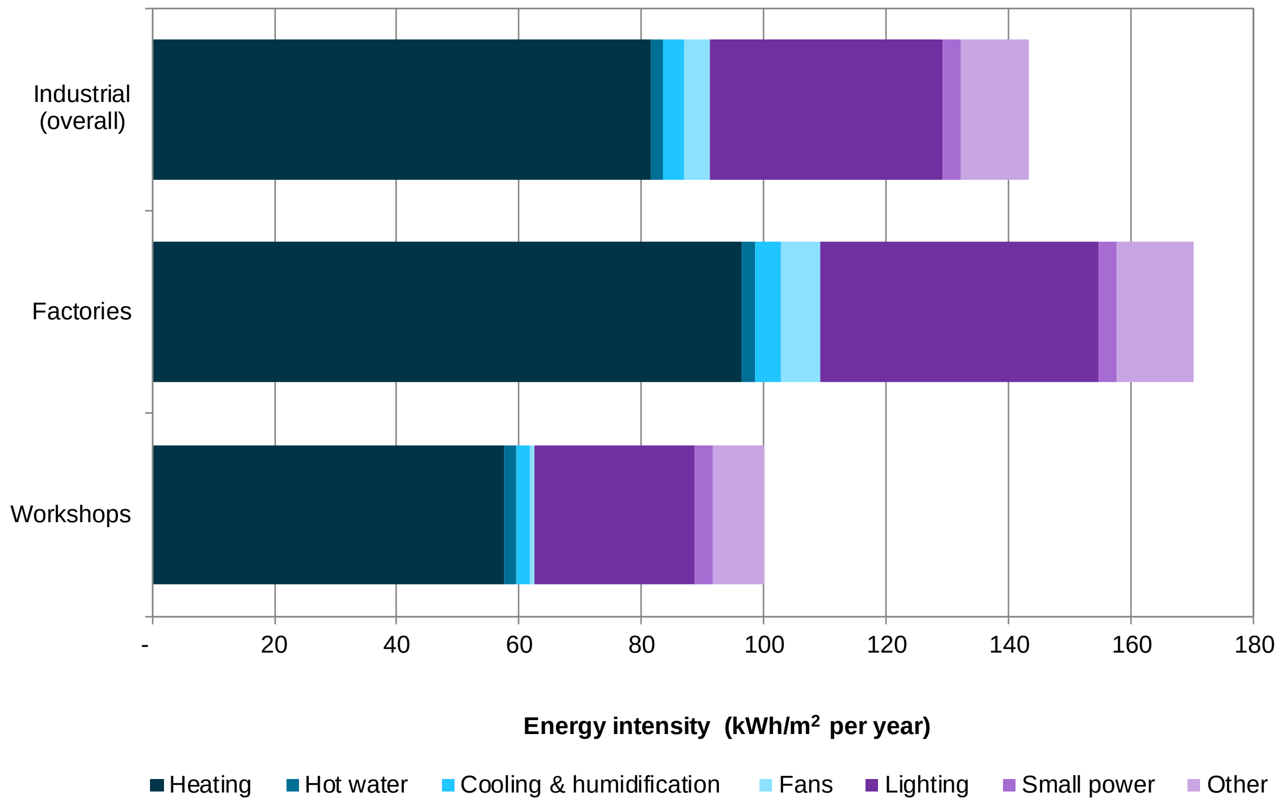
Heating energy intensity was the largest contributor to the sector's energy consumption. Heating intensity was highest in factories, and lower in workshops. There are a wide range of factors affecting heating consumption in the industrial sector and it should be noted that this data is presented with lower confidence[24].

Hot water energy intensity was low in both sub-sectors. This was due to low occupancy levels in the majority of premises. Cooling and humidification energy intensity was also low, with comfort cooling generally rare; where cooling was present it was usually limited to office areas and special areas such as server rooms. Small power energy intensity was also quite low across the sector; in both sub-sectors it was common to find an office space within the industrial premises, but this would typically be less than 20 per cent of the floor area.

Lighting energy intensity is significant in both sub-sectors. The major variable affecting lighting intensity was hours of use; workshops were most likely to operate office-type hours, whereas the 50 per cent of factories operated between 16-24 hours a day.

[24] Further details are provided in Appendix C.

Figure 3.7: Mean energy intensity simplified end use breakdowns by industrial sub-sector (industrial process energy use not included), 2014–15



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

Abatement potential

In this section, abatement potential[25] for the industrial 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[26], while the benefits were only based on the incremental reduction in energy consumption[27]. Replacement of systems which were not at the end of their life were therefore included. This will be more expensive than end of life replacement, as the impact on energy consumption is likely to be smaller for where equipment is newer, 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 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

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

[26] 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.

[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

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

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

Total technical abatement potential for premises in the industrial 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 is between 45 and 46 per cent of total energy consumption[28]. Each sub-sector can achieve between 38 to 45 per cent savings in electrical energy consumption and 45 to 51 per cent savings in non-electrical energy consumption. This could be achieved at an overall capital expenditure of £4.6 billion.

