Study on Energy Use by Air-Conditioning: Annex C Analysis of Energy Performance Certificate Data

BRE Client Report for the Department of Energy & Climate Change, HPR218-1001 - June 2016

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This report provides supporting information and explanation to the DECC Report "Study on Energy Use by Air-Conditioning: Final Report" (BRE Client Report HPR218-1001 The views expressed in this report are those of the authors, and not necessarily those of the Department of Energy and Climate Change (nor do they reflect Government policy).

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Annex C: Analysis of Energy Performance Certificate (EPC) Data

This Annex reports the results of analysis carried out on a sample of anonymised EPC data (Energy Performance Certificates) for 490 air-conditioned buildings with air conditioning inspection reports. The sample was drawn from the same 500 buildings as those for which Air Conditioning Inspection Reports were analysed for this study (the results are provided in Annex B). It describes the process used to identify any outlying data points and the rationale for excluding them from further analysis. It also describes the data extraction procedure and the data cleansing and quality checks performed on the data.

In addition to the overall EPC rating the data set includes information on the building envelope and installed building services along with calculated energy performance (based on standardised occupancy assumptions) and recommendations for improving cooling efficiency. For each building, the data identifies the building type, the type(s) of air conditioning system(s) installed, their reported efficiency, the proportion of floor area that is treated and the calculated energy consumption.

The analysis reported here identifies the relationships between various variables in the sample EPC data set. In particular it provides an understanding of the types of air conditioning systems found in different buildings types, including the number of systems and typical proportion of cooled floor area. It also provides information on the range of energy performance for both chillers and cooling systems in the installed stock. Analysis of the calculated energy intensity for cooling is also explored and compared to standard benchmarks. This indicates that calculated cooling energy use provides a reasonable basis for extrapolating limited monitoring data to other building and system types. The results of an analysis of the recommendations contained in EPC reports is also provided.

1. Overview

1.1. The number of buildings for which monitored air conditioning data is available for this study is very small and the sample is restricted to offices. (Monitoring results are provided in Annex D). Furthermore, it is unlikely that enough high quality monitoring data will be available to provide adequate coverage of all sectors, building characteristics or system types. Therefore EPC data was identified as an intermediate information source that can provide a basis for extrapolating some detailed monitoring data to other buildings types.

1.2. There are three main aspects to the EPC analysis carried out for this study.

- Analysis to provide a better understanding of the types of systems installed in different building types.
- Analysis to determine the expected energy performance for different system types and building types
- Analysis of those improvement recommendations provided in EPCs which are specifically related to cooling

1.3. In order to generate an EPC rating, data is collected on the building function/type, the physical characteristics of the buildings, the building servicing systems installed and the efficiency of building servicing components. Much of the input data and intermediate calculations are captured and stored during the EPC lodgement procedure

1.4. The EPC calculation procedure determines the annual energy consumption for different building services based on the actual data and a number of assumptions. The way this is done is specified in the UK's National Calculation Methodology (NCM). The actual data used in the calculation includes:

- The assumed[1] physical characteristics of the building envelope e.g., air tightness and thermal performance
- The dimensions and geometry of the buildings and layout of internal spaces within it
- The type of building servicing systems installed and the efficiency of key components
- The primary building type and the activities carried out within various internal spaces (activity areas)

1.5. Standard assumptions are applied based on the building type and on the system type. These include:

- The occupancy times and occupant density for the building type and activity area
- The amount of internal heat gains from energy using equipment
- The service level required from the building services e.g., temperature set points, lighting levels etc.
- The performance ratios for different system types that take into account ancillary energy use and the effectiveness of controls

1.6. Although the assumptions regarding occupancy and system requirements are standardised, they are based on typical values which have undergone consultation to ascertain that they are appropriate. This means that the energy consumption values calculated should, on average, provide a reasonable reflection of the actual consumption at least in relative terms.

1.7. Further details of the procedure for generating EPCs are provided in Section 2.

2. Energy Performance Certificates

2.1. Energy Performance Certificates are required for all buildings when they are built, sold or let. EPCs are intended to send market signals about the relative performance of comparable buildings. For non-domestic buildings, performance is compared to a virtual reference building that is the same size, shape and type as the actual building, but is defined to be built and serviced to a specific “recipe”, which is described in the UK NCM documents (NCM Modelling Guide and SBEM User Guide and Technical Manual).[A]

2.2. The analysis carried for this study was on data relating to the actual building and not to the reference building.

[1] These are not measured values, but are determined based on visual inspection by trained assessors.

2.3. EPC calculations must be performed using a standard procedure using an approved software program. The majority of EPCs issued for existing buildings use the government's standard software tool SBEM. The EPC sample for this study is for buildings which have undergone air conditioning inspections and are therefore existing building and the vast majority of these were calculated using SBEM. Further information on the process for calculating EPCs, including the definition of the reference building, is provided in the UK NCM documents.

2.4. In order to generate an EPC the following information must be collected and entered into the EPC software by an accredited assessor:

- General information about the building, the owner, and the certifier/assessor, and select the appropriate weather data for the building location.
- Data on the different forms of constructions and glazing types used in the fabric of the building.
- Zones that represent areas within the building which house different activities (e.g., office area, toilets, circulation spaces).
- Details of the envelopes of each zone, i.e., walls, floor, ceiling, etc. The envelopes' areas, orientations, thermal performance, the conditions of the adjacent spaces, and the constructions.
- Within each envelope element, information on the areas and types of glazing or doors.
- Details of HVAC (heating, ventilation, and air conditioning) systems, the HWSs (hot water systems), and any SES (solar energy systems), PVS (photovoltaic systems), wind generators, or CHP (combined heat and power) generators used in the building.
- Lighting system and local ventilation characteristics of each zone, together with the HVAC system and HWS which serves it

2.5. For existing buildings it is not always possible to obtain information that is sufficiently detailed e.g., U value for construction elements or energy efficiency ratios for heating and cooling equipment. In these instances default values are assumed which correspond to a relatively poor energy performance. In these instances the calculated energy performance results may not reflect the intrinsic energy efficiency of the building, however there is no reason to expect the proportion of default values to differ between different building types and system type so EPC data should still provide a good reflection of relative energy performance between different building types.

2.6. As well as efficiency rating outputs, an EPC also includes a recommendations report. This identifies actions that could be taken to improve the energy efficiency of the building. The recommendations report includes energy efficiency improvements which are automatically generated by the SBEM software based on the information entered into it by the assessor plus any additional recommendations identified by the assessor.

2.7. When an EPC is lodged onto the Register, information used to generate the EPC and some intermediate calculation values are also captured. This information is stored as an XML file. The XML files include information for both the reference building and the actual building.

2.8. The sample of EPC data provided was for buildings which also have been issued with Air Conditioning Inspection Reports (ACIRs) and related to EPC certificates issued between 2009 and 2015 and is expected to consist of buildings with air conditioning systems which have a capacity of over 12kW.[2] The vast majority of the buildings are the same as those with Air Conditioning Inspection Reports that were analysed for Annex B.

[2] Air conditioning inspection reports are required for buildings with systems >12kW within 5 years of being put into service and then every 5 years thereafter from 2009.

3. Data extraction procedure

This section describes the procedure used to extract data from the EPC files provided.

3.1 490 data files were received from DECC in XML format. These were transferred into a series of data files in Excel using the following procedure.

- The entire contents of each XML file were cut and pasted into an Excel file
- A macro was created which stripped out unnecessary separators (e.g., “<>”) and data blobs[3] from the file.
- The information was reorganised into a number of separate data tables.

3.2 All the data tables created contain the unique EPC reference no. (CEPC: RRN or building ID) for the building, and most files also include the unique air-conditioning inspection report reference number (CEPC: Related-RRN). This enables the data tables to be linked to each other and to the Air conditioning inspection reports (ACIR).

3.3 Attempts were made to match the EPC and ACIR certificates with a view to undertaking a combined analysis. However, for around 50% of the sample there were found be significant discrepancies in the either the building type, air conditioning system type and/or floor area. This is probably due to a combination of; differences in the property unit boundaries applied to the two assessment procedures (both EPCs and ACIRs may be carried out on single properties or a portion of a property (where the property houses different activities and/or occupants), and changes that have occurred in the time between the two assessments being carried out.

3.4 Some tables include data which relates to the building as a whole, in which case there is only one entry per building, but for all system level data and recommendations there may be more than one entry per building.

3.5 To avoid expending excessive resources for dwindling returns, the extraction procedures restricted the number of activity areas to 20 (one property potentially has more than 20 activity areas), and the number of system types to 10. Due to problems with file sizes and field name headings, some of the fields that were not expected to be useful for this project were omitted.

3.6 The data tables and key contents are listed below:

[3]These are long data strings which contain coded modelling inputs and intermediate calculations used to derive the EPC rating. This data cannot be analysed.

- General: Building type, location, building environment, calculated ratings and benchmarks, floor area.
- Building Areas: Activity and floor area for zones within each building (Maximum of 20 separate activity areas).
- Building Actual: Floor area, external area, assessed infiltration rate, assessed level of insulation, calculated energy use by fuel and end use (kWh/m^2)
- Building Reference: As Building Actual but with values for the reference building
- *System Types (Actual): calculated cooling demand (MJ/m^2) and calculated energy use (kWh/m^2), calculated system SSEER and assessed SEER for each system and building activity areas served by system.
- *System Types (Reference): As Building Actual but with values for the reference building.
- *Recommendations: recommendation code, description and CO_2 impact
- Technical Info: Air conditioning inspection commissioned and EPC certificate number

*For these tables there may be more than one entry per building.

