Department for
Business, Energy
& Industrial Strategy

Building Energy Efficiency Survey: Office sector, 2014–15

November 2016

Any enquiries regarding this publication should be sent to us at nondomesticbuildings@decc.gsi.gov.uk

This publication is available for download at www.gov.uk/government/publications.

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 sectors 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 office 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 or 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 record 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.

Office sector overview

The office sector consisted of public sector and private sector offices; for the purpose of this study, it did not include offices that were present in other building types[4]. The office sector had a total floor area of 118 million m^2 (15 per cent of the total non-domestic stock) across 366,200 premises (23 per cent of the total non-domestic stock). The office sector's total energy consumption was 27,620 GWh. The office sector's electrical energy consumption was 18,840 GWh (22 per cent of the total non-domestic stock) and non-electrical consumption is 8,780 GWh (12 per cent of total non-domestic stock).

The findings in this report are based on data collected through 637 telephone surveys used in the energy use and abatement models and 15 site surveys in 2014–15.

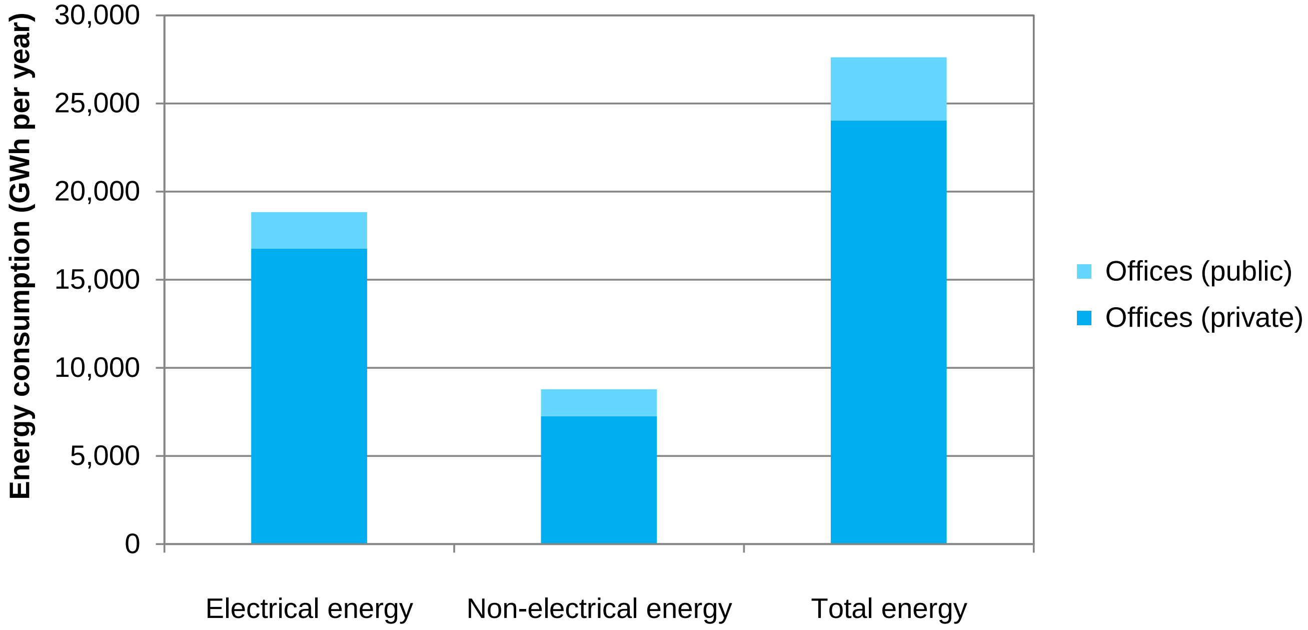
Key findings

Energy consumption in the office sector, 2014–15

- According to modelled data based on telephone survey responses, the sector consumed 27,640 GWh of energy. This included 18,840 GWh of electrical energy and 8,780 GWh of non-electrical energy per year (Figure 0.1).
- The largest energy consumer in this sector was private sector offices with 24,030 GWh total energy consumption (87 per cent of sector total). Public sector offices consumed 3,590 GWh of total energy (13 per cent of sector total).
- The difference in absolute consumption between the sub-sectors is primarily because private sector offices were significantly larger than public sector offices in terms of floor area with 102 million m^2 of private sector offices (86 per cent of total) compared with 16 million m^2 of public sector offices (14 per cent of total).
- Public sector offices had the highest median total energy intensity (178 kWh/m^2), compared with private sector offices (151 kWh/m^2).
- Public sector offices had median energy intensities of 80 kWh/m^2 for electrical energy and 100 kWh/m^2 for non-electrical energy. Private sector offices had median electrical and non-electrical energy intensities of 88 and 88 kWh/m^2 respectively.
- The energy consumption of the offices sector was broken down into specific 'end uses'. The most significant end use was space heating (9,320 GWh, 34 per cent of total energy consumption), followed by ICT equipment (6,950 GWh, 25 per cent of total).

[4] It excludes office premises in the wider public sector, such as defence, education, health and emergency services

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



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

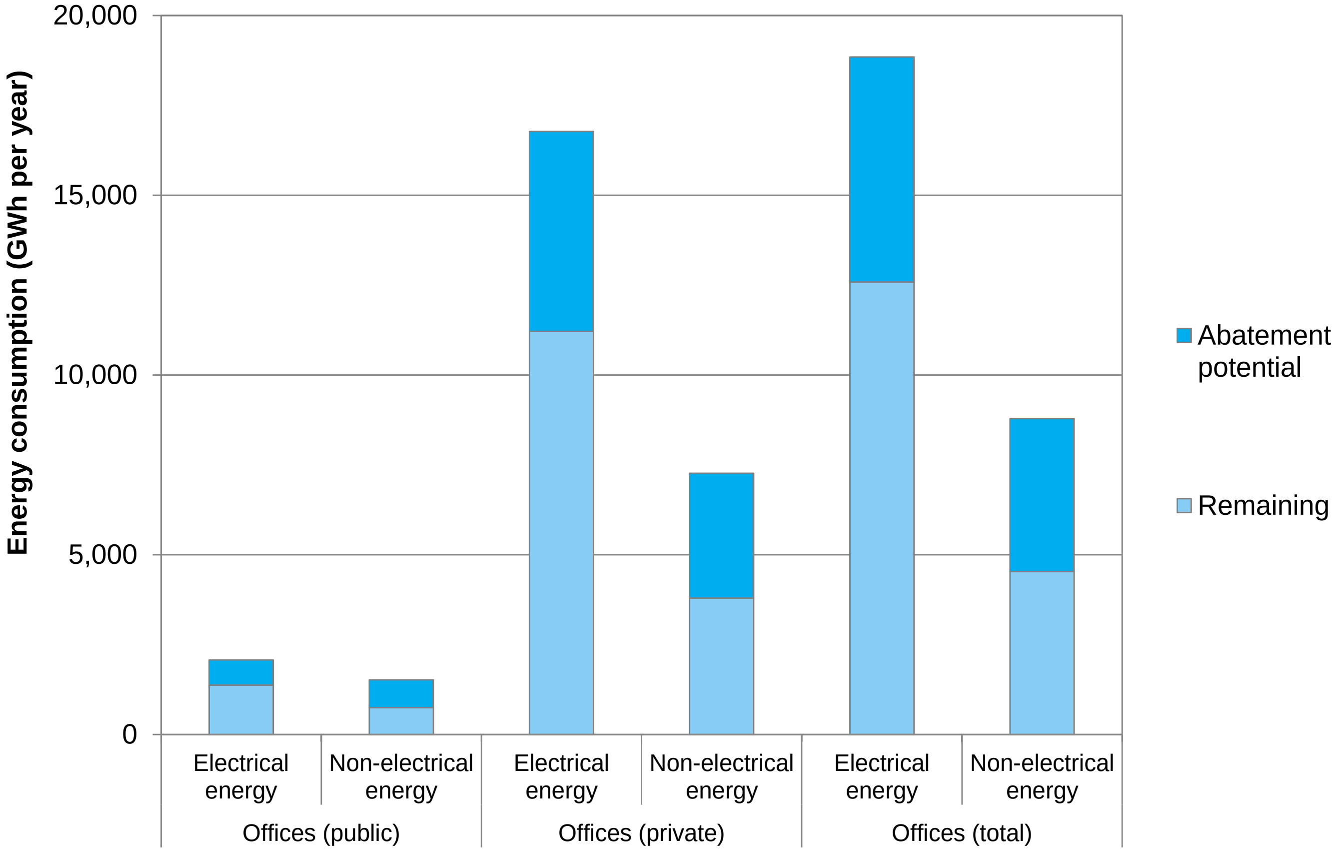
Abatement potential in the office sector, 2014–15

- According to modelled data based on telephone survey responses, Figure 0.2 shows abatement potential for the sector, broken down by sub-sector and fuel type. This represents the total abatement potential that is technically available, which relates to the possible reductions in energy consumption following implementation of all applicable measures. The results include measures that are not cost-effective and the model applies a simple assessment of measure suitability. Building specific installation requirements that may impose additional costs are not accounted for.
- The total abatement potential in the office sector was 10,570 GWh of total energy consumption (38 per cent reduction on consumption). This was comprised of 6,270 GWh of electrical energy (a 33 per cent reduction on consumption) and 4,280 GWh of non-electrical energy (a 49 per cent reduction).
- This could be achieved at a capital cost of £6.8 billion. The socially cost effective potential was 1,650 GWh of total energy, all of which was electrical energy consumption. Companies are more likely to be influenced by the payback period for improvement: overall there were 1,950 GWh of total energy savings with a private payback period[5] of 3 years or less (1,250 GWh of electrical energy abatement and 700 GWh of non-electrical energy abatement).
- Whilst the relative reduction potential in private sector offices was similar to that in public sector offices (41 per cent compared to 38 per cent, respectively), on an absolute level,

[5] Payback is calculated by dividing the total cost associated with a measure (the capital cost installation cost and annual operational costs) and dividing these by the annual financial savings achieved based on energy cost reductions.

because of the private sector's greater scale, the total savings for the private sector are far greater (9,090 GWh and 1,480 GWh, respectively).

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



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

Table 0.1 shows the abatement potential by measure type. Definitions of measure type are included in Appendix D. The largest group of savings for the office sector – in terms of reductions in energy consumption – relate to the implementation of lighting measures (e.g. lighting upgrades) and improved carbon & energy management (e.g. energy awareness campaigns). The largest group of savings – in terms of the potential energy bill savings – relate to the implementation of lighting upgrades.

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

Measure type	Savings					
	Total annual energy bill saving (£ thousands)	Total annual greenhouse gas saving ($ktCO_2e$)	Total annual electrical energy savings (GWh)	Total annual non-electrical energy savings (GWh)	Total annual energy savings (GWh)	**Total capital cost of measure (£ thousands)[6]**
Air conditioning and cooling	56,500	160	570	-	570	525,500
Building fabric	50,100	240	240	1,020	1,260	1,035,300
Building instrumentation and control	65,600	310	400	1,030	1,430	425,700
Building services distribution systems	14,100	40	140	-	140	281,400
Carbon and energy management	142,100	530	1,250	700	1,950	348,700
Hot water	7,400	40	20	200	220	99,800
Humidification	100	0	1	1	1	1,700
Lighting	163,500	460	1,650	-	1,650	721,100
Cooled storage	700	2	7	-	7	3,700
Small appliances	101,900	320	1,020	9	1,030	1,610,800
Space heating	59,800	310	270	1,310	1,580	987,000
Swimming pools	-	-	-	-	-	-
Ventilation	70,400	210	700	20	720	784,100
Total	**732,100**	**2,640**	**6,270**	**4,280**	**10,550**	**6,825,000**

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

[6] The total cost consists of the capital cost installation cost and annual operational costs.

1. Office sector

This report relates to the office sector (one of ten sectors covered in the Building Energy Efficiency Survey (BEES)). This section provides definitions for the two office sub-sectors (private sector offices and public sector offices). It then sets the office 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 office sector.

Table 1.1: Table of office sub-sector definitions[7]

Sub-sector	Definition
Public sector offices	Refers to premises[8] in which business, clerical, or professional activities are undertaken on behalf of central and local government services. It excludes office space in other public sector premises, such as defence, education, health and emergency services.[9] It includes parts of predominantly office premises which have minor parts used for non-office activities e.g. an office building with retail premises on the ground floor.
Private sector offices	Refers to premises in which business, clerical, or professional activities are conducted on behalf of non-government services. It includes parts of predominantly office premises which have minor parts used for non-office activities e.g. an office premises with retail premises on the ground floor.

Office sector in the context of the wider non domestic stock

The office sector is one of the largest segments of the non-domestic stock. It accounts for 23 per cent of the non-domestic stock in terms of premises count (366,200) and 18 per cent in terms of floor area (120 million m^2 GIA[10]).[11]

In terms of energy consumption the sector consumed 27,620 GWh of total energy per year. This comprised 18,840 GWh of electrical energy and 8,780 GWh of non-electrical energy per year, this is equivalent to 17 per cent on the non-domestic total (22 per cent of electrical and 12 per cent of non-electrical energy). This information is set out in Figure 1.1 to Figure 1.3.

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

[8] Each survey record is a premises which may represent a whole building or a part of a building . A premises is typically a contiguous area occupied by a single organisation within a building.