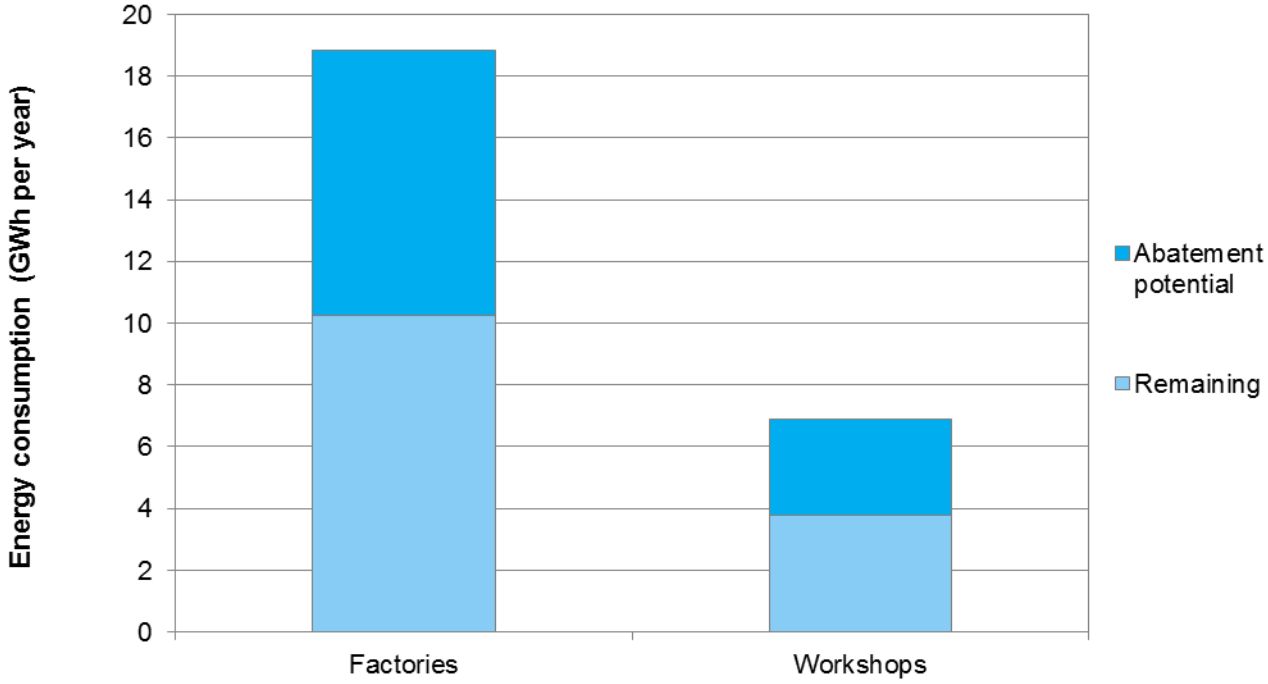
Table 0.1: Abatement potential by industrial sub-sector, 2014–15

		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)
Factories	2,446,600	8,080	10,760	3,070	5,540	46
Workshops	2,120,100	3,240	3,650	1,450	1,650	45
Total	**4,566,700**	**11,320**	**14,410**	**4,520**	**7,190**	**46**

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

[28] 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 0.1: Abatement potential for buildings by industrial sub-sector, 2014–15

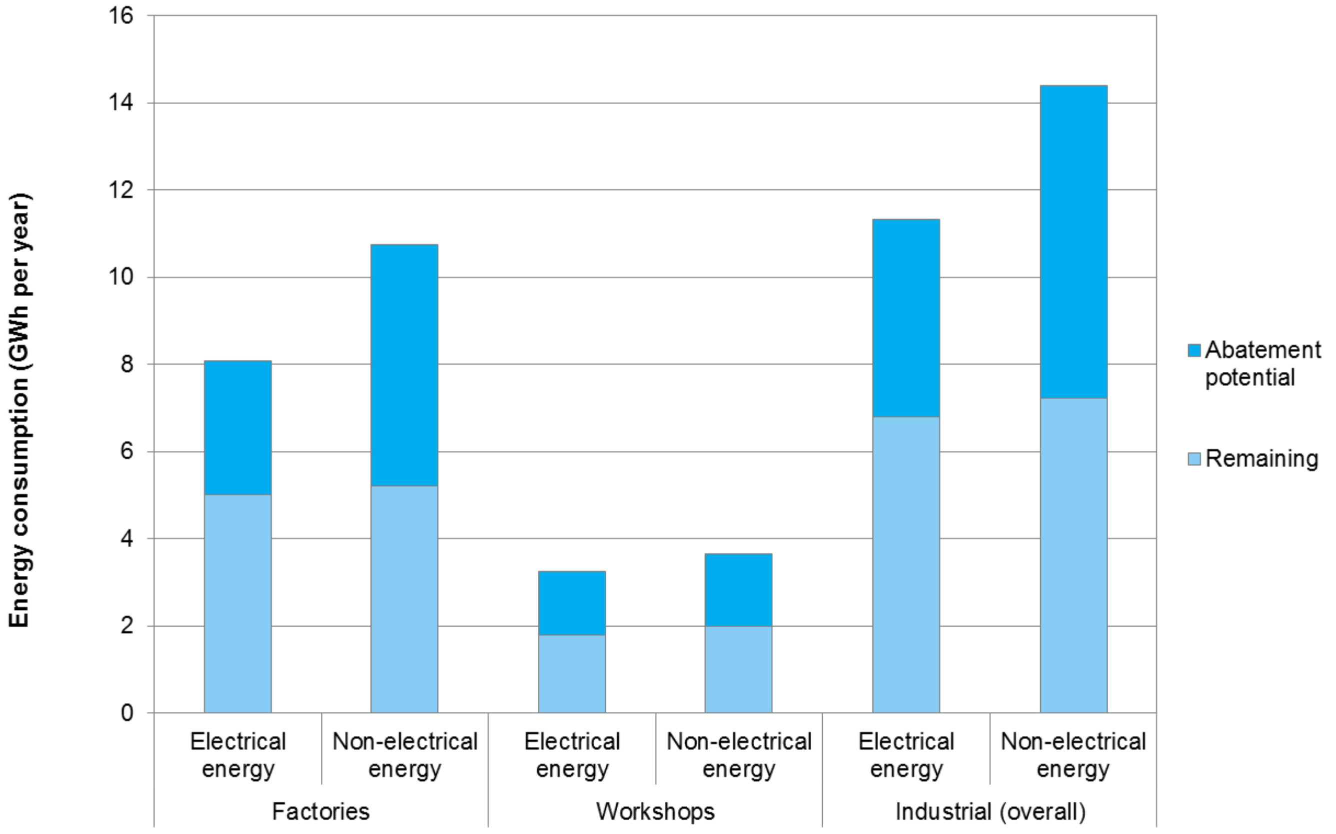


Source: Abatement model results by sub-sector, England and Wales

Figure 4.2 shows that the total technical abatement potential in 2014-15 varied by sub-sector: Factories had the largest absolute scope for reduction of 8,610 GWh of total energy, comprised of 3,070 GWh of electrical energy (38 per cent reduction on consumption) and 5,540 GWh of non-electrical energy (51 per cent reduction on consumption). Factories also had the largest proportional scope for reduction (46 per cent overall), compared with 45 per cent in workshops.