4 Characterisation of the EPC sample

4.1 The sample of EPC data was restricted to those for which ACIR certificates had already been issued. As ACIR certificates have only been required from 2009 onwards and the latest EPC data related to 2015 this means that the EPC assessment could have been carried out up to 6 years after the ACIR certificate was issued. The vast majority of the buildings are the same as those with Air Conditioning Inspection Reports that were analysed for Annex B.

4.2 The remainder of this section presents descriptive statistics for the EPC sample which can be used as a basis for extrapolating more detailed monitoring results to other system types and buildings.

4.2.1 This first part of the analysis identified the prevalence of different system types across the building stock. It explored which types of systems are found in:

- Different building types
- Different activity areas within buildings
- Geographic location
- Building size

It also determined

- the number of system types per building
- the proportion of total building floor area treated

4.2.2 The property types for EPCs align with Town and Country Planning Use Classes which are outlined in Table C1.

Building Type	Description
A1/A2 Retail and Financial/Professional services	Shops, retail warehouses, hairdressers, undertakers, travel and ticket agencies, post offices, pet shops, sandwich bars, showrooms, domestic hire shops, dry cleaners and funeral directors. Banks, building societies, estate and employment agencies, professional and financial services and betting offices. It also includes launderettes.
A3/A4/A5 Restaurant and Cafes/Drinking Establishments and Hot Food takeaways	For the sale of food and drink for consumption on the premises - restaurants, snack bars and cafes. Public houses, wine bars or other drinking establishments (but not night clubs). Also premises for the sale of hot food for consumption off the premises.
B1 Offices and Workshop businesses	Offices, research and development, light industry appropriate in a residential area.
B2 to B7 General Industrial and Special Industrial Groups	Use for the carrying on of an industrial process other than one falling within TCP Use class B1 and including those within TCP Use classes B3 to B7.
B8 Storage or Distribution	Use for storage or as a distribution centre.
C1 Hotels	Hotels, boarding and guest houses where no significant element of care is provided.
C2 Residential Institutions - Hospitals and Care Homes	Residential care homes, hospitals and nursing homes.
C2 Residential Institutions – Residential schools	Residential boarding schools, residential colleges and training centres. These follow a schedule of work similar to the schools schedule (with similar working days, breaks and holiday periods).
C2 Residential Institutions - Universities and colleges	Universities and other residential campuses. These follow a schedule of work similar to the universities schedule (with similar working days, breaks and holiday periods).
C2A Secure Residential Institutions	Use for a provision of secure residential accommodation, including use as a prison, young offenders institution, detention centre, secure training centre, custody centre, short term holding centre, secure hospital, secure local authority accommodation or use as a military barracks.
D1 Non-residential Institutions - Community/Day Centre	Crèches, day nurseries and day centres.
D1 Non-residential Institutions - Crown and County Courts	Law courts
D1 Non-residential Institutions - Education	Non-residential education and training centres.

Building Type	Description
D1 Non-residential Institutions - Education	Art galleries, museums and libraries.
D1 Non-residential Institutions – Primary Health Care Building	Non-residential clinics and health centres.
D2 General Assembly and Leisure plus Night Clubs and Theatres	Cinemas, music and concert halls, bingo and dance halls, swimming baths, skating rinks, gymnasiums or sports arenas (except for motor sports or where firearms are used). This type also includes night clubs and theatres.
Others - Car Parks 24 hrs	Enclosed or underground car park reserved for parking cars with 24 hrs operation.
Others - Emergency services	Includes fire stations
Others - Miscellaneous 24hr activities	Miscellaneous 24hr activities.
Others - Passenger terminals	Airport, Bus, Train and Sea Port passenger terminals.
Others - Stand-alone utility block	Modular building that just provides shower/toilet facilities
Residential spaces	Residential spaces within non-domestic buildings not designed or altered for use as a separate dwelling (as defined in DCLG's Guide to energy performance certificates for the construction, sale and let of non-dwellings, section 4.4).

Table C1: Buildings Types for EPCs

4.2.3 Descriptions of the HVAC system types used in EPCs are shown in Table C2.

System Type	Description
Split Systems	This category comprises both single splits systems and multi-split systems. Multi-split systems are similar to single split systems except that they are multiple indoor units which serve separate rooms or zones. These are individually connected to a single outdoor unit via refrigeration pipework. A split system can usually operate in cooling only mode or in heat pump mode for heating.
VRF	VRF (Variable Refrigerant Flow) multi-split systems are a more sophisticated version of the multi-split system. These systems supply heating and cooling and may have either 2-pipe refrigerant pipework, or 3-pipe refrigerant pipework which enables heat to be transferred from a room that requires cooling to another within the same building that requires heating. A variable speed compressor allows the system capacity to be varied to accurately match the building heating and cooling loads.
Rooftops	These are packaged units where both sides of the refrigeration cycle are housed in a single unit which is located on the outside of the building (often on top of the roof) together with an air handling unit which supplies the conditioned air to the building via ducts.
All Air Constant Volume (CAV)	These systems provide a constant volume air supply at a single temperature. Cooling of the air is normally provided by a chilled water or direct expansion (DX) cooling coil in an air-handling unit (AHU) which distributes the cooled air to rooms via ductwork. The air-handling unit is usually able to vary the proportion of fresh to recirculated air to meet the ventilation requirements of the building and to minimise cooling requirements. Some systems also include terminal reheat coils to allow different air supply temperatures in different rooms or zones.
All Air Variable Air volume (VAV)	As above but different cooling requirements of individual rooms or zones can be accommodated by varying the volume of air supplied to each room or zone. The AHU fan speed is varied to match the overall supply air flow rate and therefore significant fan energy savings are possible when the overall cooling requirement is low.
Water based fan coil unit (FCU)	Chilled water (and sometimes also hot water) is circulated around the building to supply terminal units in the rooms where a fan blows room air over a cooling coil. Most fan coil systems are also supplied with conditioned fresh air from a central AHU. The room air and ducted fresh air are mixed at the inlet to the FCU.
Water based induction	Similar to the above except that a minimum quantity of conditioned fresh air from an AHU is injected through nozzles to induce a flow of room air over a chilled water coil before the mixed air flow is supplied to the room.
Heat Pump Loop	This system is based on a constant temperature water loop circulated around the building with self-contained heat pumps providing either heating and cooling of individual rooms or zones by transferring heat from or to the water loop. These systems are sometimes referred to by their historical trade name “Versatemp”. Some versions are also fed with ducted conditioned fresh air from an AHU which is mixed with room air at the inlet to the unit. The water loop is kept cool by a central chiller, cooling tower or dry air coolers.
Chilled Ceiling/Passive chilled beam/other construction embedded cooling	High temperature chilled water is circulated through embedded cooling pipes, passive coils or cooled ceiling panels to provide cooling by conduction and natural convection.
Active chilled beam	As with passive chilled beams, high temperature chilled water is circulated within cooling coils but room air flow is induced through the coils by a minimum quantity of conditioned fresh air supplied from a central AHU and injected through nozzles but at a lower pressure than with induction units.

Table C2: System Types for EPCs

4.2.4 Table C3 shows the number of buildings and total floor area for the sample of EPCs broken down by Building type.

Building Type	Number of Buildings	Floor Area (m²)
A1/A2 Retail	319	391,313
A3/A4/A5 Restaurants & Cafes	32	20,522
B1 Offices	99	376,660
B2/B7 Industrial	5	53,432
B8 Storage and Distribution	6	22,980
C1 Hotels	16	132,255
C2 Hospitals and Care Homes	1	8,221
C2 Universities and Colleges	1	558
D1 Libraries Museums and Art Galleries	1	2,351
D1 Primary Health Care	4	4,424
D2 General Assembly and Leisure	6	13,827
Grand Total	**490**	**1,026,543**

Table C3: Number of buildings and total floor area for EPC sample broken down by building type

4.2.5 In terms of number of buildings, retail premises account for 65% of the sample, with offices accounting for a further 20% of the total, and hotels, restaurants and cafes accounting for the majority of the remainder. In terms of total floor area, retail premises account for 38% of the sample with offices accounting for a further 37% of the total, and hotels, restaurants and cafes accounting for the majority of the remainder.

4.2.6 The predominance of retail and offices premises in the sample is in line with expectations from an analysis of historic (1994) VOA data which showed that they account for around 90% of non-domestic buildings premises with either full or partial air conditioning.

4.2.7 However, it should be noted that on a direct comparison between VOA data on premises and from other sources may not coincide due to differences in the property unit boundaries. Whilst both EPCs and valuations can be carried out on single properties or a portion of a property (where the property houses different activities and/or occupants. The extent of the difference used to apportion properties is subjective and this will be exacerbated by the fact that non-domestic spaces frequently undergo changes in building use and/or occupants. In addition, a rating valuation may be carried out on a number of adjacent properties on the same site (where they house the same primary building activity and occupants activities)

4.2.8 Figures C1 and C2 show the percentage breakdowns of the EPC sample of buildings by building type in terms of number of buildings and floor area, respectively.