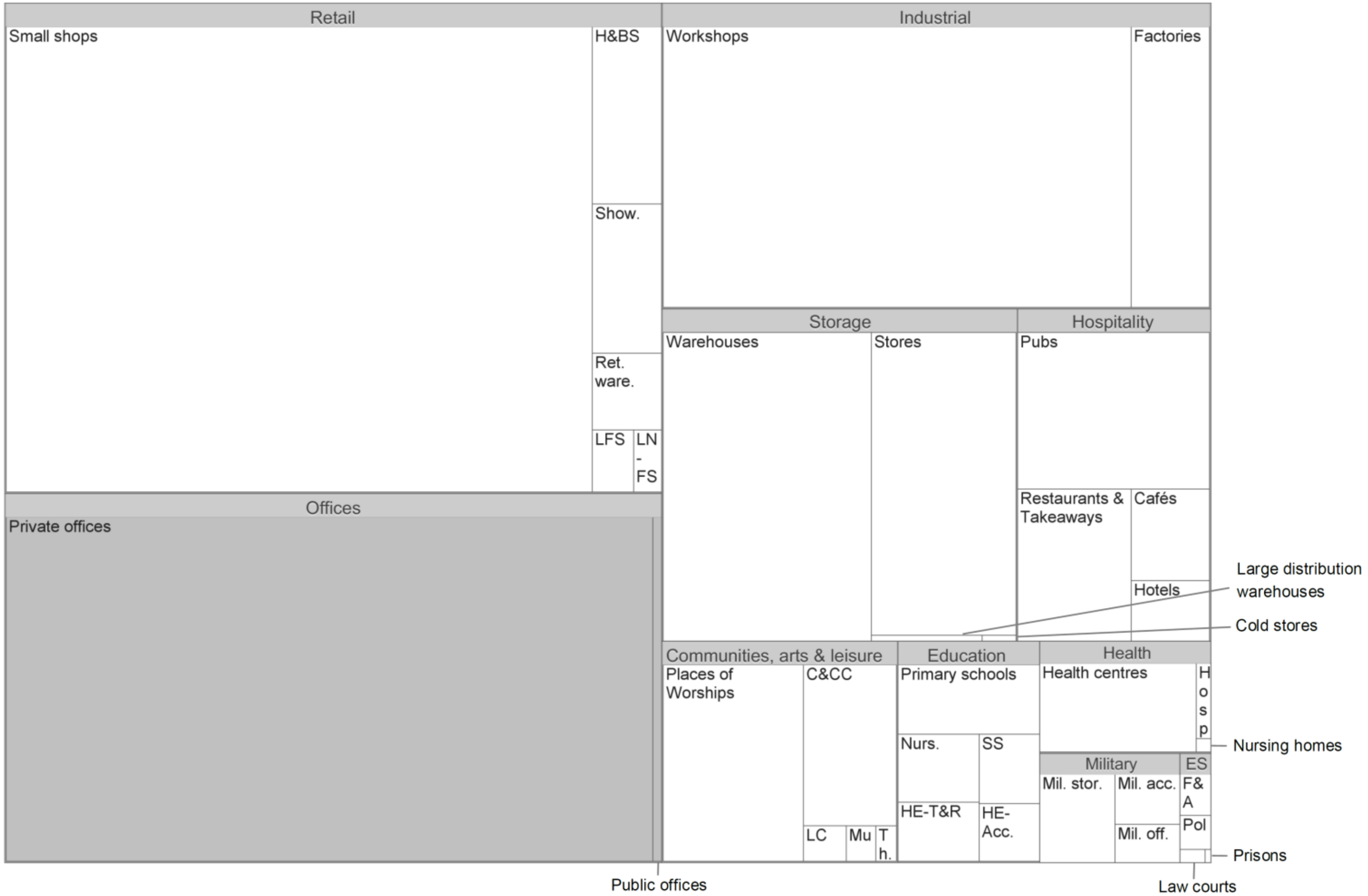
[9] For further information on office use in other sectors please refer to the associated sector reports on defence, education, health and emergency services, for example.

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

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

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

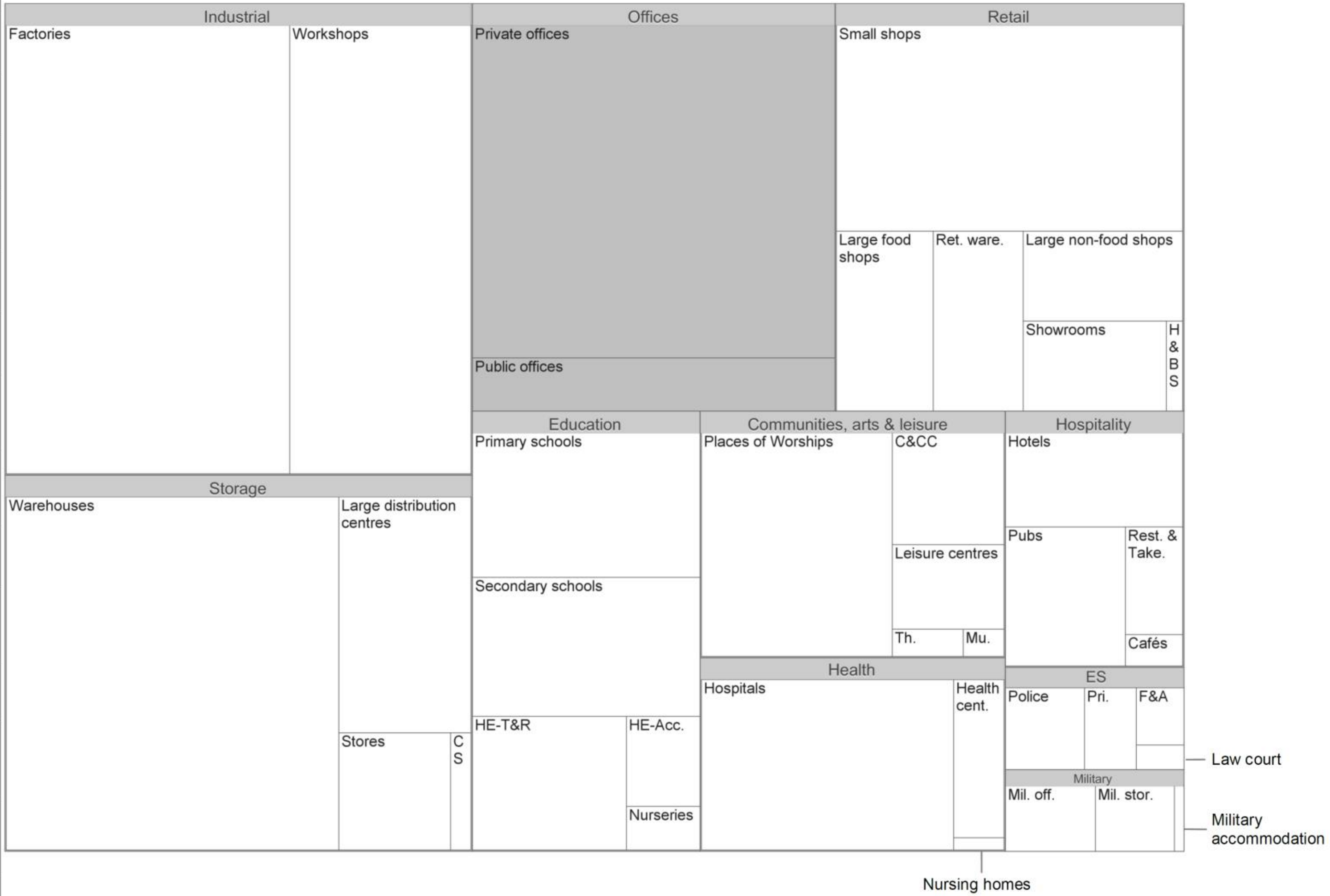
ID	Sub-sector
H&BS	Hairdressing & beauty salons
Show.	Showrooms
Ret. ware.	Retail warehouses
LFS	Large food shops
LN-FS	Large non-food shops
C&CC	Clubs & community centres
LC	Leisure centres
Mu.	Museums, Art galleries and Libraries
Th.	Theatres, cinemas and concert halls
Nurs.	Nurseries
SS	Secondary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

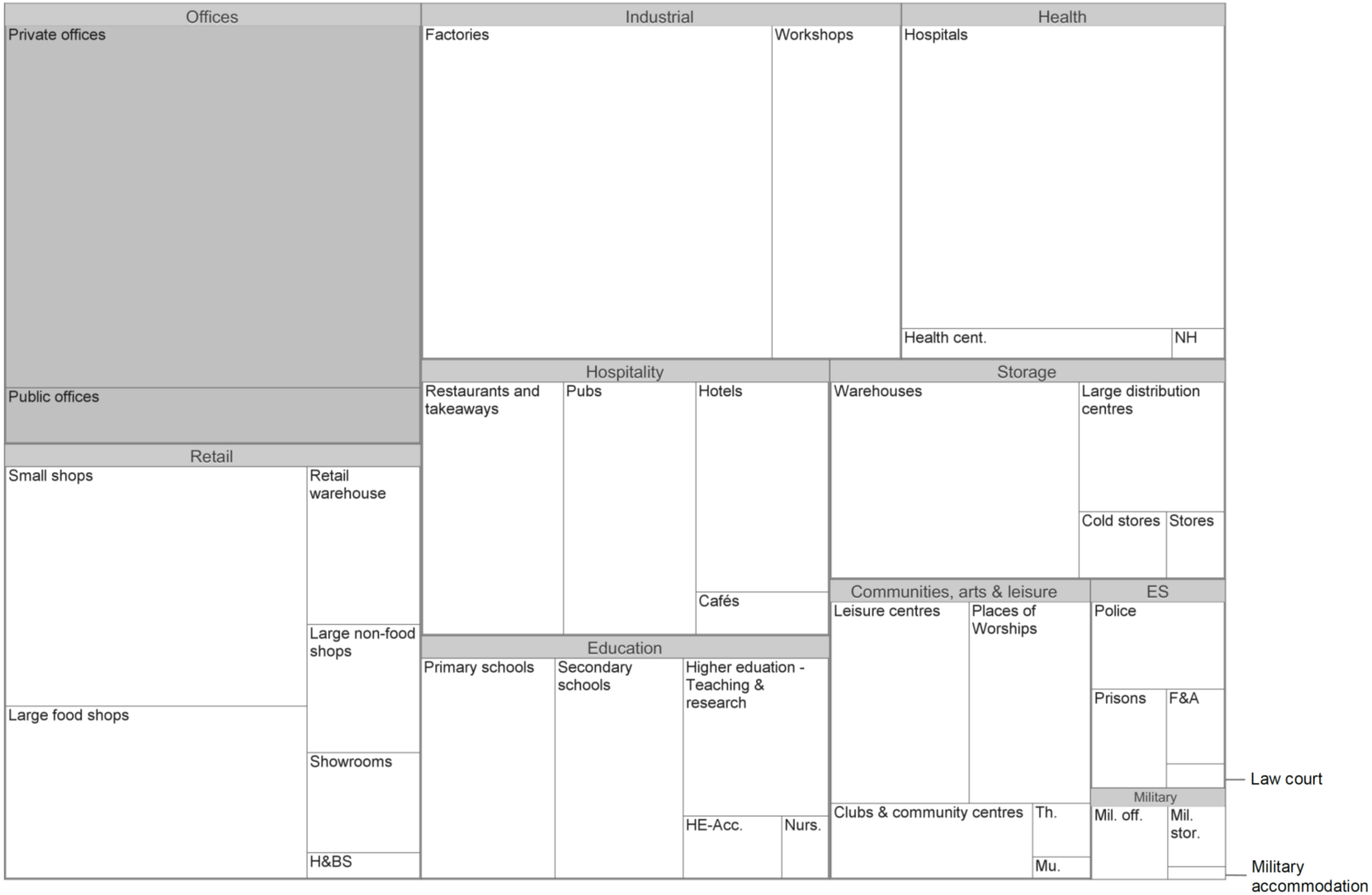
ID	Sub-sector
Ret. ware.	Retail warehouse
H&BS	Hairdressing & beauty salons
CS	Cold stores
HE-T&R	HE—Teaching and research
HE-Acc.	HE — Accommodation
C&CC	Clubs & community centres
LC	Leisure centres
Th.	Theatres, cinemas and concert halls
Mu.	Museums, Art galleries and Libraries
Health cent.	Health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

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

Office premises varied greatly in size and complexity from small, naturally ventilated premises with a handful of occupants to very large city centre tower blocks with extensive mechanical ventilation and air conditioning, very high density of occupants and extensive IT infrastructure. Most office premises had moderate to high levels of glazing to provide natural light to occupants. Over half of office premises were rented, either to a single occupant or multiple occupants; the interaction between the landlord and the tenant(s) is therefore a significant factor in the energy management of these premises.

The dominant activity found in most office premises was desk-based working of a clerical or professional nature. Office premises usually exhibited a number of key characteristics including moderate to high occupancy density, a trend towards weekday working schedules, and extensive desk based IT equipment (computers, phones, printers etc.). Other activities commonly found in office premises included meeting facilities, staff catering facilities, common areas and staff rest facilities, lifts, server rooms and communications facilities. Less common energy intensive activities such as large data centres, trading floors, call centres, gyms, swimming pools and mobile phone masts were also to be found in some office premises.

Summary statistics for the office sector

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

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

Based on the floor area weighted records, organisations occupying offices in the public sector and private sector operated reasonably differently:

- Public sector offices tended to be occupied by large organisations, be in larger premises and be owner occupied;
- Private sector offices were far more diverse in terms of the occupant’s organisation size and the typical premises floor area. They also tended to occupy newer premises and be leased;
- In both office sub-sectors , the majority of premises had opening hours, and peak operating hours, of fewer than 15 hours a day. Both sub-sectors also had a similar proportion of premises located in only part of a building.

There was a clear division across the two sub-sectors in terms of the typical organisation size. The majority of public sector offices were occupied by large organisations (95 per cent in total, organisations which employed more than 250 employees). In contrast, private sector offices were occupied by a range of organisation sizes.

Private sector offices occupied premises across a range of floor area bandings. Roughly half of the premises had a floor greater than 1,000m^2 (46 per cent) and half had a floor area of less than 1,000 m^2. The vast majority of public sector offices had premises over 1,000 m^2, and 31 per cent of premises were over 10,000 m^2. This is also indicative of the sample bias, noted in the method section, which has caused a distortion in the public sector floor area profile.

With regards to tenure, public sector offices tended towards being owner occupied (76 per cent). Private sector offices in contrast were reasonably evenly split between leased and owner occupied premises (56 and 43 per cent, respectively). Overall, 48 per cent of offices were owned compared to the 52 per cent leased.

Energy management interest was higher in public sector offices relative to private sector offices. In public sector offices 84 per cent of respondents described themselves as ‘seeking new ways to reduce energy use on site’ compared with only 48 per cent of private sector offices. 7 per cent of private sector offices indicated that they had not considered ways to reduce energy consumption on site. A key factor may be that private sector offices were more likely to be leased. They are therefore more likely to encounter split incentives between the landlord and the tenant,. This occurs where the building owner pays for energy efficiency improvements but cannot recover savings from reduced energy use that accrue to the tenant.[12]

Public sector offices tended to occupy older buildings than private sector offices. For example, 41 per cent of private sector offices were constructed after 1991, compared to only 17 per cent of public sector offices. Public sector offices were more likely to have been built between 1940-1985 (48 per cent).

Across both office sub-sectors, the majority occupied the whole building and not just part of the building. For example, in private and public sector offices 77 per cent and 70 per cent respectively, occupied the building in its entirety. Overall, 21 per cent of offices occupied part of a building, and 3 per cent of all offices indicated that they occupied multiple buildings on the same site.

The majority of offices in both sub-sectors had opening hours between 9 and 15 hours a day (75 per cent overall). However a greater percentage of private offices had peak operating hours of fewer than 8 hours per day (66 per cent) compared to public offices (49 per cent). Fewer than one per cent of offices had peak operating hours of greater than 15 hours per day.