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 0.2: Abatement potential by energy type and industrial 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.[29] 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

[29] 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

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 2,480 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 to measure groups with a private payback of 3 years or less was 4,930 GWh, of which 3,380 GWh was electrical energy consumption and 1,550 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 measure groups that are cost effective in a particular sub-sector, but not for the sector as a whole.

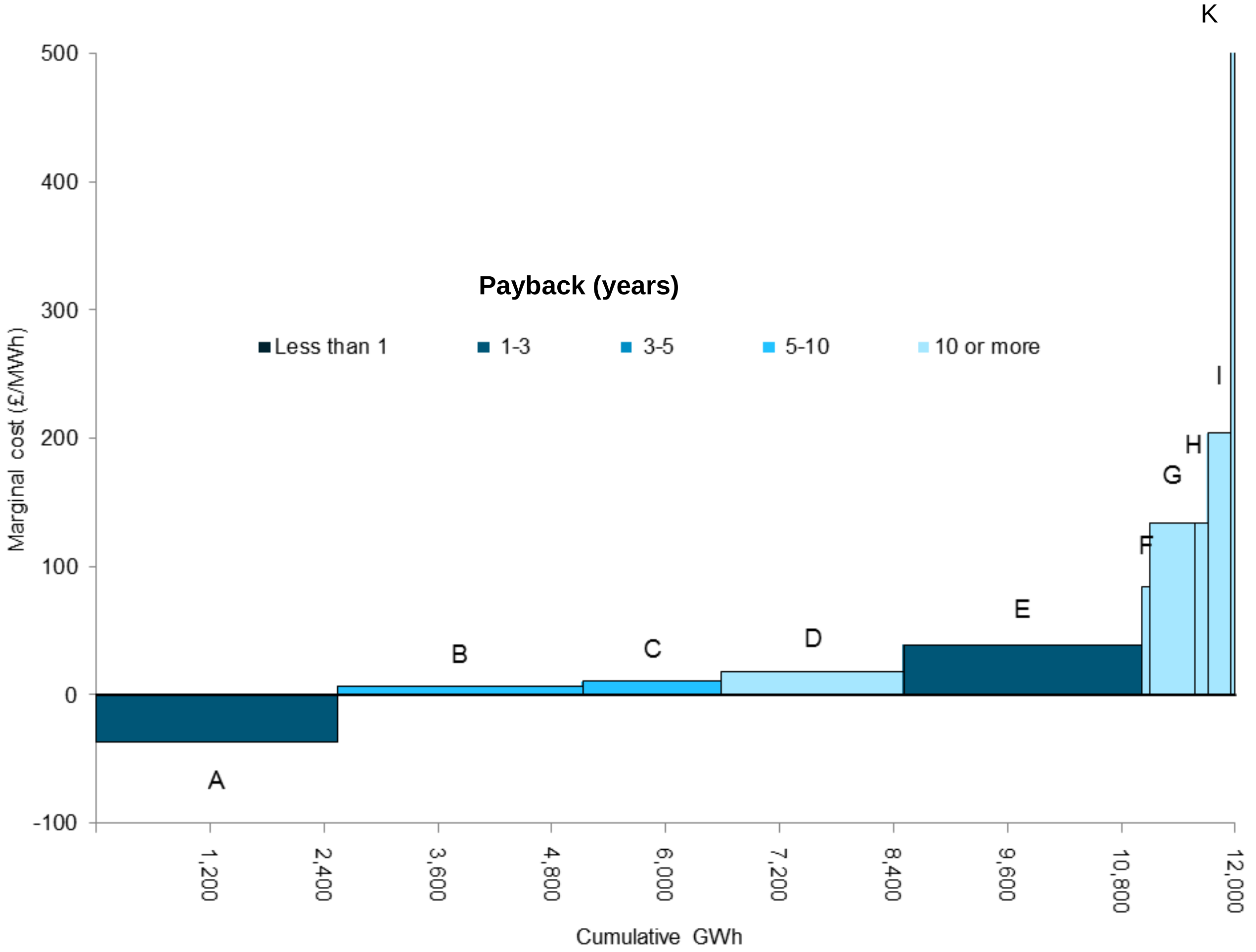
Only the lighting measure group was socially cost-effective when measure groups were considered at the sector level. If implemented, this measure group provides more financial benefits to society than costs. The lighting measure group also had relatively low payback periods, suggesting it may be more 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 heating controls upgrades, lighting upgrades, ventilation fan upgrades (variable speed drive motors which vary in speed depending on the demand for the service) and building management system recommissioning / upgrade.

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 gas-fired air heaters were in operation close to shutter doors that were fully open. Typically, Building management system time controls were also set for longer than necessary. In several premises lighting upgrades to LEDs were identified. Many of the surveyed premises were currently fitted with inefficient standard fluorescent lighting. Often, the central heating/cooling plant was also reasonably old and there was scope for additional optimum start/stop controls on the boilers. In large industrial facilities it was common for large ventilation systems to be fitted with aged belt driven fans and motors with low efficiency standards.

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 that had not been gathered in the telephone survey. An example of this would be sites where pipework carrying hot water was passing through mothballed areas and should be isolated to reduce radiant losses.

Figure 0.3: 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 perspective.