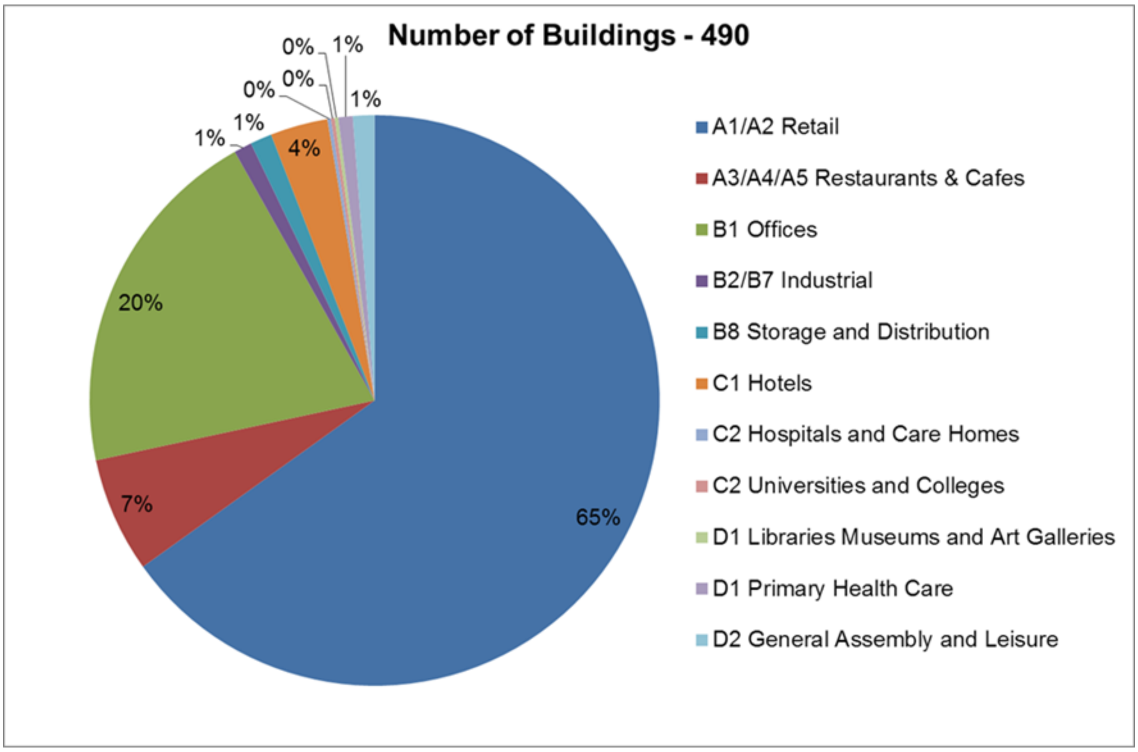

Figure C1: Breakdown of EPC sample by building type - number of buildings

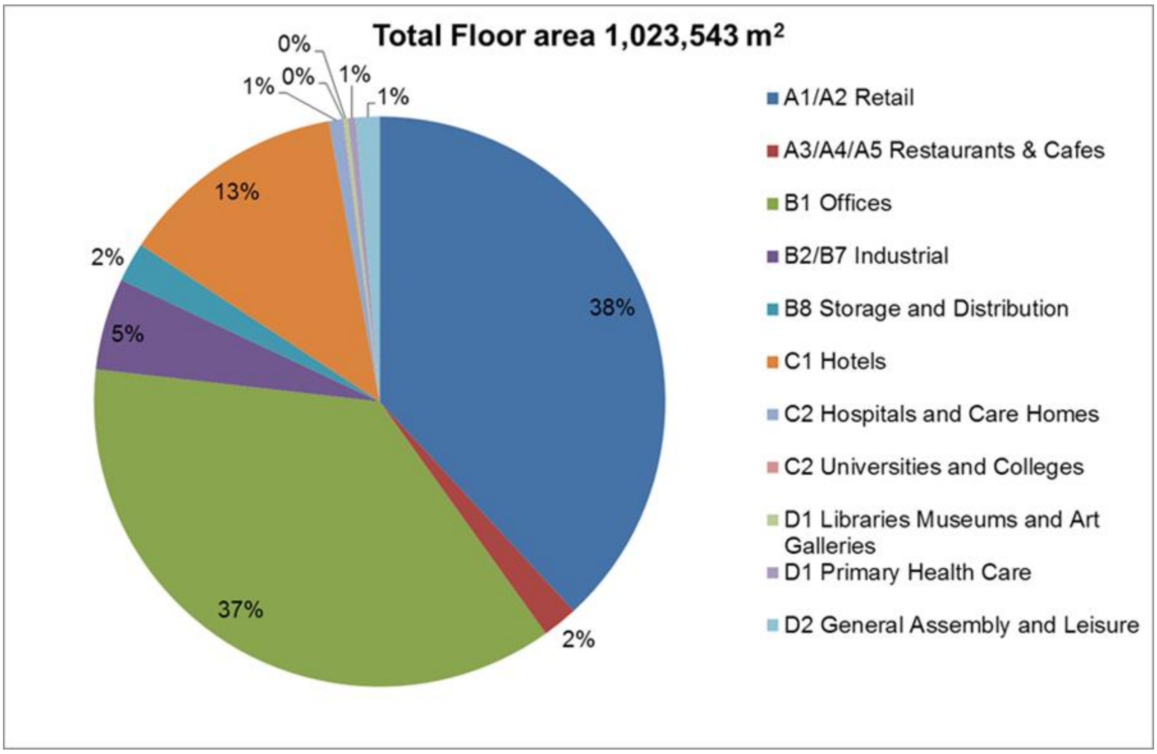

Figure C2: Breakdown of EPC sample by building type – total floor area (m^2)

4.2.10 Tables C4 and C5 show the EPC sample broken down by building type and size band in terms of number of buildings and total floor area, respectively.

Building Type / Size band (m2)	<100	100-300	300-1,000	1,000-3,000	3,000-10,000	>10,000	Grand Total
A1/A2 Retail	8	120	113	46	26	6	**319**
A3/A4/A5 Restaurants & Cafes		11	15	6			**32**
B1 Offices		7	22	35	27	8	**99**
B2/B7 Industrial	1				2	2	**5**
B8 Storage and Distribution				3	3		**6**
C1 Hotels				1	9	6	**16**
C2 Hospitals and Care Homes					1		**1**
C2 Universities and Colleges			1				**1**
D1 Libraries Museums and Art Galleries				1			**1**
D1 Primary Health Care		1	1	2			**4**
D2 General Assembly and Leisure			1	3	2		**6**
Grand Total	**9**	**139**	**153**	**97**	**70**	**22**	**490**

Table C4: Breakdown of EPC sample by building type and size band (m^2) – number of buildings

4.2.9 Table C4 shows that 60% of the buildings in the EPC sample are between 100 and 1,000 m^2 in size and 39% are larger than 1,000 m^2. However, only 10% of the floor area of the EPC sample is between 100 and 1,000 m^2 and 90% of the total floor area is in buildings >1,000m^2**.**

Building Type / Size bans	<100	100-300	300-1,000	1,000-3,000	3,000-10,000	>10,000	Grand Total
A1/A2 Retail	642	23,021	59,859	89,436	141,235	77,120	**391,313**
A3/A4/A5 Restaurants & Cafes		2,589	9,271	8,662			**20,522**
B1 Offices		1,491	13,262	62,862	145,711	153,334	**376,660**
B2/B7 Industrial	71				9,953	43,408	**53,432**
B8 Storage and Distribution				5,008	17,972		**22,980**
C1 Hotels				1,730	47,725	82,800	**132,255**
C2 Hospitals and Care Homes					8,221		**8,221**
C2 Universities and Colleges			558				**558**
D1 Libraries Museums and Art Galleries				2,351			**2,351**
D1 Primary Health Care		135	412	3,877			**4,424**
D2 General Assembly and Leisure			719	5,831	7,277		**13,827**
Grand Total	**713**	**27,236**	**84,081**	**179,757**	**378,094**	**356,662**	**1,026,543**

Table C5: Breakdown of EPC sample by building type and size band – total floor area (m^2)

4.2.10 The activity areas within each building type for the EPC sample are shown in Table C6 and Figure C3. There are no national level data sources that the sample data can be compared to, however, the proportions of different activity areas within each building type are in line those of other national data sets (e.g. VOA data).

Activity Area (grouped)	A1/A2 Retail	A3/A4/A5 Restaurants & Cafes	B1 Offices	B2/B7 Industrial	B8 Storage & Distribution	C1 Hotels	C2 Hospitals and Care Homes	C2 Higher Education	D1 Libraries Museums and Art	D1 Primary Health Care	D2 Assembly & Leisure	Grand Total
24 hrs Consulting/treatment areas	35	-	-	-	-	-	-	-	-	-	-	**35**
Assembly areas / halls	-	-	-	-	-	7,247	-	-	-	-	5,442	**12,689**
Bathroom/changing with showers	276	-	3,870	400	98	2,117	-	-	-	54	541	**7,357**
Car Park	62	-	2,784	-	15	-	-	-	-	-	-	**2,861**
Circulation area	27,593	1,189	51,035	2,447	1,502	24,215	1,173	101	144	864	1,432	**111,693**
Classroom/teaching area	-	-	-	1,658	-	-	-	391	-	-	-	**2,049**
Data Centre	19	-	2,621	297	-	17	-	3	-	15	-	**2,971**
Display and Public area	-	-	-	-	-	-	-	-	1,156	-	-	**1,156**
Domestic Areas	-	1,668	-	-	-	64,684	-	-	-	-	-	**66,352**
Eating/Drinking area	10,306	7,584	6,493	675	886	8,416	87	-	179	-	393	**35,020**
Fitness studio/gym	-	-	600	-	-	735	115	-	-	-	1,959	**3,408**
Food preparation area	3,277	1,852	2,924	-	73	2,651	190	-	-	37	332	**11,335**
Office area	36,558	930	251,728	14,428	1,316	9,957	928	10	458	1,884	1,002	**319,201**
Operating theatre	-	-	-	-	-	-	1,042	-	-	133	-	**1,176**
Plant Room/Industrial process area	3,823	243	12,907	19,122	191	2,128	478	-	77	67	582	**39,619**
Reception	640	-	6,220	249	9	2,448	166	-	-	534	446	**10,712**
Retail Display	531	-	-	-	21	-	-	-	-	-	-	**552**
Retail Warehouse	88,981	1,470	-	-	3,926	-	-	-	-	-	-	**94,376**
Sales area	137,622	95	4,498	-	4,062	-	-	-	-	336	-	**146,615**
Specialist	907	-	912	7,636	-	142	876	-	-	48	38	**10,559**
Swimming pool	-	-	-	-	-	1,359	-	-	-	-	354	**1,713**
Toilet	8,011	1,298	12,871	961	360	1,521	94	50	50	178	619	**26,012**
Ward	-	-	-	-	-	-	2,842	-	-	-	-	**2,842**
Workshop	-	-	2,393	4,809	-	43	-	-	-	-	24	**7,269**
Storage/Store room	72,669	4,195	14,785	751	10,521	4,573	229	3	288	274	662	**108,950**
Grand Total	**391,310**	**20,524**	**376,641**	**53,433**	**22,980**	**132,253**	**8,220**	**558**	**2,352**	**4,424**	**13,826**	**1,026,522**