---

[12] European Commission, 2014. (http://publications.jrc.ec.europa.eu/repository/bitstream/JRC90407/2014_jrc_sci_pol_rep_cov_template_online_final.pdf)

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

Column percentages

	Office sub-sector		
	Offices (public) (%)	Offices (private) (%)	**Office sector (%)**
Organisation size			
Micro (0-9)	0	17	15
Small (10-49)	3	21	19
Medium (50-249)	2	15	13
Large (250+)	95	45	52
Don't know	1	3	2
Total floor area (m^2)[13]			
Less than 50	-	4	3
50-99	0	8	7
100-249	0	16	14
250-499	1	11	10
500-999	0	16	14
1,000-4,999	36	34	34
5,000-9,999	32	12	14
10,000 or more	31	-	4
Don't know	-	-	-
Tenure	-	-	
Owned	76	43	48
Leased	24	56	52
Don't know	-	0	0
Energy management ambition[14]			
Active	84	49	54
Passive	16	43	40
None	0	7	6
Don't know	-	-	-
Age of building			
Pre-1900	6	18	17
1900-1939	12	9	10
1940-1985	48	14	19
1986-1990	10	9	9
1991-2006	16	35	32
2007 or later	1	6	6
Don't know	6	8	8

[13] Public sector offices were sampled from the register of Display Energy Certificates in 2012 which then DECs were only mandatory of buildings over 1,000m^2. While much of the public sector building stock is in large buildings the data are not fully representative of all public sector offices.

[14] '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

	Offices (public) (%)	Offices (private) (%)	**Offices (overall) (%)**
Building structure			
Part of building	24	20	21
Whole building	70	77	76
Multiple buildings	6	3	3
Peak operating hours[15]			
8 or less	49	66	64
9-15	50	32	34
16-23	-	1	1
24	-	0	0
Don't know	1	1	1
Opening hours[16]			
8 or less	10	19	18
9-15	76	75	75
16-23	9	5	6
24	5	0	1
Don't know	1	1	1
Unweighted base	*117*	*520*	*637*

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

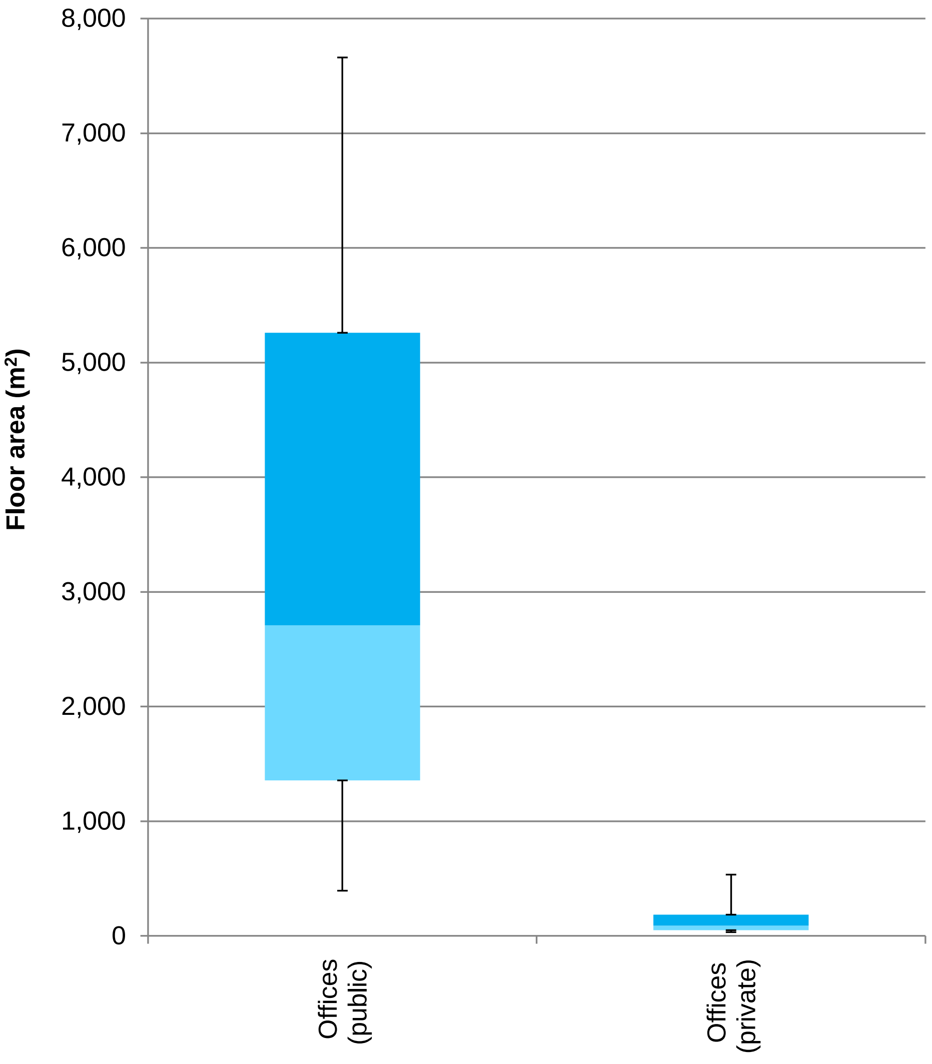
[15] Respondents were asked "How many hours in a typical working day is the premises reasonably fully occupied by your employees (at least 50% of staff present)?".

[16] 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 public sector offices had a much larger median floor area at 2,710 m^2 than private sector offices at 90 m^2. The distribution of floor area sizes for public sector offices was also much wider, with the central 50 per cent of records having floor areas between 1,360 m^2 and 5,260 $m^{2;}$ compared with a range of 50 m^2 to 190 m^2 in private sector offices.

These differences in distribution are believed to be due to a sampling bias in the public sector As described in further detail in appendix B, the public sector was sampled primarily from larger premises due to sample database consisting predominantly of premises with a floor area of greater than 1,000 m^2.

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

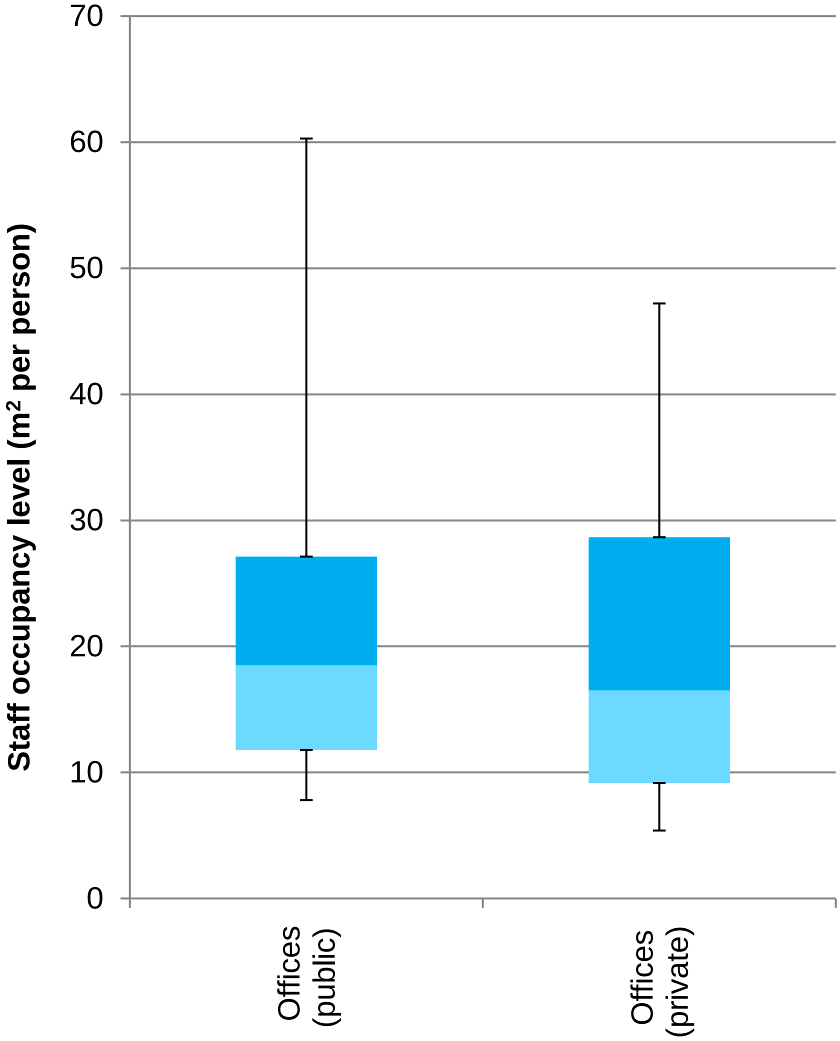


Note: In box and whisker plots, the blue columns, when combined, indicate the range of floor areas covered by the interquartile range of results (the middle 50 per cent of data points). The upper black bars extend to the 90th percentile, capturing a further 15 per cent of the total number of data points.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

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

Figure 1.5 shows the distribution of staff occupancy level (the floor area per staff member) based on the number of staff present on a typical working day. Public sector offices showed the lowest median staff occupancy level of 18 m^2 per person.[17] This compares with a median of 17 m^2 per person in private sector offices.

Figure 1.5: Staff occupancy level by office sub-sector, 2014–15



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

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

[17] 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. As an illustration, if this ratio was applied the staff densities would be 15m^2 NLA per person and 12 m^2 NLA per person in the private and public office sub-sectors respectively.

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 office sector.

Greater detail on the BEES methodology in relation to the office 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 office 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;[18]
- 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.[19]

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

Standard approach

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

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

The sub-sectors presented in the offices sector were added retrospectively so a common questionnaire and set of modelling assumptions have been use for public and private offices.

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 office sector through 637 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.

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

---

[18] 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.

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

energy end uses that may be present in a premises. For example if an office has a swimming pool this would not be captured in the survey.

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

[20] 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.

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[21].
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.[22]
    - 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.

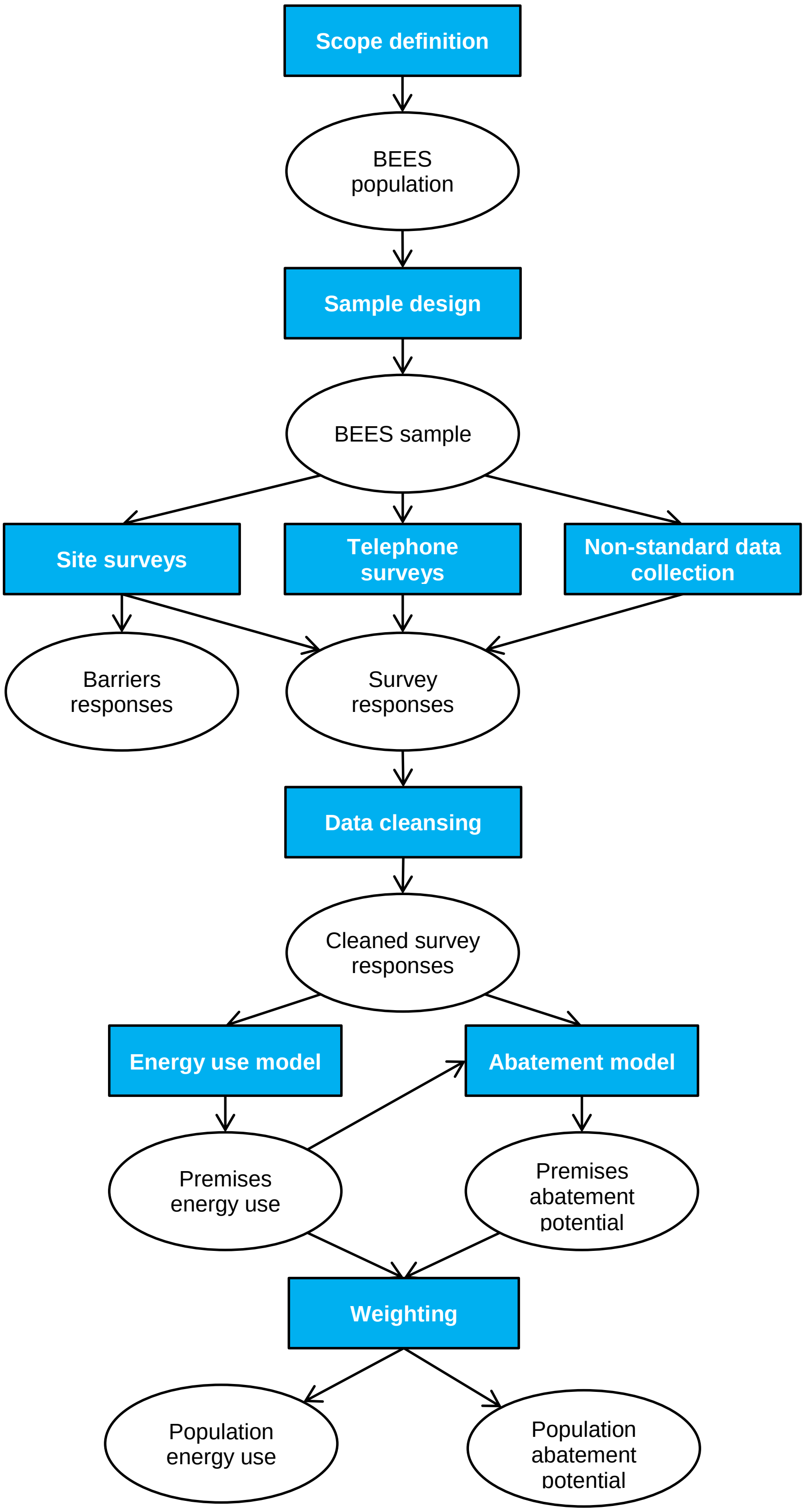
This approach was then tailored by sector. The impact of the change to the methodology within the office sector is covered in “Methodology challenges in the office sector”, which follows in this section, and in more detail in Appendix B.

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.

[21] 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.

[22] 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 office sector

For both office sub-sectors the BEES methodology was implemented as envisaged. There were however overarching complications, which needed to be accounted for during planning. These related to the handling of leased premises, where a number of parties have interests and operational influence on the whole building's energy consumption. The approach taken was to target the telephone survey at a single premises, whether this be the occupier for the whole building or only part of the building. Further information was then gathered from this premises about the building, its tenure and other occupiers This is particularly an issue in offices, where leased premises are more common than in other sectors.

A summary of further specific issues encountered is set out below and a full description is included in Appendix B.

