Department for Business, Energy & Industrial Strategy

BUILDING ENERGY EFFICIENCY SURVEY, 2014– 15

Technical Annex

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Glossary

Term	Definition
BMS	Building Management System. Central control systems (often controlled via PC) used to control the building services systems in a building.
Building Services	Plant and equipment installed in a building which ensure the comfort and safety of the occupants. Includes heating, cooling, ventilation, lighting, hot water, fire safety systems and associated pumps and controls.
CaRB2 model	A bottom-up energy demand non-domestic stock model developed by UCL alongside the ND-NEED database. https://www.ucl.ac.uk/energy-models/models/carb2
CFL	Compact fluorescent lamps (CFL) are low energy light bulbs designed to replace designed to replace a traditional incandescent lamp and generally fit into light fittings.
CIBSE TM46	Technical Manual 46 “Energy Benchmarks” published by CIBSE contains statutory building energy benchmarks for 30 building types. These were prepared to complement the Operational Rating procedure developed by the Department for Communities and Local Government for Display Energy Certificates.
DEC	Display Energy Certificate. Energy performance certificate required by law for all public buildings >250m^2 which are regularly visited by the public. The energy rating is based on actual energy consumption data.
EPC	Energy Performance Certificate. This is the formal document describing the energy performance of a building in England and Wales. The certificate is required when the building is constructed, sold, or let.
ePIMS	Electronic Property Information Management Service. The government's Property and Land asset database containing details of location, tenure and other key attributes for each asset. It includes details about the buildings, any vacant space and occupiers.
ERIC	Estates Returns Information Collection. A site level dataset containing a range of information relating to UK NHS trusts including floor area and energy data

Experian	A commercial dataset containing data relating to UK businesses including addresses, contact details and business activity
GIA	Gross Internal Area. A definition of gross floor area set by RICS, which is commonly used as a basis for energy benchmarking.
HESA	Higher Education Statistics Agency. The central source for the collection and dissemination of statistics about publicly funded UK higher education.
HID	High-intensity discharge lamps (HID lamps) are a type of electrical gas-discharge lamp which produces light by means of an electric arc between tungsten electrodes housed inside a translucent or transparent fused quartz or fused alumina arc tube.
HVAC	Heating, Ventilation and Air Conditioning
LCD	Liquid Crystal Display
LED	Light Emitting Diode
NCM	National Calculation Methodology. This is the underlying methodology used to calculate the energy consumption of non-domestic buildings for the purposes of building regulations compliance in England and Wales
NEED, ND-NEED	Non-Domestic National Energy Efficiency Database. This database compiles key data relating to the UK building stock and energy performance
RICS	Royal Institute of Chartered Surveyors
SCAT.PD	A SCAT.PD code is assigned to all rateable properties by the VOA and identifies the type of property and the recommended approach to valuation. SCAT: Special CATegory PD: Primary Description
SME	Small to Medium Enterprises
SPON’s M&E price guide	An industry standard data source for cost estimation of mechanical and electrical services in the construction industry.
UARN	Unique Address Reference Number – a unique identifier identifying a hereditament in the Valuation Office ratings list
UCL	University College London

UPRN	Unique Property Reference Number – a building level unique identifier used in the ND-NEED dataset
VBA	Visual Basic for Applications. The primary programming language used in Microsoft Office applications

1 Introduction

This technical annex has been prepared as a supporting document to the Building Energy Efficiency Survey (BEES) overarching report and sector reports. It describes the survey methodologies, processes and modelling tools employed during the BEES study together with a description of the scope of the BEES sector coverage. The BEES project has been developed collaboratively between the Department for Business Energy & Industrial Strategy (BEIS), its pre-decessor departments and the contractors Verco and GFK.

It is intended to provide a good understanding of the methods, tools and data sources used in the study.

The BEES study was designed to meet the following research objectives:

- To update understanding of how energy[1] is used, for a snap-shot in time, across the non-domestic building stock in England and Wales in more detail than is currently available;
- To update understanding of how energy use can be reduced across the non-domestic building stock in more detail than is currently available at present;
- To understand the barriers and facilitators of energy abatement.

The study collected data through a large sample of telephone surveys (3,690). A population file for BEES was produced based on a range of national-level datasets for England and Wales. The telephone survey respondents were randomly selected using the most appropriate dataset for that sector. A smaller sub-set of site surveys (214) across the telephone survey sample were conducted to validate the telephone surveys and give insight into barriers and facilitators of energy efficiency.

The telephone survey responses were the primary input into two models: an energy use model, tailored to each sub-sector was used to calculate each premises' annual energy use, broken down by end use; and an abatement model calculated the energy saving potential.

An overview of the contents of this document follows, by section.

[1] Please note that consumption related to industrial processes was excluded from the scope of the survey, but industrial buildings services (e.g. heating, cooling and lighting) were included.

Section 2: Sampling and scope

This section covers the process for describing the total non-domestic building stock in England and Wales, and setting the scope within this that the BEES study would aim to investigate. First, the data sources used to determine the "universe" of non-domestic buildings in England and Wales are set out. Then the process of splitting the non-domestic stock into sector and sub-sector groupings is described. Finally, the sampling methodology is then presented.

Section 3: Weighting

This section explains the weighting methodology used to extrapolate the results of the BEES modelling procedures (calculated at premises level over a sample of 3,690 records), to represent the each sub-sector.

Section 4: Survey methods used in BEES

This section describes the development and specification of the different surveys and data collection methods used in the BEES study: the telephone survey, the site surveys and the barriers interviews.

Section 5: Fieldwork

This section shows how the data collection instruments were applied in the field. This includes the recruitment of respondents to the telephone surveys and site surveys, the dates over which the data was collected, and how data quality was assessed during fieldwork.

Section 6: Response rates

This section records the response rates achieved (e.g. the proportion of potential respondents who were contacted who participated). This also highlights why non-standard methods had to be developed in order to boost response rates in certain sectors and sub-sectors.

Section 7: Data processing

This section details how the data collected in the fieldwork was processed so that it could be input into the energy and abatement models. This included the initial filtering of data and assessment of quality to determine which records should be included in the study. Following this, the treatment of missing data in the remaining records, and how "don't know" responses were treated in order to ensure modelling processes would operate correctly is set out. Finally, this section details how the information collected during the barriers interviews was processed and analysed.

Section 8: Modelling

This section provides a detailed description of the two main models used in the BEES study (the energy use model and abatement model). It sets out the aims and objectives of each of the tools, their structure and key methodological decisions, and an overview of the sources of information used to populate the models with data and interpret the information collected through the BEES telephone survey fieldwork. The steps in each model's calculation procedures are set out in order that the logic and processes involved can be understood.

Section 9: Quality assessment

This section sets out a review of issues affecting the quality of the data, modelling procedures and analysis utilised in the BEES study. This includes sources of numerical error or poor quality data, inherent limitations encountered during the data collection, and the limitations and assumptions associated with the modelling approach. Non-standard methodologies which were necessary in order to ensure adequate participation are described, and any consequential impact on the quality of data and project results is discussed. A comparison between the results obtained within the BEES study and other official data sources is presented, as well as a description of a peer review undertaken in the form of a peer review modelling exercise which examined the validity of the energy modelling results.

2 Sampling & scope

2.1 Population

The scope of the Building Energy Efficiency Survey (BEES) was defined as the total non-domestic building[2] stock in England and Wales.

No single dataset was available for the BEES population but the majority of non-domestic premises are recorded in the Valuation Office Agency's Non-domestic Ratings List which contains 1.8 million premises records – referred to as hereditaments. A hereditament means property which is or may become liable to a business rate, being a unit of such property which is, or would fall to be, shown as a separate item in the valuation list. Areas within a larger property that are occupied by different organisations would be listed as separate hereditaments. This definition applies to BEES premises.

The hereditaments in the ratings list are assigned a Special Category Code (SCAT) and Premises Description (PD) code by the ratings officer. Collectively these classifications were merged for developing BEES sector definitions to a *SCAT.PD code*. These are shown in table 1.1 of Appendix B.

The ratings list provided the basis of the ND-NEED data[3] . In this database, address matching was used to combine hereditaments which shared the same address, to create "building" level records[4]. In these records, the SCAT.PD code with the largest share of the total floor area was used to assign the SCAT.PD code of the building.

The ND-NEED dataset was selected as the primary source for identifying the population of UK non-domestic premises. Each SCAT.PD code used in the ND-NEED dataset was assigned to a BEES sub-sector, and the ND-NEED dataset was queried to determine the total floor area of each of these sub-sectors, giving an indication of their significance within the non-domestic population.

[2] A non–domestic building is defined as any premises that is not used as a dwelling. In a few cases the definition requires some clarification. For example, school boarding houses, dedicated student residences and military barracks are non–domestic buildings and in scope for BEES, whilst the domestic accommodation that might be integral to a public house is considered to be a dwelling and not in scope for BEES.
[3] The Non-domestic National Energy Efficiency Data-framework (ND-NEED) is produced by BEIS and matches energy consumption with building attributes from the VOA and business attributes from Experian at building level.
[4] Due to the complexities of the address matching process, this process proved to be subject to limitations, and hereditament level records were still prevalent in the ND-NEED dataset following this process. This is discussed further in Appendix A

There were some omissions in the ND-NEED dataset due to premise types being out of scope of the VOA remit for charging business rates[5] or premises which were valued through non-standard methods (e.g. not based on floor area). The population dataset was therefore constructed through a combination of ND-NEED records and other data sources, where those were deemed reliable, reasonably complete and available. However, in a number of cases, these datasets were known to be incomplete (for example the DEC dataset used included very few buildings with a floor area of less than 1,000m^2 as DECs were not mandatory for these buildings at the time; furthermore a proportion of the buildings are missing due to non-compliance with DEC legislation). As a result of limitations such as these, the sampling dataset was not always a complete description of the total stock in a sub-sector.

In order to ensure the best available data was used to quantify the total population of each non-domestic sub-sector, the BEES team reviewed the basis used in the CaRB2 study against other known sources of data and selected the data source believed to hold the most accurate data for the total floor area of the population. Data sources used are identified in 'BEES population table' (Table 3.1 of Appendix B) together with the population estimates of premises and floor area used for weighting. The data sources used are listed below:

- Display Energy Certificate (DEC) database
- CaRB2 model - UCL
- Electronic Property Information and Mapping Service (ePIMS)
- Estates Return Information Collection (ERIC)
- Higher Education Statistics Agency (HESA)
- Military Property Gazetteer (PG)
- Valuation Office Agency ratings list data (VOA)

2.2 Sectors and sub-sectors

The non-domestic stock was divided into a distinct set of sectors with further disaggregation to sub-sectors. This section details the approach used to derive the sectors and sub-sectors drawn from the available datasets describing the universe of non-domestic buildings.

This sector approach was devised in order to achieve two goals:

[5] For example, nursing homes and places of worship.

- Sub-sectors were selected, as far as reasonably practicable, such that each one described a group of premises with similar energy related characteristics and activities. This was important in order to allow effective tailoring of the fieldwork methodology and modelling assumptions across the diverse set of premises within the non-domestic stock[6].
- This disaggregation enabled the BEES reports to publish detailed disaggregation of energy use at sector and sub-sector level.
- The sector divisions allowed the findings to be compared against other existing studies on UK energy consumption (e.g. the Digest of UK Energy Statistics)

The BEES approach borrowed heavily from, then built upon and simplified, the activity classifications used in the CaRB2 model developed by University College London (UCL).[7] The basis of the CaRB2 model was 14 sectors containing 161 activity classifications derived from 457 separate VOA SCAT.PD combinations.

In order to determine the final set of BEES sub-sectors, multiple stages of analysis and consolidation were applied, using the CaRB2 model list of 161 activity classifications as a starting point:

1. The CaRB2 list of buildings was reviewed and amended, reducing 161 activity classifications to 148 BEES sub-sectors by excluding land-only classifications (no buildings present) and merging classifications which were very similar (e.g. "roller skating rink" and "sports centre, sports hall"). The initial plan was to explore all 148 of these identified sub-sectors;
2. Following the initial piloting of the BEES project, the primary method was substantially reviewed and it was necessary to customise the analysis approach by sub-sector. In order to accomplish this within the project budget, it was necessary to limit the number of sub-sectors to be studied to a maximum of 50. Using a 'de minimis' approach and consolidations[8], the number of sub-sectors was reduced from 148 to 49 (this approach is described in more detail later in this section). This process also resulted in the exclusion of the transport sector.
3. During the time the project was in the field, five sub-sectors dropped out of the study (leaving 44 sub-sectors). This was due to insufficient responses to the survey (bank/insurance/building society branches or

[6] It was apparent during the progress of the study that modelling outcomes tended to achieve better reconciliation with available comparison data in well-defined sub-sectors with high levels of internal similarity between records.

[7] The UCL CaRB2 model sought to describe the electricity and non-electrical consumption of the non-domestic buildings in England and Wales based on the best available overall stock data and building energy benchmarks.

[8] Merging together sub-sectors deemed sufficiently similar to be processed robustly through the same customised energy use model e.g. museums with art galleries, cinemas with theatres, etc.

high street agencies, data centres, post office sorting centres), or where additional information came to light indicating that the sub-sector should have been excluded in the 'de-minimis' process (garden centres) or where it was subsequently decided that a sub-sector was out of scope (agricultural buildings/horticultural glasshouses[9]).

4. One sub-sector (small shops) was split into two sub-sectors for analysis purposes[10], whilst the military sector was split into three sub-sectors[11], in each case due to the distinct energy characteristics of each type. This increased the number of sub-sectors from 44 to 47, each of which was treated discretely in the BEES analytical process.
5. Finally, a number of sub-sectors were merged or split for reporting purposes, either to preserve the anonymity of major contributors and respondents to the survey, or to simplify the presentation of data in sector-level reporting. In these cases, the modelling analysis was still carried out at the 47 sub-sector resolution, but the results were combined in the sub-sector level data resulting in 38 sub-sectors reported on in BEES. The mapping to these is shown in table 1.3 of Appendix B.
6. The original 14 CARB2 sectors were consolidated to 10 sectors in the reports. As described above, two CARB2 sectors were excluded (transport and agriculture). Additionally, two were "lost" by sector mergers for reporting purposes: ("sport" and "leisure" were merged to "leisure", and "community" was merged with "arts and leisure" to create "community, arts & leisure". The "nursing homes" sub-sector was moved from the "community, arts and leisure" sector to the "health" sector at this stage.

As shown in Table 2.1 of Appendix B, the 'de-minimis' approach was used to reduce the number of sub-sectors from 148 to 49.

To determine which sub-sectors would be included in the study, the following steps were also undertaken:

- The area and energy intensity of the 148 sub-sectors in CARB2 were quantified;
- It was calculated that around 50 sub-sectors would be needed to over 90% of total stock floor area and this was a manageable number of sub-sectors for the project.
- The 50 most significant sub-sectors were identified based on:
    - Floor area (GIA);

[9] Because all delivered energy is effectively being deployed for an industrial process (optimising the growing conditions for plants).

[10] Small shops were split into small food and small non-food shops

[11] Military was split into military offices, military storage, and military accommodation using a 'de-minimis' approach applied to the military estate.

  - Number of hereditaments;
  - Energy intensity (low or high);
  - Overall importance of energy efficiency within a premises type.

- All the remaining sub-sectors were subsequently reviewed to confirm their exclusion was appropriate, as follows:
  - Review all marginal sub-sectors: identify the 10 next most significant not selected and compare with the 10 least significant included; consider any ‘promotions’ or ‘relegations’ on a one in, one out basis. This analysis indicated that the logic used was sound – the excluded sub-sectors tended to have low energy intensity, overlap with domestic uses, or industrial cases where much of the energy consumption would be out of scope of the BEES analysis, which only explores building energy use. In comparison, the sub-sectors included tended to have high energy intensity, have high frequency (numbers of buildings), or were sub-sectors where the team had high confidence that good quality modelling could be achieved;
  - Apply consolidation: i.e. 33 excluded sub-sectors were identified which could be consolidated within existing selected sub-sectors. This was necessary to ensure overall coverage, but in cases where sub-sectors with similar characteristics were merged (for example cinemas, theatres and concert venues), an increase in the diversity of premises resulted in a greater modelling challenge in certain cases. Where this issue occurred, it is noted in the modelling challenges for the relevant sector;
  - Reject the remaining as ‘de minimis’.

On this basis, 82 original sub-sectors were deemed in scope but these were consolidated into 49 discrete sub-sectors as indicated for fieldwork purposes. If these sectors had all been achieved would have given coverage of 94 per cent of the total stock by floor area. A total of 65 sub-sectors were excluded.

Figure 2.1 below shows how the data was reduced to 82 sub-sectors by excluding 5% of floor area before these were merged into 49 sub-sectors. This meant that almost 100 sub-sectors could be excluded with little impact on the overall study outcomes, but gaining a huge saving in the time required to complete the work. [12]

[12] It is noted that this analysis was carried out early in the BEES study, and is based on gross floor areas taken from UCL’s CaRB2 model; these differ from the final floor areas used in the BEES study, as further analysis undertaken in the BEES study led to the adoption of different figures in certain sub-sectors.

Figure 2.1: Cumulative area of sub-sectors in order of size

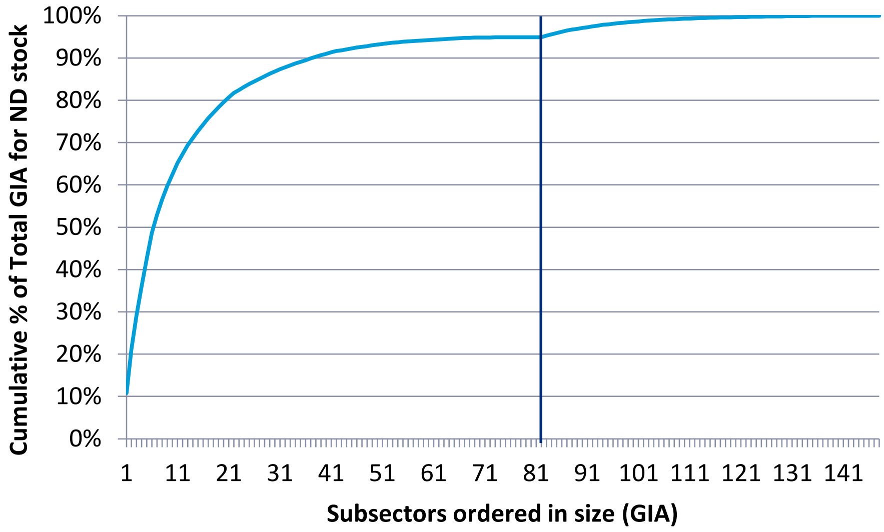


Table 2.1 sets out the total floor area and total number of sub-sectors in each sector and the floor area and number of sub-sectors by sector which are included and excluded following the application of the de-minimis threshold.

Table 2.1: Total floor area and number of sub-sectors by sector

	Total		Included		Excluded		
Sector	**Total Floor Area (GIA, thousand m^2)**	**Total sub-sectors**	**Total sub-sectors**	**Total consolidated sub-sectors**	**Excluded Floor area (GIA, thousand m^2)**	**% excluded**	**Total sub-sectors**
Agriculture	25,600	7	2	2	1,500	6%	5
Community, arts & leisure	83,000	35	18	8	18,400	22%	17
Education	83,600	13	7	5	4,600	5%	6
Emergency services	15,400	10	9	4	0	0%	1
Industrial	187,100	15	5	4	12,600	7%	10
Health	46,700	13	12	3	300	1%	1
Hospitality	49,400	8	6	5	2,000	4%	2
Military	18,700	1	1[13]	1[13]	6,200	33%	N/A[13]
Office	125,900	10	4	2	2,200	2%	6
Retail	132,100	18	11	11	2,100	2%	7
Transport	6,400	9	0	0	6,400	100%	9
Storage	197,200	9	7	4	500	0%	2
All sectors	**971,100**	**148**	**83**	**49**	**56,900**	**6%**	**66**

[13] The military sector was subsequently split into three sub-sectors (offices, accommodation and storage) in a 'de-minimis' exercise applied to the military estate. This permitted analysis of the varied stock, but resulted in the exclusion of the 6.2 million m^2 of floor area identified above.

Subsequent to the selection process detailed in Table 2.1, five further sub-sectors were excluded during fieldwork: data centres, banks, glasshouses, garden centres and post office sorting centres (reducing coverage to 44 sub-sectors). These further exclusions comprised 3.3% of the remaining floor area (or 3.1 per cent of the total non-domestic stock); the resulting coverage by BEES of the overall non-domestic stock's floor area was therefore 91 per cent (Table 2.2).

Further information can be found in Appendix B, which summarises all the sub-sector data[14].

Table 1.1	Mapping of SCAT.PD, ePIMS and DEC category codes to BEES sub-sectors
Table 1.2	Sample design and achieved quotas in the BEES study
Table 1.3	Mapping to final sub-sectors
Table 1.4	Sub-sector allocation for ePIMS building types to BEES sub-sectors
Table 1.5	SIC descriptions used to separate the small shops subsector into food and non-food shops
Table 1.6	Other segmentations/quotas
Table 2.1	Summary of de-minimis analysis process
Table 2.2	Summary statistics for de-minimis analysis process by sector
Table 3.1	BEES Population Table

[14] During the course of the project additional data was identified for population statistics on a sub-sector by sub-sector basis. The figures included in the appendix are based on the data as it was at the time that the scoping decisions were made for the BEES study and therefore may not fully align with the final population statistics reported.

Table 2.2: Total floor area and number of sub-sectors by sector following fieldwork exclusions

	Scope after de-minimis analysis		Excluded during fieldwork		
Sector	**Included Floor area (GIA, thousand m²)**	**Sub-sectors**	**Excl. Floor area (GIA, thousand m²)**	**Sub-sectors**	**% of post- de- minimis floor area excluded**
Agriculture	24,000	2	24,000	2	100
Community, arts & leisure	64,600	8			
Education	79,100	5			
Emergency services	15,400	4			
Industrial	174,500	4	1,100	1	0.6
Health	46,300	3			
Hospitality	47,400	5			
Military	12,500	1			
Office	123,700	2	1,300	1	1.0
Retail	130,000	11	3,900	1	3.0
Transport	0	0			
Storage	196,700	4			
All sectors	**914,200**	**49**	**30,200**	**5**	**3.3**

2.3 Sample unit definition

The BEES sample unit is a premises. In BEES, a premises can either be a whole building with a single occupier, part of a building occupied by the responding organisation or a collection of buildings (e.g. a campus). For records sampled from the VOA these will be hereditaments referenced by Unique Address Reference Numbers (UARNs).

When the ND-NEED dataset was compiled, the target granularity was set at the whole-building level and records at this level have been given Unique Property Reference Numbers (UPRNs). In order to combine the hereditaments within a building, address based matching was used to identify multi-hereditament buildings. In these cases, the ND-NEED record retained information on the dominant hereditament (i.e. largest floor area). In some cases a hereditament may consider itself to be part of a larger building but would have its own ND-NEED record if the building was separately listed in the address register.

As a consequence of this, when sampling records from ND-NEED it was not always possible to interview someone who could provide information on the whole building/hereditament (in many of the other sampling datasets used such as DECs and EPIMS, the base sample unit was buildings, and this issue did not occur). Where an organisation was the only occupier in a selected building, this was not an issue, but the following scenarios presented issues for the survey methodology:

- Multi-type buildings, those buildings with either multi-hereditaments and/or multiple occupiers;
- Single hereditaments which include a number of buildings on a site or campus e.g. universities.

2.3.1 Multiple-type buildings

For the purposes of data collection, the telephone survey and site survey targeted the dominant hereditament or occupier in the hereditament of multi-type buildings and the survey asked:

Q What percentage of the building does your organisation occupy?

This question was then used at the weighting stage to apply a Part of Building adjustment to these data records to reduce their level of representation in the overall dataset. This is described more fully in the weighting section.

2.3.2 Multi-building hereditaments

In the case of multibuilding hereditaments, it would not have been feasible to ask the respondent for information about all buildings on a site, due to the burden this would have placed on respondents and the negative impact this would have had on response levels. This would also have created a modelling challenge, as the modelling tools were designed to treat a single building or premises with a specific primary use.

Where DEC records were used (i.e. secondary schools, universities, NHS hospitals), the sample unit was always a building or premises[15], so the telephone survey responses were never targeted at sites. For ND-NEED records describing multi-building hereditaments, data was only provided at the overall site level and therefore a selection process needed to be introduced to identify one building within the hereditament. In order to ensure representation of different building sizes and avoid bias from a completely self-selected approach, a random element was introduced to the selection process. Interviewers rotated the order of asking for a small, large, or typical-sized building on the site.

The following questions were asked within the telephone survey to select the building.

Q How many buildings over 100 m2 are there on this site?

Q Of these how many are small, typically sized and large[16] buildings?

*Q Please select a smaller / typically sized / larger building on the site (**rotate order of asking smaller/larger/typical)** for which your organisation occupies the whole building and you know the floor area.*

Q Please provide the following details relating to the selected building:

*SQ. What is the name or reference for the building?*___________________________

SQ. Does the building include ….. ?

(Activities listed relevant to the sub-sector to confirm building fits into sub-sector)

Q. What is the floor area in m^2 for this building?

[15] Display Energy Certificates are required by law to represent "a building or part of a building which is designed to be used separately" i.e. the building or premises has separate access and egress or separate heating and building services or its own dedicated energy metering; however in the majority of cases this will constitute a separate building.

2.4 Sampling frame

The sampling frame was predominantly based on VOA data in ND-NEED. Where this was not possible, due to the data quality issues inherent in the ND-NEED database, other sources were used. These included:

- Display Energy Certificates (DECs)
- Electronic Property Information and Mapping Service (ePIMS)
- Property Gazetteer for the military estate
- Experian
- BUPA

All datasets were integrated into one single database. The sampling frame was then classified, wherever data was available, by the following:

- Sector (education, health, emergency services, military, retail, offices, hospitality, community, arts & leisure, storage and industrial[17])
- Sub-sectors were allocated based on:
    - SCAT.PD code from VOA
    - Property type from DECs
    - Building classification from ePIMs
    - Thomson Description from Experian
- Floor area (strata were created based on the distribution of the population)

Detailed categorisation of all the sub-sector typologies is shown in Appendix B. The appendix also presents changes to the initial classification of sub-sectors, some revisions were made to re-classify excluded records based on their Thomson Description.

[17] Note the sampling included 13 sectors including agriculture and community, arts & leisure dissagregated.

2.5 Overall sampling approach

This covers the overall sample design method for the telephone surveys, as well as the approach to stratification within these sub-sectors.

2.5.1 Sample Design

The sample design was a ‘Quota Design’, but to ensure the drawn sample was representative, elements of random sampling were introduced. The main issue with adopting a purely random probability design would have been the resulting prohibitively long fieldwork requirements. Given the complexity of this research in terms of data collection, a quota approach was therefore more appropriate.

In order to minimise the effect of quota sampling on data collection, the sample was released in stages. This ensured that the difficult to contact respondents had several calls attempted before releasing a new sample for. By having a limitless supply of leads the level of bias introduced was lower. Each respondent had a minimum of twelve attempted contacts across different days and times over at least two weeks before no further calls were attempted. In the response rate tables in section 6, these records are included in the ‘still live’ category.

The sampling design used for the study needed to produce suitably robust results at sub-sector level. The design therefore set a minimum of 50 surveys per sub-sector where feasible. In some cases the target set was lower than 50 where there was a limited population, for example in prisons where there are only around 140 in England and Wales. By setting this minimum target the overall sampling method was disproportionate to the number of buildings in the sampling frame with a lower proportion of surveys in the larger sub-sectors.

2.5.2 Sub-sector stratification

Within the larger sub-sectors it was possible to stratify within the sub-sector. In each sub-sector, the sample was initially stratified by floor area which in the majority of cases (where the target sample size was 50) was two strata, although for larger sample sizes up to four strata were used.

Soft quotas (ranges) were set within sub-sectors, which, in the vast majority of cases, were based on floor area strata to ensure that both larger and smaller buildings were included in the survey. Floor area was unavailable for some sub-sectors such as nursing homes and alternative quotas were used, where possible, as a proxy for floor area, which in the case of nursing homes was the number of beds.

The analytical sub-sectors each had a bespoke modelling approach but in some sub-sectors soft quotas were set for the sub-groups of buildings within them as set out in table 2.3. In the case of offices and military separate sub-sectors were developed for reporting purposes.

Table 2.3: Soft quotas for sample selection by sub-sector

Sub-sector	Additional soft quotas
Offices	• Central government offices • Local government offices • Other types of offices
Fire/Ambulance stations	• Fire stations • Ambulance stations
Health Centres	• Health centres • Dentist surgeries
Military	• Offices • Residential • Storage

Other variables such as region and nominal energy consumption available from sources within the sample register e.g. ND-NEED and DECs were also monitored, although not controlled for.

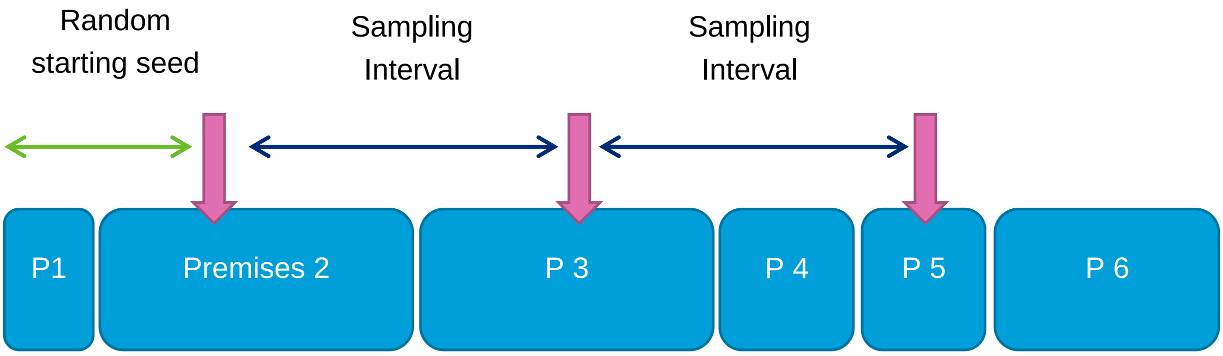
2.5.3 Sample selection

Once the target number of premises within each strata had been determined and the total floor area calculated, then a random mechanism was used to draw the actual premises to be used in the sample. The sample was initially sorted by geographic region and, where possible, the presence of electricity and gas consumption data in ND-NEED and the ‘typical’ consumption levels fields in the DEC database. This was applied prior to sampling to ensure that the resulting sample was representative on these elements.