Table C6: Breakdown of EPC sample between building type and activity areas – floor area m^2

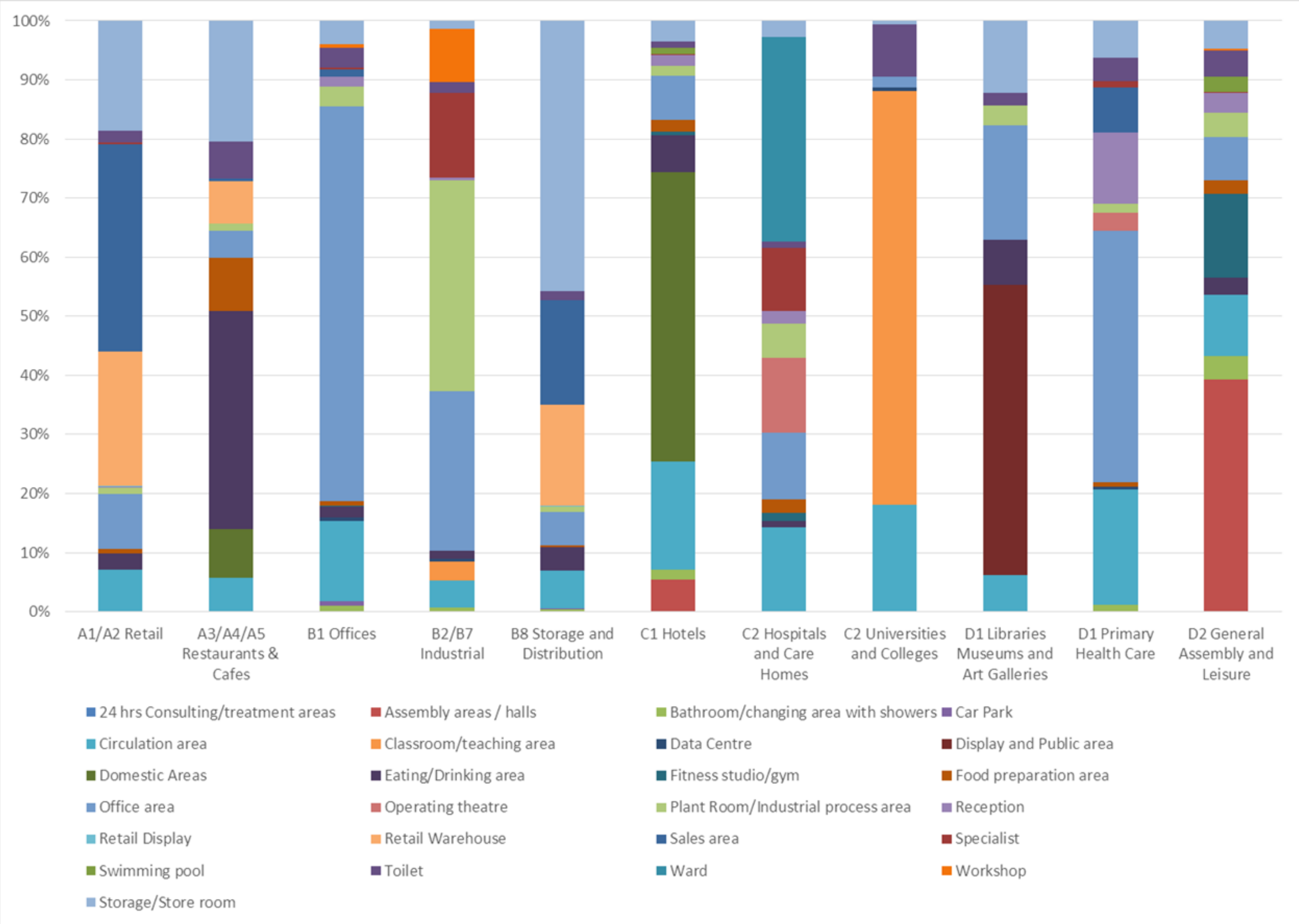

Figure C3: Activity areas as a percentage of floor area for each building type in the sample of EPCs

4.2.11 Two types of geographical location information are provided in the EPC data. The post sector location of the actual premises and the location of the weather data used to calculate the energy consumption for cooling (and also for heating). The former provides an indication of the prevalence of different types of buildings and cooling systems at a regional level, whilst the later also takes account of the impact of regional climate on the calculated energy use.

4.2.12 The weather data used to calculate energy use for cooling an EPC comes from one of thirteen major cities in the UK. The weather data used is for the closest city to the actual location of the building. For this exercise the UK "weather" cities have been mapped onto standard Government Office Regions.

4.2.13 Table C7 shows the number of buildings and total floor area for the EPC sample broken down by Government Office Region based on the building post sector area (i.e., the actual location) of the building. Comparing the percentage breakdown of floor area between the regions for the sample and for total rateable floor area in England and Wales shows that the EPC sample is regionally representative of the national stock.

Government Office Region	Number of Buildings	Floor area (m^2)	% Floor area EPC Sample	% Floor Area England and Wales (VOA 2012)
East Midlands	45	77,919	8%	7%
East of England	45	99,936	10%	9%
London	80	265,898	26%	15%
North East	19	28,309	3%	4%
North West	72	163,980	16%	12%
South East	65	120,661	12%	22%
South West	79	125,797	12%	9%
Wales	18	24,743	2%	5%
West Midlands	31	42,596	4%	9%
Yorkshire and the Humber	36	76,704	7%	9%

Table C7: Breakdown of EPC sample by Government Office Region

4.2.14 Figures C4 and C5 show the number of buildings and floor area broken down by Government Office Region and building type.

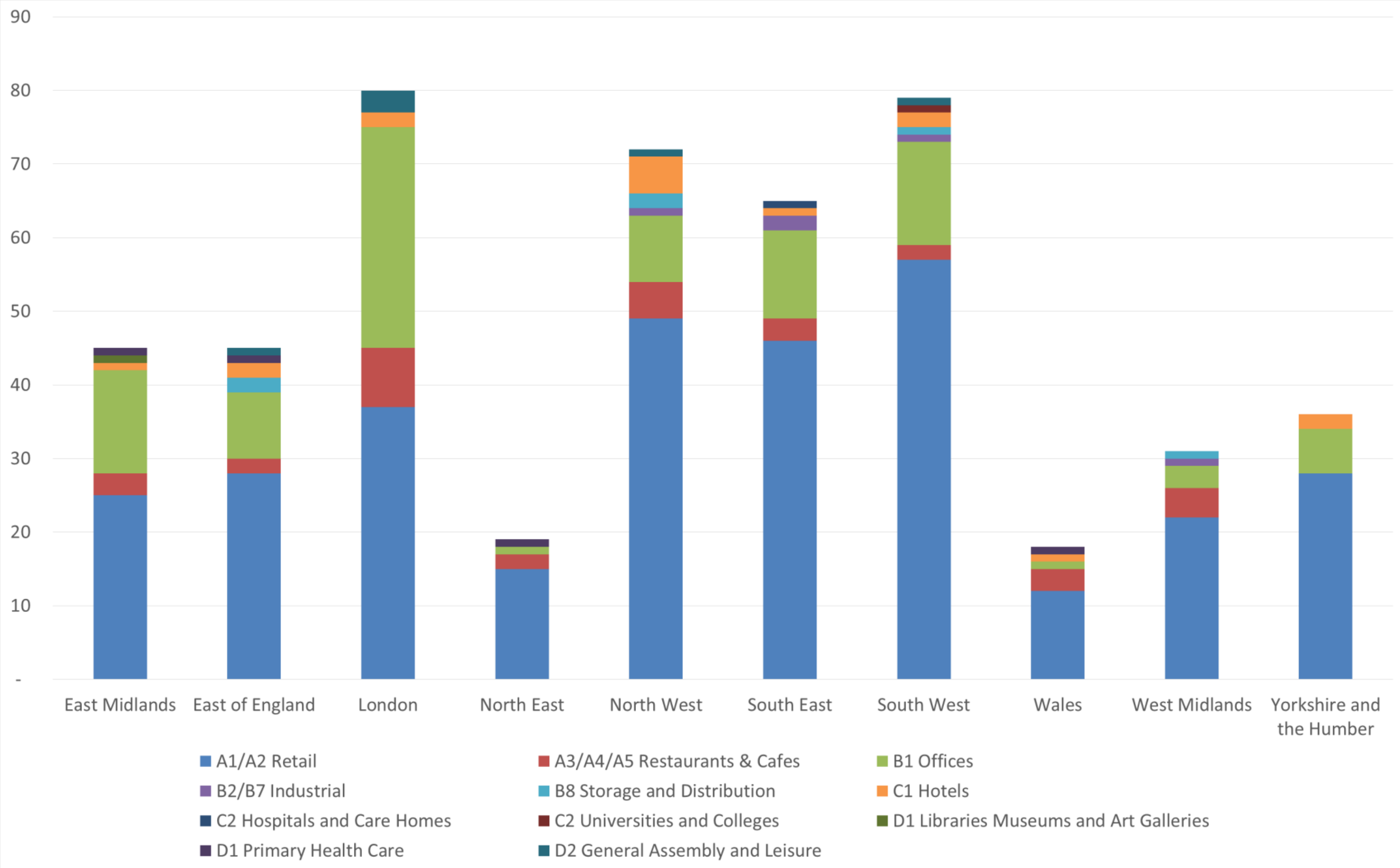

Figure C4: Breakdown of EPC sample by Government Office Region and Building Type – Number of Buildings