- Design – sampling Public sector offices were sampled from datasets with a known floor area bias towards larger premises. Public sector offices were mostly sampled from Display Energy Certificate (DEC) data and DECs at the time of design these were only required for public sector buildings over 1,000 m2. While this is likely to capture the majority of public sector office energy consumption this will affect the distribution of building sizes reported and could lead to overstatement of the energy demand for public sector offices.
- It was also not possible to accurately determine if a record was part of a building or a whole building for private sector offices. While the ND-NEED database can indicate whether a record related to part of a building or the whole building this was not possible in all scenarios. As a result quotas could not be set on this important attribute. Within the industry it is believed that multi-tenanted office buildings exhibit higher energy intensities than single tenanted buildings. It was not possible to identify multi-tenanted building or apply any modelling adjustments. This may result an underestimate of the energy intensity of private sector offices. .
- Data processing ICT loads (in particular data centres/server rooms within offices) make up a significant proportion of the total electrical energy consumption of the office sector (based on BEES data it is calculated to be 37 per cent). ICT loads were difficult to estimate from the data collected using a telephone survey approach, with no industry standard available for estimating energy consumption.Server consumption is based on the floor area of the server rooms and the energy intensity of servers derived from the site surveys, with no further tailoring at site level. This reduced confidence levels in the electrical energy consumption values reported, which are reported as being a substantial proportion of overall consumption.

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 office sector.

Energy consumption and greenhouse gas emissions in the office sector

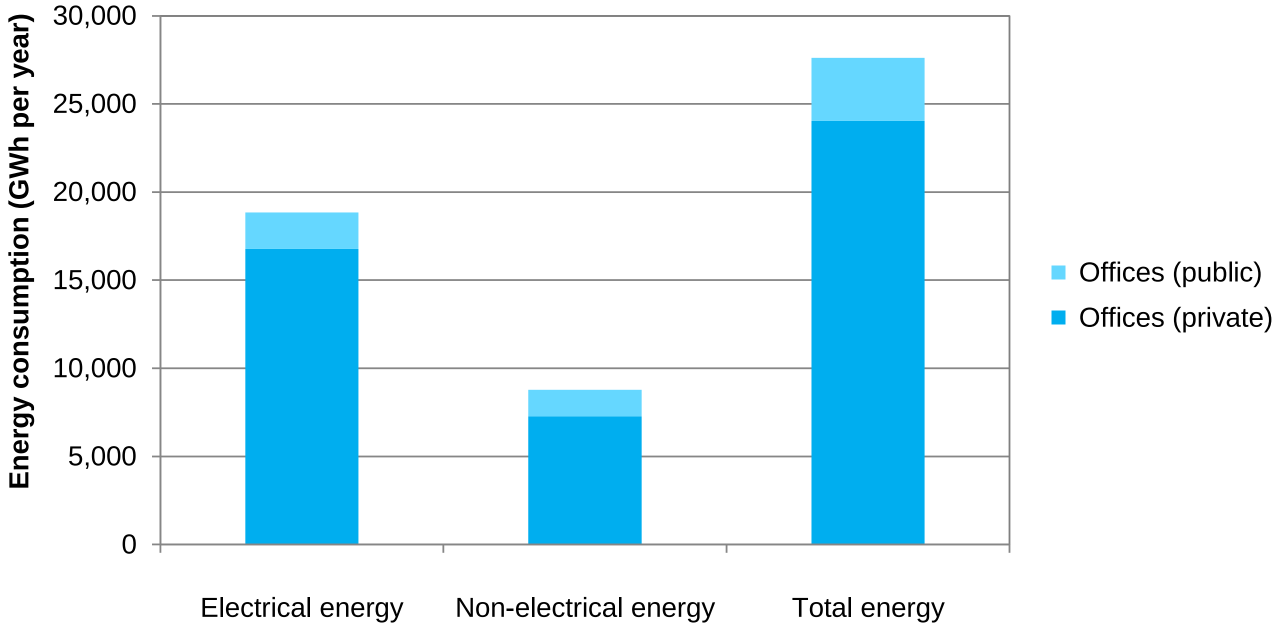
The total energy consumption, electrical and non-electrical energy consumption of the office sector is presented in Figure 3.1, broken down by the two office sub-sectors (covering both public and private sector offices).

The office sector consumed 27,620 GWh of energy. This consisted of 18,840 GWh of electrical energy and 8,780 GWh of non-electrical energy per year (Figure 3.1).

The largest energy consumer in this sector was private sector offices, with a consumption of 24,030 GWh of energy (87 per cent of total). This comprised 16,770 GWh of electrical energy (89 per cent) of sector total) and 7,260 GWh of non-electrical energy (83 per cent of sector total). This was primarily because this sub-sector is significantly larger than public sector offices in terms of floor area (102 million m^2 for private sector offices compared with 16 million m^2 for public sector offices).

Public sector offices consumed 3,590 GWh of total energy (13 per cent of total), which consisted of 2,070 GWh of electrical energy (11 per cent of sector total), and 1,520 GWh of non-electrical energy (17 per cent of sector total).

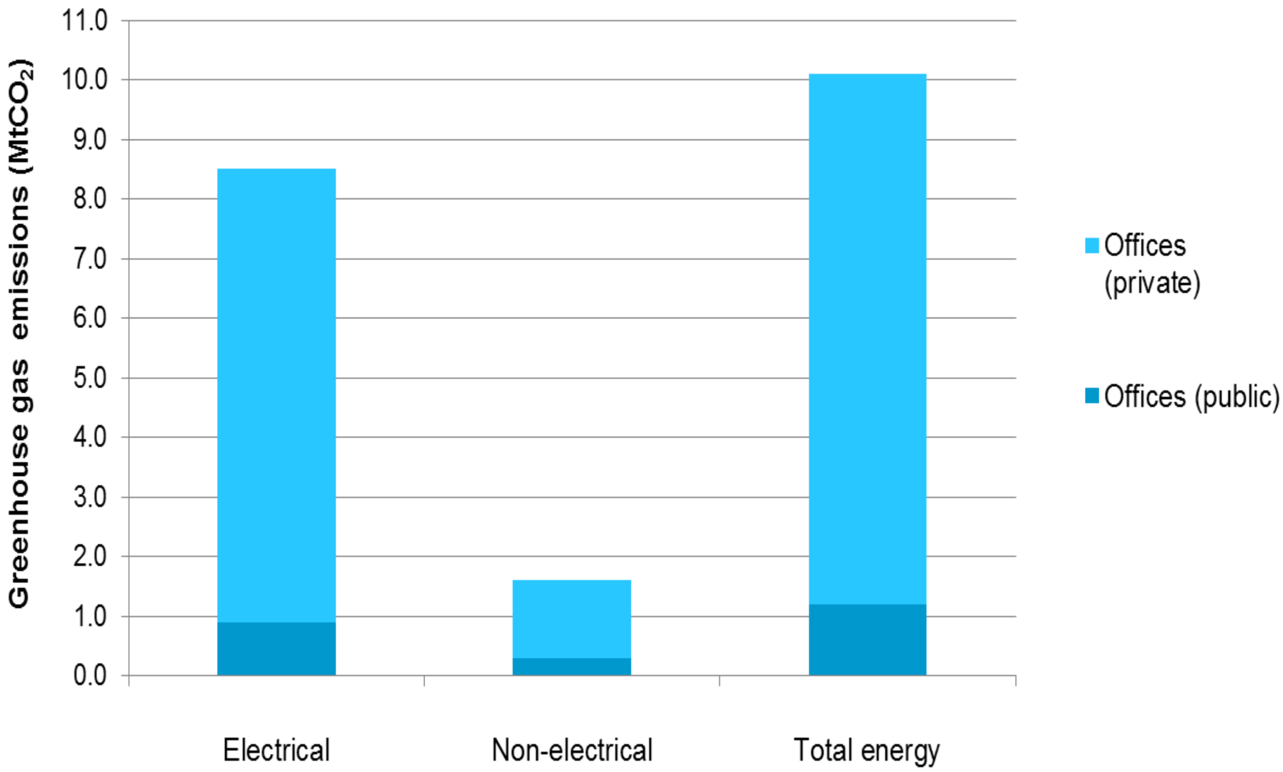
Figure 3.1: Electrical and non-electrical energy consumption by energy type and office sub-sector, 2014–15



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

The greenhouse gas emissions for the office sector are presented in Figure 3.2.[23] The total Greenhouse Gas emissions from the office sector were deemed to be 10.1 $MtCO_2e$ per year. The annual emissions from electrical energy consumption were 8.5 $MtCO_2e$ and those from non-electrical energy consumption were 1.6 $MtCO_2e$.

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



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

Energy consumption by end use

The distribution of energy consumption by end use is presented in Figure 3.3 and Table 3.1.[24]

The energy use model defines 23 separate energy end uses in its analysis. These are derived by modelling the telephone survey inputs and calibrated using site survey data. For the purposes of presentation in Figure 3.1, the 23 uses have been simplified to seven categories, covering key building services end uses (heating, hot water, lighting, fans, cooling & humidification and other) and two custom categories relevant to the sector (IT equipment and

---

[23] 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.

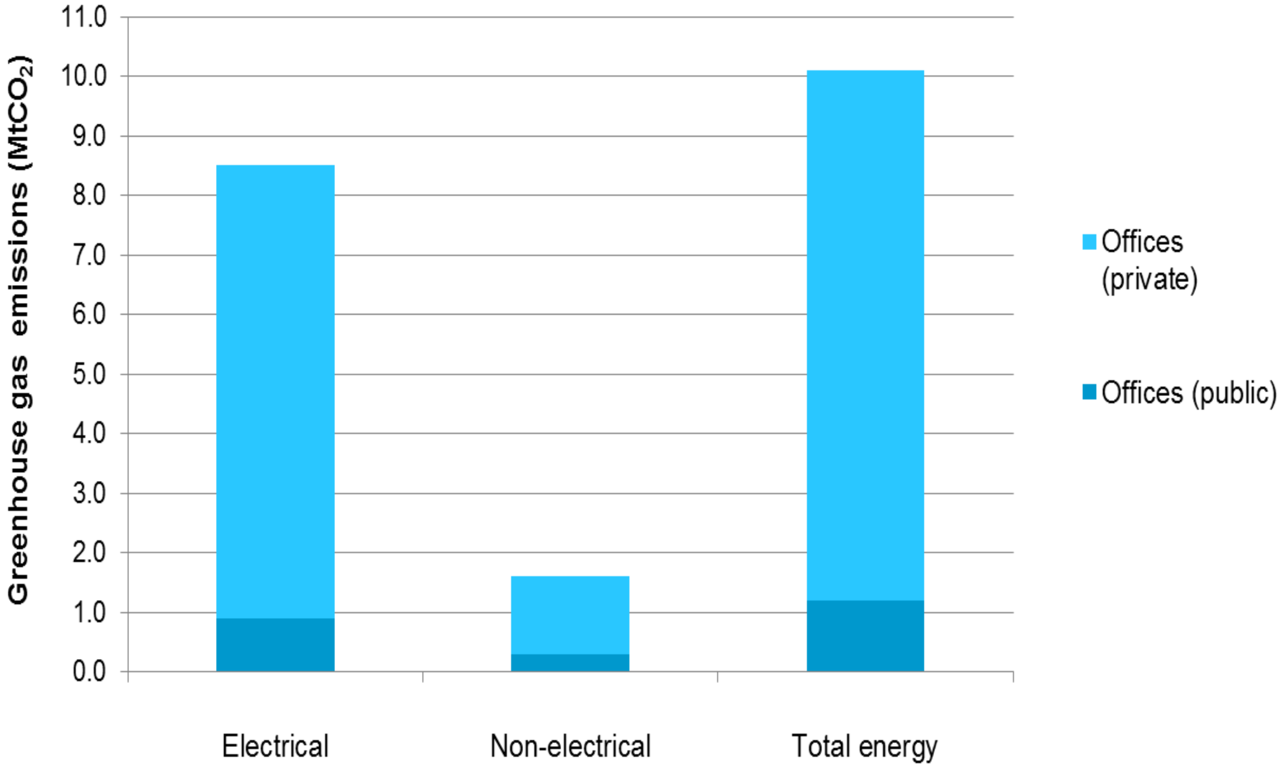
[24] In the context of the BEES study, small power represents office equipment (comprising computers, printers and ancillary desktop equipment). Other plug-in loads are disaggregated into entertainment equipment, catering, pool/leisure equipment etc.

small power). The simplified classification is shown against the more detailed classification results in Table 3.1.

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

The total energy consumption for the office sector was 27,620 GWh. The most significant end use was space heating (9,320 GWh, 34 per cent of total energy consumption), followed by ICT equipment (6,950 GWh, 25 per cent of total). The most common end uses of electrical energy were ICT equipment at 6,950 GWh (37 per cent of total), followed by internal lighting (2,580 GWh, 14 per cent). The next major end uses included space cooling (2,150 GWh, 11 per cent), small power (2,110 GWh, 11 per cent), and space heating (1,830 GWh, 10 per cent). The most significant non-electrical energy end uses were space heating at 7,490 GWh (85 per cent) followed by hot water (690 GWh, 8 per cent). Non-electrical energy consumption for heating was much higher than electrical energy consumption (7,490 GWh compared with 1,830 GWh).

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



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

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

Energy end use category (Simplified)	BEES end use category[25]	Electrical energy consumption (GWh/year)	Non-electrical energy consumption (GWh/year)	Total energy consumption (GWh/year)
Heating	Space heating	1,830	7,490	9,320
Hot water	Hot water	550	690	1,240
Cooling & humidification	Cooling	2,150	130	2,270
Fans	Fans	1,400	-	1,400
Lighting	Lighting - internal	2,580	-	2,580
Catering	Catering	350	310	660
Small power	Small power	2,110	-	2,110
ICT equipment	ICT equipment	6,950	-	6,950
Other	Pumps	200	-	200
	Controls	170	-	170
	Lighting - external	320	-	320
	Vertical transport	120	-	120
	Cooled storage	10	-	10
	Entertainment equipment	60	-	60
	Pool/leisure	20	160	190
	Other	20	-	20
Total		**18,840**	**8,780**	**27,620**
Unweighted base		*637*	*544*	*637*

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

Office 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.[26] Figure 3.5Figure 3.5 and Figure 3.6 present the distribution of energy intensity for all modelled records in each sub-sector within the office sector, in terms of total energy intensity, electrical energy intensity and non-electrical energy intensity respectively.[27] In this report all intensity figures (excluding box plots) have been calculated using the total sector or sub-sector floor area regardless or whether they have a particular energy source or end-use.