A Lighting [MAC: £-37 per MWh. GWh: 2,480]

B Building instrumentation and control [MAC: £7 per MWh. GWh: 2,520]

C Space heating [MAC: £12 per MWh. GWh: 1,430]

D Building fabric [MAC: £18 per MWh. GWh: 1,870]

E Carbon and Energy Management [MAC: £39 per MWh. GWh: 2,450]

F Hot water [MAC: £84 per MWh. GWh: 80]

G Ventilation [MAC: £133 per MWh. GWh: 470]

H Air conditioning and cooling [MAC: £134 per MWh. GWh: 130]

I Building services distribution systems [MAC: £204 per MWh. GWh: 240]

J Small appliances [MAC: £515 per MWh. GWh: 30]

K Cooled storage [MAC: £718 per MWh. GWh: 10]

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

Table 0.2 shows the abatement potential by measure type. The most significant available savings were associated with building instrumentation and control, lighting and carbon and energy management measures.[30]

Table 0.2: Abatement potential by measure type, 2014–15

Measure type	Savings: Total annual energy bill saving (£ thousands)	Savings: Total annual greenhouse gas saving ($ktCO_2e$)	Savings: Total annual electrical energy savings (GWh)	Savings: Total annual non-electrical energy savings (GWh)	Savings: Total annual energy savings (GWh)	**Total capital cost of measure (£ thousands)**
Air conditioning and cooling	13,200	40	130	-	130	177,300
Building fabric	55,900	350	110	1,760	1,870	1,454,500
Building instrumentation and control	76,300	490	160	2,360	2,520	520,300
Building services distribution systems	23,700	70	240	-	240	342,500
Carbon and energy management	128,500	580	900	1,550	2,450	350,500
Hot water	2,700	20	10	70	80	86,200
Humidification	-	-	-	-	-	-
Lighting	246,700	700	2,480	-	2,480	662,300
Cooled storage	700	2	7	-	7	35,500
Small appliances	2,200	7	20	5	30	73,400
Space heating	39,900	270	50	1,390	1,430	322,200
Swimming pools	-	-	-	-	-	-
Ventilation	42,700	140	420	60	470	542,200
Total	**632,600**	**2,650**	**4,520**	**7,190**	**11,710**	**4,566,700**

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

[30] 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)
Factories	73	± 12
Workshops	47	± 4
Industrial	**63**	**± 5**

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

	Mean (kWh/m^2)	Confidence interval (kWh/m^2)
Factories	97	± 31
Workshops	53	± 7
Industrial	**80**	**± 13**

Response rates

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

	Factories (%)	Workshops (%)	**Industrial sector (%)**
Completed interview	9	9	9
Still live[31]	61	71	69
Screening failure/other non-response[32]	1	2	1
Refusal	13	10	10
Other non-response	7	3	4
Invalid contact details	9	6	7

[31] 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).

[32] 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: Industrial method challenges and data collection

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

Industrial sector methodology challenges

In the case of the industrial 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: Industrial sector approach challenges

Stage	Challenge	Response	Impact
Data collection	Site survey recruitment in industrial sub-sectors had low uptake.	Direct contact with industrial organisations was undertaken in order to boost the selection of site survey candidates. Participants were asked to contribute multiple sites if willing. This boosted the site survey total in factories.	The range of industries covered by the site surveys was reduced compared to a random sample, which is likely to have introduced a bias in the calibration process.
Data collection & processing	Only a small number of telephone survey responses and site surveys could be recruited in the large industrial sub-sector. This was subsequently merged with factories. This caused significant limitations in the processing of the data, as a separate calibration could not be undertaken for this sub-sector.	The large industrial sub-sector was processed last, after factories and workshops. This ensured that all the learning from these previous sub-sectors was already incorporated in the energy model prior to running the large industrial sub-sector.	The lack of calibration against site survey results and matched data reduces confidence in the energy consumption and end use estimates for this sub-sector.
Data processing	The presence of out-of-scope process loads in industrial premises causes two issues: Firstly, the presence of industrial processes within	In order to estimate the impact of processes on building energy loads, questions were asked in the telephone survey to identify where these effects occurred.	Overall confidence in estimated energy consumption is lower in industrial sub-

Stage	Challenge	Response	Impact
	premises has a knock on effect on other building loads e.g. heat gains offsetting heating demand or creating a need for comfort cooling; gases or heat from processes requiring additional ventilation. Secondly, it prevents direct use of matched energy data as a validation source in energy model calibration processes, as the BEES energy model only predicts non-process loads.	The impact on energy use was estimated by asking how many months per year of heating and/or cooling were required and the air change rate required for any general ventilation. From a calibration perspective, the calibration activities focussed on validating the in-scope energy consumption estimates compared to the site survey findings. Comparison with matched energy data was limited to confirming that the model predicted lower energy use on average than the matched data i.e. to confirm that an excess existed to cover process loads. It was noted that despite the actions taken, there were many further variables affecting heating and cooling loads which could not be accounted for, due to the vast range and complexity of industrial activities.	sectors. Confidence in results for the heating, cooling and fans end uses is very low in industrial sub-sectors. Confidence in other end uses is medium, as total energy consumption could not be verified against matched data.
Data processing	High variability in the activities and usage of spaces in the workshops sub-sector created a modelling challenge. Our modelling approach assumed that industrial/workshop space would be the majority activity in the premises and the telephone survey was written accordingly. However, in the workshops sub-sector examples were identified where (for example) office space was more prevalent than workshop areas.	It was not possible to amend the modelling procedures to account for these issues within the limitations of the study. It is therefore necessary to caveat the results for the workshop sub-sector, noting that the high variability of the premises in this sub-sector resulted in poor modelling confidence.	Energy end use and overall energy estimates in the workshops sub-sector are presented with a low confidence.