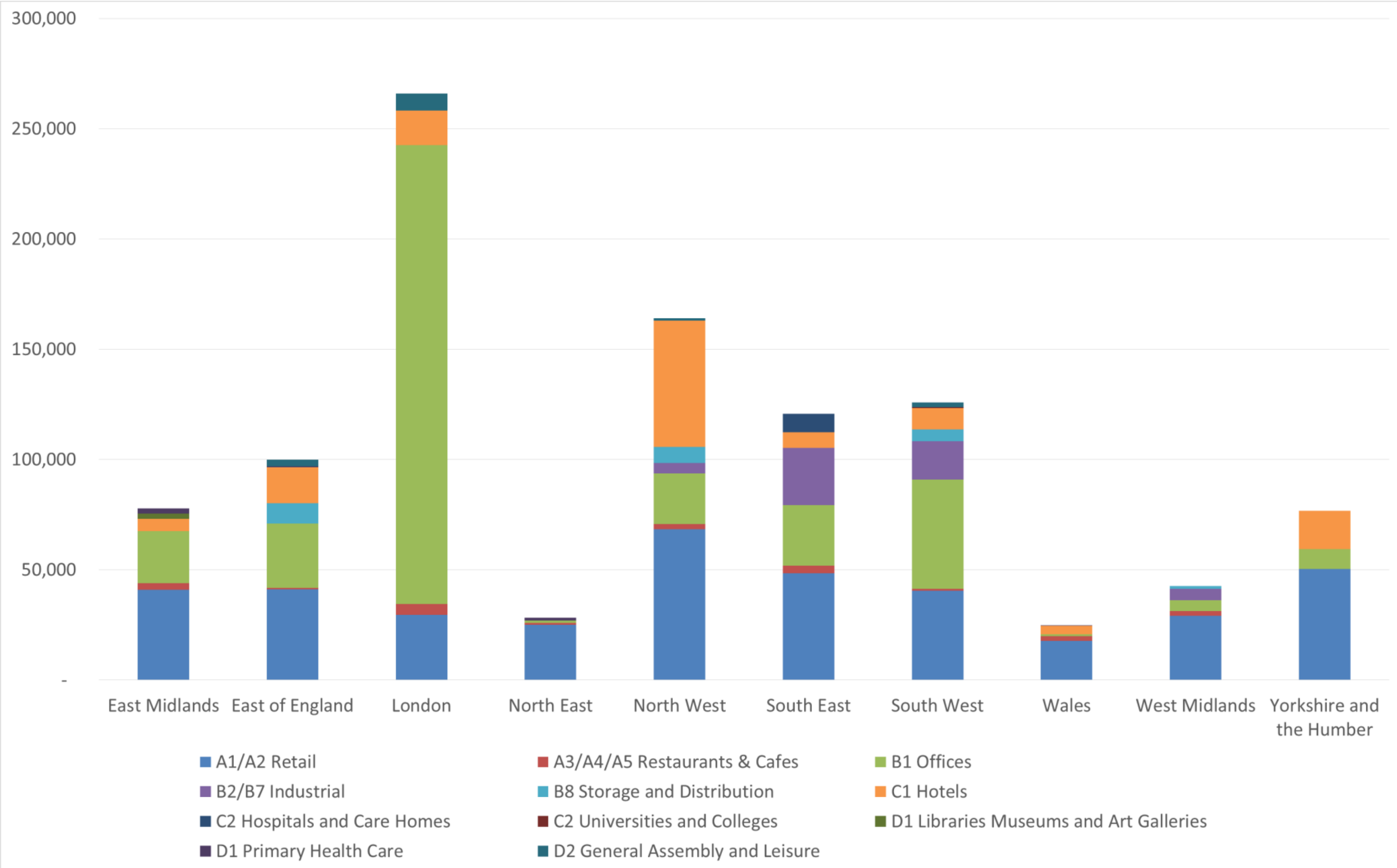

Figure C5: Breakdown of EPC sample by Government Office Region and Building Type – Floor area (m^2)

4.3 This section identifies the types of systems found within the sample of EPC buildings. It identifies the prevalence of different types of cooling systems within the buildings of the EPC sample.

4.3.1 The first step for this analysis was to identify within the sample data HVAC systems within the sample data that include a cooling function. A list of the HVAC systems which include cooling is shown below:

- Active chilled beams
- Chilled ceilings or passive chilled beams and displacement ventilation
- Constant volume system (fixed fresh air rate)
- Constant volume system (variable fresh air rate)
- Dual duct (constant volume)
- Dual-duct VAV
- Fan coil systems
- Indoor packaged cabinet (VAV)
- Induction system
- Single room cooling system
- Single-duct VAV
- Split or multi-split system
- Terminal reheat (constant volume)
- Water loop heat pump

4.3.2 The prevalence of systems within the sample that were identified as having a cooling function is shown in Table C8 and shown graphically in Figures C6 and C7. This shows that over three quarters of the system are split or multi-split systems: of the remainder, 8% are fan coil systems, 4% constant volume systems with fixed fresh air rate, 3% single duct VAV and 3% constant volume systems with variable fresh air rates. Figures C8 and C9 show the system types in the sample broken down by building type for the number of systems and floor area cooled, respectively.

Cooling System Type	Number of Systems	Cooled Floor area (m^2)	Average Cooled Floor area (m^2)
Active chilled beams	1	5,171	5,171
Chilled ceilings or passive chilled beams and displacement ventilation	4	44,368	11,092
Constant volume system (fixed fresh air rate)	32	88,444	2,764
Constant volume system (variable fresh air rate)	13	46,721	3,594
Dual duct (constant volume)	2	1,895	947
Dual-duct VAV	7	26,298	3,757
Fan coil systems	59	162,752	2,759
Indoor packaged cabinet (VAV)	6	3,505	584
Induction system	3	8,320	2,773
Single room cooling system	21	6,668	318
Single-duct VAV	25	62,673	2,507
Split or multi-split system	594	322,473	543
Terminal reheat (constant volume)	1	69	69
Water loop heat pump	1	3,089	3,089
Grand Total	**769**	**782,443**	**1,017**

Table C8: Breakdown of cooling systems within the EPC sample by number of systems, cooled floor area and average area cooled