Sampling using PPS (Probability Proportional to Size) was then conducted by effectively sequentially calculating the cumulative (total) area within each cell, within each sub-sector. The desired sample size was then used to divide this total area to obtain a sampling interval. A random starting point was used to select the first sampling record within the first sampling interval was then chosen and whichever cell lies in that area, in the sequential list, had its first sampling element selected. The area was then increased incrementally by the sampling interval and the cells corresponding to the area in which each interval ends were selected for sampling (or one was added to the required sample within that cell) as shown in Figure 2.2.

With this method, the first m^2 of all buildings had an equal chance of being sampled, but buildings with larger floor areas had a higher probability of being selected than would have been the case if a proportionate design based on buildings only had been used.

Figure 2.2: Sample selection methodology



The sample was drawn in the ratio of 1:20 to take into account the level of telephone matching, which averaged out at approximately 33% and variable response rates by building type, with the aim of using a 1:8 ratio of initial sample to final sample size for the telephone fieldwork. Telephone look-up uses an automatic process which is dependent on high quality sample details including organisation and address details as well as postcode. Matching rates varied by sub-sector (see Appendix B table 1.2) and was generally low due to the quality of the sample. Manual look-up was needed for many sub-sectors to supplement the automatic matching and the success of this was dependent on the availability of information on organisations in the public domain. For instance, retail organisations had a higher success rate for manual look-up than warehouses.

2.6 Sample Achieved

A total of 4,158 surveys were achieved in the study, of which 3,792 were standard telephone surveys, and 366 were collected using non-standard methods (internet surveys, mystery shopper records, paper based surveys, direct contact with respondents, or by site surveyors completing them during a site survey). Table 2.4 summarises the telephone and equivalent records collected in each sub-sector. Following data processing and exclusion of poor quality records, 3,690 records were used in the final analysis. Overall 468 (11%) of records were excluded with the highest sectoral exclusion rate in education (25%) and lowest in industrial (4%). This will add some bias with organisations less knowledgeable about their buildings more likely to be excluded.

Table 2.4: Telephone surveys and equivalent records collected by sub-sector

Sector	Sub-sector	Number of standard telephone surveys completed	Number of non-standard telephone surveys completed	Total number of telephone surveys (or equivalent records) completed	Number of telephone survey records retained post-screening for reporting analysis
Industrial	Factories	105	6	**111**	**106**
	Workshops	383	0	**383**	**369**
Education	Nurseries	50	0	**50**	**35**
	Primary schools	54	0	**54**	**41**
	Secondary schools	54	0	**54**	**42**
	Higher Education – teaching & research	36	1	**37**	**23**
	Higher Education - residential	4	21	**25**	**24**
Military	Military accommodation	0	30	**30**	**24**
	Military offices	0	29	**29**	**24**
	Military storage	0	19	**19**	**16**
Health	Health centres	62	0	**62**	**52**
	Hospitals	72	0	**72**	**57**
	Nursing homes	58	1	**58**	**57**
Emergency services	Fire/ambulance stations	25	36	**61**	**53**
	Police stations	0	24	**24**	**19**
	Law courts	51	0	**51**	**43**
	Prisons	20	0	**20**	**14**

Hospitality	Cafes	49	5	**54**	**48**
	Hotels	51	0	**51**	**44**
	Pubs	109	0	**109**	**93**
	Restaurants & takeaways	93	10	**103**	**87**
Offices	Office (public)	141	0	**141**	**117**
	Office (private)	634	0	**634**	**520**
Retail	Hairdressers & beauty salons	50	10	**60**	**57**
	Large food shops	8	55	**63**	**63**
	Large non-food shops	20	58	**78**	**74**
	Retail warehouses	24	26	**50**	**49**
	Showrooms	96	0	**96**	**89**
	Small shops	731	29	**760**	**701**
Storage	Large distribution warehouses	46	4	**50**	**43**
	Warehouses	242	1	**243**	**225**
	Stores	118	1	**119**	**109**
	Cold stores	21	0	**21**	**21**
Community, arts & leisure	Leisure centres	87	0	**87**	**77**
	Clubs & community centres	100	0	**100**	**96**
	Museums	47	0	**47**	**41**
	Theatres	50	0	**50**	**46**
	Places of worship	101	0	**102**	**91**
Totals		**3,792**	**366**	**4,158**	**3,690**

3 Weighting

3.1 Weighting method

The purpose of the weighting exercise in the BEES project was to extrapolate the modelling results (calculated for a sample of premises within each sub-sector) to represent the entire non-domestic stock of England and Wales in each of the BEES sub-sectors.

The weighting factor is the value used to gross up each BEES record in order to arrive at the energy and abatement estimate for the entire population of each sub-sector. Overall there were 1.57 million premises within the scope of the survey and the findings from BEES are based on 3,690 records.

3.2 Area based weights

The main set of weights used in BEES were designed to be representative of the population floor area. Although there were occasional discrepancies between the floor area in the sample frame and that reported in the telephone survey / site-survey.

Floor area data for the survey record has been taken in priority order from the list below:

1. Area determined during site survey (if available, c. 220 cases);
2. Area stated by respondent in the telephone survey (for part of building, campus records or sub-sectors such as places of worship where floor area was not available in the sample dataset);
3. The area given in the source sampling dataset.

Given the strong association between floor area and energy consumption within sub-sectors this provided the best representation of energy consumption.

The weighting method was based on the 47 analysis sub-sectors included in the BEES survey. Following the completion of fieldwork some sub-sectors were merged or split to leave 38 sub-sectors. This was done to provide more robust results, preserve anonymity of contributors and simplify the message where sub-sectors had similar attributes.

3.2.1 Selection Probability weight

The first issue that the weighting needed to address was the variation in the probability that a particular building was sampled. The design used made the probability of selection of the first square meter of each building equal.

The selection weight was the inverse of the probability that a building is selected:

Which is equivalent to:

$$P_{building} = \frac{\sum_{subsector} buildings\ in\ sample}{\sum_{subsector} buildings\ in\ population} \cdot \frac{Area_{building}}{\overline{Area}_{subsector}}$$

$$wt_{selection(buidling,subsector)} = \frac{\overline{Area}_{subsector}}{Area_{building}}$$

The treatment of Part of Building (PoB) premises assumed each part of building had an equal chance of being sampled. The weighting effectively treated all PoB records as the floor area covered by the survey (the premises, rather than the whole building) at all stages.

Note that an adjustment was applied at this stage where only the part of a building was covered so the actual floor area covered was represented. While the chance of each building being sampled was proportionate to the whole building area, the chance of the business unit being sampled was lower and therefore applying a PoB adjustment before the calculation of the selection weight was justified.

Therefore, the area was adjusted by the proportion of the part of the building occupied, where this was less than 100%.

So:

$$Area_{building,final} = Area_{building,raw} \cdot PoB$$

Where PoB was the part of building occupied, expressed as a percentage and obtained from the survey data.

Henceforth in the calculations this is referred to as $Area_{building}$.

The weighted data needed to have an equal chance of selection for each m^2 in the sample. So, using the sampling method employed, the resulting probability of selection for each m^2 was:

$$P_{Area\ Unit} = \frac{\sum_{subsector} buildings\ in\ sample}{\sum_{subsector} buildings\ in\ population} \cdot \frac{Area_{building}}{\overline{Area}_{subsector}} \cdot \frac{Area_{building}}{\overline{Area}_{subsector}}$$

A bias was introduced for each building which was proportional to its area. Therefore a selection weight was applied which was inversely proportional to this selection probability. This was the first stage of the weighting:

$$wt_{selection(building,subsector)} = \frac{\overline{Area}_{subsector}}{Area_{building}}$$

The selection weights were capped to eliminate extreme weighting factors at this stage of the calculation. The caps applied were 5 at the upper and 0.2 at the lower end. This still allowed a ratio of 25 from the highest to the lowest weight, which should have allowed the weights to compensate for the bulk of the differences caused by the disproportionate sampling, whilst limiting that difference so that the final weighting efficiency was not adversely affected by the weighting.

3.2.2 Design probability weight

The main design weight for BEES was calculated as the ratio of floor area in the achieved sample and the population floor area. This was calculated within the 47 original sub-sectors with additional stratification where possible.

It was felt that, given the non-random elements remaining within the sample and the unknown effect of non-response, that there should be an additional element of weighting which corrected for remaining differences between the distribution of the final sample and the overall population.

Although the soft quotas were set on area only, information on region and electricity consumption and intensity were also available in most sub-sectors. Given the sample size, region was disregarded as a variable given the low numbers within each region, leaving floor area and energy intensity. The quotas were largely based on two strata (there was some variation depending on sub-sector) for each of these metrics resulting in the generation of up to nine strata per sub-sector (Table 3.1).

Table 3.1: Sample stratification matrix

		Floor Area		
		High	Low	Unknown
Energy Intensity	High	A	B	C
	Low	D	E	F
	Unknown	G	H	I

Within these nine strata the total floor area in the population was calculated using the information in the sampling masterfile as a proxy for this. The ratio of this figure to the floor area in the sample generated a design weight for each strata:

$$wt_{strata} = \frac{\sum_{bin} Area\ in\ Population}{\sum_{bin} Area\ in\ Sample \cdot wt_{building}}$$

This was then repeated for each sub-sector.

Note that the selection-weighted estimate of floor area was used in this equation so that the sample area already reflected the differential sampling probabilities.

The final weight was therefore defined as:

$$wt_{building,subsector\ strata} = wt_{building} \cdot wt_{strata}$$

Analysis was conducted on a sub-sector by sub-sector basis to examine the sample size within each of the strata and, if any particular strat had fewer than 10 observations within it, it was merged with an adjacent cell (i.e. either by floor area or electricity consumption). Priority was given to merging within the same floor area where such instances occurred. A minimum strata size of 10 allowed the exercise to be conducted amongst a greater number of sub-sectors. Of the 47 sub-sectors analysed 13 had 30 or fewer observations within them and a further 19 had fewer than 50 observations.

3.2.3 Further weighting adjustments

As well as the two main weights, a further scenario occurred, where the record comprises more than one building.

In this scenario, the so-called campus situation, the organisation or hereditament contains several buildings, although we only gather information about a single building from the respondent. Analysis was conducted to determine whether the information about floor area and electricity consumption from the sample register referred to the individual building or the whole hereditament. There was evidence from some datasets (i.e. display energy certificates) to suggest that it was solely the building. This meant that no data adjustment was needed to make any further adjustment to weights due to this.

Therefore, a final area weight was applied evenly to all observations within a sub-sector which was constructed to ensure the weighted total of all the observations in terms of floor area matched the best population estimate available.

$$wt_{building,subsector} = wt_{building,subsector\ bin} \cdot \frac{\sum_{subsector} Area\ in\ population}{\sum_{subsector} Area\ in\ sample}$$

3.3 Premises based weights

The main BEES results for energy use and share of floor area within a sub-group of the non-domestic building stock are derived using the area based weights. Even within a sector there is high variation in the size of premises and Appendix C of the BEES Overarching report presents alternative analysis of the non-domestic stock that is representative of the number of premises.

The premises based weights are derived based on the main area based weights by multiplying the weight by the average size of premises in the strata over the floor area of the premises.

Premises weight = Area weight * (average strata floor area)/(record floor area)

4 Survey methods used in BEES

4.1 Telephone survey

A standard overall approach was designed to gather information on energy use in premises relying on telephone surveys of an average of 25 minutes and a limited number of site surveys. An initial pilot of the telephone survey method tested a two-stage process with the aim of collecting more detailed information and restricting each survey stage to 15 minutes maximum and allowing the second stage to be completed online. As described in section 5.2, achieving sufficient responses to the second stage survey was found to be unworkable, hence the move to a single stage but longer survey.

The telephone survey asked respondents a broad range of questions relating to their premises and energy use. In general, each question was intended to achieve one of three goals:

- Verify or confirm that data used in the sampling selection was correct (e.g. correct organisation has been contacted, confirm address is their building/premises, confirm that building/premises matches sub-sector description). These questions would typically be yes/no questions.
- Identify new information about the building or organisation (e.g. type of cooling system, attitudes to energy management, presence of meters on fuels, etc.). These questions used a multiple choice answer to facilitate efficient analysis.
- Quantify information about the building or organisation (e.g. number of staff, hours of occupation, size of swimming pool, etc.). Where possible a direct numerical response would be requested, with number ranges offered if the respondent answered “don’t know” at the first request.

The survey was broken down into two key elements (the **core survey** and **sub-sector specific questions**). An example questionnaire for primary schools is provided in Appendix A.

The core survey was designed to collect data which would be required for all records, regardless of sub-sector. Where required, the question text of core survey questions could be tailored to suit a specific sub-sector or sector, but the subject matter of each core survey question remained the same throughout the study.

A brief summary of the telephone survey is presented in table 4.1 below.

Development of the sub-sector specific questions was led by energy experts within the BEES team. Where suitable individuals could be identified, specific sector or sub-sector experts were contacted and asked to provide an “expert interview”.

Expert interviews were conducted relating to 17 of the 47 BEES analysis sub-sectors, and these interviews provided extremely valuable critical insight into energy consumption within those sub-sectors. This insight was particularly valuable when designing the sub-sector specific telephone survey questions, for several reasons:

- The experts were able to advise who the best target respondent would be within organisations in that sub-sector;
- The experts provided advice on the most important energy related issues in the sub-sector which the telephone survey should address;
- The experts advised on the appropriate level of technical detail to seek in the questionnaire (for example, if organisations were likely to have specialist energy managers then more technical questions could be asked than if the respondent was unlikely to be a specialist);
- The experts were often able to highlight high quality information in the public domain, portfolio datasets, or individuals with further expertise in that sub-sector who might be willing to support the survey.

Table 4.1: Overview of the telephone survey

Survey element	Section	Sub-section	Purpose
Core survey	Recruitment	Recruitment	Introduce study
			Obtain consent to participate
	Recruitment	Legal issues	Make respondent aware of data protection & legal issues
	Respondent and survey unit validation	Validate sampling unit	Confirm the correct organisation has been contacted & the address from sample relates to their premises
			Confirm/identify the most appropriate respondent
	Basic property details	Premises form	Is the premises a whole building, part of a building, or a multi-building site?
			If a site, select a suitable building from the site to survey & estimate size
	Basic property details	Energy supplies and metering	Identify all energy supplies and whether meters/sub-meters are present
	Organisation and management	Organisation details	Identify primary activity of the organisation
			Identify organisation size & distribution of premises
			Confirm building meets sub-sector requirements
	Organisation and management	External activities	Identify external activities relating to the building
	Organisation and management	Occupancy	Identify weeks per year, days per week and daily hours of use
			Identify number of staff & main visitors present
	Energy characteristics	Basic energy characteristics	Identify:
			- Who is responsible for main plant

			- Main heating fuel, hot water fuels used
			- Presence and extent of heating , ventilation and comfort cooling systems
			-Presence of renewable energy & low carbon technologies
			- Presence of key energy intensive activities (e.g. server rooms, laboratories)
	Energy characteristics	Quantification of energy intensive activities	Quantify common energy intensive activities:
			- Catering (no. meals)
			- Server rooms (type)
			- Data centre (area)
			- Swimming pool (area)
			- Laboratory (type)
			- Laundry (weight processed)
	Energy characteristics	Building services details	Identify further detail on building services systems - heating, ventilation, cooling and lighting covering:
			- System type
			- Control type
			- Control effectiveness
			- Age of system
Sub-sector specific questions	Sub-sector specific questions	schedule of accommodation	Identify activities undertaken in building and their share of total space; identify key points about building form and fabric
	Sub-sector specific questions	Internal energy uses	Identify key energy and organisational characteristics for the sub-sector (five multi-part questions)
	Sub-sector specific questions	External energy uses	Identify/quantify two common external energy uses for the sub-sector (e.g. car parks, sports floodlighting)

Core survey	Basic property details	Smart metering	Identify presence of smart meters and how data is used
	Organisation & management	Energy management attitudes and capacity	Identify attitude towards energy management
			Identify human resources available for energy management
	Basic property details	Age, condition and form	Identify:
			- If building has been refurbished recently
			- Age of building
			- Condition of building fabric
			- Presence of asbestos (pre-1986 buildings only)
			- No. storeys
	Close-out	Respondent details	Identify respondent job title
	Close-out	Site survey recruitment + follow up	Identify willingness to participate in site surveys
			Identify willingness to be re-contacted
	Close-out	Data accuracy	Identify respondent's view on data accuracy
			Identify interviewers' view on data accuracy
			Interviewer's comments

4.2 Overview of the site survey assessment

As part of the data collection process, 214 site surveys were undertaken on a subset of premises chosen from the telephone survey sample. These were not chosen through a random sample but selected based to give a range of sites across a sub-sector in terms of size and energy intensity. The site surveys gathered detailed information on the energy end use consumption, activities (extent and intensity), abatement potential and the barriers and enablers to implementing energy efficiency measures in the building. The site survey results were compared to the modelled results for the record. Where necessary specific modelling assumptions would be used for particular sub-sectors. Examples of updates include typical floor area conventions and net to gross ratios comparing whole building floor area with that associated with core activities as well typical plant ratings for key equipment. Data collected on site was also used to verify and, if necessary, correct and overwrite findings from the initial telephone survey.

The site survey process gathered a broad range of data across the following subject areas:

- Activities
- Occupancy
- Equipment list
- Building fabric information
- Energy end-use breakdown
- Abatement measures that had been implemented or were suitable for the site
- The potential energy savings that viable measures could achieve
- Energy consumption data (whole building and sub-metered)
- Information relating to barriers and enablers affecting the site and recipient organisation

The data collected under each of these subject areas is discussed in more detail. In order to maximise consistency across the site survey results, the BEES team partnered with a proprietary software provider. A software tool was required for the collection of data during site surveys, such as floor areas, energy data, and the types and energy consumption of assets within different spaces on site. The team built upon the basic structure of an existing survey product to produce a bespoke tool for collecting data in a format which closely matched the modelling approaches used in the BEES study. This approach had a number of advantages:

- Utilising an existing software structure reduced the development and testing time required compared to starting from scratch;
- The data collected from each survey could be easily amalgamated into a coherent database covering all the surveys;

- Error reporting could be built into the software to ensure that essential inputs were not missing from the assessment (effectively introducing a checklist of key data items);
- When identifying abatement measures, the software could generate a checklist of all the measures which might be applicable based on the end uses and activities present in the building, to ensure that all surveyors considered a consistent list of measures across the study;
- The software permitted efficient export of data into a consistent report format.

In order to develop a tool suitable for use for the BEES study, a significant degree of software development, testing and bug resolution was required. Due to the timescales associated with this development process, a completed tool was not available when surveyors first started working in the field; these surveys were carried out manually using spreadsheet based data collection processes based on the site survey specification, and transferred into the software tool at a later date. This affected the emergency services, health, education and military sectors. As a consequence, data collection procedures were more varied in these early sectors and were more dependent on the skillset of the individual surveyor.

It should also be noted that the detail and quality of outcomes from the site survey process was highly dependent upon the involvement and engagement of the site contact, and the quality of data they were able to provide relating to the premises. Furthermore, size and complexity of the survey premises had a significant impact on the quality of the outcomes of the survey.

At the time of confirming the date for the site visit, the respondent was contacted with a preparation email. This set out requests for access to information and the areas of the building the surveyor would need to access, such as plant spaces, server rooms and any restricted areas where special permission or safety considerations might have applied.

4.2.1 Activities

The survey classified the space type breakdown of the building in a manner consistent with the BEES energy model methodology, as percentage of total floor area (GIA) assigned to each space type (indoor and outdoor). This allowed the energy consumption of discrete equipment items to be assigned to the correct space type to assist in model calibration procedures. The approach was tailored to suit the size and complexity of the building. Table 4.2 identifies the typical approach taken, depending on the complexity of the building.

Table 4.2: Space type breakdown approach matrix

	Complexity of layout

Number of space types	Simple/repeated layout	Complex layout
Few (up to 4)	Measurement from plans, calculation from room schedule or physical measurement	Calculated from room schedule
Typical (5-8)	Calculation from room schedule / estimation from floor plans	Calculation from room schedule / estimation from floor plans
Many (9+)	Calculation of a sample floor from schedule/plans, or estimation based on walk through.	Estimation based on floor plans or walk through

Validation

Where possible, the gross floor area would be validated against appropriate existing records such as the Valuation Office Agency's ratings list, or any existing energy certificates (DEC or EPC), or measurement of external dimensions where other sources are not available.

4.2.2 Occupancy data

The site surveyor collected occupancy data covering the number of occupants at peak occupancy, and partial occupancy where this was significant in energy terms. The surveyor identified the core and partial hours of use of the building as a whole, and at space type level where this differed from the whole building hours of use. Further contextual information such as building hours of access was also collected where this was material.

The information collected was used as an input in calculating end use energy consumption of equipment present in different space types, and during the calibration processes for the energy use model.

A quality hierarchy was applied, so where formal information on staff capacity, shift patterns and opening hours was available this would be used. However, in the majority of cases occupancy data required a degree of estimation from the on-site contact or based on the surveyor's observations as they moved around the site during the day.

Validation

The telephone survey included estimates of peak occupation/opening hours and partial hours of occupation, and the number of staff and visitors on site at peak times. These were validated/amended by the surveyor's findings on site.

4.2.3 Equipment list & calculation of energy end use consumption

The surveyor collected data on the items of energy consuming equipment on site, and assigned these to the appropriate energy end use category according to the methodology used in the BEES energy use model. This included direct asset information such as type, nameplate power rating, actual maximum power use, typical actual power use (where there is potential for variable power capacity), level of service provided (e.g. air flow rate for fans, temperature for heating systems) and finally details relating to any automated controls or the hours of use of the items. The utilisation factor was also collected (the proportion of time that power is being drawn compared with the total length of time when the equipment is available to be used).

Again, a data hierarchy was applied; where possible, data was sourced from equipment rating plates, operation and maintenance manuals (where available), or by collecting manufacturer information via the internet. The surveyors were also provided with databases of typical values for a range of equipment items which commonly do not state their power ratings, where these are commonly inaccessible (for example ratings for commercial refrigeration equipment and desktop equipment), or for items of equipment where the stated power rating usually differs significantly from the in-use consumption (for example desktop computers). In certain cases, estimates were required for rare or unbranded equipment items, or where energy consumption information for a product is not published (this was common with, for example, gym equipment).

Detailed information under each end use was captured in a manner which allowed close or direct comparison with the energy model tree diagram calculation structure. In practice, to fully describe a building might involve hundreds of data items, so data collection was focussed on specific areas of priority selected by energy end use. As a result, a pragmatic approach was taken, for example where sub-metered data allowed energy consumption for a particular end use to be accurately determined, other elements of data collection for that end use might be simplified in order to free up time to carry out a full bottom-up calculation of a more complex and significant end use.

The data collected in this exercise allowed the surveyor to calculate the end use consumption for the majority of significant end uses within the building (typically where an end use comprised >5-10% of total energy consumption by fuel, this would be deemed significant). In more complex buildings where there were many different end uses present, the use of estimates or benchmarks, or the assignment of a proportion of the building's energy use as "unreconciled", was sometimes required. Where this was the case, the surveyor would record their observations explaining the end uses which made up the unassigned energy use; where benchmarks were used the surveyor provided notes as to the benchmarks used, the justification for the values selected and any relevant contextual observations to aid in subsequent analysis of the data.

Approaches to source data for different equipment types

For each equipment type there could be an array of data sets to collect. A simple prioritisation system was used to focus the surveyor's efforts on the most energy significant items, as indicated in Table 4.3; thus, common, high energy intensity items were treated as highest priority, and uncommon low energy intensity items were assigned the lowest priority. This ensured that time was spent on the most significant end uses.

Table 4.3: Prioritisation system for energy intensive equipment during site surveys

		Energy intensity	
		Low	High
Quantity	Few	3	2
	Many	2	1

Any automated controls would also be investigated in order to determine the hours of use/utilisation factor for different equipment items, and identify the potential for abatement of energy use. This was particularly significant for building services systems such as heating, ventilation and air conditioning, where controls are often sophisticated and significant opportunities for energy reduction may exist; a significant amount of time was spent examining Building Management Systems (BMS) and automated lighting controls where these were present.

Validation

Limited pre-existing data on equipment type and quantity was collected in the telephone survey; primarily in the sub-sector specific questions. Where this was the case, the surveyor would validate the responses given.

4.2.4 Fabric information

The surveyor examined main fabric components of the building, and recorded comments on the type and condition of fabric elements. Where an abatement opportunity was identified, the surveyor would also identify:

- The area of the building fabric element suitable for the abatement measure;
- The U-value of the current building fabric element (usually estimated based on fabric type from typical values).

The energy use modelling did not directly incorporate fabric details, as there was no building envelope model included. However, the abatement potential identified in the site audits was used to validate the calculations used in the abatement model

Validation

In certain cases, sub-sector specific questions asked about the presence of insulation and building fabric types. Where this was the case, the site surveyor validated the responses given.

4.2.5 Identify abatement measures that have been implemented/are suitable

During the walk-through and the energy end use calculation process, the surveyor identified a list of energy saving opportunities suitable for the site, as well as discussing any measures which had already been implemented with the site contact.

In addition to this, the software used to process the site audit data featured an automated checklist system, which identified possible abatement measures for the building, derived from the features, systems and equipment entered into the software by the surveyor. The surveyor reviewed this checklist, removing all measures that they did not consider suitable for the building. For example, entering a heating boiler system in the software would add relevant measures such as boiler upgrades, heating controls upgrades, draught-proofing, re-commissioning etc. to the abatement measures checklist. This ensured that all surveyors considered a consistent master list of measures, and did not miss out any items as a result of oversight or having a differing knowledge base to another surveyor.

Abatement measures were not used in the energy use modelling process, but the findings from the site survey process fed into the abatement modelling calculations.

Table 4.4 below lists the categories of abatement measures which were incorporated in the checklists, and the measures included in each category.

Table 4.4: Abatement measures

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[18]	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 Display lighting controls

[18] T5, T8, T12 are all tubular fluorescent lights. The number is the diameter of the tube in eighths of an inch.

Small appliances	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

Validation

Data on equipment, controls and hours of use was collected in the telephone survey, both in the core survey and the sub-sector specific questions. Where this was the case the data was validated on-site by the surveyor.

4.2.6 Quantification of abatement measures

Having identified the list of appropriate abatement measures, the site surveyor then calculated the expected abatement potential for that measure when applied to the specific building. These calculations were carried out in the software tool, but could be supported by the surveyor’s own calculations in order to account for the unique circumstances encountered on an individual site.

The software was pre-populated with default variables describing the typical effectiveness of the abatement measures listed within the tool, either as a percentage of an end use consumption, or based on the power rating of an equivalent replacement (for example, when calculating the impact of replacing fluorescent tube lights with LED fittings, the software would identify an equivalent LED light fitting and calculate the energy saved on a per fitting basis). The surveyor reviewed each relevant abatement calculation, and made adjustments based on the detailed insight from the site visit.

Where the surveyor chose to make amendments to default savings estimates, more detailed calculations were used for higher priority and more significant abatement measures, whereas measures with low savings potential were more likely to use the default assumptions, or a simple approach to calculate savings. During the study, the surveyor team also developed a number of supporting tools to assist in calculating end use energy consumption (for example, cooling of beer cellars) which could also be used to assess abatement potential in these more specialised cases. Finally, in isolated cases, good practice energy benchmarks were used where a direct calculation based on installed equipment could not be carried out.

The resulting set of abatement calculations provided a comparison dataset for the wider abatement modelling task, and the insights gained by site surveyors into the applicability and constraints affecting certain measures in certain sub-sectors or sectors were used to inform the abatement calculations in the abatement model.

The abatement calculations for each site were included in the master database for future reference.

Estimation of the cost of abatement opportunities was typically based on supplier quotes for similar opportunities and prorated based on scale/size/quantity of equipment using the software tool. Other costing inputs used to populate the software tool included industry standards such as SPON’s M&E price guides, or Verco’s experience and rules of thumb. Where a surveyor chose to overwrite the cost data used in the calculations, this was usually in response to a quote the site contact had received, or based on the specific knowledge of the surveyor.

Validation

The scale of savings identified for a given measure were validated against corresponding data from portfolio analysis or similar studies carried out by Verco.

No data was collected relating directly to abatement potential during the telephone survey, so no verification of telephone survey responses was required in this regard.

4.2.7 Collection of energy data

In order to verify the accuracy of the energy data for a site survey record obtained from the matched energy data, the surveyors collected onsite bill data for the annual energy consumption of the premises. Where available, and the time allowance permitted, sub-metered data would also be collected, where this provided a useful insight into the end-use energy breakdown of the building.

A data quality hierarchy was used for data sources, prioritising high resolution (half hourly, monthly) data based on actual meter readings from energy supplier sources or building BMS systems, through to worst case situations where documentation was very poor and estimation from partial data or estimated readings might be required. In a small proportion of cases, it was not possible to collect energy data at all (for example buildings on military or university sites which were not sub-metered).

The whole building or premises data was used for the following purposes:

- For validation of other energy datasets (ND-NEED, DEC, energy data provided by respondents to the survey);
- For use in calibration processes for the energy use model;
- Where half hourly or other high resolution data was available, for investigation into building energy baseloads outside occupied hours.