Stage	Challenge	Response	Impact
	It was also noted that it was common for multiple heating systems to be present on site (e.g. gas fired unit heaters in workshop areas and local heating and cooling units i.e.VRF/split units in office areas). The energy model used in the BEES project is not able to model multiple heating systems discretely.		
Data processing	In many of the site surveys it was observed that users had much wider comfort level bandings than compared to users in other sectors – the tolerance for temperatures that would be usually too high or too low in other environments was accepted.	Questions were included in the telephone survey asking whether there were any processes or equipment releasing significant amounts of heating or cooling which would need to be compensated for.	The typical energy end use estimates for heating, cooling and ventilation in space types such as offices may have differed from the same results in analogous sub-sectors, as the variety in perceived comfort levels was greater.
Data processing	It was observed in the site surveys that standard space uses would often be carried out in environments that were not purpose built for the activity. An office activity might be conducted in a refurbished area within a warehouse for instance.	No special treatment was given to space areas conducted in areas which were not purpose built.	Some of the typical assumptions that apply to such spaces may not have been as applicable. This may have impacted the energy end use stimates for the sector.

Telephone survey and site survey data collection

Table B.2 shows that 475 telephone survey or equivalent records and 15 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[33]	Average interview length (mins.)	Target sample size	Site surveys completed
Factories	127	105	6	111	106	25	24	11
Workshops	490	383	0	383	369	24	12	4
Industrial sector	**617**	**488**	**6**	**494**	**475**	**n/a**	**36**	**15**

Source: Telephone survey or equivalent records, England and Wales

[33] 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 industrial 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 below.

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	Small power
	Pumps	Other
	Controls	Other
	Lighting - display	Other
	Lighting - external	Other
	Vertical transport	Other
	Cooled storage	Other
	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 industrial sub-sector and for the sector combined. Tables C.5 and C.6 show energy intensity by end use for each industrial sub-sector and for the sector combined.

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

Simplified end use category	**BEES energy end use category**	**Electrical energy consumption (GWh per year)**		
		Factories	Workshops	**Industrial (overall)**
Heating	Space heating	180	390	570
Hot water	Hot water	80	60	140
Cooling & humidification	Space cooling	460	160	610
Fans	Fans	720	60	780
Lighting	Lighting - internal	5,020	1,800	6,830
Small power	Small power	340	190	530
Other	Medical equipment	-	-	-
	ICT equipment	220	50	270
	Cooled storage	10	10	20
	Pumps	180	50	220
	Controls	30	30	70
	Humidification	-	-	-
	Laundry	1	3	4
	Lighting - display	0	-	0
	Lighting - external	640	270	910
	Entertainment lighting	-	-	-
	Vertical transport	4	1	5
	Distributed catering	20	90	110
	Central catering	70	-	70
	Entertainment equipment	20	30	50
	Lab equipment	-	-	-
	Pool/leisure	-	-	-
	Other	80	50	130
Total		**8,080**	**3,240**	**11,320**
Unweighted base		*106*	*369*	*475*

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

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

Simplified end use category	BEES energy end use category	Non-electrical energy consumption (GWh per year)		
		Factories	Workshops	Industrial (overall)
Heating	Space heating	10,480	3,580	14,050
Hot water	Hot water	160	80	240
Catering	Catering	120	1	120
Other	Medical equipment	-	-	-
	Pool/leisure	-	-	-
	Humidification	-	-	-
Total		**10,760**	**3,650**	**14,410**
Unweighted base		*92*	*280*	*372*

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

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

Simplified end use category	BEES energy end use category	Electrical energy intensity (kWh/m2 per year)		
		Factories	Workshops	Industrial (overall)
Heating	Space heating	2	6	3
Hot water	Hot water	1	1	1
Cooling & humidification	Space cooling	4	2	3
Fans	Fans	7	1	4
Lighting	Lighting - internal	45	26	38
Small power	Small power	3	3	3
Other	Medical equipment	-	-	-
	ICT equipment	2	1	1
	Cooled storage	0	0	0
	Pumps	2	1	1
	Controls	0	0	0
	Humidification	-	-	-
	Laundry	0	0	0
	Lighting - display	0	-	0
	Lighting - external	6	4	5
	Entertainment lighting	-	-	-
	Vertical transport	0	0	0
	Distributed catering	0	1	1
	Central catering	1	0	0
	Entertainment equipment	0	0	0
	Lab equipment	-	-	-
	Pool/leisure	-	-	-
	Other	1	1	1
Total		**73**	**47**	**63**
Unweighted base		*106*	*369*	*475*

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

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

Simplified end use category	BEES energy end use category	Non-electrical energy intensity (kWh/m^2 per year)		
		Factories	Workshops	**Industrial (overall)**
Heating	Space heating	95	52	78
Hot water	Hot water	1	1	1
Catering	Catering	1	0	1
Other	Medical equipment	-	-	-
	Pool/leisure	-	-	-
	Humidification	-	-	-
Total		**97**	**53**	**80**
Unweighted base		*106*	*369*	*475*

Source: Energy use model results by sub-sector, 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 industrial 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. Please note that this list contains the full set of abatement measures used across the project, including some which were not employed in this sector.

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).

Factories

In factories there was an annual abatement potential of 3,070 GWh of electrical energy and 5,540 GWh of non-electrical energy (equivalent to 1,930 $ktCO_2e$ combined). This equates to a 38 per cent and 51 per cent reduction on energy consumption respectively. The capital cost to achieve this is £2.45bn. The annual savings delivered would be £446m[34]. These figures are grouped according to measure type in Table D.2. The total abatement potential of the socially cost effective measure groups was 6,480 GWh, of which 2,310 GWh was electrical energy consumption and 4,170 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 to measure groups with a private payback of 3 years or less was 5,360 GWh, of which 2,300 GWh was electrical energy consumption and 3,060 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 factories, 2014–15