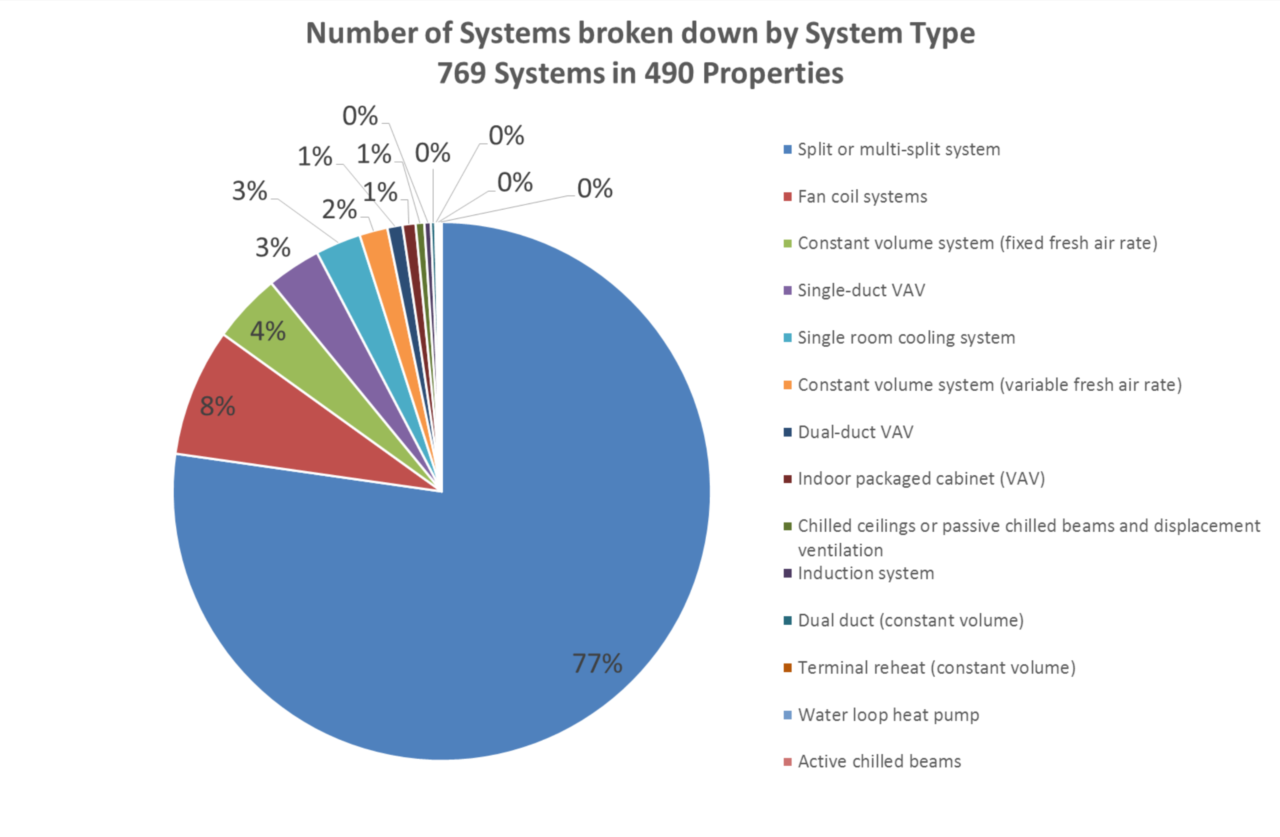

Figure C6: Number of systems broken down by system type in the EPC Sample

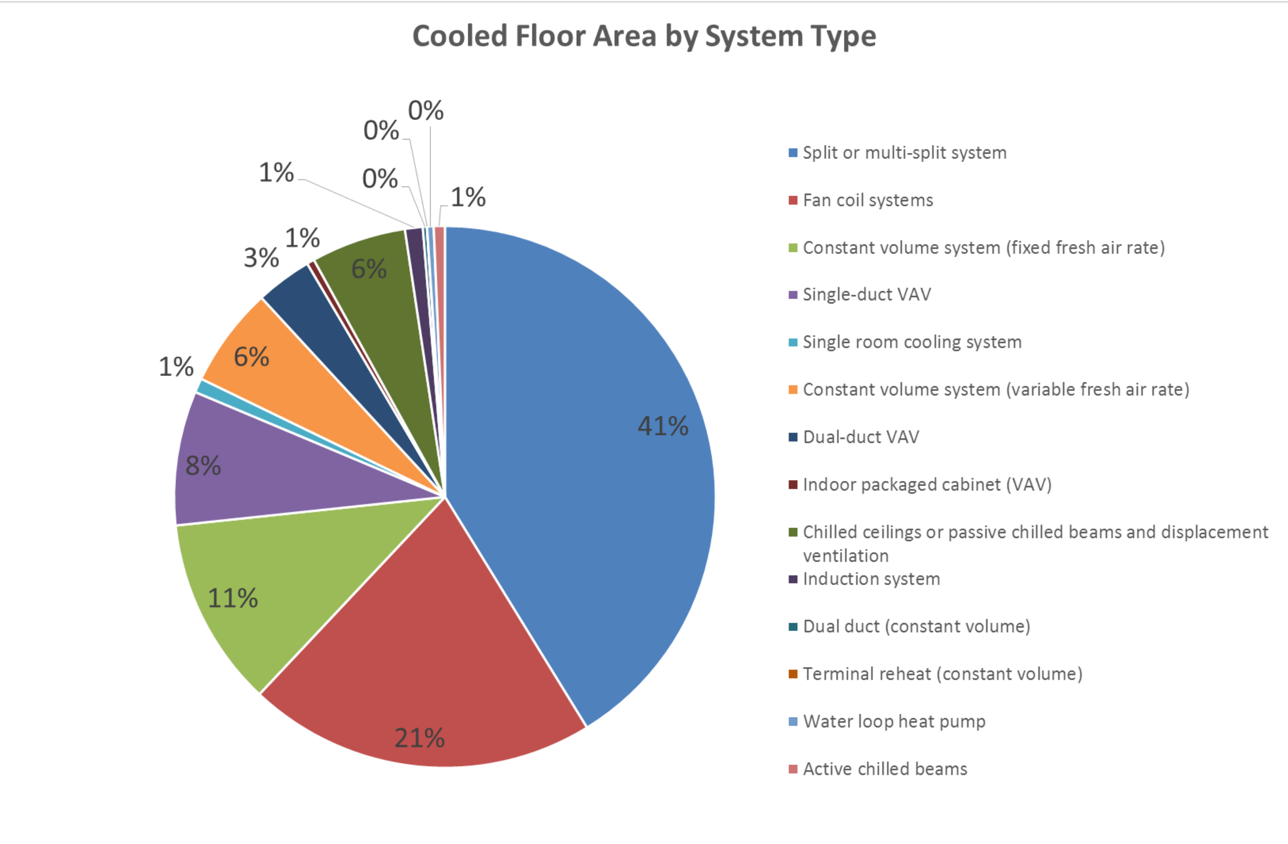

Figure C7: Cooled floor area broken down by system type in the EPC Sample

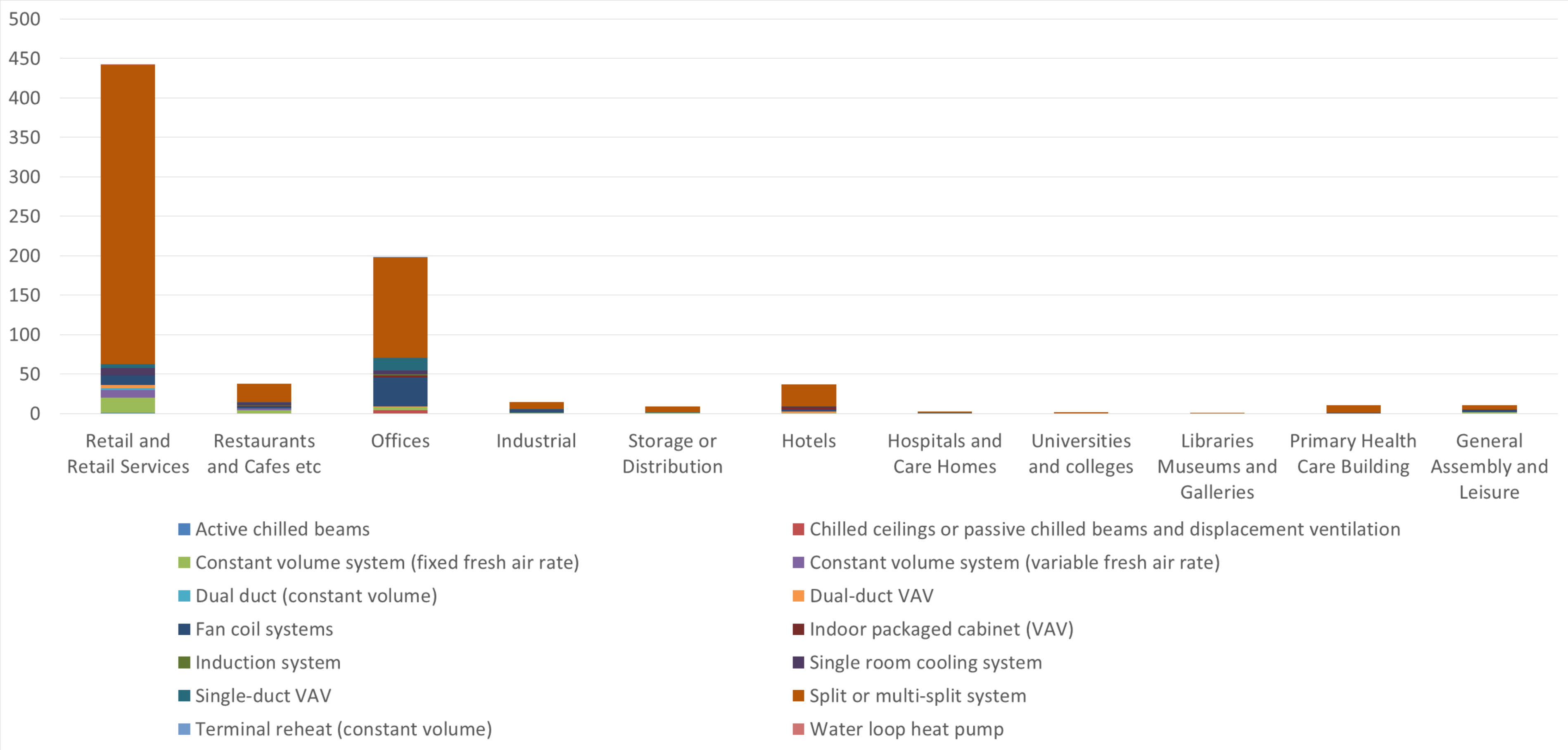

Figure C8: Number of systems broken down by building type and system type

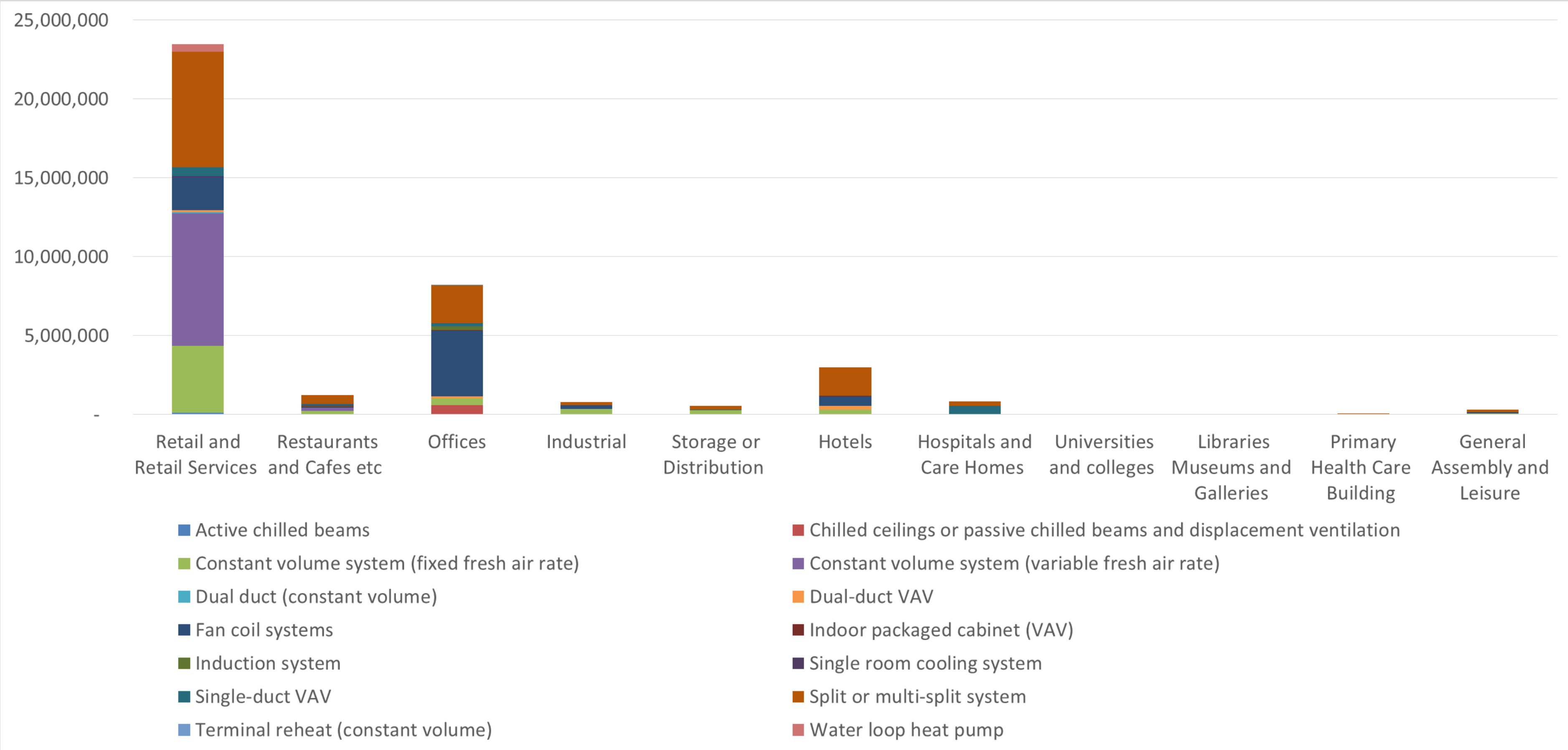

Figure C9: Cooled Floor Area (m^2) broken down by building type and system type

4.3.3 The EPC data contains two values that relate to the efficiency of the cooling system. The Seasonal Energy Efficiency Ratio (SEER) of the cooling generator, which provides average seasonal efficiency of the chiller (this is measured using a standardised testing procedure which gives the aggregated performance over a range of typical operating conditions.) The other value is the SSEER (Seasonal System Energy Efficiency Ratio), which is the calculated efficiency of the whole system Within the Simplified Building Energy Model (SBEM), which was used to generate the vast majority of the EPC data analysed here, default values are provided for the SEER which depends on the type of chiller (air cooled, water cooled, remote condensing or heat pump), its cooling capacity, the energy source and whether or not it is eligible for ECAs (Enhanced Capital Allowances).