Sub-metered energy data was used for:

- Obtaining detailed insight into individual energy end uses;
- Investigation of base load of individual or multiple energy end uses;
- For validation of effectiveness of BMS systems or other controls systems (by confirming hours run for building systems).

Availability of sub-metered data was relatively rare, and was generally only present in large, complex, or recently constructed buildings.

Validation

Pre-existing data from matched datasets was verified on site by the surveyor using one of the above methods.

4.3 Barriers interview questionnaire

4.3.1 Interview purpose

The purpose of the semi-structured barriers interview was to identify factors affecting the recipient organisation’s ability to implement energy efficiency measures at the premises. The target respondent was the individual accompanying the site surveyor, although in cases where a single organisation consented to multiple site surveys, a single, central contact may have been selected to conduct the interview.

The interview was broken into three parts. The first focussed on opportunities for implementation. The second covered a wider discussion of opportunities and barriers but not referencing any particular measures. The final part considered what factor or factors would make the most significant difference in enabling further emission reductions.

When investigating barriers, the method aimed to identify a root cause behind the issue identified using the “5 why’s” technique – the logic being that it may take several levels of thinking to identify the true root cause of an issue.

The site surveyors were trained in appropriate interview technique, but were not qualified social researchers. This was a necessary compromise, as the cost of sending two individuals to site rather than one would have been prohibitive. The training addressed good practice approaches including introducing the interview, recording of interviews, note taking and verbatim responses, avoiding leading questions, engaging the respondent, consistent delivery of questions, use of lay terms and maintaining focus. It should however be noted that the non-specialist nature of the interviewers did introduce a risk of reduced data quality in this area of the study.

It was also noted that the type of respondent had a significant impact on their ability to respond fully to the interview process; in small premises e.g. an independent café, the respondent might be the proprietor, who had no formal or informal experience of energy management and did not actively pursue energy management or reduction in any form. These respondents tended to find the interviews difficult to respond to as they had little pre-existing knowledge or experience to draw on when responding. In comparison, respondents in large organisations with direct energy responsibilities e.g. energy or facilities managers tended to find the interview easier to understand and respond to in detail.

In the following text, the structure of the interview and the approach is summarised.

4.3.2 Interview 1: Abatement measure case studies (20 minutes)

The interviewer identified three abatement measures. These were identified following the site audit and hence had direct relevance to the respondent.

Each abatement measure fitted in one of three categories; behavioural change, controls optimisation or capital investment. This range enabled the interviewer to determine the different factors affecting each abatement measure type, while covering the full range of typical opportunities.

The interviewer began with open questions on what barriers to implementation applied to each abatement measure. The interviewer then used the framework set out in

Table 4.5[19] to capture issues the respondent might not immediately consider, to ensure coverage of a broad range of possible barriers.

Table 4.5: Example interview framework

Abatement measures	Financial	Behavioural	Technical	External
Behavioural Change				
Controls optimisation				
Capital investment				

Following the completion of this exercise, the respondent was asked to rank each of the barriers in terms of high, moderate and low impact.

The framework used was suitable for both owned and rented properties, and could capture the issue of split incentives between landlord and tenant where this arose. Where necessary, interviewers would use prompt questions, examples of which are set out below.

Initial question: Why have you not implemented <the ABATEMENT MEASURE NAME> in this premises?

Table 4.6: Interview prompt question examples

Question	Purpose
You mentioned <BARRIER NAME> as an issue for not implementing ….<ABATEMENT MEASURE NAME>, what are the key reasons for this being an issue?	Identify the root cause associated with barrier
What other reasons have made <BARRIER NAME> stop you implementing ….<ABATEMENT MEASURE	Identify the root cause associated with barrier

[19] Barriers were classified as follows:
- Financial – Barriers relating to accessing capital to make the investment
- Behavioural – Barriers relating to people and their behaviour
- Technical – Barriers relating to technical issues associated with implementation
- External – Barriers relating to external factors affecting the investment

NAME>

How large an impact does <BARRIER NAME> have on your ability to implement the measure?	Identify the barriers relative significance – Closed responses of High, Medium, Low
When it comes to the people who use ….. <NAME OF SPACE>, how do they impact on your ability to implement…<ABATEMENT MEASURE NAME>?	Identify behavioural barriers
Probe: How else do they impact on your ability to implement .. <ABATEMENT MEASURE NAME>?	Identify behavioural barriers
Are there any financial issues that affect your ability to implement this measure?	Identify financial barriers
What are those financial issues? Are there any other financial aspects which impact on your ability to implement …. <ABATEMENT MEASURE NAME>?	Identify financial barriers
What about the external environment , such as energy prices, suppliers, customers etc., has this impacted on your ability to implement measures?	Identify external barriers
What other barriers, if any, have affected your ability to implement…. <ABATEMENT MEASURE NAME>?	Identify any other barriers

4.3.3 Interview 2: Organisational attributes (15 minutes)

This section of the interview was an organisational capabilities assessment of the respondent organisation (not the respondent). The basis of the interview was the typical carbon management framework, a common framework used by many in the energy management sector to evaluate the maturity of an organisation's energy management system. This approach is often presented as a graphic identifying the maturity of the organisation's systems across a range of key management areas.

The 15 questions asked to inform the production of the graphic were as follows:

1. Which of the following best describes your organisations commitment to reducing energy usage?

- ☐ Target set for whole organisation for carbon and energy consumption reduction
- ☐ Target set for whole organisation for energy consumption reduction
- ☐ Vision for energy reduction clearly stated and published
- ☐ Draft energy policy or vision present but not clearly stated
- ☐ No policy

2. Which of the following best describes how energy reduction is managed in your organisation?

- ☐ Executive team review progress against targets on quarterly basis and progress against target published externally
- ☐ Sponsor reviews progress and removes blockages through regular Programme Boards and progress against targets routinely reported to Senior Management Team
- ☐ Core team regularly review EM progress:
- ☐ Ad hoc reviews of EM actions progress
- ☐ No EM monitoring

3. Which of the following best describes your organisation's allocation of responsibility for energy management in terms of the core team?

- ☐ Key individuals have accountability for energy reduction
- ☐ Energy reduction a part-time responsibility of a few department champions
- ☐ No recognised Energy reduction responsibility

4. Which of the following best describes your organisation's allocation of responsibility for energy management in terms of the executive team?

- [ ] Energy management integrated in to responsibilities of department heads
- [ ] Senior Sponsor actively engaged
- [ ] No recognised energy reduction responsibility

5. Which of the following best describes your organisation's allocation of responsibility for energy management in terms of the wider staff and other occupiers?

- [ ] Staff and other occupiers engaged though Green Champion network
- [ ] Staff engaged though Green Champion network
- [ ] No recognised CO2 reduction responsibility

6. Which of the following best describes how your organisation manages energy data

- [ ] Energy data compiled on a regular basis. This is collated through automatic metering feeds on fiscal meters. Where relevant sub-metering has been installed
- [ ] Energy data compiled on a regular basis. This is collated through automatic metering feeds on fiscal meters.
- [ ] Energy data compiled on a regular basis, but majority is based on bill data only.
- [ ] No energy data compiled and high reliance on estimated billing

7. Which of the following best describes your organisation's energy management systems

- [ ] Data is stored in energy management system
- [ ] Data is stored in various MS excel files or other similar none energy focused systems/tools
- [ ] No systemic means of capturing data

8. Which of the following best describes how your organisation validates energy data

- [ ] Data is verified against a bill validation process
- [ ] Data is verified against a bill with accounts team
- [ ] No data verification

9. Which statement best describes your organisation's approach to energy management training towards you?

- [ ] Environmental / energy group(s) given comprehensive operational training
- [ ] Environmental / energy group(s) given comprehensive technical training
- [ ] Environmental / energy group(s) given ad hoc training
- [ ] Environmental / energy group(s) provided basic energy management information on ad-hoc basis
- [ ] No training

10. Which statement best describes your organisation's approach to energy management training in terms of the wider staff and other occupiers?

- [ ] All staff given formalised energy management training:
- [ ] Staff given energy management information on ad-hoc basis
- [ ] No communication or training

11. Do you test staff awareness on energy management through a survey

- [ ] Yes
- [ ] No

12. Which statement best describes your organisation's approach to financing energy efficiency in terms of ring fenced funds?

- [ ] 2 year or more plan agreed with financial budget for carbon reduced initiatives, with a ring fenced finance programme
- [ ] 2 year or more plan agreed with financial budget for carbon reduced initiatives
- [ ] 1 year plan agreed with financial budget for carbon reduced initiatives
- [ ] Some financial budget allocated to energy reduction, but no clear plan
- [ ] There is a clear plan in place but no budget assigned
- [ ] All finance allocated to energy reduction is done so on an ad hoc basis

13. What is the investment metric you use for energy saving projects? And what is the value you need to achieve?

Method used	
Value used	
Comment	

14. Which statement best describes your organisation's approach to financing energy efficiency in terms of use of external funds?

- [ ] External funding being routinely obtained
- [ ] Ad-hoc external financing
- [ ] No specific funding for CO_2 reduction projects

15. Is there any financial representation from the organisation on the energy management team?

- [ ] Yes
- [ ] No

Figure 4.1: Maturity level by competency

	Competency					
Level	Corporate strategy	Programme management	Responsibility	Data management	Comms & Training	Finance & investment
5	Long term target set for whole organisation for carbon and energy consumption reduction.	Executive team review progress against targets on quarterly basis and progress against target published externally.	Key managers have accountability for energy reduction, energy management integrated into responsibilities of senior management and staff and other third parties engaged though green champion network.	Energy data compiled on a regular basis. This is collated through automatic metering feeds on fiscal meters. Where relevant sub-metering has been installed. Data is also verified against a bill validation process and data is stored in energy management system.	Central operational team given comprehensive operational training. All wider staff given formalised energy management training and staff awareness tested through surveys.	2 year or more plan agreed with financial budget for energy reduction initiatives, with a ring fenced finance programme. External funding being routinely obtained and a finance representative is on the energy management team.
4	Short term target set for whole organisation for energy consumption reduction.	Sponsor reviews progress and removes blockages through regular programme boards and progress against targets routinely reported to senior management team.	Key managers have accountability for energy reduction, energy management integrated into responsibilities of senior management and staff engaged though green champion network.	Energy data compiled on a regular basis. This is collated through automatic metering feeds on fiscal meters. Data is also verified against a bill validation process and data is stored in various MS excel files or other similar none energy focused systems/tools.	Central operational team given comprehensive technical training and all wider staff given formalised energy management training.	2 year or more plan agreed with financial budget for energy reduction initiatives. Ad-hoc external financing sought. There is no finance representative on the energy management team.
3	Vision for energy reduction clearly stated and published.	Core team regularly review energy management progress.	Key managers have accountability for energy reduction and senior sponsor actively engaged but has no formalised targets.	Energy data compiled on a regular basis, but majority is based on bill data only. Data is also verified against a bill with accounts team and data is stored in various MS excel files or other similar none energy focused systems/tools.	Central operational team given ad hoc training and wider staff given formalised energy management training.	1 year plan agreed with financial budget for energy reduction initiatives. Ad-hoc external financing sought. There is no finance representative on the energy management team.
2	Draft energy policy.	Ad hoc reviews of energy management actions progress.	Energy reduction a part-time responsibility of a central operational team member.	Energy data compiled on a regular basis, but majority is based on bill data only. Data is verified against a bill with accounts team but there is no systematic means of capturing data.	Central operational team given energy management information on ad-hoc basis and wider staff given energy management information on ad-hoc basis.	Some financial budget allocated to energy reduction, but no clear plan. Ad-hoc external financing sought. There is no finance representative on the energy management team.
1	No policy .	No oversight and monitoring.	No recognised energy reduction responsibility within central operational team.	No energy data compiled and high reliance on estimated billing, No systematic means of capturing data and there is no data verification.	No training to central operational team and no communication or training to wider staff.	All finance allocated to energy reduction is done so on an ad hoc basis. Ad-hoc external financing sought. There is no finance representative on the energy management team.

4.3.4 Interview 3: Enabling factors (25 minutes)

The final interview identified three key factors or actions that could enable easier implementation of energy efficiency measures. They were asked to identify three factors, and each of these was examined in detail to identify why it would have a significant impact on the respondent's ability to implement measures, using the "5 whys" principle. The measure and the five responses to asking "why" were recorded in each case.

For each factor, the respondent was asked the likelihood of such an event occurring. The respondent was given the following options; highly likely, likely, unlikely and highly unlikely. For each response reasons were requested.

Example prompt questions the interviewer could use in this section are show in Table 4.7.

Initial question: What do you think are the most significant actions that would make the biggest impact on your ability to improve energy efficiency in this building?

Table 4.7: Example prompt questions on enablers from site survey interview

Question	Purpose
Probe fully to get all the actions: What other actions could the organisation take? What else?	Identify extent of enablers
PROBE IF MORE DETAIL NEEDED ON ACTIONS: What would that action involve?	Identify the root cause associated with enabler
In what way would that action help the organisation improve energy efficiency? How else?	Identify the root cause associated with enabler
Are there any common themes between the areas you have identified?	Where respondent has many suggestions, this could help identify root reason
Of all the areas you have listed which is the most important?	Identifies the most important intervention

4.3.5 Feedback and any other points

To close the interview process the respondent was asked for feedback on the approach using a set of close questions:

1. *Did you understand all the questions?*
   - *All the questions were clear*
   - *The majority of the questions were clear*
   - *The majority of the questions were unclear*
   - *All the questions were unclear*

2. *Were the questions easy to answer accurately?*
   - *All the questions were easy to answer*
   - *The majority of the questions were easy to answer*
   - *The majority of the questions were not easy to answer*
   - *All the questions were not easy to answer*

3. *We are nearly at the end of the interview now, but do you have anything else relating to energy reduction in your building or organisation that you would like to mention?*

5 Telephone Survey Fieldwork

5.1 Recruitment approach

Table 5.1 below sets out the number of telephone surveys and Telephone Survey Equivalent Records (TSER's) achieved in each of the BEES analysis sub-sectors. TSER's were records where the telephone survey data was collected via another method rather than the standard telephone surveys. This was generally undertaken when respondent organisations were dealt with directly in order to boost or obtain participation where the standard approach alone was not sufficient. For TSER's, data collection methods included paper based surveys, internet based surveys, data extracted directly from a respondent organisation's data by the BEES team or telephone survey data completed by a site surveyor while they carried out a site survey.

Table 5.1: Number of telephone surveys (or equivalent records) achieved by sub-sector[20]

Sub-sector	Sector	Standard telephone surveys	Non-standard telephone surveys	Comments on non-standard survey approach
Nursery	Education	50	-	
HE - teaching & research	Education	36	1	The non-standard record was completed by a site surveyor during a site survey which was recruited directly (no telephone survey)
Primary schools	Education	54	-	
Secondary schools	Education	54	-	
HE – residential	Education	4	21	Recruited through direct contact with university contacts
Police stations	Emergency services	-	24	Recruited through direct contact with constabularies
Fire stations	Emergency services	25	-	
Ambulance stations	Emergency services	-	36	Recruited through direct contact with ambulance trusts
Law courts	Emergency services	51	-	
Prisons	Emergency services	20	-	
Health centres	Health	62	-	
NHS hospitals	Health	50	-	
Private hospitals	Health	22	-	

[20] A total of 4,158 surveys were achieved however only 3,690 were able to be used in the BEES modelling.

Sub-sector	Sector	Standard telephone surveys	Non-standard telephone surveys	Comments on non-standard survey approach
Military storage	Military	-	19	Direct contact with Military regional energy managers
Military offices	Military	-	29	Direct contact with Military regional energy managers
Military residential	Military	-	30	Direct contact with Military regional energy managers
Cafés	Hospitality	49	5	Low site survey uptake; additional sites were required and non-standard telephone surveys were completed by site surveyors
Hotels	Hospitality	51	-	
Pubs	Hospitality	109	-	
Restaurants	Hospitality	64	8	Direct contact with hospitality organisations
Takeaways	Hospitality	30	2	Direct contact with hospitality organisations
Offices[21]	Offices	775	-	
Betting Office	Retail	-	27	Direct contact with retailers
Department Store	Retail	-	19	Mystery shopper data collection
Hairdressers/beauty salons	Retail	50	10	Non-standard telephone surveys created based on site survey reports from BEES collaborator
Large food shop	Retail	3	29	Direct contact with retail organisations and mystery shopper data
Large non-food shop	Retail	20	39	Direct contact with retail organisations
Retail Warehouse	Retail	24	26	Direct contact with retail organisations
Showroom	Retail	49	-	
Small food shop	Retail	177	-	

[21] Subsequent to completing the data collection, Offices were split into public & private sector in sector-level reporting.

Sub-sector	Sector	Standard telephone surveys	Non-standard telephone surveys	Comments on non-standard survey approach
Small non-food shop	Retail	553	2	Direct contact with retail organisations
Supermarkets	Retail	5	26	Direct contact with retail organisations and mystery shopper data
Vehicle showroom	Retail	47	-	
Club	CAL[22]	50	-	
Community centre	CAL	50	-	
Leisure centres (with swimming)	CAL	50	-	
Leisure centres (without swimming)	CAL	37	-	
Museums	CAL	47	-	
Nursing Homes	CAL	58	1	Non-standard telephone survey completed by site surveyor (site survey recruited directly)
Places of Worship	CAL	101	-	
Theatres	CAL	50	-	
Factories	Industrial	92	5	Non-standard telephone survey completed by site surveyor (site survey recruited directly)
Large Industrial	Industrial	13	1	TBC
Workshops	Industrial	383	-	
Cold Stores	Storage	21	-	
Large Distribution Warehouse	Storage	46	4	Non-standard telephone surveycompleted by site surveyor (site survey recruited directly)
Stores	Storage	118	1	Low site survey uptake; additional sites were required and non-standard telephone surveys

[22] Community, arts & leisure

Sub-sector	Sector	Standard telephone surveys	Non-standard telephone surveys	Comments on non-standard survey approach
				were completed by site surveyors
Warehouses	Storage	242	1	TSER completed by site surveyor (site survey recruited directly)
Totals		**3,792**	**366**	

Note: Some of the sub-sectors presented above have been merged in the final reporting

Details of recruitment approaches used for site surveys are found in Section 0 of this document.

5.2 Survey approach and dates

Over time the methodological approach to BEES telephone surveys evolved. Flexibility in data collection techniques ensured the most suitable methodology was employed for each sub-sector, which enabled the project team to best address the unique challenges that each sub-sector presented.

The initial approach proposed for the study was as follows:

- An initial telephone survey to collect high level information about the building/premises. Interviewers were instructed to ask respondents to provide more detailed information about energy usage in a second, follow up survey – to be conducted via telephone or online;
- If the telephone option was selected, an email and/or letter was sent out to the respondent detailing the information required. The telephone survey was then conducted;
- If the online option was selected, an email was sent to the respondent containing the survey link. The online survey could be accessed multiple times, with ‘pause’ options, giving the respondent time to provide all the information required.

Fieldwork was organised around three main clusters of fieldwork. Piloting of the fieldwork approach was undertaken in cluster 1 which included education, health, emergency services and military. Following this pilot, it was decided to redesign the method based on a single stage telephone survey approach. This removed the telephone/internet based follow-up survey in favour of collecting more information during the single telephone interview.

The decision was necessary because responses to the internet follow-up stage in the cluster 1 pilot were very low (8%), despite nearly 60% agreeing to undertake the survey. A number of efforts to help boost response, including survey reminder activity, flexibility in survey completion and a prize draw were implemented during the pilot, with little impact. Individuals in the sample were generally time-poor business people, and based on feedback from the few that did complete the follow-up stage, the survey length was also too long. The self-completion approach for the follow-up survey was also a concern in terms of data quality, given the complex nature of the study and the specific technical information required.

Therefore following a full review, a revised approach to data collection was implemented. This comprised the following stages:

A single-stage survey, conducted via telephone, capturing the critical information relevant to all sub-sectors. GfK offered flexibility in the data collection process by introducing a mixed mode methodology using Dimensions software, which allowed an online option to complete the survey if the standard telephone approach was unsuitable for any reason.

This survey included a ‘standard’ set of questions and additionally a set of unique sub-sector specific questions tailored for each sub-sector to allow variation in responses for specific characteristics of the premises.

At the end of the survey, respondents were asked if they would be willing to be included in a further element of the research which involved a site visit to the respondent’s premises.

The target respondent - as prompted for in the telephone survey script- was the person who would have the most knowledge about the types of energy usage in the premises; with examples of job roles being Facilities Manager, Energy Manager, Energy or Sustainability Executive, Maintenance or Building Manager, Operations Manager, Operational Director, Managing Director or Owner. There was considerable variation in job roles amongst respondents to the survey although as a general rule larger organisations were more likely to have dedicated staff in roles directly related to energy or facilities management, whilst in smaller organisations general managers, directors or administrative staff were more likely to have been interviewed as the most suitable respondent.

Given the nature of the study was to interview business respondents, the first point of contact with respondents was generally to set up an appointment to conduct the interview, as respondents were not always available to speak at the time of initial contact. Every effort was made to ensure flexibility for the respondent, such as calls being made outside of normal working hours if necessary and appointment setting was managed via GfK’s Sample Management System.

During fieldwork, each sector presented its own unique challenges, particularly in terms of methodology and sample sourcing. In the majority of cases a standard approach was adopted, i.e. sample was sourced from the ND-NEED database and a Computer-assisted telephone interviewing (CATI) and/or Online methodology was employed. Where this was not the case, a non-standard approach was employed, where efforts were made to tailor requirements to the specific needs of the sub-sector. An overview of each sector and corresponding sub-sectors are shown in Table 5.2. In these tables, the information has been presented based on the BEES fieldwork sub-sectors (i.e. before mergers, splits and sector transfers made for reporting purposes).

Table 5.2: Summary of fieldwork issues

Sector	Sub-sector	Survey Methodology	Number of telephone surveys achieved[23]	Fieldwork Dates	Average interview length (mins)	Issues encountered
Education	State Primary	CATI	54	June-July 2014	22	
	State Secondary	CATI	53	June-July 2014	25	
	University non-residential	CATI/Online/Site Survey	37	June-August 2014	24	Despite the number of buildings being relatively large, difficulties were encountered due to the limited number of universities and target contacts. In some cases, Universities that agreed to take part undertook more than one interview
	University residential	CATI/Site Survey	26	June-July 2014	19	As above. Also, the definition of this sub-sector led to a number of screen outs
	Nursery	CATI	50	June-July 2014	17	
Emergency Services	Police Stations	Online	24	August-September 2014	n/a	Non-standard sub-sector Agreement needed from police force in first instance and email sent with online links. Some firewall issues encountered and some of the stations selected from DEC

[23] Note: This data does not include TSER's

Sector	Sub-sector	Survey Methodology	Number of telephone surveys achieved[23]	Fieldwork Dates	Average interview length (mins)	Issues encountered
						records were no longer in existence
	Prisons	CATI	20	June-August 2014	23	
	Fire/Ambulance station	Fire Station: CATI Ambulance: Paper	61 25 Fire Stations 36 Ambulance Stations	June-August 2014	20	Non-standard sub-sector No direct contacts available and therefore engagement was needed at a higher level. Contacts completed interview on paper.
	Law courts	CATI	51	June-July 2014	22	
Health	Health centres	CATI	62	June-July 2014	19	
	Hospitals NHS	CATI	50	June-August 2014	25	
	Private Hospital	CATI	22	July-August 2014	28	Due to a lack of floor area information for this sub-sector, additional questions were added to the survey. Limited sample, further complicated by small number of private hospital groups
Military	Military Offices	Online	29	July-September 2014	N/A	Non-standard sub-sector Military engagement needed at a high level and surveys completed online
	Military Residential	Online	30	July-September 2014	N/A	Non-standard sub-sector Military engagement needed

Sector	Sub-sector	Survey Methodology	Number of telephone surveys achieved[23]	Fieldwork Dates	Average interview length (mins)	Issues encountered
						at a high level and surveys completed online
	Military Storage	Online	19	July-September 2014	N/A	Non-standard sub-sector Military engagement needed at a high level and surveys completed online
Offices	Central Government / Local Government / Other Offices	CATI/Online	775 (766/9)	October 2014 – March 2015	21	Non-standard sub-sector Central Government Offices given the option of a telephone or online interview
Retail	Betting office	Site Survey	27		N/A	Non-standard sub-sector Limited number of independent betting offices. Calls going through to central call centre meant standard approach was not feasible
	Hairdressing/ beauty salon	CATI	60	July-August 2015	20	
	Department stores	Mystery shopping	19	July 2015	N/A	Non-standard sub-sector Very few independent stores. Many of the big chain stores refused to take part. All data collected through observation
	Hypermarkets	Site Survey/Mystery shopping	16 (5/11)			Non-standard sub-sector Very few independent stores. Many of the big chain stores refused to take part. Mix of

Sector	Sub-sector	Survey Methodology	Number of telephone surveys achieved[23]	Fieldwork Dates	Average interview length (mins)	Issues encountered
						data collected through site survey and observation
	Large food shop (> 750 m2)	CATI /Mystery Shopping	32 (3/29)	January 2015/July 2015	25	Non-standard sub-sector Very few independent stores. Many of the big chain stores refused to take part. Mix of data collected through CATI and observation.
	Large non-food shop (> 750 m2)	CATI/Online/Mystery Shopping	58 (20/5/33)	January-February 2015/July 2015	25	Non-standard sub-sector Very few independent stores. Many of the big chain stores refused to take part. Mix of data collected through CATI, online observation.
	Retail warehouse	CATI/Site Survey/Mystery Shopping	50 (24/15/11)	January-February 2015/July 2015	23	Non-standard sub-sector Very few independent stores. Many of the big chain stores refused to take part. Mix of data collected through CATI, site surveys and observation.
	Showroom (not vehicles), auction rooms	CATI	49	November 2014-January 2015	21	
	Small non-food shop	CATI	553	November 2014-February 2015	21	Some issues due to interviewing around near busy Christmas period – smallest shops more difficult to pin down for an interview

Sector	Sub-sector	Survey Methodology	Number of telephone surveys achieved[23]	Fieldwork Dates	Average interview length (mins)	Issues encountered
	Small food shop	CATI	177	November 2014-February 2015	24	Some issues due to interviewing around near busy Christmas period – smallest shops more difficult to pin down for an interview
Hospitality	Café	CATI	54	October 2014-January 2015	24	Flexibility needed in appointment times to reflect working patterns of premises
	Hotel, motel, coaching inn	CATI	51	October-December 2014	24	
	Public House/Wine bar	CATI	109	October 2014-January 2015	23	Flexibility needed in appointment times to reflect working patterns of premises
	Restaurant	CATI	72	October-December 2014	24	Flexibility needed in appointment times to reflect working patterns of premises
	Takeaway food outlet/ restaurant	CATI	32	October 2014-Feburary 2015	25	Generally limited sample as most fast food restaurants classified as ‘restaurants’. Difficulties were encountered in finding someone available to be interviewed due to the busy nature of the premises
Community, Arts & Leisure	Museums, art gallery, arts centre, libraries	CATI	47	May-July 2015	28	

Sector	Sub-sector	Survey Methodology	Number of telephone surveys achieved[23]	Fieldwork Dates	Average interview length (mins)	Issues encountered
	Place of worship	CATI	100	April-June 2015	28	No coverage in Experian matched within ND-NEED used to select sample, but no floor areas, so relevant questions added to the survey for this sub-sector. Finding right person difficult as many respondents were volunteers
	Cinema, Theatre, concert hall	CATI	50	May-July 2015	31	Limited availability of sample for cinemas and many ‘chain’ organisations
	Club, institution (not sports club)	CATI	50	April-July 2015	23	Smaller premises were often not staffed so no response was received when calling
	Leisure centre with swimming	CATI	50	May-June 2015	27	Some sample records were found to be in schools, universities
	Leisure without swimming	CATI	37	May-July 2015	26	Many premises categorised as without a swimming pool were found to have swimming pools when contacted
	Community centre/ day centre	CATI	50	April-May 2015	24	Finding right person to interview was difficult as many were volunteers

Sector	Sub-sector	Survey Methodology	Number of telephone surveys achieved[23]	Fieldwork Dates	Average interview length (mins)	Issues encountered
	Nursing home	CATI	50	April-May 2015	26	Limited sample availability. Experian used as sample, but no floor areas, so relevant questions added to the survey for this sub-sector
Storage	Cold store	CATI	21	April-July 2015	23	Very limited sample and low match rate – many records also on same site e.g. Billingsgate Market
	Store, storage depot, storage land	CATI	118	May-July 2015	22	Very low telephone matching rate
	Warehouse	CATI	242	April-July 2015	23	
	Large distribution warehouse	CATI	46	May-July 2015	26	Limited sample availability
Industrial	Factory	CATI	92	April-June 2015	23	
	Large industrial (more than 20,000 m2)	CATI	13	May-July 2015	28	Limited sample availability. Many records in ND-NEED were listed as having a floor area of less than 20,000m2
	Workshop/ vehicle repair shop	CATI	383	April-July 2015	20	

5.3 Quality control

Quality control checks were carried out on a continuous basis through remote listening in to telephone surveys and on-screen verification - ten per cent of all interviews were monitored in this way. To ensure effective quality control, the ratio of supervisors to interviewers was set at a maximum of 1:10. For queries that arose during the course of fieldwork, either on the part of interviewers or respondents, there was an established procedure in place, with queries escalated to senior team members for resolution.

All interviewers and supervisors are fully trained to the guidelines in the ISO 20252:2006 market, opinion and social research standard. These guidelines mirror the market research industry's IQCS (Interviewer Quality Control Scheme) standards to which GfK also adhere, with all interviewers receiving two full days of training before starting work, and being subject to constant quality control thereafter.