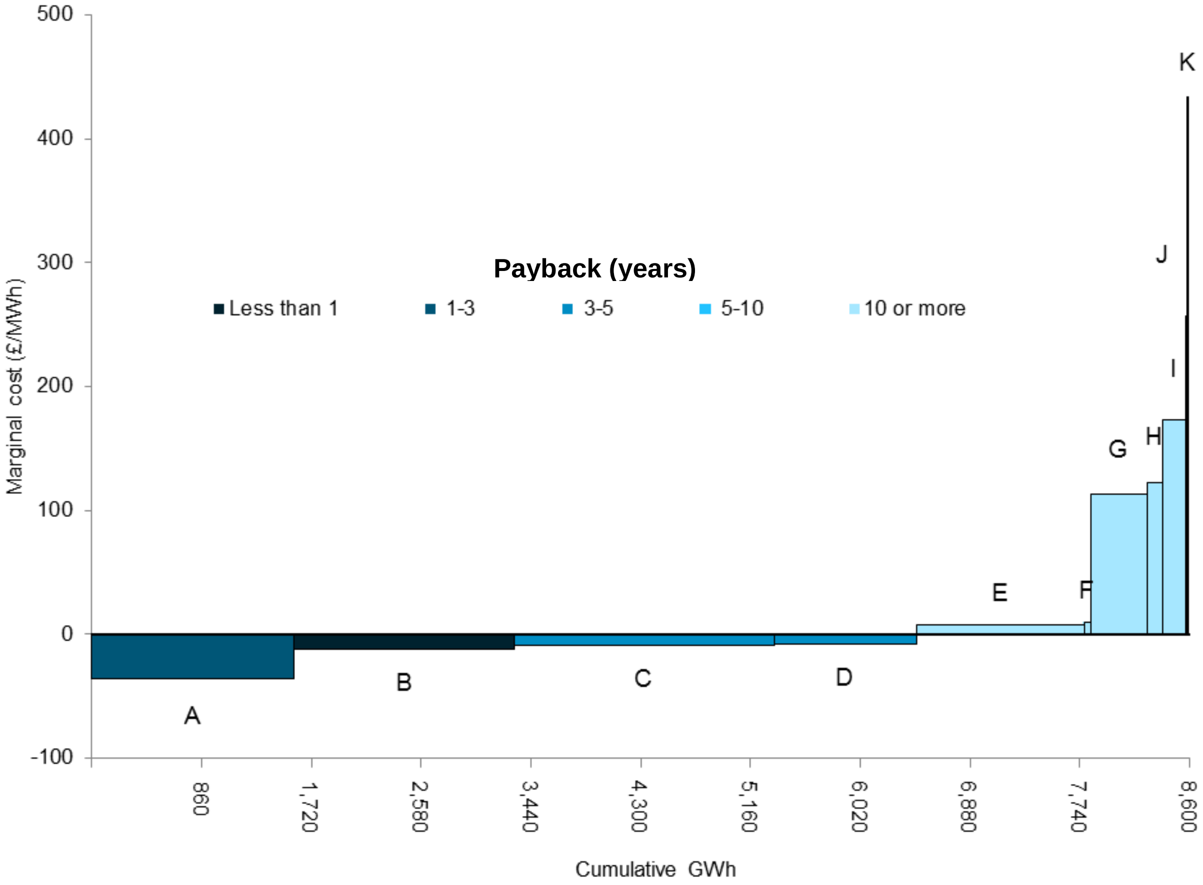
	Savings						
Measure type	Total annual energy bill saving (£ thousands)	Total annual greenhouse gas saving ($ktCO_2e$)	Total annual electrical energy savings (GWh)	Total annual non-electrical energy savings (GWh)	Total annual energy savings (GWh)	**Total capital cost of measure (£ thousands)**	**Pay -back period (years)**[35]
Air conditioning and cooling	11,500	30	120	-	120	135,100	14
Building fabric	36,800	250	50	1,260	1,310	739,100	12
Building instrumentation and control	59,100	390	90	1,950	2,050	219,600	3
Building services distribution systems	18,900	60	190	-	190	239,800	10
Carbon and Energy Management	89,700	410	620	1,110	1,730	77,700	1
Hot water	1,800	10	6	50	50	20,600	9
Humidification	-	-	-	-	-	-	-
Lighting	157,400	450	1,590	-	1,590	418,500	2
Cooled storage	500	2	5	-	5	11,700	19
Small appliances	800	3	7	4	10	26,200	24
Space heating	29,800	210	20	1,110	1,120	111,600	3
Swimming pools	-	-	-	-	-	-	-
Ventilation	40,000	130	390	50	440	446,700	8
Total	**446,400**	**1,930**	**3,070**	**5,540**	**8,610**	**2,446,600**	‘’

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

[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.1: Marginal abatement cost curve for factories, 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: £-36 per MWh. GWh: 1,580]
B Carbon and energy management [MAC: £-12 per MWh. GWh: 1,730]
C Building instrumentation and control [MAC: £-9 per MWh. GWh: 2,040]
D Space heating [MAC: £-7 per MWh. GWh: 1,120]
E Building fabric [MAC: £8 per MWh. GWh: 1,310]
F Hot water [MAC: £10 per MWh. GWh: 50]
G Ventilation [MAC: £114 per MWh. GWh: 440]
H Air conditioning and cooling [MAC: £123 per MWh. GWh: 120]
I Building services distribution systems [MAC: £173 per MWh. GWh: 190]
J Cooled storage [MAC: £257 per MWh. GWh: 10]
K Small appliances [MAC: £434 per MWh. GWh: 10]

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

Workshops

In workshops there was an annual abatement potential of 1,450 GWh of electrical energy and 1,650 GWh of non-electrical energy (equivalent to 720 $ktCO_2e$ combined). This equates to a 45 per cent reduction on both electrical and non-electrical energy consumption. The capital cost to achieve this is £2.1bn. The annual savings delivered would be £186m[36]. These figures are grouped according to measure type in Table D.3.The total abatement potential of the socially cost effective measure groups was 900 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 to measure groups with a private payback of 3 years or less was also 900 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.2).