4.3.4 Figure C10 shows the frequency distribution of SEERs[4] from the EPCs broken down by system types.

4.3.5 Most of the SEER values fall within the expected range, although there is one value of 179 which is implausibly high and several which are < 0.2 which is unrealistically low. There are also two significant spikes at 2.0-2.2 and 2.4-2.6 in the frequency distribution.

4.3.6 Figure C11 shows the SEER values for all systems without systems with SEER >10 or <0.2, which were deemed technically implausible and were excluded and with SEERs that coincided with SBEM default values also excluded from the analysis. This shows a more normal distribution for the SEERs of split systems with the mode occurring between 3.2 and 3.4. The number of other system types in the sample is too small to draw conclusions regarding the distribution of their SEERs.

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[4] The software used to generate EPCs requires assessors to enter the SEER value for the equipment. Where SEER values are not available (pessimistic) default values are substituted

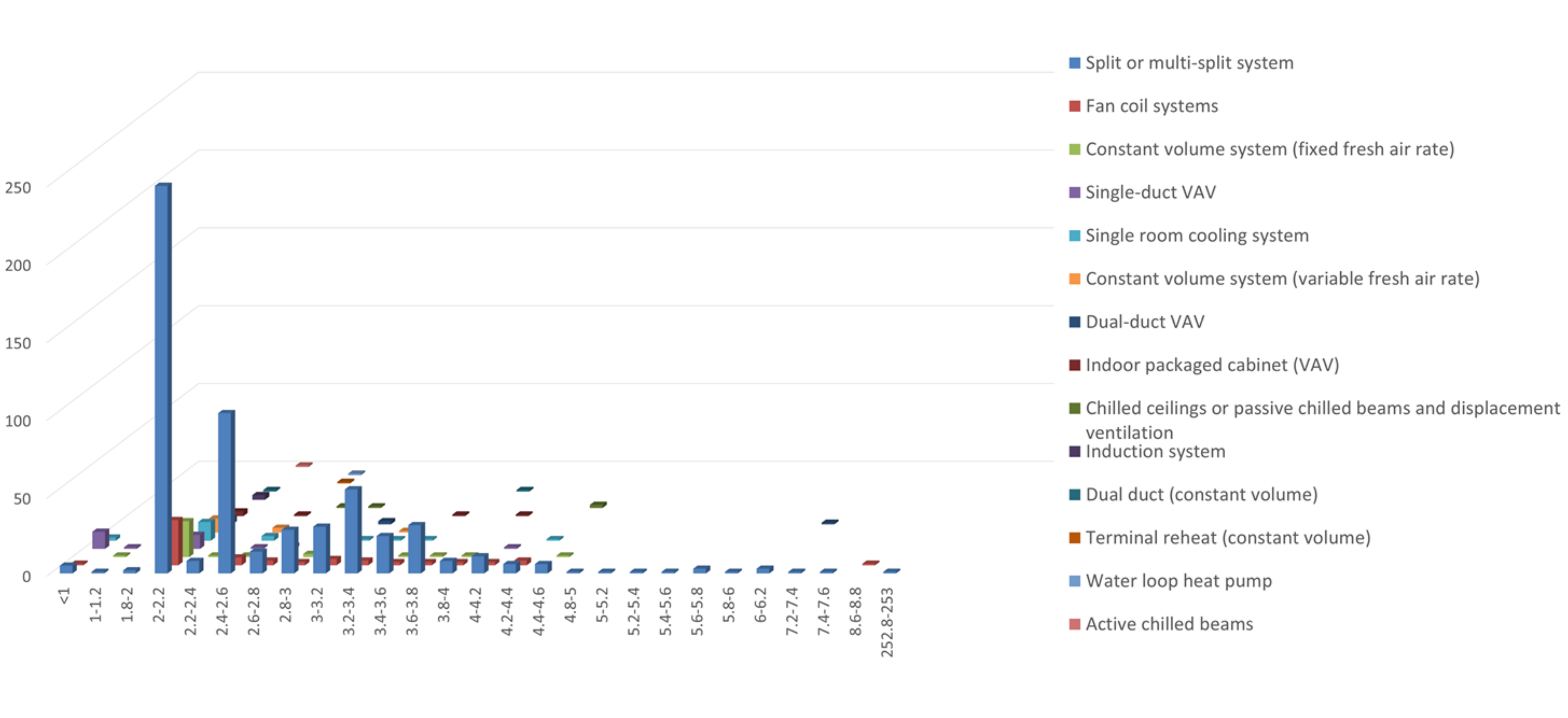
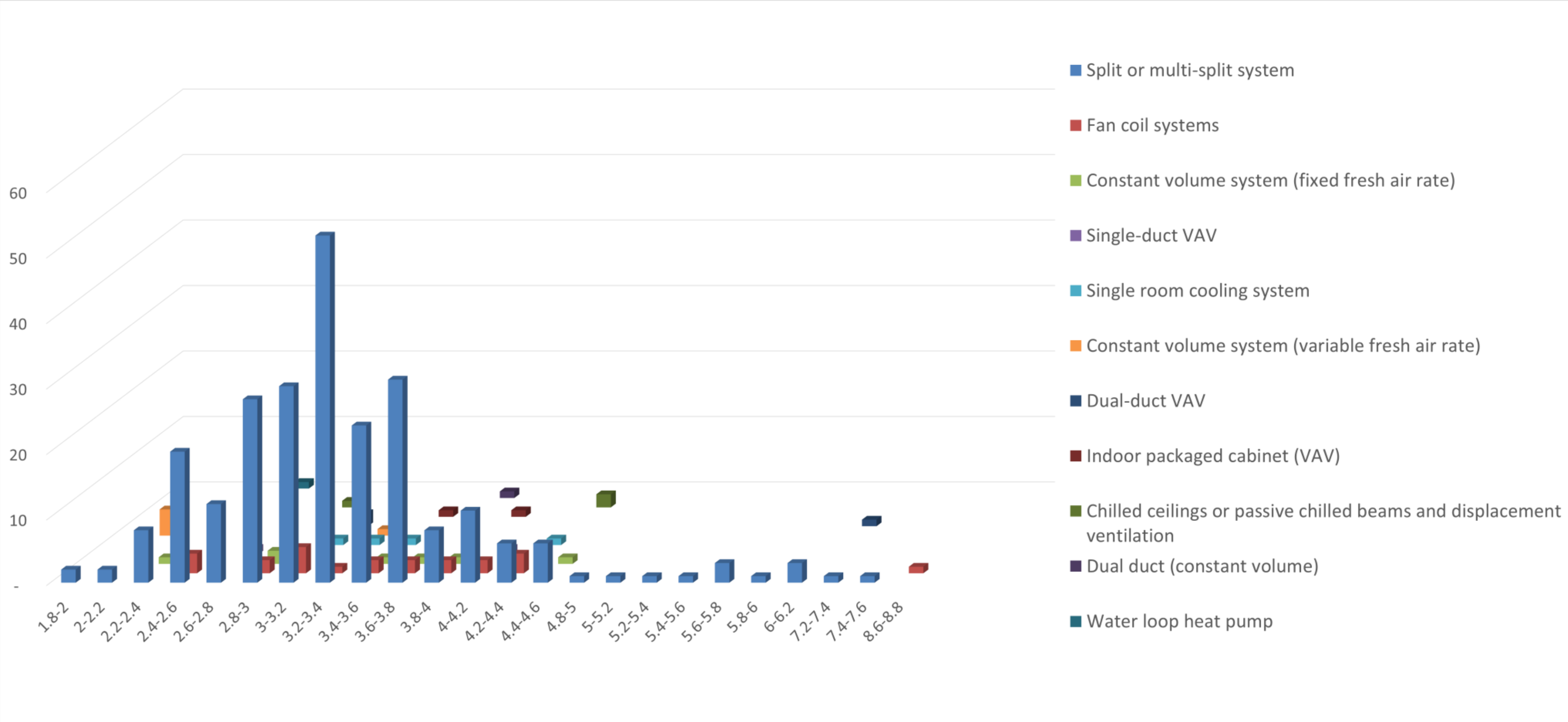