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

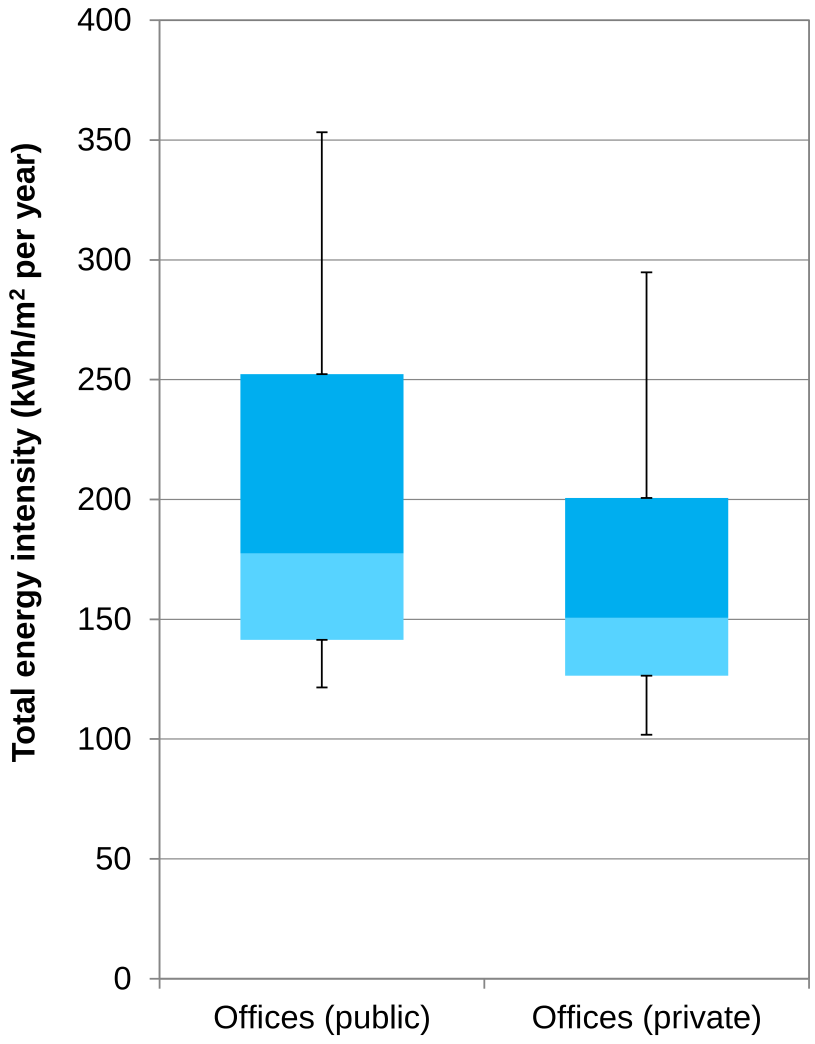
[26] As employed in CIBSE TM46 Energy Benchmarks (available at: http://www.cibse.org/knowledge/cibse-tm/tm46-energy-benchmarks), and others.

[27] 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.

Figure 3.5 shows that the public sector offices had the highest median total energy intensity (178 kWh/m^2),compared with private sector offices (151 kWh/m^2). Figure 3.5 and Figure 3.6 show that public sector offices had median energy intensities of 79 kWh/m^2 for electrical energy and 99 kWh/m^2 for non-electrical energy. Private sector offices had median electrical and non-electrical energy intensities of 88 and 88 kWh/m^2 respectively.

The distribution of electrical and non-electrical energy intensities was slightly narrower for private sector offices than for public sector offices. The tendency for public office premises to have been sampled from larger premises may be distorting the comparison, however, as larger premises are more likely to be highly serviced.

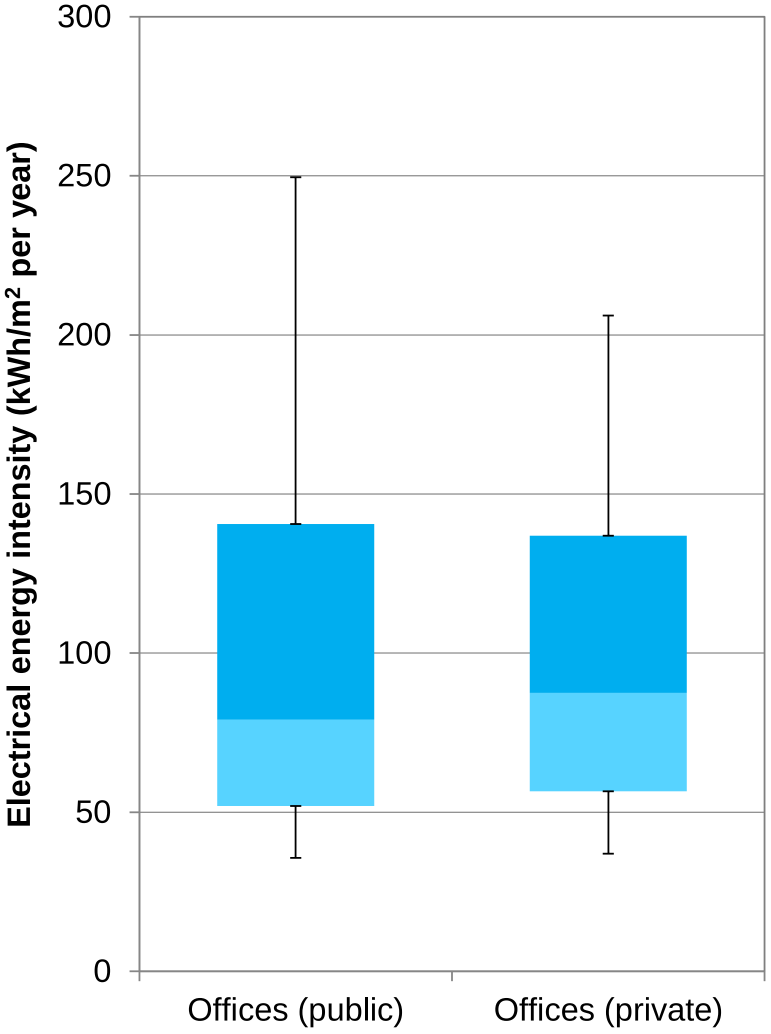
Figure 3.4: Distribution of total energy intensity by office sub-sector, 2014–15



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

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

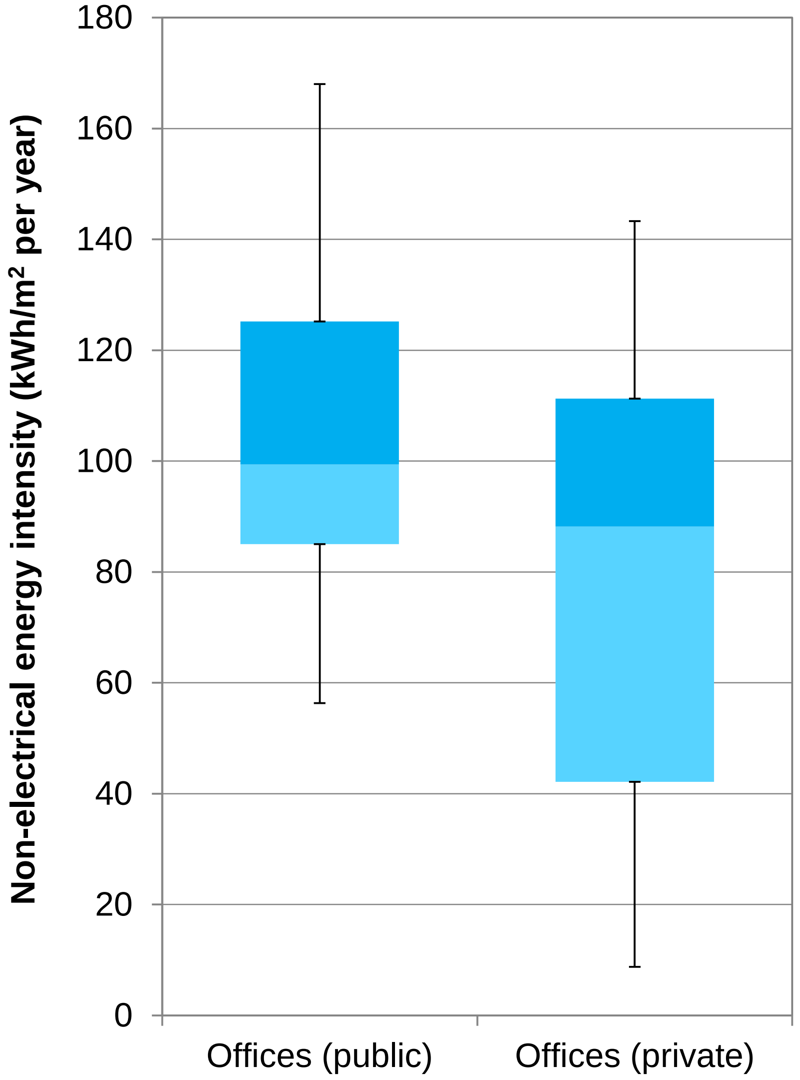
Figure 3.5: Distribution of electrical energy intensity by office sub-sector, 2014–15



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

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

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



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

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

Office sub-sector energy end use breakdowns

The top two bars of Figure 3.7 show the mean modelled energy intensity by end use for the two sub-sectors in the office sector (public sector and private sector). Each end use estimate (kWh/m^2) was calculated by summing the entire predicted energy consumption for that end use for all records, and dividing by the total floor area for the same records. Further data is provided in Appendix C where energy intensity is provided separately for electrical and non-electrical energy end use breakdowns by sub-sector.

The mean energy intensity of private offices was 6 per cent higher than that of public offices, even though the median was 8 per cent lower. In end use terms, this was primarily due to the significantly higher ICT loads in private sector offices – the floor area within private sector offices used as data centres made up 1.2 per cent of the total floor area in this sub-sector compared to only 0.6 per cent in the public sector offices. It is noted that modelling ICT loads is an end use where the energy use model is weaker.

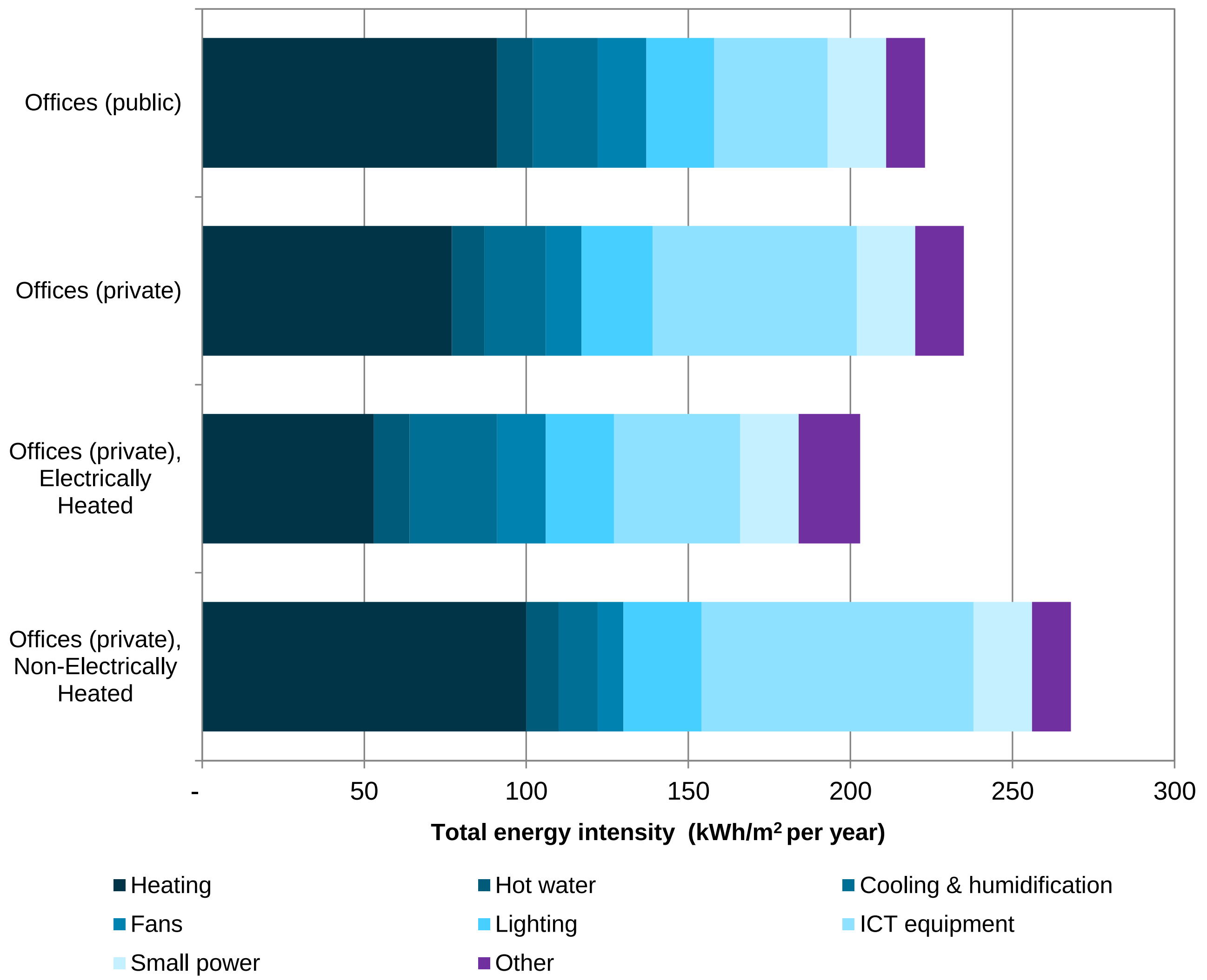
In other end uses (hot water and small power), public sector offices exhibited a slightly higher energy intensity than their private sector counterparts. The main contributory factor to this was the higher staff occupancy density observed in public sector offices.

The lower two bars of Figure 3.7 show data only for the private sector offices, one bar for the 178 private sector records which have electricity as their main heating fuel, and the other for those heated with a fuel other than electricity. The electrical heating in many premises is via reversible heat pumps[28], which means delivered energy intensity for space heating tends to be lower than for those premises with fossil fuel-fired heating systems.

A higher incidence of electric heating via heat pump split systems in private sector offices is one factor producing the lower heating energy intensity of private sector offices compared with the public sector, when the all-electric premises are not separated out (first two bars of Figure 3.7).

[28] Heat pump split systems use an air to air heat pump which typically supply 2-4 units of heat per unit into the premises for each unit of electrical energy consumed. This is approximately 3 times as “efficient” as a natural gas boiler in terms of the overall energy intensity of the premises, but the fuel used (electricity) has significantly higher carbon dioxide emissions than natural gas.

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



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

4. Abatement potential

In this section, abatement potential[29] for the office 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[30], while the benefits were only based on the incremental reduction in energy consumption[31]. Replacement of systems which were not at the end of their life were therefore included, but will be more expensive, as the impact on energy consumption is likely to be smaller for new equipment, while the full capital costs are taken into account. This means that a measure may be cost-effective if the system is replaced at the end of its life - especially as at the end of life the cost of the more energy efficient alternative would be compared to replacement with a less efficient alternative - but, the same measure may not be cost-effective if the system is replaced earlier in its life. Replacing measures at the end of life will be less costly for organisations, but it would take longer for the full potential to be realised. While the costs include an allowance for installation costs and hassle costs, this may not 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

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

[30] 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.