Quality control - Interviewer briefings

Prior to fieldwork commencing, great importance was placed on making the interviewer briefing process as comprehensive and engaging as possible. Interviewers were briefed face to face by senior telephone survey experts supported by building technical experts to ensure that unfamiliar technical terms were correctly explained and understood by the survey team. For this study, each sub-sector was briefed at the outset, covering the following elements:

- Background to the project
- Methodological approach
- Respondent types/sample management
- Run through of survey questions
- Explanation of technical terms – glossary provided for interviewers
- Q&A with Verco
- Role play/dummy interviews

A discrete interviewing team was dedicated to this project throughout its life, to ensure appropriate experience was maintained on the project.

Quality control - Pilot study

Given the complex nature of the study, and the unique questionnaire tailoring required, it was important to pilot the questionnaires for each sub-sector. The main objective of the pilot studies was to ensure the surveys were fit for purpose for each sub-sector.

In addition to this, results from the pilot studies provided crucial information on:

- whether the terminology for identifying the correct person within the organisation was effective;
- respondent type;

- ensuring that the appropriate, understandable wording has been employed
- assessing survey length;
- assessing general engagement to the survey including ability to reach suitable respondents (allowing the GfK team to highlight any concerns).

Executives from the GfK project team listened in to the telephone interviews as they progressed, and close contact was kept with team leaders through this time to ensure issues or queries were resolved as quickly and efficiently as possible.

Quality control - Interviewer assessment questions

In addition to the quality checks set out above, reassurances around quality of response were sought from both the respondent and interviewer during the fieldwork period. This comprised a set of statements asked to both respondents and interviewers respectively, as shown below.

In terms of your responses given to questions where factual information is provided, how accurate do you think your responses have been?

- *Mainly accurate*
- *Mix of some accurate and some guesswork*
- *Mainly guesswork but should be about right*
- *Don't know*

Perceptions of accuracy between respondents and interviewers were broadly in line across all sub-sectors, with the vast majority perceiving responses to be ‘mainly accurate / high quality responses’.

Figure below summarises the data accuracy perceptions across all respondents. Table 5.3 presents the results by sector. Generally, there was good agreement between interviewer and respondent assessments of accuracy, with “Mainly accurate” the most common response in all sectors.

Figure 5.1: Data accuracy perceptions: all respondents

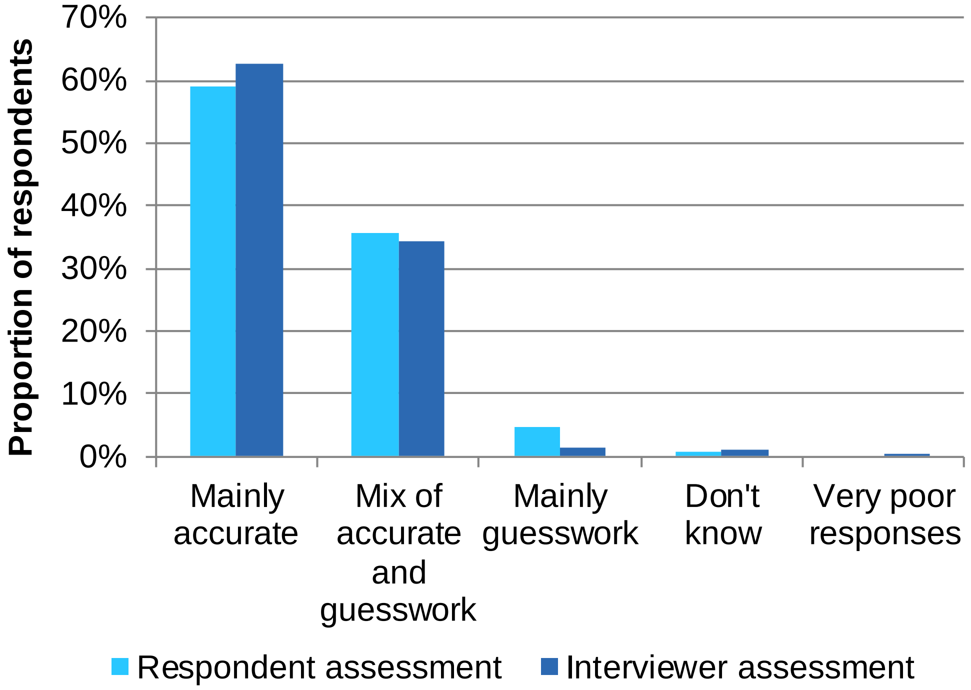


Table 5.3a: Data accuracy perceptions by sector - Respondent

Quality of answers	Education	Emergency services	Health	Military	Hospitality	Offices	Retail	Storage	Community, arts & leisure	Industrial	Overall
Mainly accurate	58	54	53	44	48	60	62	68	52	65	59
Mix of accurate and guesswork	37	41	46	53	42	35	33	28	43	30	36
Mainly guesswork	4	4	1	3	9	5	5	3	5	5	5
Don't know	1	1	0	1	0	1	1	1	0	0	1
Very poor responses	0	0	0	0	0	0	0	0	0	0	0

Table 5.4b: Data accuracy perceptions by sector – Interviewer

Quality of answers	Education	Emergency services	Health	Military	Hospitality	Offices	Retail	Storage	Community, arts & leisure	Industrial	Overall
Mainly accurate	67	42	69	N/A	52	66	64	67	53	68	63
Mix of accurate and guesswork	31	32	31	N/A	44	32	33	31	45	31	34
Mainly guesswork	2	2	0	N/A	4	1	2	1	1	1	1
Don't know	1	1	0	1	0	1	1	1	0	0	1
Very poor responses	0	25	0	N/A	0	1	1	0	0	0	1
	1	0	0	N/A	0	0	1	0	0	0	0

6 Response rates

6.1 Response rate summary

The telephone survey response rates are set out in Table 6.1 by sub-sector.

Table 6.1: Telephone survey response rates by sub-sector

		Telephone survey statistics					
BEES sector	**BEES sub-sector**	**Completed interview (%)**	**Still live[24] (%)**	**Out of quota/screening failure[25] (%)**	**Total refusals (%)**	**Other non-response (%)**	**Total invalid contact details (%)**
Education	Nurseries	16	63	0	8	3	10
	Primary schools	11	63	0	6	3	18
	Secondary schools	7	72	0	5	2	14
	HE - teaching & research	10	2	0	2	5	81
	HE - residential	2	0	1	1	2	93
Emergency Services	Fire/ambulance stations	17	42	0	3	14	23
	Police stations	N/A	N/A	N/A	N/A	N/A	N/A
	Law courts	9	30	0	5	5	50
	Prisons	16	13	0	5	4	62

[24] 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).

[25] 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.

Health	Nursing homes	10	68	1	10	4	8
	Health centres	11	50	0	10	3	27
	Hospitals	9	22	0	3	2	63
Offices	Offices (public)	16	14	11	35	0	24
	Offices (private)	23	5	9	42	0	20
Hospitality	Cafes	9	54	1	19	5	13
	Hotels	10	61	0	18	4	8
	Pubs	9	68	0	13	3	7
	Restaurants & takeaways	10	59	0	15	6	10
Retail	Large food shops	N/A	N/A	N/A	N/A	N/A	N/A
	Large non-food shops	N/A	N/A	N/A	N/A	N/A	N/A
	Retail warehouses	N/A	N/A	N/A	N/A	N/A	N/A
	Showrooms	10	48	7	22	0	13
	Small shops	16	46	5	24	0	10
	Hairdressers & beauty salons	17	26	7	40	0	9
Community, arts & leisure	Leisure centres	7	64	4	6	4	15
	Clubs & Community centres	10	70	0	3	7	9
	Museums	9	55	2	3	15	16
	Theatres	10	43	3	4	22	17
	Places of worship	8	55	1	7	6	23
Storage	Warehouse	10	27	24	26	0	13
	Store	10	44	20	17	0	9
	Large distribution warehouse	7	33	30	12	0	19
	Cold store	7	27	32	14	0	20
Industrial	Factories	9	61	1	13	7	9
	Workshops	9	71	2	10	3	6

Source: BEES telephone survey statistics

The definitions for each field are as follows:

- Completed interview
    - Interview completed successfully
- Live outcomes
    - Stopped interview - call to complete
        - Respondent asked for the interview to stop at some point during the call, but was willing to be called back to complete. Completed interview had not been secured before the end of fieldwork.
    - Arrange call-back
        - Contact had been identified within organisation and had agreed to an appointment, but this had not been successfully converted to a completed interview before the end of fieldwork
    - Arrange call-back with other
        - General response from organisation to call again and contact another person in the organisation
    - No Answer
        - Telephone was ringing, but no-one answered the phone on last contact
    - Engaged/Busy
        - Engaged tone on last contact
    - Send information (will be re-called)
        - Respondent requested further information about the study before being willing to commit to an appointment
    - Voicemail – respondent
        - Voicemail for identified respondent on last contact
    - Voicemail – general
        - General organisation voicemail on last contact
- Out of Quota
    - Sample in quota groups which can be identified from the sample is moved into this category once those quotas have been successfully filled
- Screening Failures
    - There was no eligible respondent within the organisation who could respond to the survey
    - No suitable building could be identified for the study
- Refusals
    - Refusal to participate
        - Respondent did not want to take part in the study
    - Refused company policy
        - Initial contact at organisation was unwilling to connect interviewer to anyone else due to company policy of not taking part in research
    - Quit (partial interview)
        - Respondent asked for the interview to stop at some point during the call, and was unwilling to be called back to complete.
- Other Non-response

  - Not available during fieldwork
    - No suitable respondent was available during the fieldwork period to be interviewed
  - Referred - no response
    - Interviewer was referred to another person and no contact was achieved through the referral
  - Tried maximum number of times - set to 12
    - Interviewer had tried to call the sample record at least 12 times, thereafter this is classified as unusable to avoid unnecessary annoyance
  - Language barrier
    - Interviewer was unable to secure an interview due to a language barrier with the respondent
- Invalid
  - Residential number
    - Telephone number was incorrect – residential, not business
  - Moved/Closed down
    - Organisation was no longer in existence
  - Wrong type of site
    - Identified site did not fall into the correct sub-sector and did not qualify for another sub-sector
  - Wrong number
    - Telephone number was not for the identified site
  - Wrong region
    - Identified site was not in England or Wales
  - Unobtainable number
    - Telephone number was not in service
  - Duplicate number
    - Telephone number for the site was already in the sample

6.2 Site survey recruitment methodology

The standard approach to site survey recruitment was designed based on initial piloting of the telephone survey approach. This piloting indicated that a significant proportion of respondents were interested in site surveys.

The aim of the standard method was to ensure that the site surveys recruited would give insight into the sub-sector from a range of premises sizes and energy intensities. It was not possible to create a representative sample of the stock in any sub-sector due to the relatively high cost and time requirements of the activity together with limitations on the sites agreeing to have a site survey but actions were taken to control bias where possible.

Due to the varying significance and complexity of sub-sectors within the non-domestic stock, the number of site surveys targeted in a given sub-sector was also varied, with additional surveys assigned to sub-sectors with the greatest significance (in terms of floor area and/or share of energy consumption) e.g. offices, factories, to maximise the quality of the findings where the impact was greatest.

The selection method split the telephone survey respondents within each sub-sector into nine cohorts using two criteria – small, medium and large buildings and low, medium and high energy intensity. The thresholds for these cohorts were determined on a sub-sector by sub-sector basis. Telephone survey respondents who had expressed an interest in receiving a site survey were contacted, with the aim of recruiting site survey participants across as wide a range of the nine cohorts as possible. Where the target number of site surveys within a sub-sector was less than nine, it was not possible to cover all the cohorts but a range of respondents would be sought. In sub-sectors with fewer respondents or a high degree of non-standard data collection methods used, obtaining a varied sample was more challenging.

In practice, take up of site surveys varied significantly between sectors, and a lower proportion of respondents who expressed an interest during the telephone survey actually took up the offer than had been anticipated. Site survey participants were offered a free energy report following the survey as an incentive to participate, as well as the opportunity to consult with the site surveyor during the visit. Despite this, the target number of site surveys was not achieved across the board following the standard approach, and a compromise was necessary between meeting the initial aims of achieving a wide range of respondents, and meeting the required sample size. The uptake for site surveys was significantly lower than for telephone surveys, likely due to the increased time and effort required from participants. Table 6.2 shows the number and percentage of rejecting a site survey, having shown willingness to take part at the telephone survey stage – often between 30 and 50 per cent of sites were no longer willing at this stage.

Table 6.2: Rejection rates for site survey candidates

Sub-sector	Completed site survey (%)	Still live (%)	Total refusals (%)
Cafe	26	30	43
Clubs & community centres	14	67	19
Cold Store	0	43	57
Factory	21	47	32
Fire/ambulance stations	17	61	22
Hairdressing/beauty salon	0	78	22
Health centre	14	79	7
Hospitals	18	71	11
Hotel	32	60	8
Large distribution warehouse	23	45	32
Large food shops	100	0	0
Large non-food shop	100	0	0
Law court	12	65	24
Leisure centres	25	59	16

Sub-sector	Completed site survey (%)	Still live (%)	Total refusals (%)
MOD	43	57	0
Museum	39	33	28
Nursery	13	47	40
Nursing home	8	46	46
Office	6	90	5
Place of worship	10	89	2
Police station	25	75	0
Primary school	17	67	17
Prison	33	67	0
Pub	33	52	15
Restaurants & takeaways	17	53	30
Retail warehouse	100	0	0
Secondary school	14	83	3
Showrooms	23	64	14
Small shops	12	83	5
Store	15	48	37
Theatre	8	84	8
University - non residential	21	79	0
University- residential	67	33	0
Warehouse	14	42	45
Workshop	4	55	40

A wide range of factors reduced uptake, including staff turnover, respondents who had had a similar survey done recently, scepticism about the value of the outputs or motives behind the survey, or concerns about the time investment needed from their own staff. Organisational issues included staff turnover preventing repeat contact with the original respondent, and cases where the original respondent did not have the authority to accept and co-ordinate the survey.

Three approaches were taken to boost uptake when the standard approach failed to meet the target number of surveys:

1. **Reduce the ambition in achieving a varied sample of site surveys:** In this case, respondents who indicated an interest would be contacted in the normal way, and the quota was met, but the spread of energy intensity and size did not meet initial hopes (e.g. no high energy intensity examples, or no large sites accepting a survey).

2. **Supplemented by direct contacts:** In this case, organisations which had offered to contribute telephone survey records directly for multiple records (a non-standard telephone survey data collection method) were asked to participate in site surveys, often contributing site survey candidates. In these cases, it was usually possible to ensure a good spread of size and energy intensity from within the respondent organisation’s portfolio, but this introduced a bias as the organisation would be over-represented in the site survey results.

3. **Supplemented from wider sample:** In this case, all telephone survey respondents who indicated an interest in were re-contacted, and the quota was not met. Direct contacts were not available in the sub-sector, so contact details for additional records were extracted from the sampling files used to identify potential telephone survey respondents. These potential respondents were contacted and offered a site survey directly, without a telephone survey. In these cases, it was generally not possible to ensure a good spread of energy intensity and size due to the large number of respondents who needed to be contacted to make up the sample.

Table 6.3: Non-standard site survey selection methods employed by sector

Sector	Target no. surveys	Surveys achieved	Contacted	Uptake (%)	Approaches taken			
					Standard	Standard with poor spread	Supplemented by direct contacts	Supplemented from wider sample
Education	30	18	49	37	Y	Y	Y	N
Military	9	9	9	100	N	N	Y	N
Health	16	13	34	38	Y	Y	N	N
Emergency services	15	14	36	39	Y	Y	Y	N
Hospitality	37	30	86	35	Y	Y	Y	Y
Offices	15	15	220	7	Y	N	N	N
Retail	69	48	155	31	Y	Y	Y	N
Storage	30	18	114	16	Y	Y	Y	N
Industrial	36	15	141	11	Y	Y	Y	N
Community, arts & leisure	39	32	171	19	Y	Y	Y	N

7 Data processing

The overall dataset for the study was very large including nearly 4,000 variables at the end of fieldwork. This was in part due to the number of tailored questions for each sub-sector included in the study, as well as the evolving survey structure over three clusters of fieldwork.

One element of the data processing activities was a reduction exercise to combine variables which were the same across sub-sectors but which had not been combined at the scripting stage. This was a large exercise and resulted in a reduction of more than 2,000 variables to around 1,700 variables in the final dataset.

7.1 Data quality review and record exclusion process

While every effort was made to ensure that telephone survey records were suitable for the target respondents, not all respondents could be expected to know the answers to all the telephone survey questions. A “don’t know” response was generated in these cases. There were also cases (usually occurring as a result of non-standard data collection methods) where a response was left blank by the respondent.

A variation in quality of responses was anticipated in the telephone survey data, and this proved to be the case in reality. While some respondents answered all the questions, others struggled to answer a large proportion of the information requested. Where a high proportion of the responses were “don’t know”, this raised concerns about the quality of the remaining information.

Prior to modelling, the data was cleansed firstly through record exclusion. Records were screened for outliers before being reviewed for quality. The outlier analysis was based on typical operating metrics, such as occupancy (the number of square metres per person in a building). Where extreme values were identified the record would be excluded from the modelling processes. This outlier exclusion provided an additional filtering for any records for which the respondent misunderstood the extent of the building or premises they were being asked to provide responses for.

The quality analysis identified the proportion of questions for which no response was provided (‘Don’t know’ responses). The number of ‘don’t know’ responses was monitored record-by-record across the full question set including sub-groups of questions critical to the generation of energy predictions. Any records which failed to meet the minimum data quality thresholds, measured by the percentage of ‘don’t know’ responses, were excluded. For example, within the health sector, a total of 192 telephone survey or equivalent records were collected – following the record exclusion process a total of 166 records were retained for analysis. In this sector the share of records excluded was moderately low (14 per cent of total), as many of the records in the available sample yielded a low proportion of 'Don't know' responses, considered to indicate poor record reliability, while others did not have a reliable matched floor area. Table 7.1 shows the exclusion thresholds, as a percentage of responses given within a specific sub-group of questions, by sub-sector.

Table 7.1: Exclusion percentage thresholds by sub-sector (Public sectors only, Cluster 1)

	Exclusion percentage threshold (% of total responses)			
Sub-sector	**All questions**	**Sub-sector specific questions**	**Building services questions**	**Occupancy questions**
Fire/Ambulance	15%	30%	15%	20%
Health centre	10%	15%	10%	20%
Hospital, NHS	15%	20%	15%	20%
Law court	15%	20%	20%	20%
Nursery	10%	15%	10%	20%
Police station	15%	20%	15%	20%
MOD Accommodation	15%	30%	15%	60%
MOD Office	15%	30%	20%	30%
MOD Storage	15%	30%	20%	30%
Prison	10%	15%	10%	20%
Private Hospital	15%	20%	15%	20%
State Primary	10%	15%	10%	20%
State Secondary	10%	15%	10%	20%
University (non-residential)	10%	15%	10%	50%
University (residential)	10%	15%	10%	50%

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 building's core services and equipment. In practice, different exclusion thresholds were required for different sub-sectors, due to the difference in the content and quantity of sub-sector specific questions applied in each case. If the same thresholds had been applied across the board, an excessively high proportion of the sample would have been excluded from certain sub-sectors.

In certain sub-sectors, further exclusions were required during the analysis process in exceptional cases. Examples of the reasons for these exceptional exclusions included:

- The telephone survey response indicated that the building did not fit within the sub-sector it had been sampled from, but this had not been picked up in the telephone survey screening. (For example, a museum where the primary activity was a theatre, or stores which were actually retail premises). In this case the respondent would have been asked an incorrect set of sub-sector specific questions and modelled incorrectly.
- The respondent indicated an improbably high level of catering activity, resulting in an improbably high energy use prediction for the building.
- The telephone survey indicated that the building was never used.
- A site survey of the record indicated that the building did not fit in the sub-sector it had been sampled in (e.g. a store which turned out to be a workshop)

- Where statistical analysis comparing model predictions with matched data identified concerns relating to the modelled energy consumption predicted for the record[26].

7.2 Treatment of missing data and "don't know" responses

Following the data cleansing and quality analysis processes, a low level of "don't know" responses remained in the dataset. Responses to certain telephone survey questions, particularly those occurring in the core survey, were essential for correct function of the energy use model and abatement model. For example, fundamental information on whether the building had heating, ventilation and air conditioning systems installed was essential to determining whether these systems should be included in the energy and abatement modelling. It was not possible to exclude all records where 'don't know' responses occurred in essential telephone survey questions, as this would have excluded an excessively high proportion of the remaining records. Therefore, in order to produce a dataset which could be used in the modelling processes, record amendment was conducted on the remaining data.

Telephone survey data was reviewed and in some cases data was amended to overcome infrequent but significant instances of 'don't know'. Where a numerical answer was not known, an appropriate weighted average would be determined based on the completed responses within that sub-sector (e.g. number of occupants would be determined by the average number of occupants per m^2 floor area across the completed records multiplied by the floor area of the record with the 'don't know' response). Where a multiple choice text answer was not known, the amendment would be based on logical inference from other questions (where possible), or the most common response for the sub-sector would be used if a strong trend was evident in the remaining data.

In some cases, responses to telephone survey questions were absent from the telephone survey entirely. This occurred when non-standard data collection methods had been applied, and it was not possible to ask the question due to restrictions in the information available or the data collection approach (for example some "mystery shopper" covert surveys were used in the retail sector; these were not able to collect any information which could not be identified through visual surveys of the customer areas or outside of the store). In this case, one of two approaches would be used:

- Where the sub-sector contained sufficient telephone survey responses collected via the standard approach, the missing data would be substituted using the same approach as the 'don't know" substitution procedure described above, based on the data collected using the standard approach.
- Where the sub-sector did not contain a sufficient number of records collected via the standard route, it was necessary to make or derive assumptions in order to complete

[26] This analysis was conducted internally by BEIS.

the essential data required for the modelling. For example, matched energy data was used to estimate whether a record used gas or electricity for their primary heating in the retail sector.

Due to the complexity of the telephone survey data processing exercise, it is not possible to reproduce a full account of all the data amendments carried out.

7.3 Processing of barriers interview information

As part of each barriers interview, respondents took part in a semi-structured interview to identify factors they perceived to affect their ability to implement energy efficiency measures on site. The target respondent was the individual accompanying the surveyor at a BEES site visit (although in some cases it was necessary to telephone other staff members based off site to get this information).

There were three parts to the interview:

- Barriers interview: this focussed on barriers to implementing energy efficiency measures. The respondent was presented with three potential energy efficiency measures[27] identified on the site visit and asked to name any factors impacting their ability to implement them. The participant was also asked to rank these barriers according to their impact using a 3-point scale (low, medium or high) [28].
    a. Following the interview, notes were recorded by interviewers and these were later coded into five overarching barrier categories - financial, behavioural, external, technical or other.
    b. Barriers were also classified on a more granular level according to a published barrier typology[29]. It should be noted that this process of coding barriers was undertaken by the research team and can be by its nature reasonably subjective on a case by case basis.
    c. The extracts noted are based on these interview notes rather than necessarily direct quotes from respondents.

Barriers were also classified on a more granular level according to an industry-standard typology detailed in a paper published by Cagno et al. This typology was used in the context of industrial energy efficiency, but was applicable for non-domestic energy also. The typology is reproduced in Table 7.1.

[27] one 'behavioural' measure (e.g. an energy awareness campaign among staff), one 'controls' measure (e.g. improved – and controls on the heating system) and one 'capital expenditure' measure (e.g. an upgrade to LED lighting)
[28] Interviewees were asked to rank barriers based on their impact on the likelihood of a measure being implemented. The impact grades ranged from 'high' to 'low'.
[29] Cagno, E., Worrell, E., Trianni, A. and Pugliese, G., (2013). A novel approach for barriers to industrial energy efficiency, Renewable and Sustainable Energy Reviews, pp. 290 – 308. Available at: https://www.researchgate.net/publication/256438140_A_novel_approach_for_barriers_to_industrial_energy_efficiency

- Structured capability survey: this part of the interview focussed on the energy management practices conducted on site. This consisted of a structured interview of 15 questions.
    a. The responses were scored for each site according to energy management competency in the following six categories: Corporate strategy, Programme management, Responsibility, Data management, Communications & Training and Finance & investment.
    b. These scores were derived by associating different development levels in a competency based on the responses. These development levels were defined by the research team and were broadly based on the typical energy management matrices [30], where each response directly links to maturity of an organisation for a given competency.
- Enablers interview: this part of the interview focussed on the potential 'enablers' which might allow the respondent to better implement energy efficiency measures on site.
    a. These were also classified according to type and the likelihood of implementation.

Table 7.2: Cagno Barrier typology

Barrier area	Barrier	Description
Technology-related barriers	Technologies not adequate	The technical characteristics of energy-efficient technologies might be very particular, resulting in their being very unlikely to be adopted in some cases, irrespective of their costs
	Technologies not available	Current technologies are not available which provide the required solution
Information barriers	Lack of information on costs and benefits	There is a lack of information on the costs and benefits of technologies
	Unclear information by technology suppliers	Energy-efficient technologies might be ignored if suppliers are not able to communicate their effective performance.
	Trustworthiness of the	If "companies that manufacture, distribute and service energy-efficient products provide only limited training to

[30] For an overview of maturity matrices please refer to BRECSU and ETSU, 1996, Good practice guide 119, Organising energy management - a corporate approach, a digital archived copy is available at http://www.cibse.org/getmedia/8e7d033a-56e1-49f5-9344-d7a78329ac3b/GPG119-Organising-Energy-Management-a-Corporate-Approach.pdf.aspx

	information source	keep their employees abreast of the latest technologies'', their customers will not be sufficiently and adequately informed, thus possibly selecting inefficient or even obsolete technologies.
	Information issues on energy contracts	Different options in energy contracts can be presented in a form that might be unclear and not-vivid, thus resulting in being unattractive for the customers
Economic	Low capital availability	Even with a great awareness on the benefits of energy-efficient technologies, and considerable commitment of management and personnel to energy, the firm does not have sufficient own capital to invest in energy-efficient technologies
	Investment cost	The investment cost is too high to proceed with an investment
	Hidden costs	Costs might differ significantly from the estimate in investment analyses, and all the transaction costs to obtain information on energy-efficient technologies and related personnel training fall within this category
	Intervention-related risks	Some uncertainties and risks occur when implementing the energy efficiency interventions
	External risks	Implementation of the investment: the introduction of new technologies may require the interruption, at least partially, of normal operations, thus incurring disruption costs
	Interventions not sufficiently profitable	Some enterprises often rationally discard investments with a rate of return lower than their internal rate of return. This can be particularly critical especially for energy-efficient technologies requiring a significant change
Behavioural	Lack of interest in energy-efficiency interventions	Includes several elements, each of those contributing to the perception that energy issues are not sufficiently interesting: Energy costs do not have sufficient weight with respect to the firm's production costs; The firm perceives itself as already efficient
	Other priorities	Where decision-makers might be focused almost uniquely on few core business activities. Therefore, they tend to exclusively evaluate the interventions with considerable impact on the main production system activities, thus disregarding energy efficiency

	Inertial	This barrier represents the resistance to change and risk, and the more radical the change, the higher the barrier will be. It can result in preferring interventions with quick and low investments and returns
	Imperfect evaluation criteria	The decision-makers might lack the proper knowledge or criteria to evaluate investments. In particular the decision-maker might adopt approximate criteria or routines that do not allow him/her to thoroughly evaluate the effective performance of the interventions. In other cases the decision-maker might adopt criteria for the evaluation (as pay-back period, or rate of return of the investment) without any relationship with the uncertainty associated to the considered alternatives.
	Lack of sharing the objectives	Some misalignments between the behaviour of personnel and energy management objectives might occur, resulting in a low implementation of energy management practices
Organisational	Low status of energy efficiency	The functions devoted to energy management do not have sufficient power to act effectively to improve energy efficiency
	Divergent interests	The decision-maker might not gain the benefits from improving energy efficiency
	Complex decision chain	If the decision-making process involves several functions, the information flow might not be straight and smooth.
	Lack of time	The decision maker does not have enough time to consider energy efficiency opportunities
	Lack of internal control	Without adequate control systems established by the management, the personnel within firms might not implement energy efficiency practices
Barriers related to competences	Identifying the inefficiencies	Even with awareness of the energy issues, and consciousness of the benefits of energy-efficient technologies, specific competences on methods and tools to identify energy waste are lacking
	Identifying the opportunities	The difficulty to identify the opportunities to improve energy efficiency
	Implementing the interventions	The difficulty to implement practices and interventions for energy efficiency, without the support of external consultants or personnel
	Difficulty in	Points out a market problem rooted outside the

	gathering external competences	company
Awareness	Lack of awareness or ignorance	Pointing out the ignorance of the decision-makers in which they simply ignore the possible benefits coming from the implementation of energy efficiency opportunities.

The second part of the interview focussed on the energy management practices conducted on site. This consisted of a structured interview of 15 questions, the responses to which enabled the surveyor to score the site according to 6 energy management competency criteria: Corporate strategy, Programme management, Responsibility, Data management, Communications & Training and Finance & investment.

The third part of the interview focussed on the potential ‘enablers’ which might allow the respondent to better implement energy efficiency measures on site. These were also classified according to type and the likelihood of implementation.

8 Modelling

8.1 Overview of the modelling of BEES

In order to make use of the data collected in the BEES fieldwork (in the form of telephone surveys, site surveys and barriers interviews) and translate this into a quantitative analysis representative of the overall population of non-domestic buildings in England and Wales, two main modelling tools were developed.