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

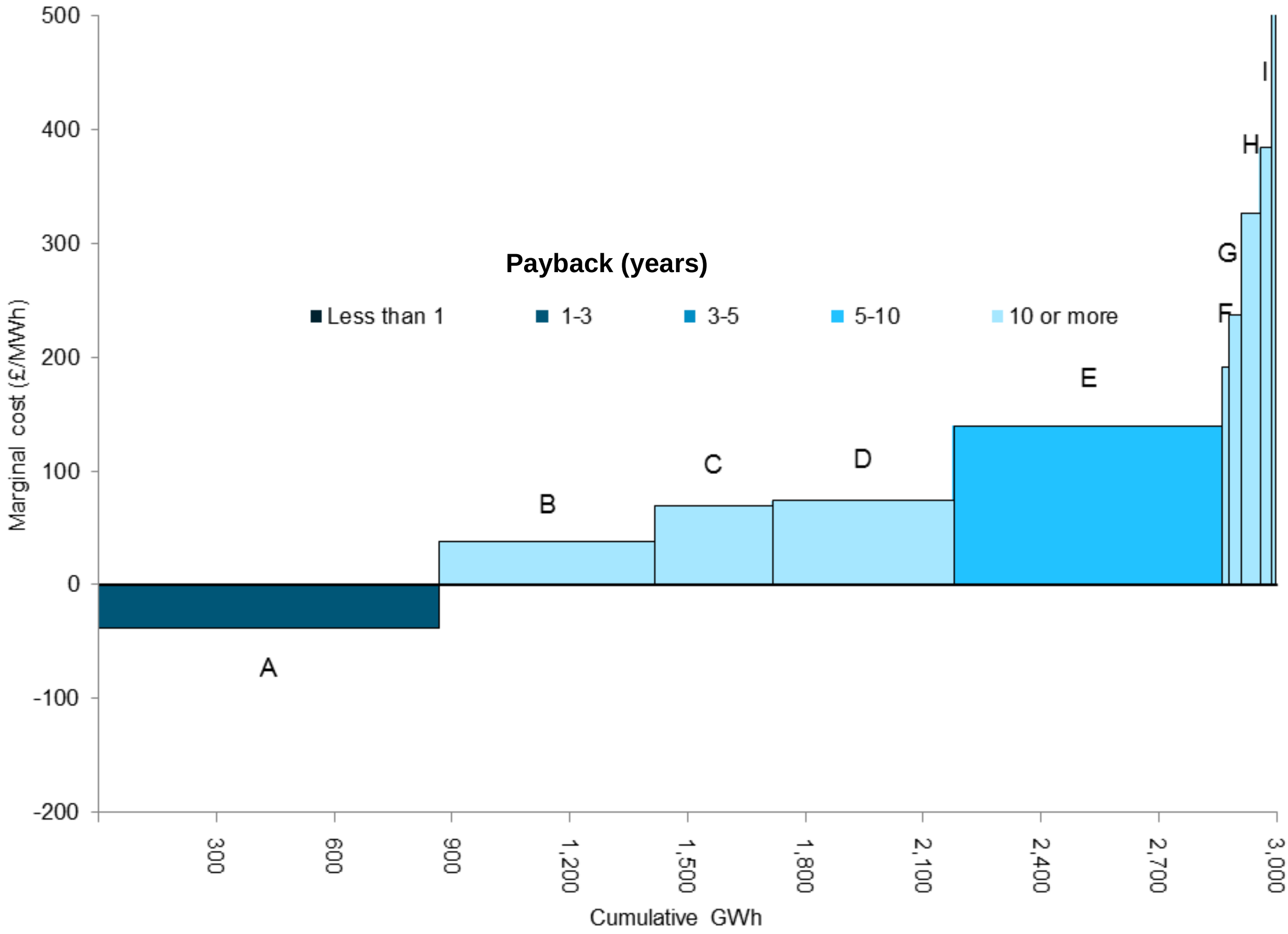
	Savings						
Measure type	Total annual energy bill saving (£ thousands)	Total annual greenhouse gas saving ($ktCO_2e$)	Total annual electrical energy savings (GWh)	Total annual non-electrical energy savings (GWh)	Total annual energy savings (GWh)	**Total capital cost of measure (£ thousands)**	**Pay -back period (years)**[37]
Air conditioning and cooling	1,700	5	20	-	20	42,200	42
Building fabric	19,200	110	60	500	570	715,400	27
Building instrumentation and control	17,200	100	70	410	480	300,700	13
Building services distribution systems	4,800	10	50	-	50	102,700	9
Carbon and Energy Management	38,700	170	280	440	710	272,900	5
Hot water	900	5	3	20	30	65,600	64
Humidification	-	-	-	-	-	-	-
Lighting	89,400	250	900	-	900	243,800	2
Cooled storage	100	0	1	-	1	23,800	165
Small appliances	1,400	4	10	1	20	47,200	25
Space heating	10,100	60	30	280	310	210,500	15
Swimming pools	-	-	-	-	-	-	-
Ventilation	2,700	8	30	3	30	95,500	23
Total	**186,200**	**720**	**1,450**	**1,650**	**3,100**	**2,120,100**	‘’

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

[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.2: Marginal abatement cost curve for workshops, 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 has been capped for presentation purposes.

A Lighting [MAC: £-38 per MWh. GWh: 900]
B Building fabric [MAC: £38 per MWh. GWh: 570]
C Space heating [MAC: £70 per MWh. GWh: 310]
D Building instrumentation and control [MAC: £74 per MWh. GWh: 480]
E Carbon and energy management [MAC: £139 per MWh. GWh: 710]
F Air conditioning and cooling [MAC: £191 per MWh. GWh: 20]
G Hot water [MAC: £237 per MWh. GWh: 30]
H Building services distribution systems [MAC: £326 per MWh. GWh: 50]
I Ventilation [MAC: £384 per MWh. GWh: 30]
J Small appliances [MAC: £573 per MWh. GWh: 20]
K Cooled storage [MAC: £2,603 per MWh. GWh: <1]

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

Appendix E: Industrial process definition

Scope definition for energy use in industrial premises

Energy use within the industrial sector required special treatment due to the way policy instruments are applied in the UK. Industrial energy consumption is a distinct policy area which is treated separately within UK government to the non-domestic building energy consumption which the Building Energy Efficiency Survey (BEES) investigated.