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

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

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

Total technical abatement potential for office sector

The abatement potential for each sub-sector where it is available is shown in Table 4.1 and Figure 4.1. The offices sector can achieve a reduction of around 38 per cent in energy consumption[32]. This could be achieved at an overall capital expenditure of £6.8 billion.

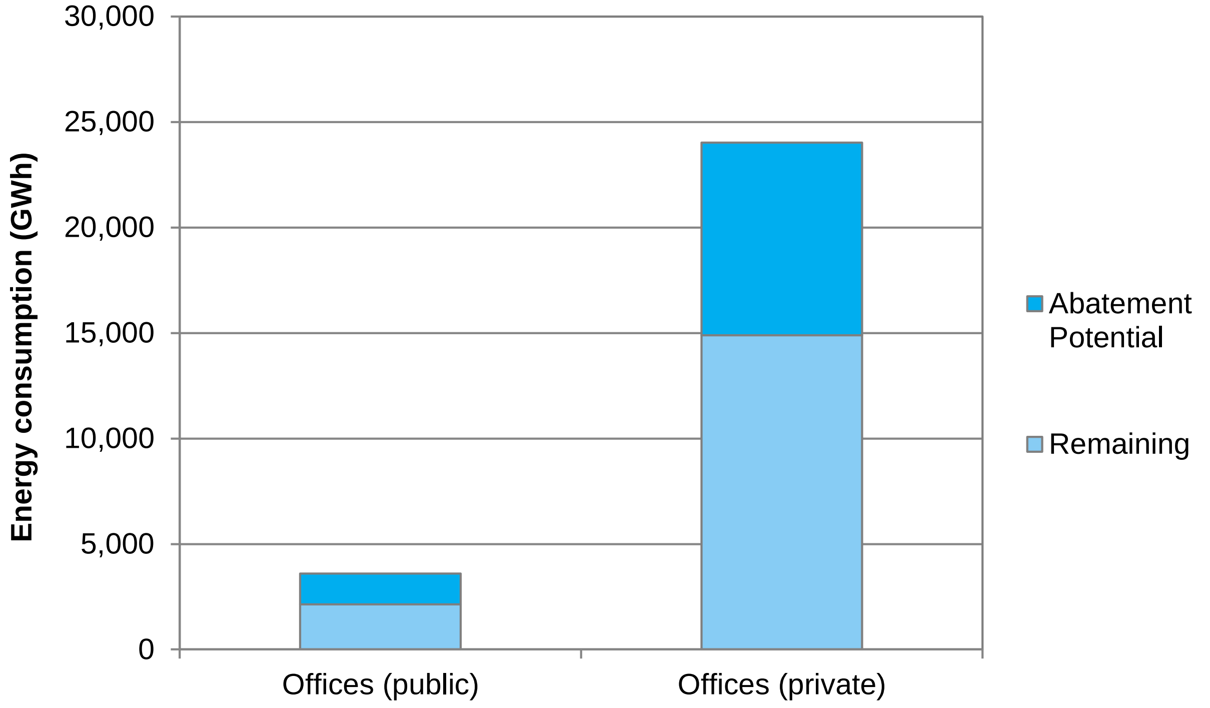
Table 4.1: Abatement potential by office sub-sector, 2014–15

		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)
Offices (public)	725,500	2,070	1,520	700	770	41
Offices (private)	6,099,400	16,770	7,260	5,570	3,510	38
Total	**6,825,000**	**18,840**	**8,780**	**6,270**	**4,280**	**38**

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

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

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

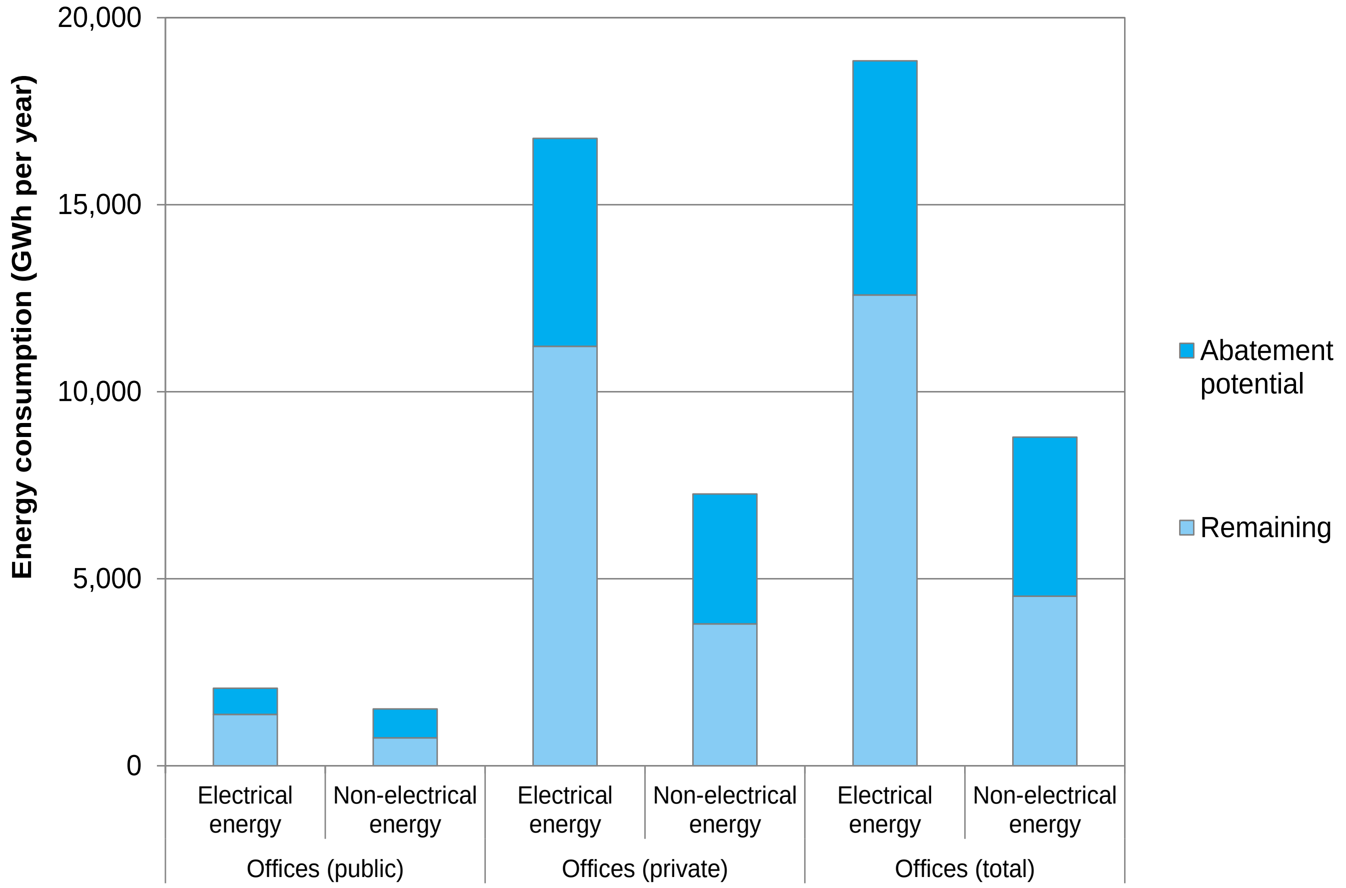


Source: Abatement model results by sub-sector, England and Wales

Figure 4.2 shows that the total technical abatement potential in 2014–15 varied by sub-sector: Public sector offices had a slightly greater scope for reduction compared with private offices (41 and 38 per cent, respectively). This was likely to be due to the greater opportunities for improvement that are typically associated with larger and therefore highly serviced premises; a known bias for the public offices sample as mentioned in the Methods section.

The results were separated into electrical and non-electrical energy. On a percentage basis there was marginally more abatement potential associated from savings in non-electrical energy use. This is due to the relatively simplistic approach the abatement model takes towards ICT measures, which is a significant electrical end use in this sector. Further detail of the abatement potential for each sub-sector is provided in Appendix D.

Figure 4.2: Abatement potential by energy type and office 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.[33] This takes into account the capital expenditure, operational expenditure, social cost of energy, air quality impacts, and value of emissions, all discounted at the social discount rate. While this includes the main categories of costs, it was not possible to include the costs and benefits of all impacts on occupants: for example some measures may provide a potentially better occupant experience through improved illumination, or a potentially worse occupant experience through lack of control over light switches.

A measure is socially cost effective if the total social benefits outweigh the total social costs of the measure across the lifetime of the measure. This is a static measure of cost effectiveness based on current expected costs and benefits - for example this does not take into account potential reductions in capital costs that could result from more of that technology being installed. To enable groups of measures to be compared, a metric of social-cost effectiveness was calculated: Net Present Value of costs and benefits (NPV) divided by total energy savings over the lifetime of the measures in the group and plotted on a Marginal Abatement Cost Curve (MACC), which shows the level of abatement opportunity available and the costs associated with this opportunity if they were all implemented in 2014–15. The MACC in Figure 4.3 graphically represents each group of abatement opportunities as a block. The width of the block represents the total amount of abatement the measure can deliver in GWh and the height represents the cost-effectiveness. Because the measure groups are ranked by cost-effectiveness, the most cost-effective (delivering abatement at the least-cost per GWh) will be found on the left of the diagram. Moving to the right, measure groups become subsequently more costly.

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

The total abatement potential of the socially cost effective measure groups was 1,650 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 1,950 GWh, of which 1,250 GWh was electrical energy consumption and 700 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.

There were a number of measure groups that were socially cost-effective. If implemented, these measure groups provide more financial benefits to society than costs. The largest cost-effective

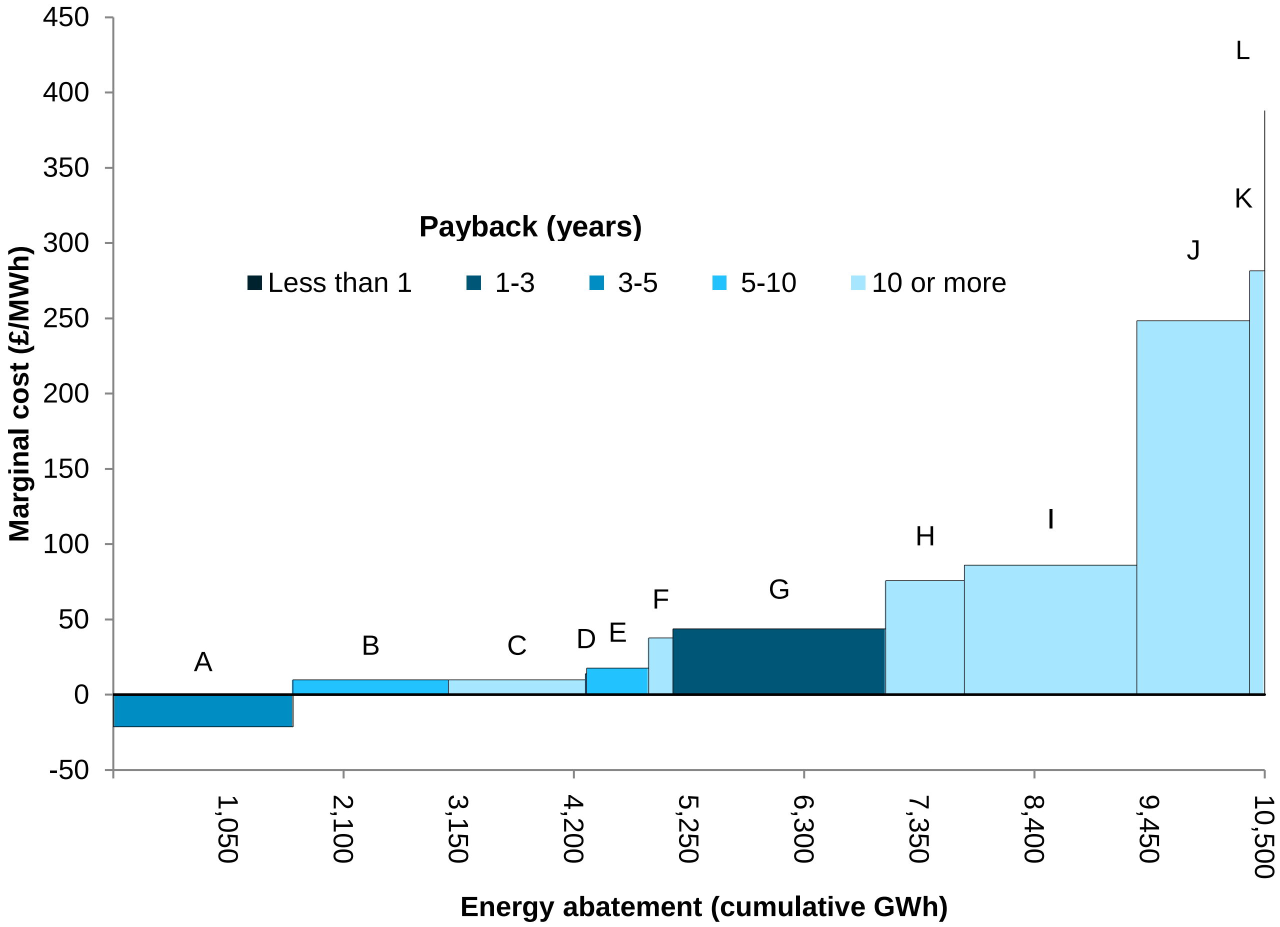
[33] Supplementary guidance to the HM Treasury Green Book on Appraisal and Evaluation in Central Government: https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/483278/Valuation_of_energy_use_and_greenhouse_gas_emissions_for_appraisal.pdf

opportunities were behavioural measures under carbon and energy management, lighting upgrades and building instrumentation and control measures. These measures also had relatively low payback periods, suggesting they may be more likely to get taken up, but recognising that take-up will also depend on the extent to which there are barriers. Interestingly, air conditioning and ventilation equipment also have relatively low payback periods, but are not socially cost effective to implement.

This modelled findings corresponded broadly with opportunities identified in the site surveys. Typically site surveys identified major opportunities associated with lighting upgrades, building instrumentation and controls and behavioural measures.

Site survey provided some evidence that in some situations the potential for energy savings are greater than predicted from the abatement model. For example one survey was conducted for a cellular office - one in which each individual office is separate from the others, in contrast to an open-plan office - and here the scope for savings arising from behavioural awareness campaign was greater as staff tended to leave equipment and servicing running despite not being in the room. On another site survey, the premises had not been purpose built to house the server rooms stored on site. This resulted in excessive cooling of the entire premises, as the cooling required for the running of the servers also cooled the rest of the premises, which affected both the premises efficiency and the occupants comfort.