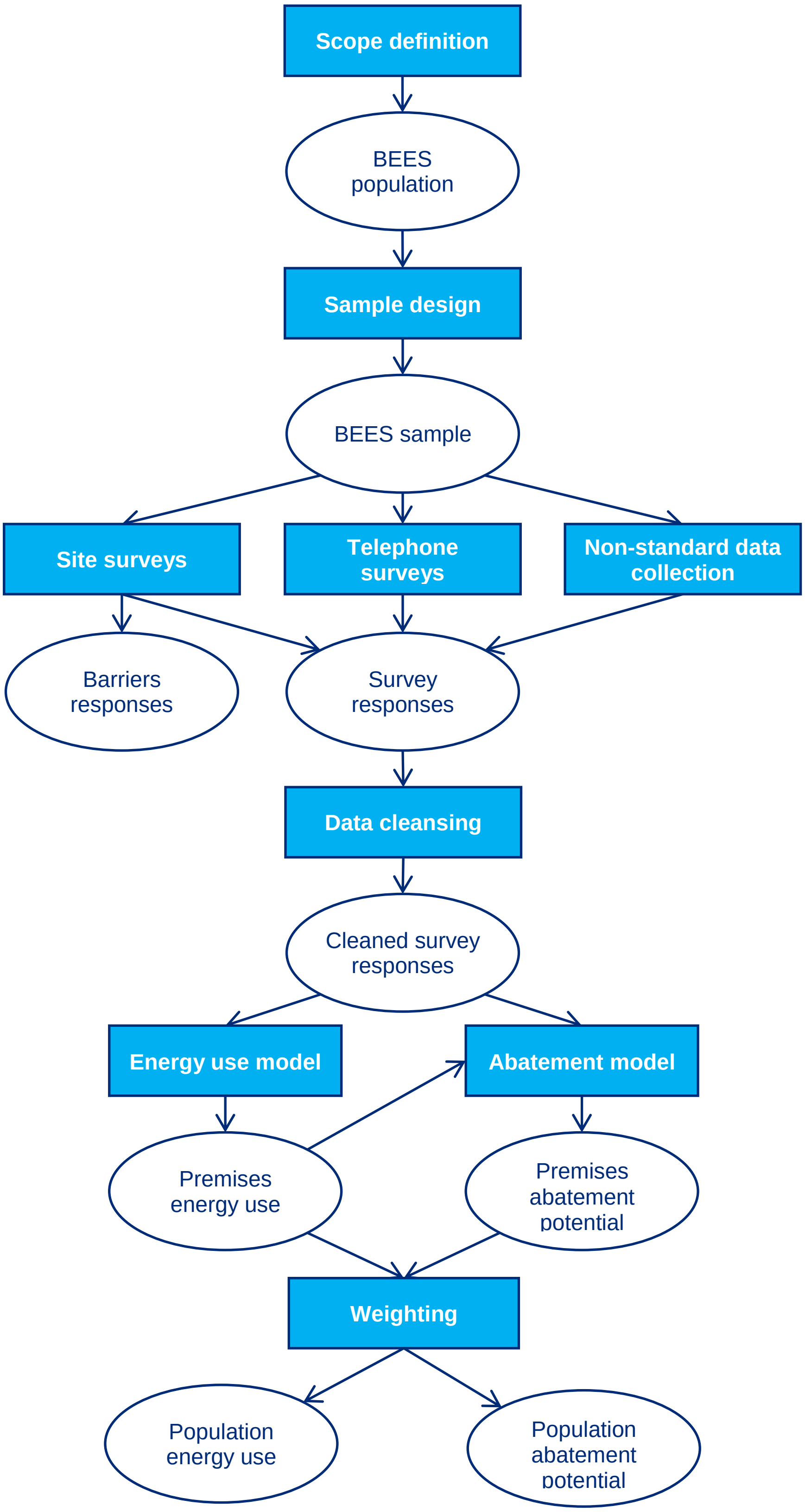
Figure 8.1 sets out an overall process flow for BEES culminating in two models developed for the BEES analysis; the energy use model and the abatement model.

The energy use model was developed to interpret the telephone survey data collected for an individual record and translate this into a tailored estimate of energy consumption at an end use level of resolution for that record.

The abatement model then used the telephone survey data to identify abatement measures which were appropriate for that record, and utilised the energy use model end use consumption estimates as a basis for quantifying the potential savings that these measures might achieve, and the likely cost of implementation.

Prior to final reporting, the record-level results from the energy use model and abatement model were then weighted up in order to render the sub-sector totals representative of the entire sub-sector population in England and Wales.

Figure 8.1: BEES methodology



8.2 Energy use model

8.2.1 Overview

The underlying method of the energy use model was to estimate an energy consumption by end use breakdown (e.g. heating, lighting, small power, etc.) for a typical building or premises, based on a pre-defined description of energy end use for a specific sub-sector. This pre-defined typical building energy use model was then tailored to the real building (premises) in an individual record using the information from the telephone survey for that building (premises) conducted in BEES.

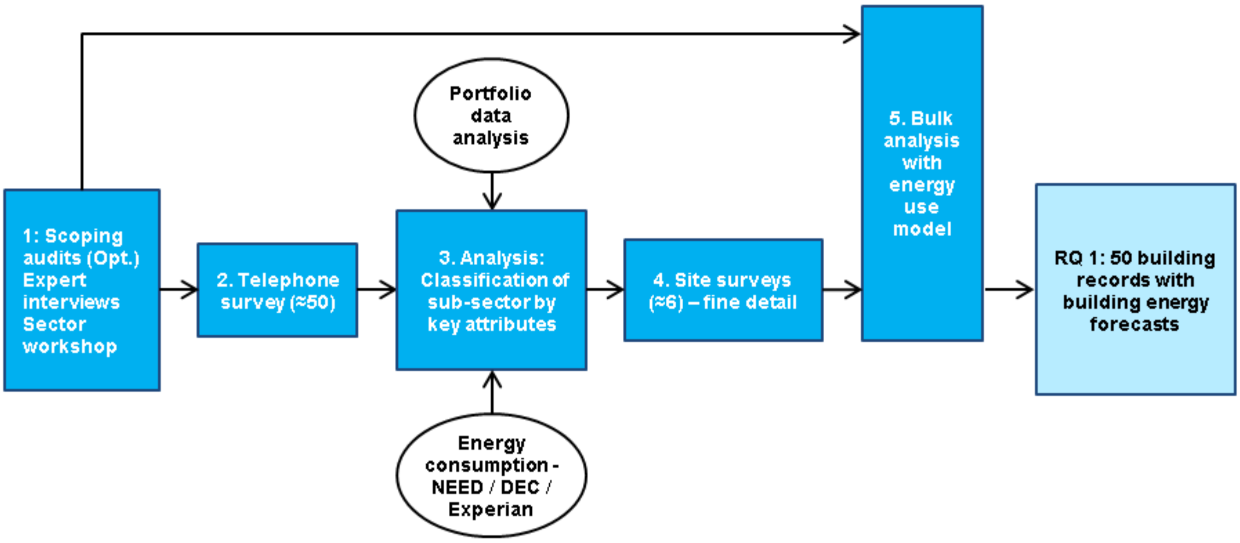
The model accounted for both energy use directly associated with the building and those with activities within buildings. Building energy uses would be; heating, cooling & humidification, ventilation, fans, pumps, controls systems and interior lighting. These energy uses are regulated within Building Regulations and would count towards the score on an Energy Performance Certificate. Other energy uses e.g. catering, office equipment, entertainment equipment. The model aimed to be capable of dealing with the full variation of non-domestic building stock with the exception of industrial process loads.

The energy use model was initially populated with data and assumptions derived from existing knowledge and understanding of each sub-sector, anchored to a range of reference sources including the National Calculation Methodology for non-domestic buildings used for EPCs, CIBSE TM46 benchmarks, Energy Efficiency Best Practice Guides and other sources. This knowledge was then expanded through the BEES surveys, analysis of portfolio data, sub-sector expert input and site audits prior to the running of the energy use model to analyse the telephone survey data for each record. In some sub-sectors, the existing knowledge was found to be very detailed, and the energy use model performed well with few modifications, whereas in others, extensive analysis of data from the BEES fieldwork was required in order to achieve an acceptable model performance. Where sub-sector expert input was available (17 of 47 BEES analysis sub-sectors), this offered considerable benefit to the approach, maximising the effectiveness of the questions asked in the telephone survey and the team's understanding of their impact on energy consumption in the subsequent data processing.

8.2.2 Relationship between the energy use model, the survey process, and how BEES fieldwork data was used to refine energy use estimates

Figure 8.2 presents the energy use model analysis process within the BEES project, for a single sub-sector. In the initial cluster of analysis, "hypothesis buildings" were created and formally reviewed at stage 3 of the process, prior to analysis of site survey data and bulk data analysis. In later clusters, this process was more flexible due to the limited availability of reliable benchmark data and sub-sector expertise. However, in each sub-sector the energy use model was always populated with the required input data (from the available records) and used to generate sample energy estimates for each sub-sector prior to undertaking analysis of all records in the sub-sector. During the bulk analysis of the telephone survey data, the energy use model was employed in an iterative fashion. In this process, findings from research tasks (portfolio analysis, site surveys, comparison with matched energy data) were used to tailor the energy use model input assumptions and the calculations that were used to interpret the "sub-sector specific questions". This calibration process allowed the model performance to be improved and a better agreement with matched energy data to be achieved.

Figure 8.2: BEES energy use model analysis process



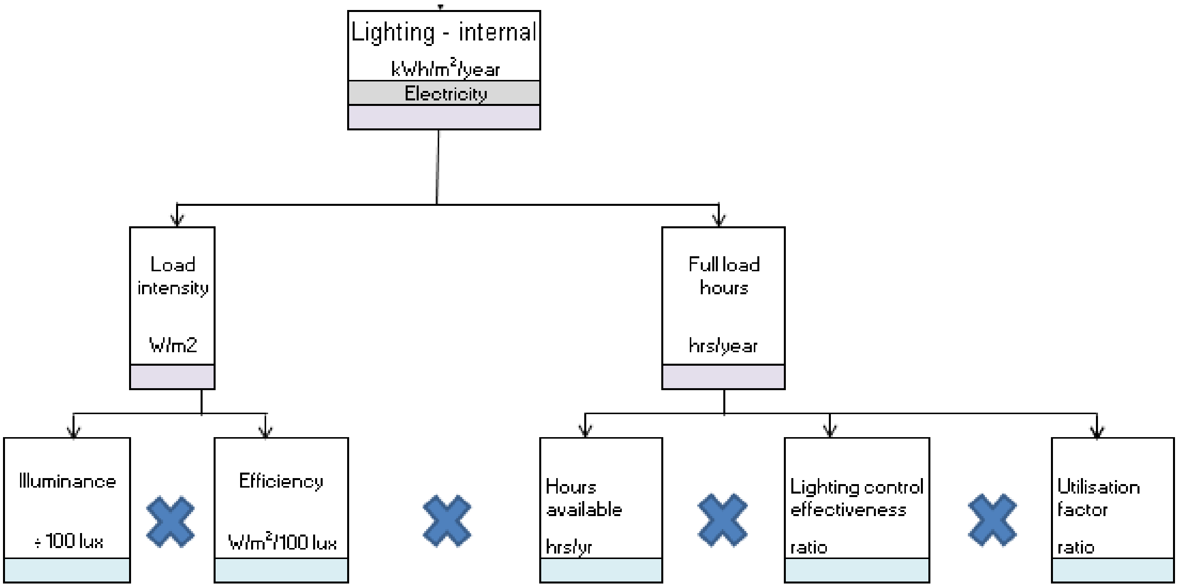
8.2.3 Energy use model structural decisions

The energy use model was developed based on several fundamental structural decisions:

1. **Buildings were assigned a "sub-sector" based on their primary usage.** This was based on the VOA SCAT.PD code if the building had a record in VOA or on some other basis if the building was selected from supplementary datasets (e.g. cross classification of DEC and ePIMS typologies, or sub-sector specific data such as Military estate data).
2. **Calculation of energy use breakdown was carried out at a "space type" level.** A space type is an activity area within a building with a distinct set of energy characteristics which relate to that activity – for example office space, frozen food retail or a classroom. 60 different space types were used during the BEES analysis. In order to define a building in the energy use model, it was assigned a total floor area (GIA) and this was split between the different space types on a percentage of floor area basis. When estimating the energy consumption for a specific telephone survey response, this breakdown was amended in response to answers given in the telephone survey. Building energy consumption was calculated at a space type level and summed to determine the building total. The space types used were based around, and their energy using 'attributes' informed by, the National Calculation Model (NCM) used for the calculation of EPCs.

3. **Tree diagram structure.** Energy consumption by end use for a given space type was calculated from a set of parameters which define the 'roots of consumption' i.e. installed power levels and annual hours of use. Within the energy use model, the input database contained representative high, medium and low values for each of the tree diagram parameters. These parameters typically defined equipment installed loads either in terms of 'point sources' (e.g. kW power rating) or by specifying a system specific efficiency (e.g. W/m^2/100 lux for lighting) and a level of service provision (e.g. the lux level for lighting). The hours of operation for each end use were calculated by specifying the operational hours and the management and control factors for each energy end use. Some very specific end uses, such as medical equipment, deviated from this approach. An example of the tree diagram calculation for internal lighting is presented in Figure 8.3.

Figure 8.3: Example tree diagram calculation



4. **Relating premises level questions to space type level calculations.** Due to the time restrictions inherent in the telephone survey, and the necessity for consistency within the questions, the majority of telephone survey questions could only be asked in relation to the whole premises. Wherever possible, the questions would be asked in a manner which identified the predominant situation (*e.g. what is the predominant type of lighting in the premises?*) and the response would be assumed to apply to the whole premises.

   In order for the energy use model to calculate results at space type level, it was sometimes necessary to apply assumptions in order to interpolate the building level telephone survey response at space type level. For example, the following values required interpolation for every premises in the study:

   a) **Premises occupancy density:** The telephone survey usually collected the total number of staff and visitors present in the building during normal use. Certain end uses (e.g. hot water, small power) used the occupancy density as a calculation variable. In order to assign the occupants within the space type structure of the energy use model, the total number of people in each space type were assigned pro-rata based on the typical occupancy density within each space type.

b) **Hours of use:** Within the initial assumptions for each sub-sector, the hours of use for the building as a whole and the individual space types were defined based on typical usage patterns. For example, within a police station, the custody suite (containing the cells) was set to 24 hour usage by default, but the office spaces would operate a weekday schedule.

In the telephone survey, the building level hours of use were collected. The ratio between this value and the assumed building hours of use was then used to adjust the energy consumption estimates for each space type by end use. These adjustments were assigned in one of two ways for each end use.

The first method was direct proportionality, where a doubling of the building level hours of use doubled the energy consumption (e.g. a space lit for twice as long would use twice as much energy for lighting).

The second method was a lesser adjustment, where a 30% factor was applied to the adjustment - hence a doubling of the hours of use would increase the effective energy use by 30%. This was used for end uses where longer hours of use do not result in directly proportional increases in energy use, e.g. heating energy consumption. This method mirrors the approach used in adjusting benchmark values in the Display Energy Certificate benchmarking methodology and represents current UK practice for a simple calculation of this type. The selection of the 30% factor was made following a review of the factors used in the DEC methodology for different building types with an uplift applied to account for the conservative approach used when extending benchmarks.

c) **Space type areas:** For each premises level record, the energy use model started with a “typical” breakdown of internal[31] space types for that sub-sector. Where the telephone survey identified more detailed information on the space types present, the energy use model adjusted the space type breakdown accordingly. As the gross internal floor area of the record was fixed during sampling, a simple pro-rating calculation was used in order to make these adjustments. This is an example of how this calculation worked:

An office building started with a floor area breakdown of 80% office space and 20% common areas. The telephone survey identified that a particular office building record included a trading floor occupying 20% of the gross floor area. The energy use model would adjust the floor area for the trading floor space type from 0% to 20%, and correspondingly reduce the other floor areas in the building by 20% to compensate. The final floor area breakdown would be 16% common areas, 64% office space, and 20% trading floor.

[31] Outdoor space types such as car parks or sports fields could be added to the model with any area and were not subject to pro-rata adjustments in this way, as they are not constrained by the GIA of the record.

Similarly, if a space type which was already present in the model had its area adjusted, all other internal space types would be adjusted pro-rata to account for the change made to that space type.

In some cases, multiple space type adjustments were required within a sub-sector. Where this was the case, each subsequent adjustment would affect all previous adjustments, and it was not possible to achieve an end result where every space type's area matched the information collected in the telephone survey. Where this was the case, the adjustments for the most energy intensive space types would be processed last, in order to minimise any negative impacts of the method used.

5. **The structure of the questions and possible responses in the telephone surveys were designed to be closely linked with the energy use model description of the sub-sector energy end use breakdown.** This approach ensured that the model could be readily programmed to tailor the energy use estimate for an individual record based on responses provided in the telephone survey process. An estimate of energy use and energy end use breakdowns was generated for each building surveyed. These estimates were compared with the matched electricity and gas consumption data from the sampling datasets (e.g. ND-NEED and DEC databases, or energy data provided by respondent organisations) in order to test the plausibility of the energy use model's estimates.

8.2.4 Energy end uses

The energy end uses included in the energy use model are defined in Table 8.1. In end uses where non-electrical energy is commonly used (e.g. heating), the energy use model was constructed such that the energy consumption could be assigned to the correct energy type. For the majority of end uses, electrical energy was by far the dominant energy type, and the energy use model assumed that this would always be the case.

Table 8.1: Energy end uses included in the energy use model

End use category		Energy type(s)	Description
1	Space heating	Electrical, non-electrical	Energy consumption for space heating (including via ventilation), excluding domestic 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.
2	Hot water	Electrical, non-electrical	Energy used for domestic 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.

End use category		Energy type(s)	Description
3	Space cooling	Electrical	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	Electrical	Ventilation fans, including recirculation fans and mechanical plant room fans, excluding condenser and cooling tower fans
5	Pumps	Electrical	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	Electrical	Controls for mechanical and electrical services, building energy management systems, security and alarm systems.
7	Humidification	Electrical, non-electrical	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)	Electrical	All general internal lighting including task lights and emergency lights
9	Lighting (External)	Electrical	All external lighting associated with the premises, including for dedicated car parks and street lighting for dedicated access routes
8	Lighting (Display)	Electrical	All display lighting including retail/artwork display or demonstration lighting, decorative lighting in lobbies etc.
10	Small power equipment	Electrical	Office equipment uses within the general premises space comprising computer workstations, printers, and desk based telecommunications equipment. Also includes electronic point of sale equipment.

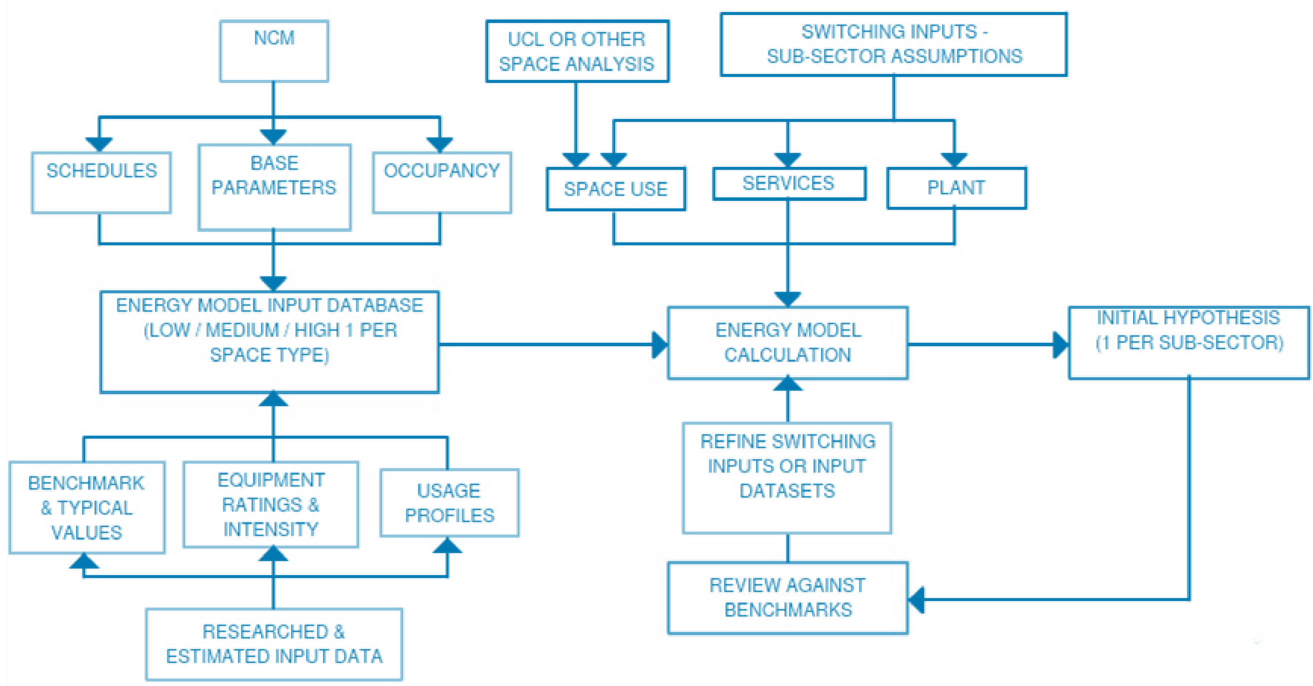
End use category		Energy type(s)	Description
11	ICT equipment	Electrical	All servers, central computers, telecommunications equipment, transmitters, etc. Typically but not always found in a dedicated room. Includes dedicated computer and telecommunication cooling systems. Excludes control equipment.
12	Vertical transport	Electrical	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.
13	Catering - central	Electrical, non-electrical	Kitchen (or café) catering preparation and servery equipment including dishwashers, and water heating associated with catering. Excludes restaurant lighting, ventilation and air conditioning.
14	Catering - distributed	Electrical	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.
15	Cooled storage	Electrical	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.
16	Entertainment: lighting	Electrical	Stage or performance lighting.
17	Entertainment: equipment	Electrical	Audio-visual equipment, gaming machines, etc. Includes projectors, TV screens, sound systems in all premises types
18	Laundry	Electrical, non-electrical	Fabric washing and drying machines
19	Medical equipment	Electrical, non-electrical	Energy used for medical equipment or health services in hospitals, doctor’s surgeries, dentists, vet centres, etc. Excludes equipment in laboratories.
20	Laboratory	Electrical	Energy used for equipment in laboratories.

End use category		Energy type(s)	Description
	equipment		
21	Pool/leisure	Electrical, non-electrical	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.
22	Other normal	Electrical	Any other energy uses which fall outside categories 1 to 21, which are "normal" - i.e. are typical for the specific building type.

8.2.5 Energy use model structure and building definition process

The structure of the energy use model, associated data and the process of constructing a building specification is outlined in Figure 3.4.

Figure 3.4: Structure of energy use model



In order for the energy use model to function, a typical basic building specification was populated for each sub-sector. This initial building template included key data such as floor area, a standard set of space types, a default level of servicing (natural ventilation, mechanical ventilation or air conditioned), typical operational hours for the building and each space type, staff and visitor numbers and typical catering parameters. This basic specification provided enough information for the energy use model to calculate an energy breakdown for a simple building, using typical parameters from the energy use model input database.

In order to produce bespoke energy predictions tailored to an individual building, further detail was required in the form of a response to the telephone survey. Answers to questions in the telephone survey were used to trigger adjustments in one or more tree diagram variables within the energy use model. In most cases this would take the form of selecting between the high, medium and low value for that variable in the energy use model input database. For example, if the predominant lighting type in the building specification for a primary school was selected as “T5 fluorescent” this would trigger the use of the “medium” system efficiency value in the lighting calculations. In certain cases, it was possible to directly calculate the value of a variable based on a response to the telephone survey (for example multiplying the number of display screens in a betting shop by a typical power rating gives the total electrical load, which could be used to directly update the end use installed load parameter).

During cluster 1 of the project, a full building description for a “typical” building was created for each sub-sector (comprising the basic specification and a complete telephone survey response). This was based on the best available data and knowledge for the sub-sector and sector. The hypothesis building for each sub-sector represented a typical building of that type, based on the project team’s view of the most commonly observed features for that sub-sector. The energy use model was run and an energy consumption estimate by end use was generated. This approach allowed the typical building’s energy consumption to be compared with energy benchmarks to verify that the model outputs were plausible prior to using the model for bulk analysis of the telephone survey records, and also provided a reference point for comparison with the results obtained when the energy use model was used to calculate energy predictions at record level for the telephone survey sample.

In clusters 2 and 3, it was common for sub-sectors to incorporate a very high variation in building characteristics and it was often not possible to create a single typical buildings for the sub-sector (for example, the ‘Theatres’ sub-sector included theatres, cinemas and concert venues). It was also more common for existing studies and evidence to be biased or lacking in detail (clusters 2 and 3 were dominated by private sector stock, where organisations are often more protective of their data than in the public sector). In response to these challenges, more flexible approaches to modelling were developed; the telephone survey requested a more detailed set of information on space types/activities present in the building, and this data was used to tailor the space type breakdown of the building in more detail.

8.2.6 Calculating carbon emissions from energy use estimates

The emissions estimate for energy uses were estimated from the energy consumption estimates using the 2015 emissions factors from the Government’s Valuation of energy use and greenhouse gas emissions for appraisal guidance. These are shown in table 8.2 below.

Non-electricity use has been modelled as a single variable within BEES although respondents were asked about their main heating fuel[32]. This response has been used as a proxy for disaggregation of non-electrical energy. It has been assumed that all non-electrical energy use within the premise/building is the same as the main heating fuel. In the case where the main heating fuel is electricity, it is assumed non-electrical energy is oil.

Table 8.2: Energy end uses included in the energy use model[33]

	$ktCO_2/GWh$
Electricity	0.45
Natural gas (& other)	0.18
LPG	0.21
Oil	0.27
District heating	0.22

In the abatement calculation the marginal emissions factors are used since that reflects what the actual impact in the current energy system of saving electricity. This means a lower emissions factor of 0.33 $ktCO_2/GWh$ was used. This means that the share of emissions abatement opportunity will be lower than the share of energy abatement opportunity.

8.2.7 Model validation procedures

A range of model validation procedures were performed on energy use model outputs.

1. In cluster 1, validation of the energy consumption estimates for “typical” buildings was undertaken against available benchmarks. This consisted of populating all necessary input data for a “typical” building in each of the cluster 1 sub-sectors, running the energy use model and comparing the energy intensity estimates produced against appropriate benchmarks for that sub-sector – primarily those from DEC data.
2. As part of the sub-sector level calibration process, energy use model results were compared at end-use level against the overall results obtained during the site surveys (i.e. the comparison was made for the sub-sector group of site surveys, rather than case by case). Where a significant deviation was apparent between the modelled value and the actual value, this was investigated to determine the probable cause. Where deviations in a particular end use were common, model recalibration would be undertaken. For example, in health centres, consultation

[32] It is recognised that this is an approximation for example in the case of buildings heated by district heating, that this would in reality be limited to space heating and hot water provision in the main. This discrepancy is rather small given the small level of district heating.

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

rooms were found to be over-lit in many cases. In response, the lux level for lighting in this space type was increased. This improved the accuracy of the model estimates in that sub-sector.

3. Calibration of the model outputs was also undertaken by comparison with matched energy data where this was available. This data was only available at building level (total electricity/total thermal energy) but could be used to identify trends within sub-sector datasets, and to ensure that model predictions were not systematically over- or under-estimating energy consumption. In this comparison, the aim was to achieve a variance of less than 15% between the sum of matched electrical and non-electrical energy consumption and the aggregate of the modelled values for those records where matched data was available. Availability of robust matched energy data varied considerably from 100% of records in some sub-sectors to no matched data in the poorest sub-sectors. The results of this comparison can be found in section 9.4.
4. An internal review of the final energy use model results in each sub-sector was carried out with the project's Technical Director. This review examined the spread of the modelled results, the median energy intensity compared to benchmarks, the average breakdown of energy end use within the sub-sector and scatter charts showing the relationship between modelled data and matched data. Where further actions were deemed necessary these were documented and carried out.
5. Finally, an external peer review exercise was carried out by UCL. Overall, the energy use model was found to be fit for purpose. That is, it produced reasonable estimates of energy use given the available input data, especially when aggregating to the subsector level or above. It was also found that the energy use model included the key variables that impact the energy use in a building, though it was noted that uncertainty in the input telephone survey data could still lead to uncertainty in energy use estimates for an individual building, regardless of the model used to produce these estimates.

8.2.8 Caveats and model limitations

As in any modelling exercise, the energy use modelling process was subject to inherent assumptions and limitations relating both to the modelling approach and the quality and detail level of the various sources of data employed in the study. General assumptions and simplification to the overall method are presented in Table 8.3, and assumptions applied to specific end uses in Table 8.4.

Table 8.3: General energy use modelling assumptions and simplifications

Caveats or simplifications	Detail and implications
Use of an annual average value as the basis of all calculations	Insight into seasonal loads is not provided. Crude estimates were required for utilisation factors to account for seasonal loads such as heating and outdoor lighting.
Out of hours energy use	Most non-domestic buildings are used intermittently, some, like schools and many offices, for less than 3,000 hours per year, which means that they are unoccupied for at least two thirds of the hours in a year. Energy continues to be used “out of hours” by e.g. servers which must continue to run, but also by other office equipment, ICT, HVAC, lighting, etc., usually at a low level but often at a rate that can be reduced by better energy management. The energy use model approach made it difficult to model unnecessary low level out of hours energy use.
Typical space type proportions were used; capacity to tailor space types to specific building was limited	Breakdown of space types in modelled building will not accurately reflect the actual building. Less common space types & mixed use buildings cannot be fully accounted for. Significant energy using spaces were prioritised.
The calibration process was manual and relied on site surveys and matched energy data	A lack of automation in the calibration process, by necessity, meant that the same level of scrutiny will not have been applied to each end use across every sector. The energy use model was calibrated in response to the results obtained in BEES site surveys, and matched energy data associated with telephone survey records (where available). As a result, sub-sectors where a large, varied site survey sample was available provided a much richer basis for model calibration and validation, which increased confidence in the results compared with those where site survey data was limited.
In many cases, parameters were limited	In order for questions to be clear and manageable for respondents, closed responses were used

to 3 values (low, medium, high)	in the telephone survey in most cases. This limited the detail applied in the modelling response.
Let spaces in multi-tenanted buildings could not be distinguished from whole buildings in the modelling approach.	A tenant space in a multi-tenanted building was effectively treated as a whole building in modelling terms – it would be subject to the same assumptions regarding the share of common parts area (WC's, lifts etc.) as a whole building record.
No building envelope model was incorporated into the approach.	Physical features such as glazing extent, atria, exposure, orientation, shading, courtyards etc. could not be accounted for in modelling.
The calibration process assumed accuracy of matched energy data for whole building records	It was not possible to check the accuracy of matched energy data from ND-NEED or other sources used in the calibration process. While part-of-building records were given lower priority in calibration, errors in meter matching could have affected certain subsectors.