Furthermore, the limitations of the telephone survey approach used did not permit sufficient data collection to attempt to predict both the energy consumption of building uses and the vast range and highly customised complexity of industrial process activities which occur within buildings in the industrial stock (manufacturing, assembly, food processing, mining, repair and maintenance activities, etc). As a consequence of this, BEES only sought to investigate and quantify energy consumption associated with building loads in the industrial stock. Industrial processes are excluded.

In order to apply this exclusion it is necessary to split industrial premises into two elements – industrial process areas and non-industrial spaces:

- **Industrial process areas** are spaces inside or outside the building where physical, chemical, electrical or mechanical steps to aid in the manufacture, modification or repair of an item or items are carried out, often on a very large scale.
- **Non-industrial spaces** are all other areas inside or outside the building within the curtilage of the property. This typically includes offices, staff rest and training areas, storage areas, car parking and vehicle yards, but may include any areas where no industrial process activity takes place.

Energy consumption in scope

All energy consumption in non-industrial spaces was in scope. These areas were treated in exactly the same manner as other sectors.

In industrial process areas, only building energy loads were in scope. Building energy loads were defined as all heating, ventilation, cooling, lighting, pumps, controls and associated equipment which are used to condition the internal or external space for the comfort and safety of the people working in the space. All other energy consumption was excluded and was considered to be associated with industrial processes. For clarity, dedicated heating, cooling, ventilation, lighting, pumps and controls present whic directly served the industrial process being carried out -and not the general working environment for human comfort or safety- were out of scope.

Examples of in-scope and out-of-scope energy in industrial process areas are presented in Table E.1. These are not exhaustive but seek to clarify the distinction between energy used for the comfort of staff and common industrial process uses.

Table E.1: Examples of end uses included and excluded for the industrial sector

End use	In scope examples	Out of scope examples
Space heating	General space heating for the comfort of operatives serving a space containing an assembly line	Boiler systems used to heat space for the benefit of the industrial process e.g. elevated temperatures in a space for drying of a product
Hot water	Hot water generation associated with basic hygiene (toilets, showers) for staff working on a factory floor	Hot water boilers for process specific hygiene systems (e.g. sterilisation, decontamination) Hot water used for general cleaning of industrial process areas or equipment
Ventilation	General ventilation to extract fumes or heat from an industrial process area where people work without breathing apparatus	Dedicated extract ventilation serving a stage in a manufacturing process e.g. ovens, a chemical reaction vessel, a paint spray booth, a steam boiler, for a drying room or kiln
Lighting	General lighting allowing staff to move around a factory floor safely and carry out general working tasks	Dedicated task lighting for specific activities on an assembly line Ultraviolet lighting used for sterilisation Safety warning lights relating to industrial processes Small areas with task specific elevated lighting levels e.g. an area where microelectronic circuits are assembled
Cooling & humidification	Air conditioning systems installed to cool a general factory space where heat gains would otherwise make the space too hot for staff to work in comfort	Dedicated cooling systems cooling a small area only e.g. paint spray booth Cooling systems which serve a production line (e.g. cooling a product, not a space where people work) Blast chilling or freezing processes
Pumps	Pumps associated with general heating, hot water, ventilation and cooling for the comfort of staff	Pumps serving production lines and process boilers Pumps used to move liquid or gaseous products within the facility
Controls	Control systems associated with general heating, hot water, ventilation and cooling for the comfort of staff	Controls governing industrial processes e.g. production lines, ovens, conveyors.

Practical assessment of building loads in industrial spaces

In practice, estimation of the in-scope loads in industrial process areas was complex due to three main reasons:

- In certain cases distinguishing process loads from building loads can be complex; in some cases large spaces may be conditioned for the benefit of the industrial process, rather than the workers.
- Tolerance of varied working conditions is very common in industrial environments, so a wide range of temperatures are often endured (and different clothing levels employed) as a consequence of industrial process activities.
- Process activities commonly influence the energy required to achieve comfort conditions for staff. For example, heat gains from production lines offsetting space heating demands or introducing a requirement for comfort cooling where this would not usually be required, or background ventilation requirements in a facility where solvents are widely used.

In order to address these issues, BEES employed a combination of assumptions and sub-sector specific questions in the telephone survey in order to attempt to quantify the impact of these issues.

In order to address the issue of varied comfort conditions, the telephone survey asked whether main industrial spaces were heated, and if so, the temperature set point of the main industrial spaces and type of heating system used. This allowed adjustments to be made to heating consumption estimates.

The telephone survey also asked whether the industrial processes released heat or cooling to the working environment in the main industrial spaces and whether this affected heating or cooling demand. This was determined by asking how many months of the year heating and cooling were required in the main industrial space, and adjustments were used to increase or decrease the heating and cooling consumption accordingly.

The approach was not able to clearly distinguish cases where a respondent's site was primarily heated, cooled and ventilated for the benefit of the process itself, not the occupants. In these cases, the respondent's answers to the questions on heating and cooling systems would be processed in the normal manner, and some loads which would strictly be defined as process related might be included in the energy estimate. However, such cases are expected to be very rare, with the most common examples being chilled working environments for food production or very close control of conditions and air quality for pharmaceutical production. The impact of these unusual cases is expected to be minimal.

It should be noted that only limited data could be collected in the telephone survey and the true nature of these impacts is subject to many complex variables. As such confidence levels in heating, cooling and fans end use energy estimates was low in the industrial sector.

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