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



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

A Lighting [MAC: £-21 per MWh. GWh: 1,650]

B Building instrumentation and control [MAC: £10 per MWh. GWh: 1,430]

C Building fabric [MAC: £10 per MWh. GWh: 1,260]

D Cooled storage [MAC: £14 per MWh. GWh: 10]

E Air conditioning and cooling [MAC: £18 per MWh. GWh: 570]

F Hot water [MAC: £38 per MWh. GWh: 220]

G Carbon and energy management [MAC: £44 per MWh. GWh: 1,950]

H Ventilation [MAC: £76 per MWh. GWh: 720]

I Space heating [MAC: £86 per MWh. GWh: 1,580]

J Small appliances [MAC: £248 per MWh. GWh: 1,030]

K Building services distribution systems [MAC: £281 per MWh. GWh: 140]

L Humidification [MAC: £388 per MWh. GWh: 1]

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

Table 4.2[34] shows the abatement potential by measure type. The most significant available savings were associated with carbon and energy management, lighting upgrades, space heating and building fabric.

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

Measure type	Savings					
	Total annual energy bill saving (£ thousands)	Total annual greenhouse gas saving ($ktCO_2e$)	Total annual electrical energy savings (GWh)	Total annual non-electrical energy savings (GWh)	Total annual energy savings (GWh)	**Total capital cost of measure (£ thousands)**
Air conditioning and cooling	56,500	160	570	-	570	525,500
Building fabric	50,100	240	240	1,020	1,260	1,035,300
Building instrumentation and control	65,600	310	400	1,030	1,430	425,700
Building services distribution systems	14,100	40	140	-	140	281,400
Carbon and energy management	142,100	530	1,250	700	1,950	348,700
Hot water	7,400	40	20	200	220	99,800
Humidification	100	0	1	1	1	1,700
Lighting	163,500	460	1,650	-	1,650	721,100
Cooled storage	700	2	7	-	7	3,700
Small appliances	101,900	320	1,020	9	1,030	1,610,800
Space heating	59,800	310	270	1,310	1,580	987,000
Swimming pools	-	-	-	-	-	-
Ventilation	70,400	210	700	20	720	784,100
Total	**732,100**	**2,640**	**6,270**	**4,280**	**10,550**	**6,825,000**

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

[34] 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)
Public sector offices	165	± 28
Private sector offices	129	± 24
Offices	**160**	**± 26**

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

	Mean (kWh/m^2)	Confidence interval (kWh/m^2)
Public sector offices	71	± 10
Private sector offices	94	± 9
Offices	**74**	**± 9**

Response rates

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

	Offices (public) (%)	Offices (private) (%)	**Office sector (%)**
Completed interview	16	23	**19**
Still live[35]	14	5	**25**
Screening failure/other non-response[36]	11	9	**9**
Refusal	35	42	**30**
Invalid contact details	24	20	**17**

[35] 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).

[36] 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: Office method challenges and data collection

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

Office sector methodology challenges

In the case of the office 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: Office sector approach challenges

Stage	Challenge	Response	Impact
Design	Public sector offices were sampled from datasets with a known floor area bias towards larger premises. Public sector offices were partially sampled from the Display Energy Certificate database and these certificates were only obtained if premises exceeded floor area thresholds. The minimum floor area threshold for premises requiring a DEC when this data was sampled was 1,000 m^2. The sampling strategy was designed for the office sector, not at sub-sector level. As a result, whilst the private and public sector offices response frequency was monitored the achieved floor area distributions were not based on quotas for public and private sector offices.	During reporting the impact of this bias was noted. There were also a small number of public sector office records (20) that were sourced from ND-NEED. This group offered an insight on smaller public sector offices.	The bias has been noted and the effect it has on truncating the distribution of public sector offices and should be considered when reviewing the results of the study.
Data collection	Telesurvey respondents were often unaware of the size of their server rooms. Ignoring the presence of server rooms in these premises resulted in a significant shortfall in modelled electrical energy consumption, so estimates were required.	An average value (server room area as proportion of Gross Internal Area) was used in the processed version of the telesurvey data to estimate the size of these server rooms.	Server room energy consumption is subject to low confidence. As the energy intensity of server rooms is extremely high, a significant proportion of the office sector electrical energy consumption

Stage	Challenge	Response	Impact
			is dependent on estimated input data.
Data collection	Central government departments had to volunteer to participate in the study.	The sample selection was not random for government departments. The Verco team approached all government departments and requested their support, - only four government departments offered premises for inclusion in the study.	There is therefore a risk that the sample of premises for this sub-group of public sector offices is not representative.
Data collection	Where a respondent occupied only part of the building there was a risk that the respondent may not have been clear about the extent of the building they should have answered about in the telephone survey.	The Verco team screened the responses received against minimum quality criteria to ensure no records were included that were based on misinterpretations of the survey	Following screening the impact on final reporting was minimal.
Data collection	The sample design for the office sector was designed on the basis of the sector being reported as one sub-sector (offices and data centres). Following data collection, and lack of achieved data centres it was decided that public and private sector offices should be reported separately. This means that the sample quotas did not monitor all elements of bias across both sub-sectors.	During reporting the impact of the public sector floor area bias was noted. The weighting method accounts for a selection weight which corrects for elements of the selection bias.	The bias has been noted and should be considered when reviewing the results of the study.
Data processing	Surveys for central government department premises were typically completed by one respondent responsible for multiple premises. This often resulted in a simplified/cruder response, where respondents rapidly populated fields to minimise the administrative burden of completion. The accuracy of the response was also often weaker because the respondent may not have been directly familiar with the premises.	The Verco team screened the responses received against minimum quality criteria to ensure no records were included that were overly distortive. [as above]	Following screening the impact on final reporting should be minimal.
Data processing	Determining the correct floor area for "Part of Building" (PoB) records was challenging. The parent ND-NEED dataset did not reliably identify the number of hereditaments in a building or their type, so multi-tenanted	In order to minimise the impact of this uncertainty on the model calibration procedures, PoB records were excluded from the energy use calibration process.	The study was not able to investigate the energy and abatement characteristics of multi-tenanted offices buildings as distinct from single tenanted

Stage	Challenge	Response	Impact
	office buildings could not be distinguished from, for example, a single tenant office above a shop.	As a result, PoB records were treated in the same way as single building records in the modelling. While this ensures that errors in data collection in the PoB records did not have a negative impact on the plausibility of model results, it also prevented any tailoring of model performance in this significant element of the office stock.	offices. Other studies have indicated that multi-tenanted offices often display higher energy intensities than single tenanted buildings, so there is a risk that the results will under-estimate overall energy consumption in the office sector. It is also likely that abatement measures in PoBs will not reflect the full cost of the installation, which is likely to be increased where multiple occupiers are involved.
Data processing	Estimating the energy consumption of server rooms based on telephone survey data was very challenging. Available studies on server and data centre energy intensity tend to use complex technical data on which to determine energy use, which telephone survey respondents are very unlikely to know. The exclusion of Data Centres as a separate sub-sector in the study (due to lack of participation in the survey) reduced the amount of insight the study gained into this critical end use.	In the study the only indicators included in the telephone survey were server room floor area and the number of PCs in the premises (for estimating server room consumption). Site surveys were then examined to determine average energy intensity per square metre for server rooms, and this intensity was used in the modelling. The data collected was considered to be a good quality snapshot of energy intensity, but is limited to a small number of examples. In the case of local server rooms an estimate per PC served was used in the modelling, but due to a lack of sub metering at this scale, site survey data was not sufficient to validate the assumptions used. It was found through calibration with matched energy data that the number of PCs was a relatively weak indicator of energy use.	Server room energy consumption is still subject to a low degree of confidence, despite mitigating measures. The most likely impact is that ICT use would be underestimated in smaller premises as a consequence.

Telephone survey and site survey data collection

Table B.2 shows that 775 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 [37]	Average interview length (mins.)	Target sample size	Site surveys completed
Public sector offices		141	-	141	117	21		8
Private sector offices		634	-	634	520	21		7
Office sector	**810**	**775**	**-**	**775**	**637**	**21**	**15**	**15**

Source: Telephone survey or equivalent records, England and Wales

[37] See section 2: Method 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 office 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 below

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.

End use category		Description
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.
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**	Energy used for equipment in laboratories.

End use category		Description
	equipment	
22	**Pool/leisure**	All energy use associated with pool and sport leisure facilities within the premises. This should include heating, lighting, pumps, ventilation, humidification, and dedicated controls, alarms etc.
23	**Other**	Any other energy uses which fall outside categories 1 to 21, which are "normal" - i.e. are typical for the specific building type.

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

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

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

Energy type	Detailed end use category	Reduced end use category
Electrical	Space heating	Heating
	Hot water	Hot water
	Space cooling	Cooling & humidification
	Fans	Fans
	Lighting - internal	Lighting
	Central catering	Catering
	Distributed catering	Catering
	Pumps	Other
	Controls	Other
	Lighting - display	Other
	Lighting - external	Other
	Small power	Other
	Vertical transport	Other
	Cooled storage	Other
	Entertainment equipment	Other
	Pool/leisure	Other
	Other - normal	Other
Non-electrical	Space heating	Heating
	Hot water	Hot water
	Catering	Catering
	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 office sub-sector and for the sector combined. Tables C.5 and C.6 show energy intensity by end use for each offices sub-sector and for the sector combined.

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

Simplified end use category	**BEES end use category**	**Electrical energy consumption (GWh per year)**		
		Offices (public)	Offices (private)	**Office sector**
Heating	Space heating	130	1,700	1,830
Hot water	Hot water	40	500	550
Cooling & humidification	Space cooling	270	1,750	2,020
Fans	Fans	240	1,160	1,400
Lighting	Lighting - internal	330	2,250	2,580
ICT	ICT equipment	570	6,380	6,950
Small power	Small power	290	1,810	2,110
Other	Pumps	30	170	200
	Controls	20	150	170
	Humidification	20	100	130
	Laundry	-	1	1
	Lighting - display	-	10	10
	Lighting - external	40	280	320
	Entertainment lighting	-	-	-
	Vertical transport	30	90	120
	Medical equipment	-	-	-
	Distributed catering	20	150	170
	Cooled storage	-	10	10
	Catering	10	170	180
	Entertainment equipment	10	50	60
	Lab equipment	-	-	-
	Pool/leisure	-	20	20
	Other	-	3	3
Total		**2,070**	**16,770**	**18,840**
Unweighted base		*117*	*520*	*637*

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

Simplified end use category	BEES end use category	Electrical energy consumption (GWh per year)		
		Offices (public)	Offices (private)	**Office sector**
Heating	Space heating	1,340	6,150	7,490
Hot water	Hot water	130	560	690
Central catering	Central catering	20	290	310
Other	Pool/leisure	-	160	160
	Humidification	20	100	130
Total		**1,520**	**7,260**	**8,780**
Unweighted base		*117*	*520*	*637*

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

Simplified end use category	BEES end use category	Electrical energy intensity (kWh/m^2 per year) Offices (public)	Offices (private)	**Office sector**
Heating	Space heating	8	17	15
Hot water	Hot water	3	5	5
Cooling & humidification	Space cooling	17	17	17
	Humidification	2	1	1
Fans	Fans	15	11	12
Lighting	Lighting - internal	21	22	22
ICT	ICT equipment	35	63	59
Small power	Small power	18	18	18
Other	Pumps	2	2	2
	Controls	1	1	1
	Laundry	0	0	0
	Lighting - display	-	0	0
	Lighting - external	2	3	3
	Entertainment lighting	-	-	-
	Vertical transport	2	1	1
	Medical equipment	-	-	-
	Cooled storage	-	0	0
	Catering	2	3	3
	Entertainment equipment	1	0	0
	Lab equipment	-	-	-
	Pool/leisure	-	0	0
	Other	-	0	0
Total		**129**	**165**	**160**
Unweighted base		*117*	*520*	*637*

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

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

Simplified end use category	BEES energy end use category	Non-electrical energy intensity (kWh/m^2 per year)		
		Offices (public)	Offices (private)	**Office sector**
Heating	Space heating	83	60	63
Hot water	Hot water	8	5	6
Catering	Catering	1	3	3
Other	Pool/leisure	-	2	1
	Humidification	2	1	1
Total		**94**	**71**	**74**
Unweighted base		*117*	*520*	*637*

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

Appendix D: Abatement potential

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

Measure type definitions

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

Table D.1: Measure type definitions

Measure type	Definition	Measure name
Air conditioning and cooling	Measures associated with air conditioning and cooling plant	Cooling time controls Cooling re-commissioning Cooling temperature control Cooling plant upgrade (0-8 years old) Cooling plant upgrade (8-15 years old) Cooling plant upgrade (more than 15 years old) Free cooling Cooling zone controls
Building fabric	Measures associated with the external building fabric	Flexible plastic curtains on loading bays High speed shutter doors to loading bays Interlocks between heating systems and loading bay or vehicle access doors Replace glazing Cavity wall insulation Loft insulation Clean windows Ground insulation Insulation maintenance Internal/external wall insulation Reflective coatings for windows Blinds Flat roof insulation Draught proofing Double glazing

Building instrumentation and control	Measures associated with improving the controls and monitoring on standard building services	BMS installation BMS re-commissioning BMS maintenance Energy meters for kitchen facilities Energy meters for lifts and escalators Heating zone controls Time controls on the heating system Weather compensator controls on heating Time control on hot water system Lift maintenance
Building services distribution systems	Measures associated with improving the efficiency of the building's distribution systems	Voltage optimisation
Carbon and energy management	Measures associated with organisational policy, users of the building and the capacity of the core delivery teams	Awareness campaign targeted at HVAC (heating, ventilation and air conditioning) HVAC maintenance Improve sub-metering Procurement Energy management Awareness campaign targeted at catering usage Awareness campaign targeted at lift usage 'Low hanging fruit' energy awareness campaign Cooled storage procurement Catering equipment procurement Keeping external doors shut (retail) Reduced use of air curtains (retail) 'Intensive' energy awareness campaign Minimise simultaneous operation of heating and cooling systems
Cooled storage	Measures which improve the efficiency of the refrigeration plant	Optimise refrigeration controls Relocate catering equipment Replace central catering refrigeration equipment Replace cooled storage refrigeration equipment
Hot water	Measures associated with improving the efficiency of hot water used for domestic services; such as hot tap water	Replacement of central generation of hot water with point of use Domestic hot water maintenance Hot water efficiency measures (low flow taps, showers & baths)
Humidification	Measures associated with the systems regulating building humidity	Humidification control maintenance