Table 8.4: Energy use model caveats

End use	Simplifications, assumptions and implications
Space heating	A simple static model was used as limited data could be collected on building form, insulation, glazing etc. This model was unable to identify or account for excess consumption as a consequence of poorly calibrated or faulty controls.
Hot water	A simple model was used based on typical per person consumption, the number of occupants in the building, the breakdown of activity areas (space types) in the building, and the hours of use. Quality of data on hot water consumption from site surveys was limited as it was difficult to separate from other loads, which limited the accuracy available to verify the energy use model. Standing losses and hot water controls were not accounted for in the modelling.

End use	Simplifications, assumptions and implications
Cooling (air conditioning)	A simple model similar to the heating model was used, subject to the same limitations. Validation of cooling estimates was difficult due to limited site survey data in many sub-sectors and difficulties separating cooling from other loads.
Fans	Energy consumption was estimated based on typical ventilation rates and occupancy areas for different space types. Novel ventilation strategies and poorly set controls could not be accounted for.
Pumps	Estimation of energy consumption for pumps was calculated as a percentage of heating and cooling consumption. This was rarely tailored in response to telephone survey data. No amendments for variable speed drives were made in the modelling.
Controls	There is very little data on the energy consumption of building controls systems, as consumption is low. A simple estimate was used in the BEES modelling, and no telephone survey questions were included on this end use.
Humidification	A simple model was used which estimated humidification loads relative to typical ventilation rates. This simplistic treatment was justified by the rarity of these systems. Humidification was only included in the energy use model where sub-sector specific questions were asked about humidification systems.
Internal lighting	Estimation was based on typical lux levels, hours of use and equipment efficiency in different space types. This end use is well understood and model results were tailored extensively in many sub-sectors; however, non-functional and poorly set controls could not be accounted for.
Display lighting	A simple model was used compared to general internal lighting. Often difficult to distinguish from general lighting in real buildings. Where present in a sub-sector this was adjusted for in the

End use	Simplifications, assumptions and implications
	efficiency of the lighting type only, no other factors could be accounted for.
External lighting	Calculated in a similar manner as internal lighting, but subject to a lower confidence level as it was less common, and less detail was collected in the telephone survey. Site survey data indicated that lighting levels and hours of use were also highly variable from one premises to another.
Small power (office and point of sale equipment)	At the basic level this was calculated based on an assumed number of workstations/tills per person in each space type and the number of occupants in the premises. Tailoring adjusted the installed load based on the type and number of workstations/screens and hours of use were adjusted based on the use of auto shut down controls.
ICT equipment (server rooms and data centres)	Server room energy use was estimated based on a simple allowance per workstation in the building (derived from industry data). Data centres within buildings were estimated based on the floor area of the data centre, using data derived from the site surveys in the BEES study. No further adjustments were made and this end use is presented with low confidence.
Vertical transport	Energy consumption for lifts was estimated based on data from European research. The number of floors and size and type of building were accounted for in this method, but consumption was not adjusted for the number of occupants in the building, type of lift motor or controls. No suitable existing methodology could be identified for estimating escalator energy use.
Central catering	This end use describes all energy consumption relating to hot meals and drinks produced in catering facilities. The estimation of energy consumption was based on the number of meals stratified by a simple set of meal types, using existing benchmarks and data derived during the BEES study. A significant body of work has been published on energy efficiency in commercial kitchens, with studies indicating that while number of meals is the best parameter for use in a simple estimation model, it is still a weak indicator of energy consumption. No further adjustments

End use	Simplifications, assumptions and implications
	could be made to account for cooking practices or efficiency of cooking equipment.
Distributed catering	This was calculated based on simple estimates of typical loads for kitchenettes and vending machines. No further adjustments were made.
Cooled storage	This was estimated based on typical load intensity and utilisation factors for refrigerated storage in different space types. Sub-sector specific questions were used to adjust load intensities for special cases such as cellar cooling in pubs, and display fridges in customer areas in cafés. Further adjustments were made based on whether respondents purchased energy efficient equipment. This end use was difficult to quantify accurately in site surveys, as commercial equipment often lacked power rating data, and ambient temperature has a significant impact on energy consumption. A poor response to sub-sector specific questions on cooled storage for food sales in the retail sector severely limited scope for tailoring end use consumption in this sector.
Entertainment lighting	This end use was rare, and was based on simple low, medium and high load intensity and utilisation estimates based on typical load ratings for stage lighting equipment. Due to the complexity and variation in use of these systems it was not possible to collect detailed information in the telephone survey; tailoring of the estimate was based on the age of the technology present only.
Entertainment equipment	This end use was significant in very few sub-sectors. In most cases it was based on typical load intensity and hours of use in different space types. In sub-sectors where it was a significant use, further tailoring based on equipment quantities was included in the modelling approach.
Laundry	Estimation of energy consumption was based on EU energy labelling data for domestic scale machines, and industry data based on tonnage processed for commercial scale laundry

End use	Simplifications, assumptions and implications
	equipment. It was assumed that domestic scale laundry is electrical only; commercial scale laundry was assumed to use both electricity and gas. In certain cases, estimates were adjusted based on the energy efficiency of the laundry equipment. No adjustments were made to account for wash temperatures or other factors.
Medical equipment	A separate tool (outside the energy use model) was used to estimate medical equipment use in hospitals. This was based on data collected in the telephone survey on energy intensive equipment and operating theatres present. This tool incorporated assumptions for the hours of use and power ratings of medical equipment. In health centres, estimated energy intensity was used for medical equipment in consulting rooms. The results for this end use have a low confidence level.
Laboratory equipment	Limitations on time in the telephone survey heavily restricted detail which could be collected on this complex end use. Estimation of energy consumption was based on typical ventilation rates and data from surveys carried out in the S-lab project supported by HEEPI. However, this data was based on a limited sample and the results for this end use are presented with a low confidence due to the extremely wide variation in research activities and the heavily customised nature of most laboratories.
Pool & leisure equipment	This end use was modelled using discrete space types for swimming pools and saunas. All energy consumed by/in swimming pool halls is included. Simple estimates were used based on benchmark data from Energy Consumption Guide 78 – Sports and Recreation buildings, calibrated where required based on findings from BEES site audits. Separation of swimming pool hall loads from other building loads in leisure centres was a complex task for site surveyors and was subject to limited confidence; this lowered the applicability of the findings to the calibration process for the BEES energy use model.

End use	Simplifications, assumptions and implications
Other normal	This end use covers items which do not fall in any other end use category e.g. manual handling equipment in storage buildings. In most cases typical estimates were used in different space types, tailored in response to sub-sector specific questions where the load is significant (e.g. automated stock retrieval in distribution facilities).

8.3 Abatement Model

8.3.1 Overview

The primary function of the Abatement Model was to estimate the energy efficiency potential in each premises. This was calculated at an energy end-use level (e.g. heating, lighting, and small power), based on the following inputs:

- An energy end-use prediction for each premises, generated by the energy use model.
- Telephone survey responses on the premises.
- A database of energy efficiency measures, with defined energy saving impacts and cost factors, drawn from a range of sources and calibrated for the model.

The Abatement Model estimated abatement potential in a particular building by calculating the abatement potential for each measure in that building. The applicability of a measure in a particular building was determined based on responses to the telephone survey for that building. If a measure was applicable, the energy calculation variables were adjusted according to the relative impact associated with the measure (for example, total installed load of lighting (W/m^2) might be decreased by 3% in the case of a lighting measure). These updated variables were then used to recalculate the energy end-uses of the building, following the same tree diagram approach as the energy use model. Energy savings were calculated by comparing the energy consumption of the buildings with and without the measure. The cost of the measure, if it were installed in the building, was calculated using various cost metrics. Each of the applicable measures in a building were then ranked in order of return on investment and installed sequentially to take the overlap of impacts into account.

The Abatement Model accounted for all major energy uses as identified in the energy use model and results were aggregated up to the sub-sector total using the weighting factors for each sample building.

8.3.2 Abatement model structural decisions

1. **Measure applicability.** Measure applicability data was taken from the telephone surveys, This allowed the model to tailor the measures applied to the building being modelled. However, in many cases, the telephone survey did not include an explicit question or answer relating to a specific energy efficiency measure. Where necessary, inferences were made from other – more general – questions, such as those regarding the level of awareness and general attitudes to energy management.
2. **Effects of measures.** The energy use model determined a building's energy consumption by space type. However, due to limitations in Excel, the abatement model determined the abatement potential of different measures by changing key energy use model variables at the building level, using a space type weighted average of the variable. In practice, this meant that the energy use model variables that could be affected by the abatement measures were not at the most granular level. For example,

the load intensity of lighting for the building is the product of illuminance (a weighted average for the building) and efficiency of the lighting (a weighted average for the building), rather than the sum of the relevant abatement calculated from each individual space type. This had limited impact on the abatement model outputs, but did affect the detail within the model. In the example above, it would not possible to determine the impact of the improved lighting at a space type level.

3. **Measure impact.** The measures and their characteristics were developed by combining the tree diagrams used in the energy use model with a review by Verco's team of energy auditors. They have a wealth of experience in undertaking energy audits in a broad range of non-domestic buildings. Their expertise was used to determine the effectiveness of measures by varying parameters in the tree diagram associated with each measure. For example, a lighting upgrade would be modelled by varying the improved lighting efficiency.

   This method of calculating reductions on a first principles basis was effective for plant replacement opportunities. However, it was more difficult, for opportunities where the scope for reductions might vary quite significantly for each building. For instance behavioural awareness campaigns may vary significantly in their potential to reduce the building's consumption based on a large range of variables. In such circumstances a similar approach was taken, but a suitably conservative value was selected in light of the uncertainty. Behavioural, and to a lesser degree, controls related measures were affected by this issue.

   Once the list was populated, the measures were tested on a number of building sub-sectors from Cluster 1. For each test run of the Abatement Model, a full review of the measures and their inputs/outputs was conducted. The reviews involved a number of Verco staff, and the results were reconciled with industry experience of costs, savings, paybacks, and relative performance. The measure characteristics were updated on an ad-hoc basis to ensure that measure performance for each sub-sector was reflective of implementation in practice. They were also compared against site survey findings for a sub-sector through review meetings with site surveyors.

4. **Additional benefits of measures.** The model only accounts for energy saving benefits. There may be other benefits, such as reduced maintenance costs, health benefits, increased productivity, improved comfort, and increased capital value of the building, that are not considered. These additional benefits are difficult to quantify, but may form a significant part of the investment case for an energy efficiency measure.

5. **Measure ordering, overlap, and exclusivity.** In order to determine the effect of each measure, the abatement model first calculated the effect of each measure individually, ranked them in order of internal rate of return (IRR), and then applied them sequentially in order of decreasing Internal Rate of Return. This ordering was chosen to capture rational business decision making, though other solutions were also possible. This ordering meant that if two measures affected the same energy end use, the measure installed second would have a smaller impact than if it had been installed first. This is

because the energy consumption would have already been reduced by the first measure.

When more than one measure affected the same variable in the abatement model, the effect was the product of the relative impact of the measures on the variable. In other words, the model reflected the fact that the combined effect of the measures was likely to be the product of their parts. However, this does not account for non-standard effects arising from combinations of measures and system complexities. This had limited impact on the Abatement Model outputs.

Measure exclusivity refers to cases where the installation of a particular measure means other measures can no longer be installed. This was explicitly taken into account in the model. For example, only one light fitting upgrade measure would be modelled for a particular building.

6. **Cost functions.** A range of cost calculation methodologies were be used to estimate measure cost for a specific building. The methodology varied by measure and where possible was based on cost curves derived from published sources. Where this was not possible the cost was calculated based on the simple payback of a measure multiplied by the energy savings generated by the measure, employing a minimum and maximum cost to ensure realistic costs were maintained for different sized premises. This meant that some of the abatement measure payback periods were based on the literature review, combined with refinement and calibration based on the site surveys and other knowledge sources.

   For example, the literature around improved insulation indicated a typical payback period. For a particular building, the cost of improved insulation was calculated based on the abatement potential of the improved insulation in the building and this typical payback period from the literature. If the insulation cost for the building exceeded the minimum or maximum cost thresholds for the measure, then the threshold was applied.

   Cost assumptions for the energy efficiency measures were taken from different sources that cover a range of building types. This has resulted in standard costs across different building types, when in practice the specifics of a particular building could result in higher costs. The data sources used were:

   - Outputs from previous research on the abatement potential in the public sector: In analysis undertaken for BEIS on the abatement potential in the public sector, the Carbon Trust close out database was used. It contained simple payback factors (amongst other factors) for a wide range of abatement measures, and was developed as a result of analysis on the energy savings from a large-scale energy efficiency audit programme between 2001 and 2011 conducted primarily in the public sector. The database totals 17,000 separate accounts and around 175,000 separate measure recommendations (in total around 225,000 recommendations). Summary outputs from this previous research were used for BEES[34].

- Salix Finance (2011): this database contained simple payback factors for a wide range of abatement measures, as used for the assessment of energy efficiency projects funded by Salix Finance, an independent, publicly funded company, dedicated to providing the public sector with loans for energy efficiency projects. The database is constructed from circa 100 organisations and includes higher education institutions, hospitals and local government offices. It totals 1,932 measures.
- Spon's Architect's and Builders' Price Book: which provides accurate, detailed and professionally relevant construction price information. This source contained costs data on many of the abatement measures applied during the project. It is constructed through industry research with a range of suppliers on typical component prices.
- Experienced energy auditor knowledge.
- Real quoted figures from reputable contractors, were available from Verco's in-house technology database. This covered measures such as lighting upgrades and variable speed drives.
- Iterative calibration.

The modelling includes an allowance for ongoing operational costs, as a percentage of the capital cost, dependent on the abatement measure type. The operational cost was only applied if the final cost of the measure was 25% greater than the minimum cost threshold of the measure. This ensured that in the instance of small-scale measures being installed to the building, the ongoing cost of operation did not outweigh the associated energy savings, given operational costs would unlikely be deemed cost effective and thus avoided.

7. **Bundling and hassle factors.** When a package of measures is installed in practice, there are reduced costs when compared to installing each measure individually (often as a result of the sharing of fixed costs, such as installing scaffolding, or sending an engineer to site). Measures were bundled based on technology group and a discount applied when two or more abatement measures in the same technology group were installed.

   Calculated capital costs of measures were also inflated by hassle factors (typically 10-15%) as a proxy for the reduced likelihood of measure installation. These factors were sourced from prior research undertaken on the ENUSIM model, an industrial energy efficiency modelling tool, where hassle factor for engineering measures (plant replacement, for instance) was higher than for behavioural measures.

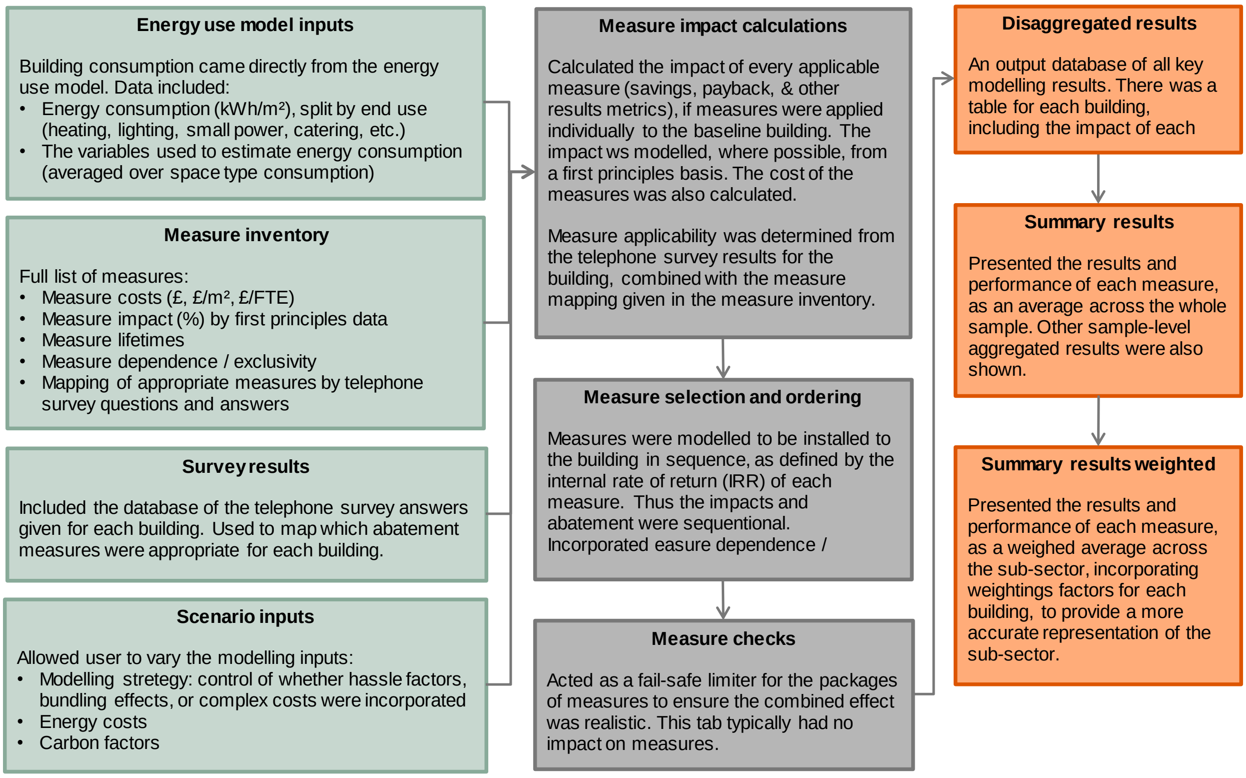
[34] https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/323113/ESOS__Analysis_of_the_Potential_for_Energy_Savings_from_Audits_FINAL.pdf

8. **Measure lifetime.** The lifetimes from the various data sources have been used to create an average measure lifetime to apply to particular types of measures (e.g. space heating controls or air tightness measures). This means that the final lifetimes used have more consistent lifetimes over groups of measures. The lifetimes of measures were sourced predominantly from Salix. This is because the database incorporates not just measure lifetime but also persistence factor (the effective lifetime of the measure, where it is providing full savings). These were then reviewed by the site surveyors.
9. **Carbon emissions.** Projected grid decarbonisation means that abatement measures installed today will have lower annual emissions savings by the time they need to be replaced. In order to calculate an annual carbon emissions saving for a measure, the total lifetime carbon savings associated with the measure (installed in 2015) were divided by the lifetime of the measure. This average annual carbon emissions saving better represented the savings over the lifetime of the measure, but was lower than the 2015 savings. The marginal emission factors were used[35].
10. **Other assumptions.** Further assumptions and data sources have been outlined below:
    - Energy costs and carbon factors have been taken from the Green Book supplementary guidance: valuation of energy use and greenhouse gas emissions for appraisal (2015)[35]. For simplicity it was assumed that all non-electrical fuel consumption was gas.
    - Discount rates have been applied to net present value (NPV) calculations, as per the Green Book guidance (3.5% for public sector buildings, and 8.5% for private sector buildings, and 7.2% for industrial buildings).

The mystery shopper data collection was also used within the Abatement Model. This was incorporated by editing the telephone survey responses to be specific to the input requirements of the Abatement Model to allow modelling of these buildings.

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

8.3.1 Abatement model structure



8.3.2 Model calibration and results validation

The calibration of the inputs and outputs of the Abatement Model has undergone an iterative process, to ensure the accuracy of the end results.

1. The inputs were reviewed by modelling experts at BEIS, and adjustments incorporated: The measure parameters were circulated to the BEIS project team for approval and where necessary further clarification was provided.

2. Expert review: the results from measures have been analysed, row-by-row, through a cycle of iterative modelling attempts, for each sub-sector. This has led to a range of refinements. This review was conducted by a team of senior consultants within the team at Verco, each having more than 7 years' experience in the field

3. Site survey comparison: As part of the sub-sector level calibration process, abatement model results were compared at measure level against the overall results obtained during the site surveys (i.e. the comparison was made for the sub-sector group of site surveys, rather than case by case). Where a significant deviation was apparent between the modelled value and the actual value, this was investigated to determine the probable cause. Where deviations in a particular measure were common, model recalibration would be undertaken. This process was undertaken through structured review workshops.

4. Mapping: the way in which the telephone survey questions and answers drive the opportunity for each measure to be installed has been reviewed. As part of the

structured review workshops, the question mapping would be reviewed to ensure it had been appropriately applied for the sub-sector.

5. Checking and sign-off process undertaken to ensure correct Abatement Model run procedure: An internal review was undertaken with BEES project manager, where each sub-sector model run was signed off. Where necessary the outputs would be escalated to the project technical director for review.

8.3.3 Model caveats – Abatement model

As in any modelling exercise, the abatement modelling process was subject to inherent assumptions and limitations relating both to the modelling approach and the quality and detail level of the various sources of data employed in the study. A list of the model caveats, as taken from the Abatement Model itself, are listed in table 8.5.

Table 8.5: Abatement model caveats

Assumption or simplification	Detail and implications
First principles data for space types were averaged over the whole building.	The energy use model provided outputs on a space type level, however, it was not practical to model abatement measures at this level of granularity. Averaging consumption over the whole building simplified the modelling.
Variables used to model impact were not impacted at the most granular level.	An example of this is for the heating energy end-use, the Abatement Model could impact the following variables: • Heat load (W/m^2) • Boiler efficiency (%) • Effective demand – full load equivalent (hrs) Whereas the End Use Model calculated the heating energy end-use from the following variables: • Heat load – fabric (W/m^2) • Heat load – infiltration (W/m^2) • Heating adjustment (ratio) • Proportion of building heated (ratio) • Hours of use (hrs) • Utilisation factor (ratio) • Heating controls effectiveness (ratio) This meant a reduced number of variables that the Abatement Model could impact. This had a negligible impact on the outputs of the model.
Measure impact was based on % terms, rather than absolute effects.	To allow the Abatement Model to process thousands of records, across a wide range of building types and sub-sectors, the abatement measures were modelled to have a percentage impact on the end-use variables. For example, heating load (W/m^2) was reduced by a fixed percentage, rather than being reduced to a fixed new heating load (W/m^2). This meant that all impacts of

Assumption or simplification	Detail and implications
	abatement measures were relative to the current building performance rather than improving building performance to a fixed level. In some cases this proportional impact was relatively easy to derive from available data (for example, for lighting measures), however, in other cases a single relative impact relied on expert judgement (for example, carbon and energy management).
Interplay between measures may not be fully accounted for. Replacement effects are not accounted for.	More complex interactions between measures were not accounted for due to the limited evidence base to use for input assumptions. For example, increased lighting efficiency may have a slight impact of increasing the heating demand.
The majority of measure cost calculations were based on simple payback methodology.	The abatement model had a suite of possible cost calculation functions that were used in specific examples (for example, cost curves of £/kW for boiler replacements). However, the simple payback methodology was the most commonly used. This meant that the cost of the measure was based on the energy savings (subject to minimum and maximum thresholds) rather than a ‘true’ measure cost. Also, in sub-sectors with many small buildings, minimum cost thresholds could render measures prohibitively expensive in many buildings.
Some of the cost data came from real installation data, which may introduce bias.	The abatement model used cost data from a variety of sources. In cases where this cost data was based on actual installations and a payback methodology used, it may provide a slight underestimate of measure cost as the measure was likely to be installed in places where it was most cost effective.
Measure applicability was based on telephone survey responses.	The abatement model relied on data collected in the telephone survey in order to identify appropriate measures for each building. Where possible, reasonable inferences were made in order to include abatement measures which were not directly covered in the telephone survey. However, renewable energy technologies, deep retrofit (involving moving occupants out of buildings to carry out wholesale energy focussed building refurbishment) and certain highly

Assumption or simplification	Detail and implications
	context specific measures were not accounted for in this analysis. Measure applicability was also reliant on the accuracy of the telephone survey responses, leading to more uncertainty in sub-sectors where respondents were typically less knowledgeable about their building.
Medical equipment abatement	Medical equipment consumption in the abatement model was based on benchmarks rather than the more detailed tool employed for the energy use model. Although no abatement measures specifically targeted medical equipment, the more general carbon and energy management measures resulted in a reduction in medical equipment consumption as part of the reduction in total building consumption. As a result, the abatement associated with medical equipment in a particular building may not directly correspond to the energy use. This had negligible impact at the sub-sector level.
The cost reduction when several similar measures were installed used a simple methodology	If more than one measure from a particular technology group was applicable to be installed, then the measures in that group received a percentage discount on the capital cost. This reduced the overall capital costs as a result of shared installation cost (for example, sending an engineer to site). However, the cost reduction was based on a fixed percentage reduction, whereas in reality it would vary based on the building and the bundle of measures installed. This introduced uncertainty in the bundling saving
The cost increase associated with disruption during installation of measures used a simple methodology	During the modelling, hassle factors were selected to be included meaning that measures received capital cost uplifts. In general, engineering measures receive a 15% uplift, and behaviour measures receive a 10% uplift. This simplification introduces uncertainty in the hassle cost.
Measures were sequenced by internal rate of return (IRR)	Abatement measures must be calculated by sequential modelling to account for potential overlap between measures. The relative IRR of the measures dictated the order in which measures in the abatement model were installed. In reality, if the package of measures were not installed at one time, then they may be split by measure type, to minimise disruption. This means the relative

Assumption or simplification	Detail and implications
	savings from each measure may differ from those modelled. Also, a different sequencing method would result in different modelled outputs.
Non-electrical abatement savings assumed to be gas	For simplicity, the non-electrical energy savings in the abatement model were assumed to be gas. This means that the associated cost and carbon savings may be very slightly underestimated due to the higher price and carbon emissions associated with oil.
Co-benefits are not included	The positive quantitative and qualitative impacts of co-benefits of energy efficiency measures (such as positive health and well-being impacts, energy security, asset values etc.) have not been included within the Abatement Model calculations. The abatement model only includes energy savings benefits and is therefore likely to underestimate the total benefits associated with abatement measures.

9 Quality assessment

9.1 Sources of error

While every effort was made to produce a BEES methodology tailored to meet the challenges of each sub-sector, some known limitations in the approach remained as a consequence of limitations of time, budget, and the diversity of the non-domestic building stock. The following section details the known limitations within in the standard and tailored methodology. The sector reports provide a focus on how these have affected individual sub-sectors.

9.1.1 Method Design

The telephone survey was limited to an average length of 25 minutes; this was based on known reductions in participation rates for longer surveys. Initial piloting of the BEES method demonstrated that use of other mediums (e.g. internet surveys) to supplement the telephone survey stage received very low participation and were not effective. The use of a telephone survey has several limiting consequences.

The data requested generally had to take the form of a multiple choice or numerical answer in order to permit subsequent automated analysis.

Sub-sector experts were not available in all sub-sectors; where this was the case, the telephone survey design was based on internal knowledge in the BEES team and existing published information, and the tailoring of the telephone survey may have been less effective as a result.

Customised energy and abatement modelling tools were used as well as a custom site survey approach, as no existing methods were deemed to meet the specification. Due to the extended nature of the study with survey and data analysis spread across an 18 month period, the tools, telephone survey scripts, and survey methods were improved iteratively as the project progressed, and later sectors of the analysis benefitted from this. However, the effect of this was partially offset by the fact that the public sector was analysed first, where participation and existing knowledge were strong, while sectors with poorer existing knowledge and greater variation within the stock (e.g. industrial) were analysed last.

It is worth noting that prior to commencing BEES a pilot of a variety of data collection methods was conducted in the retail sector.[36] This pilot study concluded that the use of

[36] BEIS, 2013, BEIS Non-domestic building energy use project phase I, Pilot study of the food and mixed retail sector available at https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/207319/DECC_Non_-_domestic_building_energy_use_project_phase_I.pdf

telephone surveys was the most appropriate approach to deliver economically the size of sample that was being targeted. The BEES telephone survey was also extensively piloted in the first six months of the programme, testing a variety of options. This included trialling a range of different question options with varying technical complexity and length as well as the use of alternative forms of data collection, such as online surveys. The team also tailored sections of the telephone survey to sub-sectors, and worked with sub-sector experts, to ensure that key energy characteristics were explored and that questions were suitably designed.

9.1.2 Sampling

The BEES study was not able to cover all non-domestic buildings in England and Wales. This section explains some of the limitations in selecting a suitable sample.

A proportion of the stock occurring in small or low energy intensity sub-sectors were excluded following an initial de-minimis review of the non-domestic stock - an initial list of 160 sub-sectors was reduced to a more manageable 50 sub-sectors.

Very large industrial complexes were excluded from the VOA data used in ND-NEED and were also excluded from the BEES study.

Royal Mail sorting offices and dedicated data centres were subsequently excluded from the study due to participation issues, and glasshouses were excluded due to the dominance of non-building (horticultural) loads which could not be modelled using the BEES approach.

The primary data source used for sampling in the study was ND-NEED. This dataset is based on Valuation Office Agency (VOA) data used to determine business rates. The VOA dataset identified premises based on the extent which is occupied by a single organisation. As a result, a ND-NEED record could be a single occupier site with multiple buildings, a single building with a single occupier, a building with multiple occupiers, or a single premises within a larger building.

Address matching is used within ND-NEED to link energy meter data to a specific record, and also within the BEES study to link telephone numbers (from the Experian dataset) to ND-NEED records. This process was subject to a degree of error and it was possible that some meters could be matched incorrectly to a building or premises, or an incorrect telephone number might be matched to a record. Questions were included in the telephone survey to confirm the address for the respondent was correct and determine whether they occupied a site, building or part of a building, but meter matching could not be verified at record level. Furthermore, energy meters may relate to a site, building, or individual premises, which may not match the premises covered by the BEES survey. This affected calibration processes for the energy modelling, as “part of building” records were subject to low confidence in their matched energy data.

Where ND-NEED was not available, other datasets were used for sampling. Some of these datasets were subject to bias or other limitations, for example the DEC dataset generally only includes buildings over 1,000m^2, and the dataset used for the Nursing homes sub-sector did not include matched energy data or building floor area. These alternative datasets were also often based on different core units to ND-NEED (e.g. buildings rather than premises).

Wherever possible, energy data matched to telephone survey records was used as a means of verifying that the energy use model was producing plausible results. However, matching rates varied in ND-NEED, and certain sub-sectors sampled from outside ND-NEED had no matched energy data available. In these sub-sectors, confidence in modelled results was reduced.

Gross Internal Area[37] (GIA) is used as a primary basis for describing the non-domestic stock. Within ND-NEED and other datasets used in the study, other measurement conventions such as Sales Floor Area or Net Lettable Area were used for some sub-sectors. Where this was the case a standard conversion factor was used to estimate the GIA of each record. In these cases, the gross floor area for some BEES records may vary significantly from the real world value but should be robust at sub-sector level.

There are also cases where VOA floor areas include outdoor spaces, or unusual exclusions (e.g. squash courts are not included in VOA floor areas as they are rated on a per court basis). UCL provided Verco with detailed VOA analysis which indicated the extent of the floor area in a given sub-sector that related to external areas. It was not possible to identify these cases at record level, but where the data indicated this might have a significant impact in a particular sub-sector, this was accounted for in the ratios used to adjust floor areas from net to gross values.

Due to limitations in how the population datasets could be split for sampling. Certain sub-sectors included a very diverse range of activities and energy characteristics that were not represented in those datasets but were considered important to disaggregate within BEES. This was a particular issue where the sub-sector distinction was set at an organisational level, or the valuation office agency definitions are very generalised, for example:

“University” in ND-NEED was split into “higher education – accommodation and “higher education – teaching and research” using the DEC dataset as a basis for sampling, but the latter still includes a very high diversity of buildings e.g. library, sports hall and restaurant.

“Small shops” in ND-NEED was split into “small food shops” and “small non-food shops” for the purposes of the BEES analysis.

The research team were advised by a team from UCL, who have worked with the VOA data extensively, on how best to overcome these issues. They were able to help identify

[37] As defined by the Royal Institute of Chartered Surveyors; see http://www.rics.org/uk/knowledge/professional-guidance/professional-statements/rics-property-measurement-1st-edition/ for further detail.

those sub-sectors most affected by a high diversity of building types, for example, to inform our sample design. They also provided statistics on the proportion of land associated with VOA record types to allow us to assess the sub-sectors most affected by the issue and determine how the sample design and subsequent data analysis should be adapted accordingly.

9.1.3 Data collection

9.1.3.1 Telephone surveys:

Information requested in the telephone survey had to take a form that respondents could answer immediately without having to refer to documentation. As a consequence, the telephone survey was not suited to asking for accurate numerical data or complex technical details (e.g. energy consumption, number of light fittings etc.) Simpler, multiple choice questions were required in many cases which tended to be more subjective and required assumptions to be made in order to interpret them in subsequent modelling activities.

When reviewing the telephone survey data, there was evidence that the quality of responses varied both within individual telephone surveys and between sub-sectors. If the telephone survey was answered by a more technical individual, building services questions tended to be answered well with few “don’t know” answers, but organisational and occupancy information was likely to be of lower quality. The opposite was likely in cases where the respondent was more organisationally focussed e.g. building manager or receptionist type roles. Respondents in sub-sectors with a high proportion of SMEs and smaller premises (e.g. hospitality sub-sectors, small shops) were more likely to be less energy aware and have more difficulty with technical questions.

To address the issues, the telephone surveyors used for the research were highly experienced and the same core team were used throughout the programme. This improved the likelihood of achieving responses from a wider range of respondents, as experienced interviewers were more familiar with the telephone survey script and the study objectives and explaining these to potential respondents.

9.1.3.2 Site surveys

Site survey time allowances were split into small, medium and large scale. However, buildings ranged from very small cafés to very large industrial and storage buildings of over 50,000m^2. In small, simple premises it was possible for surveyors to attempt to quantify all energy loads in the premises on an item by item basis, however in larger premises it was necessary to make simplifications and assumptions in order to cover all the major energy uses within the time allowance. Approaches used included area based sampling for lighting and small power loads, use of benchmarks for less significant end uses, and reliance on sub-metering data (where available).

In the early stages of the project, surveyors did not have access to the bespoke software used in later stages of the project, and had to transfer their survey findings into this format at a later date. This resulted in some loss of richness and in some cases, incomplete data as not all fields required in the full package were known at inception.

The site survey team were energy specialists; while training on appropriate techniques for carrying out barrier interviews was provided, budgets did not permit this task to be carried out by qualified social researchers and a risk of bias or false interpretation of results may remain.

The number of site surveys in each sub-sector was not sufficient to ensure a representative sample of the whole building stock, or cover a full range of energy intensive or exceptional energy uses in each sub-sector. This affected subsequent calibration procedures, as it was not possible to directly validate all assumptions made when constructing the energy use model, or validate the full range of end use results in each sub-sector.

When carrying out site surveys, the quality of data available onsite was highly variable. In some cases full Operation and Maintenance manuals were available while in others surveyors were required to estimate the ratings of items of inaccessible plant and equipment. A number of recipient organisations failed to provide energy data for their premises, or this data did not exist due to lack of sub-metering of their premises.

To improve efficiency and consistency while on site, the team used a site surveying tool. This facilitated rapid building energy use and abatement calculation and semi-automated the write-up of audit reports.

9.1.3.3 Barriers

Barriers data could only be gathered from site surveys. This means that findings are restricted to a sample size of 126 records. The barriers findings are qualitative descriptions of issues identified whilst on site.

The site survey had a number of deliverables that needed to be achieved. As a result the time for the interview on barriers was restricted to one hour. This constrained the level of detail that could be discussed on the types of barriers encountered by the site team.

The interviews were also typically only conducted with the site teams. As a result there were potentially a number of further internal and external stakeholders who could have provided a different perspective on the key barriers associated with a premises.

All the site surveyors were briefed on the research objectives of BEES and trained in social research techniques to improve the way in which they handled these interviews and the quality of the information they recorded.

9.1.4 Data screening/cleansing

Assumptions were required when imputing “don’t know” answers to telephone survey questions which were critical for modelling purposes. Where possible these would be based on telephone survey data from other records within that sub-sector, however in certain cases these substitutions had to be based on industry reference points or averages which may have masked diversity which existed in the sample.

Some sub-sectors had higher incidences of "don't know" responses in the telephone survey, and a higher percentage threshold for exclusion of records was required in these cases in order to retain an adequate sample. Where this was the case, confidence in subsequent modelling activities was reduced due to the increased prevalence of estimated data.

9.1.5 Lack of a clear truth model for the "universe" of non-domestic buildings

There is no single dataset available which adequately describes the total stock of non-domestic buildings in England and Wales, and the distribution of energy consumption within the stock. As detailed elsewhere in this report, the BEES study identified a range of alternative sources to fill known gaps, often informed by the CaRB2 model developed by UCL[38]. This made validation of BEES outputs a more complex task, as elements of the non-domestic stock may remain unaccounted for.

9.1.6 Modelling

Source of uncertainty for the energy use and abatement model are contained within Section 8.

[38] See https://www.ucl.ac.uk/energy-models/models/carb2 for further detail.

9.2 Non-standard methodologies

While every effort was made in order to maximise the applicability of the standard method to all sub-sectors in the study, challenges were encountered during the research which required the development of non-standard approaches in order to deliver the project outcomes. Table 9.1 lists the non-standard approaches taken. More detailed descriptions of the non-standard methodologies with particular significance follow the table. For a more detailed explanation of non-standard sector approaches please refer to relevant sector report.

Table 9.1: Non-standard sector approaches

Non-standard approach	Description	Reasons for implementing	Mitigation activities	Impact on BEES results	Sub-sectors affected
Telephone survey recruitment via direct contact with respondent organisations	Organisations within affected sub-sectors were contacted directly and asked to contribute multiple records to the BEES study	ND-NEED could not be matched to contact details Sub-sectors not covered by ND-NEED Poor uptake of telephone survey	None	Full random sampling was not possible so a degree of bias was introduced. Where respondents provided multiple records, repetition of telephone survey responses was noted.	Large food shops Large non-food shops Retail warehouses Military (all sub-sectors) Ambulance stations Police stations Small non-food shops Restaurants & takeaways Factories Stores Warehouses Large distribution warehouses

Non-standard approach	Description	Reasons for implementing	Mitigation activities	Impact on BEES results	Sub-sectors affected
Estimation of floor area over telephone during telephone survey	Respondents asked for a floor area in m^2, or to estimate area as a number of 3 bedroom houses.	No floor area data in ND-NEED/main sampling frame Record is part of a building or a building on a campus	Other metrics collected (no. bedrooms, max capacity) as a comparison dataset. EPCs manually sourced for Pub floor areas	Low confidence in floor areas affected calibration activities during energy modelling	Nursing homes Pubs Places of worship Private hospitals
Mystery shopper data collection	Partial telephone survey records were completed by mystery shoppers	Telephone survey uptake limited *and* direct contact with organisations in affected sub-sectors failed to recruit sufficient responses.	Additional substitution/ assumptions required in order to render mystery shopper records fit for modelling	Reduced range in outputs from the energy use model and abatement model, limiting confidence in calibration activities.	Department stores Large food shops Retail warehouses Large non-food shops

Non-standard approach	Description	Reasons for implementing	Mitigation activities	Impact on BEES results	Sub-sectors affected
Site survey recruitment via direct contact with respondent organisations	Organisations were contacted and asked to participate in the site survey programme.	Telephone survey uptake rate poor, or site survey uptake within telephone survey respondents poor. Non-standard recruitment used for telephone survey results	Site surveyor completed a telephone survey equivalent record if required.	In some sub-sectors an organisational bias was introduced to the sample	Large food shops Large non-food shops Retail warehouses Military Ambulance stations Police stations Betting shops University non-residential University residential Factories Restaurants Takeaways
Site survey recruitment from outside telephone survey sample	Site survey respondents sampled from ND-NEED and contacted directly (no telephone survey)	Uptake rate for site surveys within the telephone survey sample poor	Site surveyor completed a telephone survey equivalent response. This was used for modelling.	It was not possible to ensure a good range of energy intensity/size in site survey candidates. Minimal impact on modelling procedures.	Cafés Restaurants & takeaways Pubs
Use of non-ND-NEED datasets which were subject to bias	Certain datasets contained known bias, for example DEC data is biased towards buildings >1,000m^2	ND-NEED data did not provide an adequate sampling frame		Small buildings under-represented in the BEES study.	Detailed in sector level reporting

Non-standard approach	Description	Reasons for implementing	Mitigation activities	Impact on BEES results	Sub-sectors affected
Simplified modelling approach	Some complex end uses were modelled using a simple indicator rather than a tree diagram approach. Key end uses	Poor existing literature/knowledge on end use consumption	Calibration against telephone survey and site survey data	Poor confidence in affected end use estimates; knock on effect on confidence in overall energy estimates	Many sub-sectors; detailed in methodology challenges sections of sector reports.
Restricted calibration process	Matched energy data for industrial buildings includes out-of-scope energy used by industrial processes. Energy use model estimates could not be compared directly with matched data during calibration. Certain sub-sectors/sectors had limited matched data available, restricting the calibration process.	Scope limitation within BEES study Limitations within source datasets Sub-sector not covered by ND-NEED or DEC datasets	Industrial respondents were asked to estimate the proportion of electrical and non-electrical energy which was associated with process loads. In other sub-sectors estimates of energy consumption were requested	Confidence in BEES end use energy estimates was low in affected sub-sectors.	Factories Workshops Cold stores Places of worship Nursing homes Private hospitals Department stores MOD (all sub-sectors)

Non-standard approach	Description	Reasons for implementing	Mitigation activities	Impact on BEES results	Sub-sectors affected
Estimation of input data for energy modelling	While some sub-sectors have been the subject of extensive research which could be used to pre populate the energy use model, in other cases very little prior work has been undertaken. In these cases reasonable estimates were made in order to facilitate the modelling process.	Lack of existing knowledge of sector / sub-sector	The calibration process compared model outputs against matched data and site surveys in order to confirm the plausibility of underlying estimates.	Confidence in end use estimates in these sectors was medium	Affected individual end uses in a range of sub-sectors, but was particularly significant in: Vehicle showrooms Non-vehicle showrooms Fire & ambulance stations Nursing homes Museums Theatres Small food & non-food shops Department stores Nurseries
Industrial barrier interviews	Non-process loads were often considered insignificant by respondents, which impeded the completion of barriers interviews			Fewer findings and limited confidence in barriers data	Factories Workshops

9.2.1 Mystery shopper data collection

Poor levels of uptake for the BEES study were encountered in major high street retail chains, many of whom specifically requested that shops were not contacted directly by the telephone survey process.

In order to boost the sample size in affected sub-sectors, a survey process was developed for public areas of buildings. In this approach, a "mystery shopper" would visit a store, and attempt to collect data which could be used to complete or approximate answers to a sub-set of the questions in the retail telephone survey. 100 surveys were carried out in this way. This approach was subject to significant limitations compared to the normal telephone survey approach:

- No information on back of house/non customer/plant areas
- Mystery shoppers were not energy experts so only very limited technical information on building services and specialist energy uses could be gained, and this was subject to low confidence.
- Clipboards etc. could not be used so data was limited to simple information which could be remembered and documented after leaving the shop.
- Organisational attitudes to energy management could not be determined.

As a consequence of the partial data collected as a result of this process, subsequent energy modelling procedures were significantly affected

- In order to process records through the energy use model, extensive assumptions were required to fill in critical technical information such as main heating fuels and heating, cooling, lighting and ventilation systems (including age, controls, and type).
- Further variables such as staff and customer numbers and number of catering covers also had to be based on reasonable "typical" assumptions,
- As a consequence, energy use model results demonstrated a much narrower range than seen in other sub-sectors.

Abatement modelling procedures were somewhat affected, as the richness of data on plant and equipment normally used to estimate abatement potential could not be collected using the mystery shopper approach. However, since the majority of measures in the abatement model were contingent on core questions in the telephone survey, this meant that the typical number of measures implemented in the abatement modelling for these sites was not significantly affected. Furthermore, the use of extensive assumptions in filling in critical question responses, outlined above, meant that the majority of measures could be activated in the abatement modelling. The overall outcome is that the abatement potential for these sites is expected to be underestimated compared to sites surveyed through standard means.

9.2.2 Non-standard approaches to determining record floor area

Within the study, there were sub-sectors where no robust premises level dataset existed which included floor area data. In these cases, premises were sampled from the best available list (typically the Experian dataset) and alternative methods were used to estimate the floor area of each record.

Pubs: Estimates of floor area were requested in the telephone survey, either on a square meter basis, or by selecting an equivalent sized house (e.g. 2-bed, 3-bed) which reflected the size of the pub. This data was supplemented by manually looking up the EPC certificate for the records (where available) which was used as the primary source of data. Additional site surveys were carried out in the pubs sub-sector which provided additional validation of the floor area estimation procedures.

Nursing homes: The respondents were asked to confirm the number of bedrooms in the nursing home, and the total floor area was estimated based on this figure. Floor area estimates were also requested in metres squared, if the respondent could give a value confidently.

Private hospitals: The respondents were asked to confirm the floor area or number of beds in the hospital. In many cases the floor area data provided was a specific value (rather than a rounded number estimate) and may have been good quality. Where floor area data was heavily rounded or absent, the number of bedrooms was used to estimate site floor area.

Places of worship: The respondents were asked to confirm the floor area or number of worshippers the main space could accommodate.

Hotels: The respondents were asked to confirm the number of bedrooms in the hotel, and the total floor area was estimated based on this figure. Floor area estimates were also requested in square metres, if the respondent could give a value confidently.

In all cases, this approach reduced confidence in record floor areas and consequently, any energy intensity calculations made using the floor area data were subject to considerable uncertainty, which had a knock on effect on calibration processes. High variance between modelled predictions and matched energy data was common in these sub-sectors.

9.3 Summary table of the sampling errors

Confidence intervals have been calculated at the 95% significance level based on the weighted data[39]. The confidence intervals by sector for electrical energy intensity and non-electrical energy intensity are provided in the tables below. Confidence intervals at sub-sector level are shown in the sector reports.

Table 9.2: 95% Confidence intervals for electrical energy intensity

	Mean (kWh/m^2)	Confidence interval (kWh/m^2)
Retail	192	± 17
Offices	160	± 26
Hospitality	241	± 61
Industrial	63	± 5
Storage	53	± 13
Health	133	± 15
Education	62	± 10
Emergency services	86	± 13
Military	60	± 16
Community, arts & leisure	62	± 11
All sectors	**106**	**± 8**

Table 9.3: 95% Confidence intervals for non-electrical energy intensity

	Mean (kWh/m^2)	Confidence interval (kWh/m^2)
Retail	50	± 9
Offices	74	± 16
Hospitality	226	± 55
Industrial	80	± 13
Storage	41	± 9
Health	237	± 23
Education	126	± 11
Emergency services	203	± 21
Military	100	± 16
Community, arts & leisure	137	± 24
All sectors	**95**	**± 6**

[39] A 95% confidence interval will contain the true population mean in 95% of samples.

9.4 Comparison of BEES modelled energy use with Non-domestic National Energy Efficiency Data-framework

9.4.1 Introduction to the comparison

Part of the validation process for BEES energy use was to compare the total electricity and non-electricity uses with metered energy consumption matched for the premise matched through the Non-domestic National Energy Efficiency Data-framework (ND-NEED)[40]. This was possible where premises were sampled from ND-NEED. This report covers the offices, retail, hospitality, industrial, storage and aspects of the community, arts & leisure sectors. Comparisons for the industrial sector are particularly challenging since BEES excludes industrial process energy uses that are included in ND-NEED. It is predominately the public sectors (education, health, emergency services & military) that were not sampled from ND-NEED. In total 1,970 (53%) of electricity records and 828 (28%) of non-electricity records are included. The lower non-electricity coverage reflects the sectors excluded in particular the public sector where non-electricity is more widely used.

There are a number of limitations to making this comparison.

- In this analysis, 2010-2012 average consumption data from ND-NEED has been compared to a standard modelling estimate based on the building activities in 2014-2015.
- ND-NEED data only covers metered energy consumption. Comparisons for non-electricity are therefore all non-electrical energy in BEES but only gas in ND-NEED. Gas data in ND-NEED is weather corrected which should make it more comparable with a standard climate modelled outcome used in BEES.
- In the cases of part of building or multiple building records there is uncertainty as to whether the energy consumption from BEES and ND-NEED relate to the same floorspace.

Given these issues it is not surprising that some premises have quite significant differences between BEES and ND-NEED. It would though be reasonable to expect good comparisons within sub-sectors subject to the treatment of outliers. To help make better comparisons without the influence of the most extreme outliers the comparisons are also shown removing the top and bottom two cases in each sub-sector.

[40] BEIS Non-domestic National Energy Efficiency Data-framework (ND-NEED) https://www.gov.uk/government/statistics/non-domestic-national-energy-efficiency-data-framework-energy-statistics-2006-12

9.4.2 Overall comparison

The analysis below is based on the ratio of BEES and ND-NEED consumption for electricity and non-electricity. A ratio greater than one implies the BEES estimate is higher. Overall the comparisons are very good with the BEES estimates just 5% lower than ND-NEED for electricity and 13% of non-electricity when potential outliers are excluded. There are larger differences at sector and sub-sector level. In each sub-sector the comparison is presented with and without outliers and the rimmed ratio is better (closer to 1) in most cases. The overall all sectors comparison is slightly worse when excluding outliers in particular for non-electrical which implies the outliers excluded would reflect cases with higher BEES estimates compared with ND-NEED.

Table 9.4: Summary of overall ratio by sub-sector[41] (Ratio = BEES/ND-NEED)

		ALL CASES		Trimmed to exclude top and bottom two cases			
Sector	**Sub-sector**	**Electricity ratio**	**Non-electricity ratio**	**Electricity ratio**	**Non-electricity ratio**	***Electricity cases***	***Non-electricity cases***
OFFICES	<50m^2	*	*	*	*	*5*	*1*
OFFICES	50-100m^2	0.85	0.79	0.83	0.85	*19*	*11*
OFFICES	100-250m^2	1.47	0.69	1.40	0.66	*103*	*72*
OFFICES	250-500m2	0.97	1.11	0.99	1.08	*79*	*61*
OFFICES	500-1,000m^2	0.81	1.17	0.90	0.90	*40*	*28*
OFFICES	1,000m^2+	1.13	0.59	1.00	0.61	*33*	*23*
RETAIL	Department Store	1.14	*	1.00	*	*18*	*6*
RETAIL	Hairdressing	1.56	0.87	0.89	0.80	*42*	*19*
RETAIL	Hypermarket	*	*	*	*	*8*	*6*

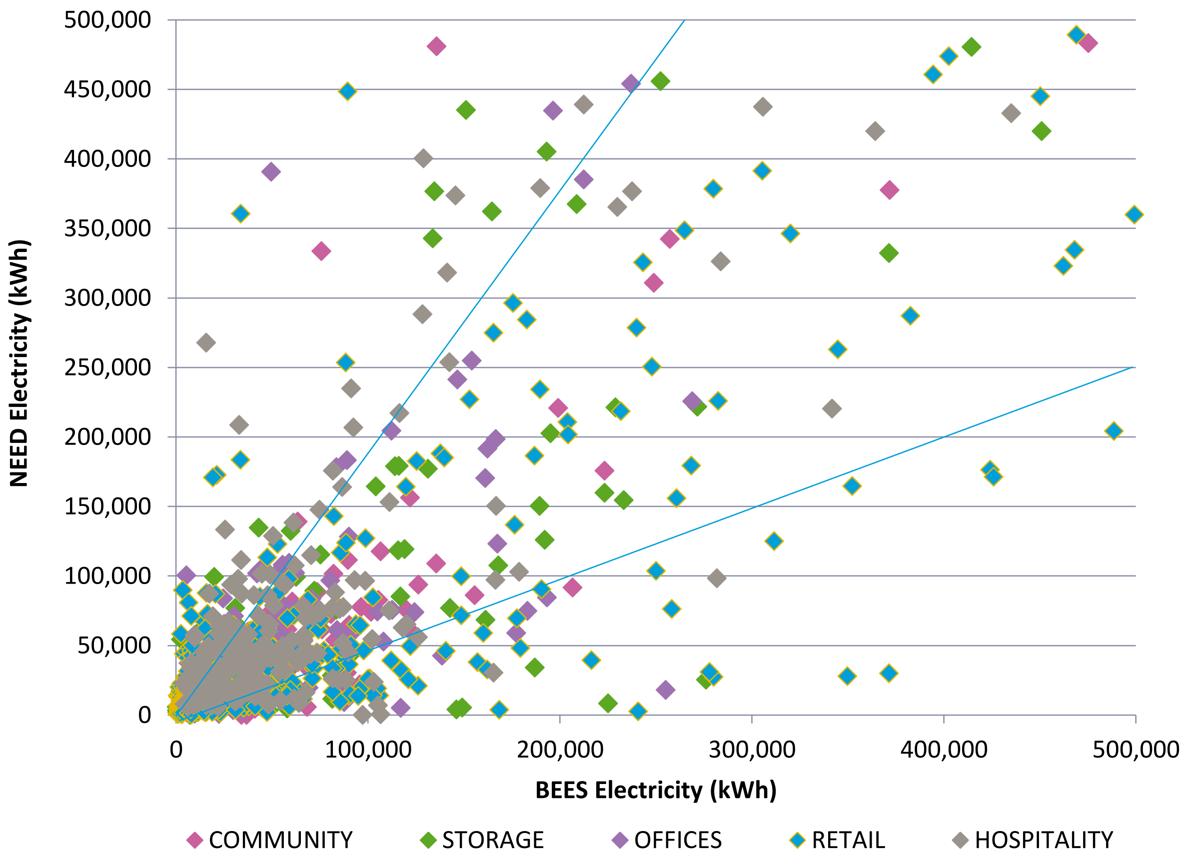
[41] In the offices sector bespoke sub-sectors based on size band have been used for this analysis. Cells with less than 10 cases are shown as "*"

RETAIL	Large Food Shop	1.38	*	1.17	*	*21*	*7*
RETAIL	Large Non-Food Shop	1.08	*	1.11	*	*28*	*9*
RETAIL	Retail Warehouse	1.32	*	1.23	*	*16*	*5*
RETAIL	Showroom	1.59	0.76	1.43	*	*25*	*11*
RETAIL	Small Food Shop	1.39	1.21	1.54	1.25	*159*	*20*
RETAIL	Small Non-Food Shop	0.96	1.15	0.93	1.18	*463*	*94*
RETAIL	Vehicle Showroom	1.22	*	1.23	*	*27*	*9*
HOSPITALITY	Cafe	0.99	0.76	0.80	-	*48*	*17*
HOSPITALITY	Pub	0.77	0.86	1.00	0.90	*87*	*70*
HOSPITALITY	Restaurant	0.69	1.36	0.69	0.92	*46*	*37*
HOSPITALITY	Takeaway	0.96	0.99	0.97	-	*19*	*14*
HOSPITALITY	Hotel	0.73	0.73	0.70	0.90	*39*	*32*
STORAGE	Cold Store	*	*	*	*	*6*	*0*
STORAGE	Large Distribution Warehouse	1.51	1.83	*	*	*15*	*5*
STORAGE	Store	0.94	0.96	0.88	0.92	*70*	*20*
STORAGE	Warehouse	0.51	1.20	0.67	1.21	*145*	*66*
COMMUNITY	Club	1.26	0.73	1.24	0.74	*43*	*30*
COMMUNITY	Community Centre	1.20	0.64	1.28	0.54	*26*	*22*
COMMUNITY	Leisure Without Swimming	*	*	*	*	*9*	*3*
COMMUNITY	Leisure With Swimming	*	*	*	*	*6*	*5*
COMMUNITY	Museum	*	*	*	*	*7*	*2*
COMMUNITY	Theatre	*	*	*	*	*5*	*5*
INDUSTRIAL	Factory	0.52	0.33	0.69	0.99	*60*	*31*
INDUSTRIAL	Large Industrial	0.29	*	*	*	*10*	*6*
INDUSTRIAL	Workshop	0.54	0.42	0.56	0.66	*243*	*81*
TOTAL		**0.97**	**0.97**	**0.95**	**0.87**	***1,970***	***828***

9.4.3 Scatter plots

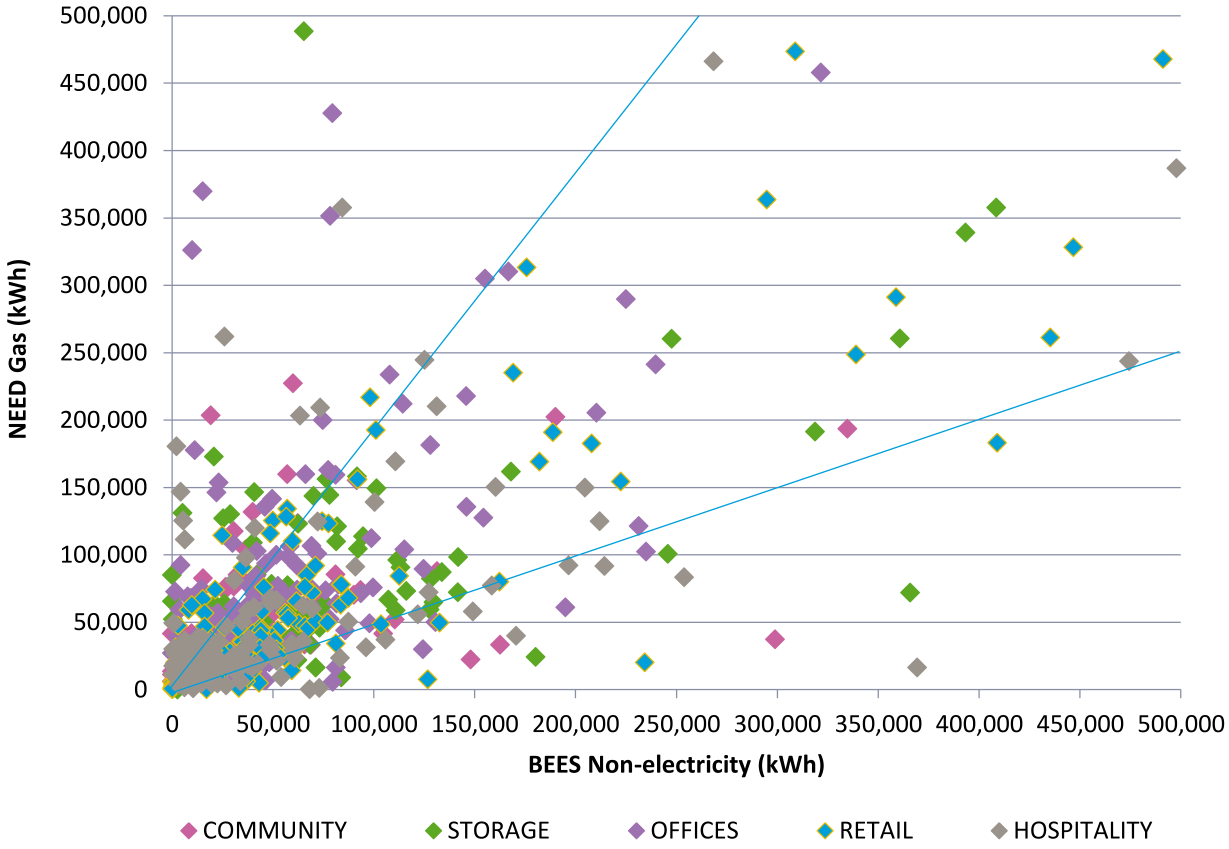
The scatter plots below show at record level the ratio of BEES and ND-NEED consumption for electricity and non-electricity. Premises with a higher BEES estimate appear in the bottom right of the chart. The points close to the diagonal are the most consistent comparisons. The axes have been truncated at 500,000kWh to make the chart viewable. In both charts lines are drawn to show the data points within a factor of 2 in the comparison. The industrial sector has been excluded as this comparison is not representative due to BEES excluding industrial process use.