Lighting	Measures associated with lighting improvements	Automatic controls on lighting Localised lighting controls CFL to LED lighting retrofit T12 to LED lighting retrofit T5 to LED lighting retrofit T8 to LED lighting retrofit T8 to T5 lighting retrofit Lighting maintenance T12 to T5 lighting retrofit External lighting – HID to LED External lighting control Dsiplay lighting controls
Small applicances	Measures associated with small power usage, such as computer upgrades	Replace catering equipment Automated shutdown for ICT usage Computer upgrade LCD flat screens Server virtualisation Thin clients Doors on fridges (retail)
Space heating	Measures that improve the efficiency of heating the building	Replace heating boiler plant with high efficiency type (0-8 years old) Replace heating boiler plant with high efficiency type (8-15 years old) Replace heating boiler plant with high efficiency type (15 years old or more) Boiler maintenance Holiday season plant shutdown Optimise heat zoning Thermostatic radiator valve (TRV) Pipe work insulation
Swimming pools	Measures that improve the efficiency of energy used for swimming pools	Energy meters for the pool complex Swimming pool covers Draught proofing of pool Pool maintenance
Ventilation	Measures that improve the efficiency of the ventilation systems	Optimising ventilation time controls Optimising ventilation zoning Variable speed drives Ventilation plant upgrade (0-8 years old) Ventilation plant upgrade (8-15 years old) Ventilation plant upgrade (15 years old or more) Motor replacement Motor controls Motor resizing

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

Public sector offices

In public sector offices there was an annual abatement potential of 700 GWh of electrical energy and 770 GWh of non-electrical energy (equivalent to 350 $ktCO_2e$ combined). This equates to a 34 per cent and 51 per cent reduction on energy consumption respectively. The capital cost to achieve this is £726m. The annual savings delivered would be £89m[38]. These figures are grouped according to measure type in Table D.2. The total abatement potential of the socially cost effective measure groups was 660 GWh, of which 340 GWh was electrical energy consumption and 320 GWh . 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 420 GWh, of which 130 GWh was electrical energy consumption and 280 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 public sector offices, 2014–15

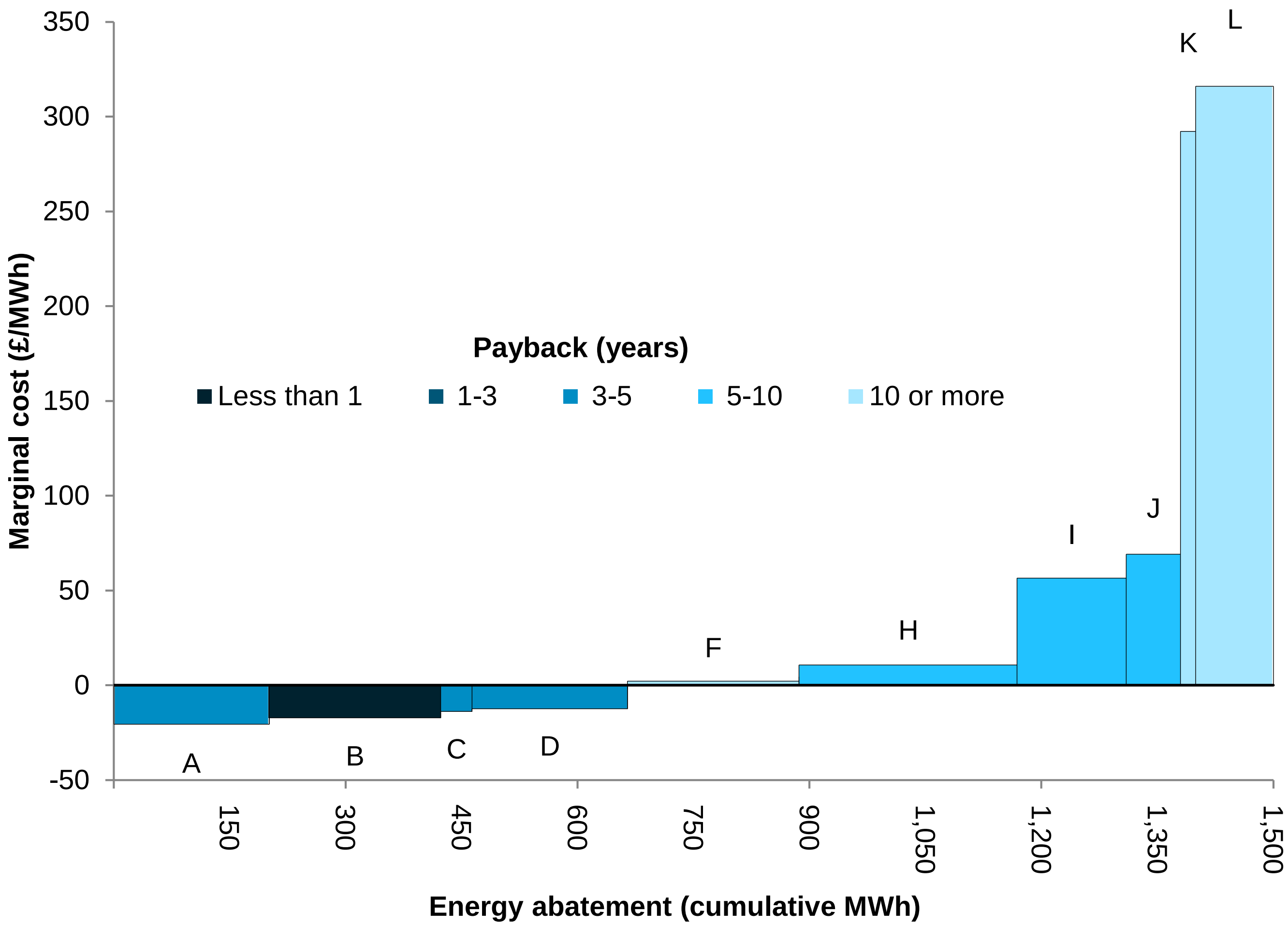
	Savings						
Measure type	Total annual energy bill saving (£ thousands)	Total annual greenhouse gas saving ($ktCO_2e$)	Total annual electrical energy savings (GWh)	Total annual non-electrical energy savings (GWh)	Total annual energy savings (GWh)	**Total capital cost of measure (£ thousands)**	**Payback period (years)**[39]
Air conditioning and cooling	6,900	20	70	-	70	62,100	11
Building fabric	7,500	40	30	190	220	131,200	11
Building instrumentation and control	7,600	40	30	160	200	25,200	3
Building services distribution systems	1,700	5	20	-	20	33,100	13
Carbon and energy management	12,900	50	100	120	220	10,100	1
Hot water	1,400	8	4	40	40	6,900	4
Humidification	100	0	0	0	1	100	3
Lighting	19,500	60	200	-	200	85,800	4
Cooled storage	200	1	2	-	2	900	4
Small appliances	9,400	30	100	1	100	181,800	17
Space heating	8,600	50	20	260	280	69,000	9
Swimming pools	-	-	-	-	-	-	-
Ventilation	13,700	40	140	5	140	119,400	6
Total	**89,500**	**350**	**700**	**770**	**1,480**	**725,500**	‘’

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

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

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

Figure D.1: Marginal abatement cost curve for public sector offices, 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: £-20 per MWh. GWh: 200]
B Carbon and Energy Management [MAC: £-20 per MWh. GWh: 220]
C Hot water [MAC: £-10 per MWh. GWh: 40]
D Building instrumentation and control [MAC: £-10 per MWh. GWh: 200]
E Cooled storage n [MAC: £-2 per MWh. GWh: 0]
F Building fabric [MAC: £2 per MWh. GWh: 220]
Humidification [MAC: £4 per MWh. GWh: 0]
H Space heating [MAC: £10 per MWh. GWh: 280]
I Ventilation [MAC: £60 per MWh. GWh: 140]
J Air conditioning and cooling [MAC: £70 per MWh. GWh: 70]
K Building services distribution systems [MAC: £290 per MWh. GWh: 20]
L Small appliances [MAC: £320 per MWh. GWh: 100]

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

Private sector offices

In private sector offices there was an annual abatement potential of 5,570 GWh of electrical energy and 3,510 GWh of non-electrical energy (equivalent to 2,290 $ktCO_2e$ combined). This equates to a 33 per cent and 48 per cent reduction on energy consumption respectively. The capital cost to achieve this is £6.1 bn. The annual savings delivered would be £642m[40]. These figures are grouped according to measure type in Table D.3. The total abatement potential of the socially cost effective measure groups was 1,450 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 1,730 GWh, of which 1,150 GWh was electrical energy consumption and 580 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.2).

Table D.3: Abatement opportunity data for private sector offices, 2014–15

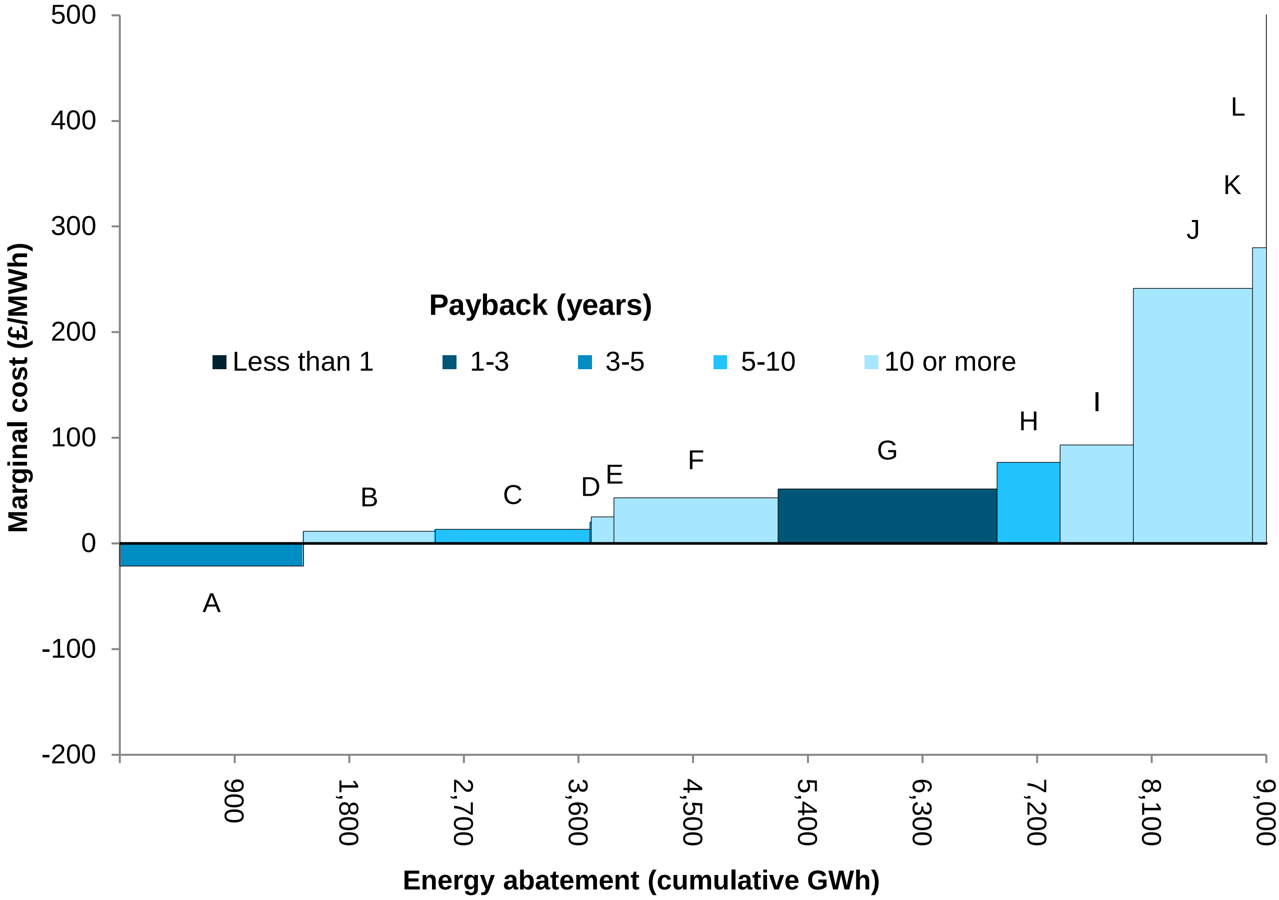
	Savings						
Measure type	Total annual energy bill saving (£ thousands)	Total annual greenhouse gas saving ($ktCO_2e$)	Total annual electrical energy savings (GWh)	Total annual non-electrical energy savings (GWh)	Total annual energy savings (GWh)	**Total capital cost of measure (£ thousands)**	**Payback period (years)** [41]
Air conditioning and cooling	49,700	140	500	-	500	463,300	12
Building fabric	42,600	200	220	820	1,040	904,100	15
Building instrumentation and control	58,000	270	360	870	1,230	400,500	5
Building services distribution systems	12,400	40	130	-	130	248,300	12
Carbon and energy management	129,200	480	1,150	580	1,730	338,600	2
Hot water	6,000	40	20	160	180	93,000	14
Humidification	0	0	0	0	0	1,500	81
Lighting	144,000	410	1,450	-	1,450	635,200	4
Cooled storage	500	2	5	-	5	2,800	5
Small appliances	92,400	290	930	7	940	1,429,100	14
Space heating	51,100	260	240	1,060	1,300	918,100	16
Swimming pools	-	-	-	-	-	-	-
Ventilation	56,600	170	570	10	580	664,800	8
Total	**642,600**	**2,290**	**5,570**	**3,510**	**9,080**	**6,099,500**	‘’

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

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

[41] 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 private sector offices, 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 'L' not displayed in this chart, as the y axis has been capped for presentation purposes.

A Lighting [MAC: £-30 per MWh. GWh: 1,450]
B Building fabric [MAC: £10 per MWh. GWh: 1,040]
C Building instrumentation and control [MAC: £10 per MWh. GWh: 1,230]
D Cooled storage [MAC: £20 per MWh. GWh: 10]
E Hot water [MAC: £30 per MWh. GWh: 180]
F Space heating [MAC: £40 per MWh. GWh: 1,300]
G Carbon and energy management [MAC: £50 per MWh. GWh: 1,730]
H Air conditioning and cooling [MAC: £80 per MWh. GWh: 500]
I Ventilation [MAC: £90 per MWh. GWh: 580]
J Small appliances [MAC: £240 per MWh. GWh: 940]
K Building services distribution systems [MAC: £280 per MWh. GWh: 120]
L Humidification [MAC: £1,450 per MWh. GWh: 1]

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

Department for Business, Energy & Industrial Strategy
3 Whitehall Place
London SW1A 2AW
www.gov.uk/beis