Figure 9.1: Comparison of electricity consumption estimates: BEES v ND-NEED[42]



[42] Note axis have been truncated at 500,000 kWh

Figure 9.2: Comparison of non-electricity consumption estimates: BEES v ND-NEED[43]



While these charts do show significant scatter at premises level, two-thirds of estimates are within a factor of 2 and around 40% are within 50% for electricity. The non-electricity comparison is similar but with a higher concentration of low BEES estimates. Table 9.5 summarises the comparisons for electricity and non-electricity.

Table 9.5: Share of matched records by band. Comparison of BEES v ND-NEED

	Electricity	Non-electricity
Less than half	19%	27%
50-100% lower	13%	13%
Within 50%	42%	38%
50-100% higher	8%	9%
More than double	17%	14%
Total	**100%**	**100%**

[43] Note axis have been truncated at 500,000 kWh

9.4.4 Actions taken

A range of actions were taken following these results. In most cases the line by line analysis of the records showed greater suspicion was with the ND-NEED data and the metered consumption was deemed to be implausible if it related to that BEES record. In two cases the BEES consumption for one or more end-uses was considered extreme and a couple of records were removed due to this.

Within the retail sector, low non-electrical intensity was found for a number of records that ND-NEED had no matched record of non-electrical use. Over 60 records were found to have non-electrical energy use of less than 1,000 kWh. In many cases the sole non-electrical end use was hot water with survey respondents claiming they had non-electrical hot water supply. This has been noted within BEES as an element of uncertainty.

9.4.5 Summary

This analysis shows that overall the BEES modelled estimates are within 15%. However there is significant uncertainty in the results at premises level and in some sub-sectors as a whole. It should be noted that the discrepancies which are seen will be contributed to by uncertainties in both datasets and whether estimates refer to a comparable amount of floor-space. A specific concern that has not been addressed in the final dataset is the low non-electrical uses in retail that may overestimate the number of sites using non-electricity.

9.4.6 Industrial summary

In the industrial sector the standard comparison was not meaningful due to the exclusion of industrial processes in BEES. Respondents to the survey were asked what share of their energy use was used for industrial processes. As table 9.6 shows, when this factor is applied BEES moves from an under-estimate to an over-estimate compared to ND-NEED with the exception of electricity for workplaces. It is known that the reliability of industrial consumption is weak as it is hard to be sure that all meters at a site have been successfully aggregated.

Table 9.6: Summary of overall ratio by sub-sector[44] (Ratio = BEES/ND-NEED)

	ALL CASES		Trimmed to exclude top and bottom two cases		Adjusted for process use	
	Electricity ratio	Non-electricity ratio	Electricity ratio	Non-electricity ratio	Electricity ratio	Non-electricity ratio
Factory	0.52	0.33	0.69	0.99	1.92	3.34
Workshop	0.54	0.42	0.56	0.66	0.81	3.30

[44] In the offices sector bespoke sub-sectors based on size band have been used for this analysis.

9.5 Comparison of BEES modelled energy use with existing BEIS statistics

9.5.1 Introduction

This section compares the BEES modelled estimates of energy consumption with existing BEIS statistics as part of the validation process. The main sources of data cover the United Kingdom and therefore adjustments are needed to reflect the reduced geographical scope of BEES (England & Wales) together with the sectors and energy uses that are out of scope. The main data sources available were:

- Digest of UK Energy Statistics (DUKES) which covers the full energy balance
- Sub-national energy data to derive the expected share of consumption within England & Wales
- National Energy Efficiency Data-framework (ND-NEED) matching energy consumption to VOA premises type.
- Energy consumption in the UK (ECUK), non-domestic end use data modelled from the N-DEEM study of the 1990s

DUKES statistics are the best estimate of total energy consumption in the UK and this is the main data source for comparisons of total energy consumption with BEES. The ND-NEED comparisons enable sector breakdowns that are similar to those in BEES, so this comparison focused on sector breakdowns. ECUK has detailed breakdowns of energy end use and was chosen to compare the BEES end use consumption break downs to. The Sub-national energy data were used to calculate a geographical adjustment to estimate the England and Wales energy consumptions for the BEIS statistics which cover the UK.

It should be noted that the comparison with ND-NEED is between non-electricity consumption in BEES and gas consumption in ND-NEED so is not a direct one.

Through carrying out these comparisons it became clear that the exclusion of Industrial processes from the scope of BEES had a large impact on the total energy consumption estimates. This was not unexpected and is covered in detail later in paragraph 9.5.4.

9.5.2 Adjustments

To make fairer comparisons between BEES and other data sources adjustments have been applied to reflect the scope of data sources.

- Geographic adjustment – used to estimate England and Wales statistics from sources covering the United Kingdom.
- Coverage adjustment – used to adjust for the non-domestic building floor area that is not covered by BEES.

The majority of the BEIS statistical sources used in this comparison cover the whole of the UK, BEES only covers England and Wales. To make the required adjustments it has been assumed when making these adjustments that the energy intensities are constant for energy both within the scope of BEES and outside BEES. This constant energy intensity assumption enabled us to estimate the amount of energy that needed to be excluded where this detailed information was not known.

A geographical adjustment has been applied to the DUKES. The adjustment for removing Scotland and Northern Ireland was estimated using DUKES and BEIS sub-national statistics. The adjustment applied to both Electricity and Non-electricity was 81%.

Table 9.4: Geographical Adjustment – Energy coverage

	Gas (GWh)	Electricity (GWh)	Comments
England and Wales	163,690	160,350	Geographic break down of meter readings 2012.
United Kingdom	203,020	199,030	DUKES industry plus services consumption 2012.
Geographic adjustment	81%	81%	England and Wales divided by UK

It should be noted that there are differences between what is included in the DUKES and Sub-national meter reading statistics. The sub-national statistics have been weather corrected whereas DUKES is not. DUKES statistics are created using a top down approach, where the sub-national figures are created using a bottom up approach starting at the meter level consumptions. For more information on the differences between these two sets of statistics please refer to the methodology documentation for the sub national meter point statistics[45]

A coverage adjustment was also applied for this analysis. As shown in table 9.5, BEES covers about 92% of the total non-domestic building floor area and so other BEIS statistics have been adjusted further by multiplying by 92%. As shown in Appendix B a de-minimus approach was taken meaning that approximately 7% of floor area has been excluded. A further 1% of floor area was lost during the field work. Table 2.2 shows the share of floor area excluded in the original data analysis. In the final floor area in table 3.1 some further sectors were removed due to insufficient responses to the survey.

[45] https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/489718/Sub-national_methodology_and_guidance_booklet_December_2015.pdf

Table 9.5: Floor area within scope[46]

BEES floor area	Floor area (GIA thousand m2)	Percentage
Area in final scope	953,400	92%
EXCLUDED in de-minimus[47]	76,700	7%
EXCLUDED in fieldwork	6,200	1%
TOTAL	**1,036,400**	**100%**

9.5.3 Comparison with DUKES

The 2014 figures published in DUKES 2015 after adjustments have been applied are 134,560 GWh for electricity and 221,080 GWh for non-electricity. These figures are somewhat higher than those calculated from BEES, electricity 84,820 GWh and 76,240 GWh non-electricity.

When the industrial processes are excluded however, and comparisons are made between the services (public administration and commercial) and the BEES figures excluding Industrial, the comparison is a lot more accurate. DUKES figures for services after all adjustments are 69,050 GWh electricity and 75,280 GWh for non-electricity, compared to 73,500 GWh electricity and 61,830 GWh non-electricity in BEES.

Table 9.6: Summary of DUKES comparisons, total and services[48]

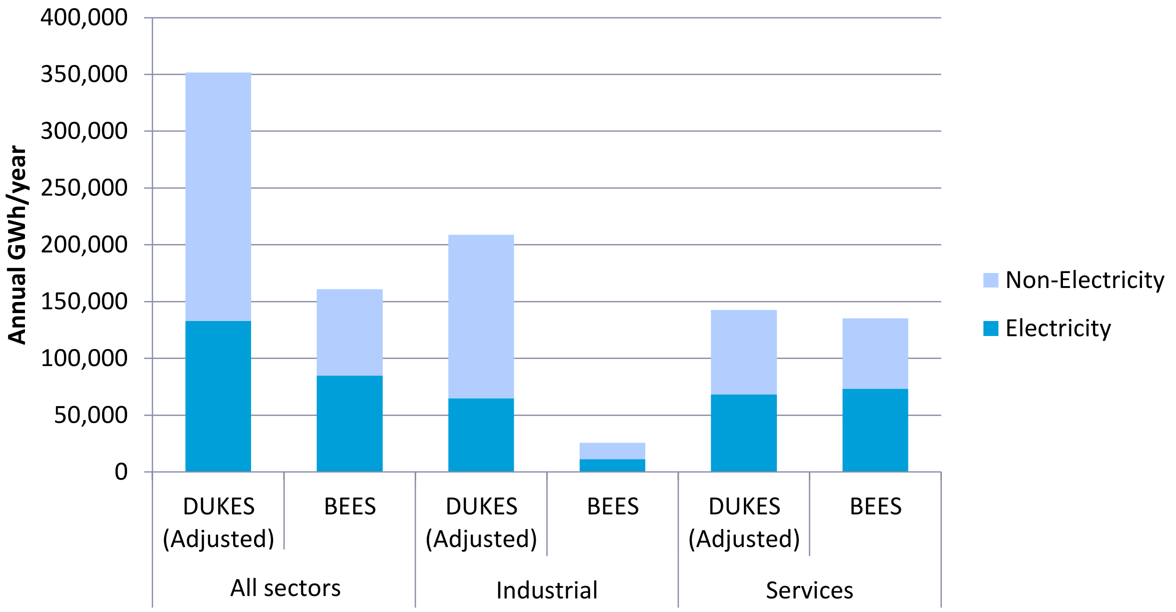
	DUKES (Adjusted) (GWh)	BEES (GWh)	Difference
Electricity total	134,560	84,820	-37%
Non-electricity total	221,080	76,240	-66%
Electricity services	69,050	73,500	6%
Non-electricity services	75,280	61,830	-18%

Figure 9.3 represents this information graphically and the all sectors comparison suggests BEES captures less than half the energy consumption found in DUKES after adjustments. The majority of this difference occurs in the industrial sector where the amount of total energy consumption captured by BEES is only 12% of that found in DUKES. The scope of BEES does not include industrial processes and most of this difference can be explained by that.

46 Figures from table 2.2 in Appendix B.
47 This includes the exclusion of the agriculture sector.
48 BEES services figures calculated by removing the Industrial sector.

When the services sector was considered separately from the industrial sector the comparisons with DUKES are much more favourable. The BEES estimate for the sum of electrical and non-electrical consumption was 6% lower than for DUKES. The comparisons for each energy type were also very good with electricity being 6% higher in BEES than DUKES and non-electricity being 18% lower. These were both within the pre-set 20% difference level that was set as being acceptable. As a result of this comparison we can conclude that the BEES estimates are credible, in particular for electrical energy consumption.

Figure 4.3: DUKES adjusted consumption comparison with BEES for Electricity and Non-electricity.



9.5.4 Industrial sector

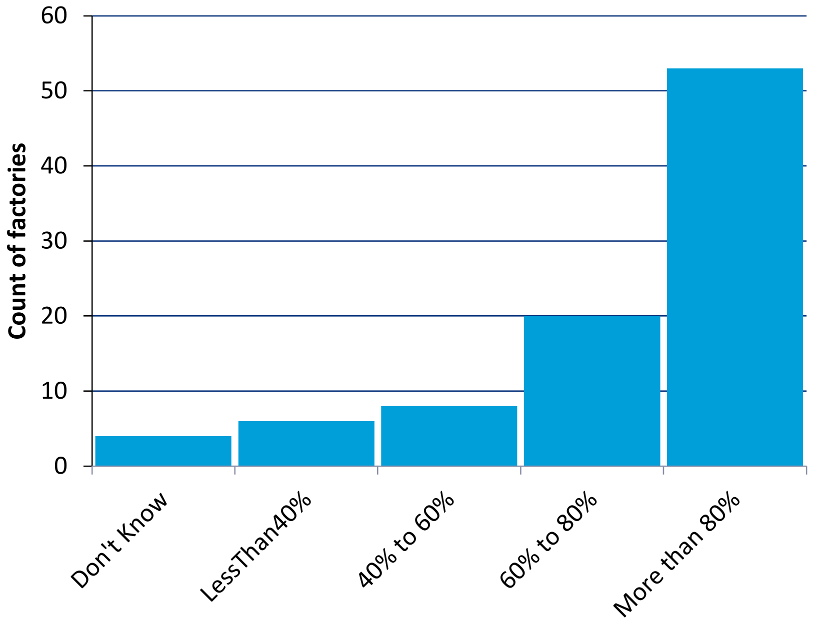
The reason for the large difference between DUKES and BEES for the industrial sector is that Industrial processes are not in the scope of BEES. These processes are in scope of DUKES and so a difference arises.

The following question was asked of the factories subsector: “What proportion of this building/premise’s electricity / non-electricity fuel consumption is taken up by factory processes?”

This question essentially askes the respondent to give an estimate of the proportion of energy consumed by the building that is out of scope of BEES. The responses to this question have been plotted in the figure 9.4 and 9.5 below for both electricity and non-electricity.

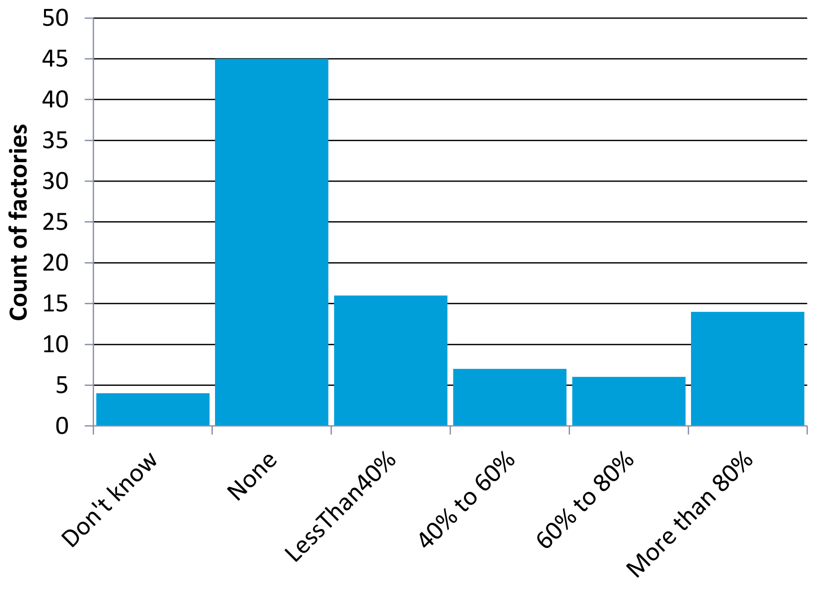
For electricity we can see that the majority of respondents said that over 80% of their factories electricity consumption was on factory processes. If these respondents are the large energy consumers, this would have a big impact on the comparison with DUKES and could go some way to explaining the differences in the previous section.

Figure 9.4: Electrical energy out of scope for BEES in the Factory sub-sector



For fossil fuels it is a slightly different situation, the most common response was that none of their fossil fuel consumption was for factory processes. However, there were still a significant proportion of respondents stating that over 80% of their consumption was for factory processes. Again, if these are the large fossil fuel consumers this could explain a large part of the difference between BEES and DUKES.

Figure 9.5: Non-Electrical energy out of scope for BEES in the Factory sub-sector



Work has been carried out to quantify this difference and is shown below.

Table 9.7 below shows the proportion of the industrial sector energy consumption that is not used for industrial processes by the different energy types. This has been calculated using weighted average from the question mentioned previously, taking the mid-point of the response category for the question and multiplying it by the consumption for that record.

When these are compared to the DUKES and BEES industrial sector comparison shown in section 9.5.3, it shows that a lot of the difference in that comparison is explained by industrial processes.

For electricity the DUKES comparison difference is very close to the amount of electricity being used for industrial processes and is out of the scope of BEES. For non-electricity an estimated 65% of the industrial sectors consumption is for industrial processes, this is lower than the 90% of DUKES consumption not covered by BEES. These results suggest that industrial processes not being in scope of BEES explains the low BEES industrial sector electricity consumptions compared to DUKES. The scope of BEES explains most of the difference for non-electricity consumption as well but to a lesser extent.

Table 9.7: Summary of the Industrial Sector Industrial Energy Consumption.

	Electricity	Non-electricity	TOTAL
Estimated share of energy not for industrial sector processes	19%	35%	24%
Ratio of BEES to DUKES industrial consumption (after adjustments)	17%	10%	12%

9.5.5 Comparison with Non-Domestic NEED

In this section, comparisons are made between Non-Domestic NEED (ND-NEED) and BEES. The Industrial sector was excluded as this is not comparable due to the exclusion of industrial process use in BEES. A geographical adjustment is not used for this comparison since both BEES and ND-NEED cover England and Wales only. The same sector coverage adjustment applied during the DUKES comparison was applied to the ND-NEED statistics.

The ND-NEED comparison was used to compare the energy use by building sectors. The sector definitions in ND-NEED are slightly different to those used in BEES, to reduce the impact of this energy intensity was used in this comparison and only the most comparable sectors are included. Medians were used as they are less susceptible to outliers making the comparisons more robust.

When looking at the electricity comparison in Table 9.8 most results were within a broadly acceptable range. Retail was the sector with the largest difference where the BEES median was 25% lower than the ND-NEED value. Overall the BEES median was 1% lower than the ND-NEED value.

Table 9.8: Median Electricity intensity comparison with ND-NEED

Electricity kWh/m^2 medians

Sector	ND-NEED 2012	BEES	Difference
Offices	84	88	5%
Retail	155	116	-25%
Warehouses	30	32	7%
All sectors[49]	**80**	**79**	**-1%**

When considering the non-electricity comparisons in Table 9.9 there were some much larger differences. It is important to note that the ND-NEED figures are likely to be over-estimated due to the ND-NEED weighting, as it is not possible to definitively determine the total number of non-domestic gas users. ND-NEED is limited by incomplete address matching but has assumed in the weighting methodology that if an electricity meter matched to a premises but not a gas meter that no gas is present. The BEES analysis casts doubt on this as explained in table 9.10.

The BEES estimated median for the retail sector was very low at 2 kWh/m^2, compared to 194kWh/m^2 in ND-NEED. This is the result of there being a lot of low but non-zero responses for hot water heating which are not likely to be real. It is more likely that electrical energy use has been recorded incorrectly and these need to be added to the electricity figures. If additional energy was classified as electricity this would increase the electricity figures. The non-electricity figures would also increase as a result of low users being taken out and these would improve the comparisons across both energy types in the retail sector.

[49] Includes other sectors not separately identified above.

Table 9.9: Median Non-Electricity intensity comparison with ND-NEED.

Non-electricity kWh/m^2 medians

Sector	ND-NEED 2012	BEES	Difference
Offices	175	89	-49%
Retail[50]	194	2	
Warehouses	60	13	-78%
All sectors	**158**	**75**	**-53%**

Table 9.10 shows that 78% of the buildings surveyed in BEES had a non-electrical meter; this is a lot higher than the 44% of electrical meters found that also had a corresponding non-electrical meter. As explained above there is considerable uncertainty from ND-NEED on the number of gas meters but the BEES figures can be considered credible as respondents have said they have non-electrical energy uses. Of course some of the BEES non-electric users will be non-gas.

Table 9.10: Proportion of premises with non-electrical energy use.

Sector	ND-NEED	BEES
Offices	45%	85%
Shops	44%	59%
Warehouses	32%	70%
Restaurants	67%	82%
Total	**44%**	**78%**

The sector comparison between BEES and ND-NEED for electricity was good which suggests that the sector break down of BEES is accurate. The comparison of non-electricity consumption was not as close but there is a known coverage issue for gas meters in ND-NEED.

[50] The BEES survey identified a significant number of cases in the retail sector with low but non-zero non-electrical energy use. The comparison of median non-electrical energy intensity is not reliable.

9.5.6 Comparison with previous modelling in ECUK

This section compares BEES estimates to ECUK statistics for services in 2014, focusing on total energy consumption and a breakdown by end uses. It is important to remember that the ECUK figures are based on a study carried out in the mid-1990s and have been extrapolated forward, so there will be differences between these and BEES that can be explained by this.

As shown in Table 9.11 and Table 9.12 respectively; comparing BEES to the ECUK after adjustments have been applied the total services the BEES figure is 15% higher than the ECUK figure for electricity and 25% lower for Non-electricity.

Table 9.11: ECUK End-use Electricity Comparison

	ECUK (adjusted) (GWh)	BEES (GWh)	Difference
Catering[51]	8,740	17,830	104%
Computing	4,020	7,640	104%
Cooling and Ventilation	5,750	9,860	71%
Hot Water	2,310	1,500	-35%
Heating	9,150	7,070	-23%
Lighting	25,860	16,800	-35%
Other	8,160	12,790	57%
Total	**63,990**	**73,500**	**15%**

Table 9.12: ECUK End-use Non-electricity comparison.

	ECUK (adjusted) (GWh)	BEES (GWh)	Difference
Catering	6,340	5,910	-7%
Hot Water	11,510	6,060	-47%
Heating	63,320	45,250	-29%
Cooling and Ventilation	240	130	-45%
Other	1,260	4,480	267%
Total	**82,670**	**61,830**	**-25%**

Figures 9.6 and 9.7 below are a graphical representation of the information from tables 9.11 and 9.12 and show the electricity and non-electricity consumption for ECUK and BEES by end use and show how the proportions of energy used for each end use have changed over time.

[51] In this comparison cooled storage is included with catering

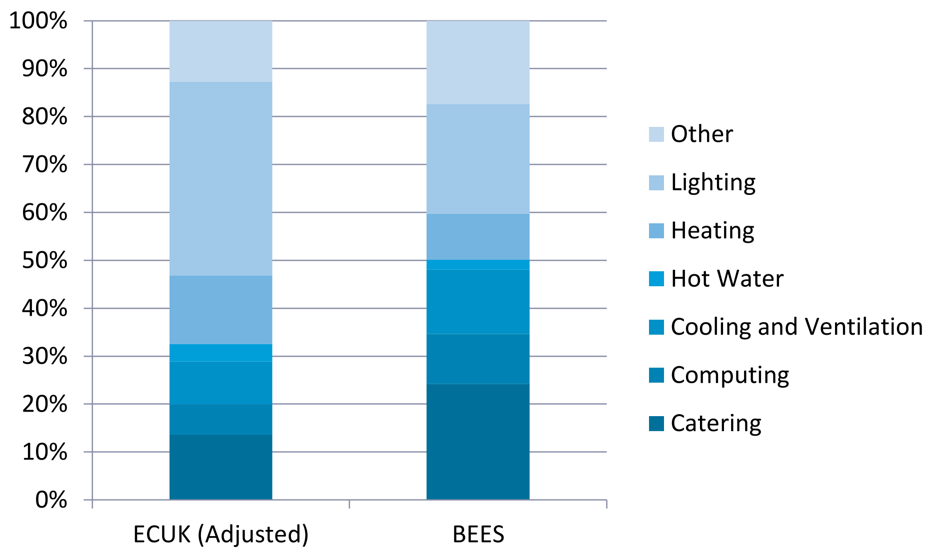
For electricity the most noticeable change is the reduction in the proportion of energy being consumed by lighting which consumes 40% of the electricity consumed in the ECUK figures and only 23% in the BEES figures. Over time there have been Improvements in the efficiency of lighting that are not included in the ECUK trend, this increase in efficiency could explain why the BEES estimate for lighting consumption is lower than the rolled forward ECUK figure.

Cooling and ventilation is another end use where there is a difference in the proportion of electricity being consumed, the ECUK figures 9% compared to the BEES figure of 13%. The same upward trend is seen in the computing end use where the proportion of electricity consumed is 6% in the ECUK figures and is 10% in the BEES figures. The reason for these differences is the increased use of these end uses since 1995; this is not taken into account when rolling forward the ECUK figures.

The proportion of electricity consumed in the “other” category for BEES is slightly higher than that of ECUK 17% and 13% respectively; this reflects the increased use of electricity for modern small power end uses.

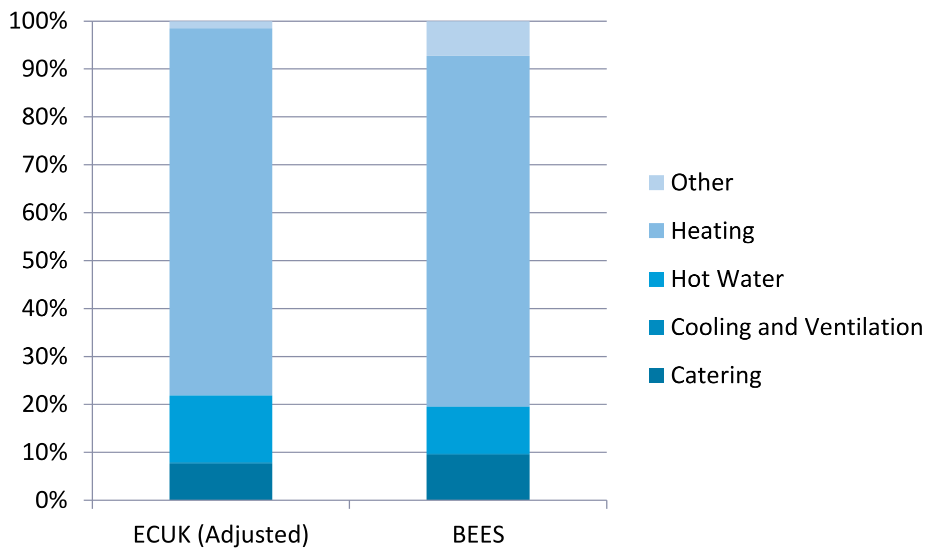
There was a large difference in the proportion of catering between the two data sources, with 14% of electricity consumption in ECUK and 24% of electrical consumption in BEES used for catering. This could reflect the rise in number of meals eaten at restaurants since 1995. It should be noted that the catering end use contains cooled storage for this comparison and any increase in the amount of warehouse style refrigeration and large food retailers may be contributing to this increase.

Figure 9.6: ECUK End-use Electricity comparison



Compared to electricity there are fewer differences between ECUK and BEES for the proportions for each end use of the total energy used. The largest end use is heating in both cases, in ECUK it accounts for 77% of non-electricity energy consumption and for BEES it accounts for 73%. Hot water and catering proportions are similar between the figures, but the other category is significantly higher in the BEES figures at 7% compared to 2% in the ECUK figures.

Figure 9.7: ECUK End-use Non-Electricity comparison



The ECUK end use results for the services sector from 2015 are now based on BEES evidence. Previous ECUK statistics were based on a study conducted in 1995 for the last 20 years and BEES is the more recent source of consumption information.

The ECUK statistics for the services sector are now based on the BEES evidence. Historic statistics prior to 2015 are based on a study conducted in the mid-1990s.

9.5.7 Summary

Overall the comparison of BEES to other energy consumption statistics show positive results. There is a clearly explained difference in the industrial sector, where a large amount of energy consumption from industrial processes which was out of the scope of BEES. When this was removed, the comparisons for the services sector were very positive.

The ECUK comparisons reflect an update in the way non-domestic buildings are consuming energy, compared to 20 years ago when N-DEEM, the survey ECUK is calculated from was conducted.

9.6 Overview of the Shadow Modelling

9.6.1 Introduction

The Building Energy Efficiency Survey (BEES) used a model to convert telephone survey answers for a particular building into estimates of energy use. These building level estimates are then weighted and aggregated up to the BEES population.

A peer review project was carried out by (University College London (UCL) to assess the ability of the BEES energy use model to represent the energy performance of non-domestic buildings, based on data obtained through the BEES telephone survey. The full report of this has been published alongside BEES on Gov.uk.

9.6.2 Summary of methodology

The buildings in a sample of two building types (health centres and offices) were modelled using an independently-developed model (the SimStock building energy stock model developed by UCL) to assess whether or not it would be possible to significantly improve the modelled results using the same data and help inform BEIS as to the level of confidence to place in the BEES energy use model.

SimStock has three main differences from the BEES energy use model:

- A simple 3D representation of the building is produced rather than reliance on only floor area.
- A dynamic buildings simulation model is used rather than a static calculation.
- Telephone survey responses are mapped to model parameters and values using a machine learning approach rather than engineering judgement and manual calibration.

During this peer review, the outputs from both the energy use model and SimStock model were compared against matched energy meter data to assess the accuracy of their predictions.

A sensitivity analysis of uncertain inputs in individually constructed building models was also carried out for a sample of site surveyed health centres and offices, to help assess the choice of variables within the energy use model.

9.6.3 Key findings

- Overall, the energy use model was found to be fit for purpose. That is, it produced reasonable estimates of energy use given the available input data, especially at the sub-sector level.
- It was also found that the energy use model included the key variables that impact the energy use in a building, though it was noted that uncertainty in the input telephone

survey data could still lead to uncertainty in energy use estimates for an individual building, regardless of the model used to produce these estimates.

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