Figure C10: Distribution of SEERs (Seasonal Energy Efficiency Ratio) from EPCs, for each system type – includes SBEM default values



C11: Distribution of SEERs (Seasonal Energy Efficiency Ratio) from the EPCs for each system type – excludes system specific SBEM default values and technically implausible values

System type	non default value	Electric non-ECA default	Electric Air cooled ECA under 500kw default	Electric Air cooled ECA 500-750kW default	Gas/oil heat pump default	Electric Air cooled ECA >750kW default	Electric water cooled ECA default	Grand Total
Split or multi-split system	254	247	83	1	1	1	1	588
Fan coil systems	22	29	2	2		1	2	58
Constant volume system (fixed fresh air rate)	7	23	1		1			32
Single-duct VAV	2	9	1	1	1			14
Single room cooling system	4	12	3					19
Constant volume system (variable fresh air rate)	5	5	3					13
Dual-duct VAV	3	4						7
Indoor packaged cabinet (VAV)	2	3	1					6
Chilled ceilings or passive chilled beams and displacement ventilation	3					1		4
Induction system		3						3
Dual duct (constant volume)	1	1						2
Terminal reheat (constant volume)			1					1
Water loop heat pump	1							1
Active chilled beams		1						1
Grand Total	**304**	**337**	**95**	**4**	**3**	**3**	**3**	**749**

Table C9: Number of systems with default and non-default SEER values

4.3.7 Across all system types around 60% of the SEER values correspond to default values offered in SBEM. This may slightly overestimate the actual percentage of default values selected by users as the actual value may indeed coincide with one of the default values offered. The proportion of cooling generators which correspond to default values is similar for most system types with the majority of cooling generation SEER values being default values. 75% of default values correspond to electric cooling generators which do not qualify for ECAs, whilst the majority of the remainder which do qualify for ECAs are for electric air cooled chillers under 500kW. Where non-default values have been entered these are on average around 50% more efficient compared to a weighted average of the default values. This is to be expected as the defaults are deliberately conservative. The non-default SEER values should therefore provide a good indication of SEER values found in this sample of buildings and it should be possible to extrapolate these results to the UK building stock.

4.3.8 Table C10 shows the average default and non-default SEER values for each system type.

System type	non default value	Electric non-ECA default	Electric Air cooled ECA under 500kw default	Electric Air cooled ECA 500-750kW default	Gas/oil heat pump default	Electric Air cooled ECA >750kW default	Electric water cooled ECA default	Grand Total
Split or multi-split system	3.4	2.0	2.5	2.6	1.0	2.7	3.3	2.7
Fan coil systems	3.6	2.0	2.5	2.6		2.7	3.3	2.7
Constant volume system (fixed fresh air rate)	3.4	2.0	2.5		1.0			2.3
Single-duct VAV	3.4	2.0	2.5	2.6	1.0			2.2
Single room cooling system	3.5	2.0	2.5					2.4
Constant volume system (variable fresh air rate)	2.3	2.0	2.5					2.2
Dual-duct VAV	4.0	2.0						2.9
Indoor packaged cabinet (VAV)	3.7	2.0	2.5					2.6
Chilled ceilings or passive chilled beams and displacement ventilation	3.8					2.7		3.5
Induction system		2.0						2.0
Dual duct (constant volume)	3.7	2.0						2.8
Terminal reheat (constant volume)			2.5					2.5
Water loop heat pump	2.6							2.6
Active chilled beams		2.0						2.0
Grand Total	**3.4**	**2.0**	**2.5**	**2.6**	**1.0**	**2.7**	**3.3**	**2.6**

Table C10: Average SEER for cooling generation broken down by system type for non-default and default value

4.3.9 Table C11 shows the SSEERs (system seasonal energy efficiency ratios) for cooling generation broken down by system type for non-default and default value. The SSEER values shown are for with plausible SEERs only.

System type	**non default value**	**Electric non-ECA default**	**Electric Air cooled ECA under 500kw default**	**Electric Air cooled ECA 500-750kW default**	**Gas/oil heat pump default**	**Electric Air cooled ECA >750kW default**	**Electric water cooled ECA default**	**Grand Total**
Split or multi-split system	2.4	1.4	1.8	1.8	0.7	1.9	2.3	1.9
Fan coil systems	2.6	1.4	2.0	1.8		2.1	2.7	1.9
Constant volume system (fixed fresh air rate)	1.3	0.8	0.9		0.4			0.9
Single-duct VAV	2.0	1.1	1.6	1.4	0.6			1.3
Single room cooling system	2.5	1.4	1.8					1.7
Constant volume system (variable fresh air rate)	1.0	0.8	1.0					0.9
Dual-duct VAV	2.1	1.0						1.4
Indoor packaged cabinet (VAV)	2.7	1.4	1.7					1.8
Chilled ceilings or passive chilled beams and displacement ventilation	3.4					2.5		3.2
Induction system		1.2						1.2
Dual duct (constant volume)	0.9	0.5						0.7
Terminal reheat (constant volume)			2.0					2.0
Water loop heat pump	1.4							1.4
Active chilled beams		1.7						1.7
Grand Total	**2.4**	**1.3**	**1.8**	**1.7**	**0.5**	**2.2**	**2.6**	**1.8**

Table C11: Average SSEER (system seasonal energy efficiency ratio) for cooling generation broken down by system type for non-default and default value

4.3.10 The SSEER for cooling systems in is restricted to those with technical plausible SEER. The SSEER is always smaller than the SEER as it takes into account heat gains arising from energy used by pumps and controls; and any losses that occur in the cooling distribution system.

System Type	Max of SSEER/ SEER	Min of SSEER/ SEER	Average of SSEER/ SEER
Split or multi-split system	1.00	0.53	0.71
Fan coil systems	0.95	0.40	0.71
Constant volume system (fixed fresh air rate)	0.48	0.36	0.38
Single-duct VAV	0.61	0.58	0.60
Single room cooling system	0.75	0.71	0.72
Constant volume system (variable fresh air rate)	0.42	0.42	0.42
Dual-duct VAV	0.52	0.49	0.51
Indoor packaged cabinet (VAV)	0.78	0.68	0.73
Chilled ceilings or passive chilled beams and displacement ventilation	0.93	0.87	0.90
Dual duct (constant volume)	0.24	0.24	0.24
Water loop heat pump	0.54	0.54	0.54
All System Types	**1.00**	**0.24**	**0.70**

Table C12: Average, minimum and maximum ratio of SSEER/SEER broken down by system type

4.3.11 Because of the way in which data is entered into the SBEM software it is possible that the user may legitimately report a single system which serves multiple floors and/or activity areas as more than one system. An analysis was therefore carried out to identify unique systems within each building e.g., where the system type, SEER and other parameters are identical.

4.3.12 This identified the number of unique systems within the sample to exclude probable instances where the same system appears more than once in the data.

4.3.13 Figure C12 shows the number of unique system types found in each building type within the sample. This shows that 70% of offices have multiple system types within the same building, whilst nearly 50% of retail premises have more than one system type. However, it is difficult to draw meaningful conclusions for building types which are less represented within the sample data.

4.3.14 Figure C13 shows the number of unique system types broken down by building floor area. This shows a clear positive correlation between the number of systems and the building floor area with over 95% of buildings over 10,000m2 having more than one cooling system, but, even for buildings with a floor area of 100 m2 or less, 33% have more than one system.

Building Types	**Number of Different Systems**										
	1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**Total**
A1/A2 Retail and Financial/Professional services	234	128	30	24	20		7				443
A3/A4/A5 Restaurant and Cafes/Drinking Establishments and Hot Food takeaways	26	12									38
B1 Offices and Workshop businesses	57	48	15	16	10	12	14	8	9	10	199
B2 to B7 General Industrial and Special Industrial Groups	1	6						8			15
B8 Storage or Distribution	4	2	3								9
C1 Hotels	5	16	3		5			8			37
C2 Residential Institutions - Hospitals and Care Homes			3								3
C2 Residential Institutions - Universities and colleges		2									2
D1 Non-residential Institutions - Libraries Museums and Galleries	1										1
D1 Non-residential Institutions - Primary Health Care Building	2			4	5						11
D2 General Assembly and Leisure plus Night Clubs and Theatres	3	2	6								11
All Buildling types	**333**	**216**	**60**	**44**	**40**	**12**	**21**	**24**	**9**	**10**	**769**

Table C13: Number of systems broken down by building type

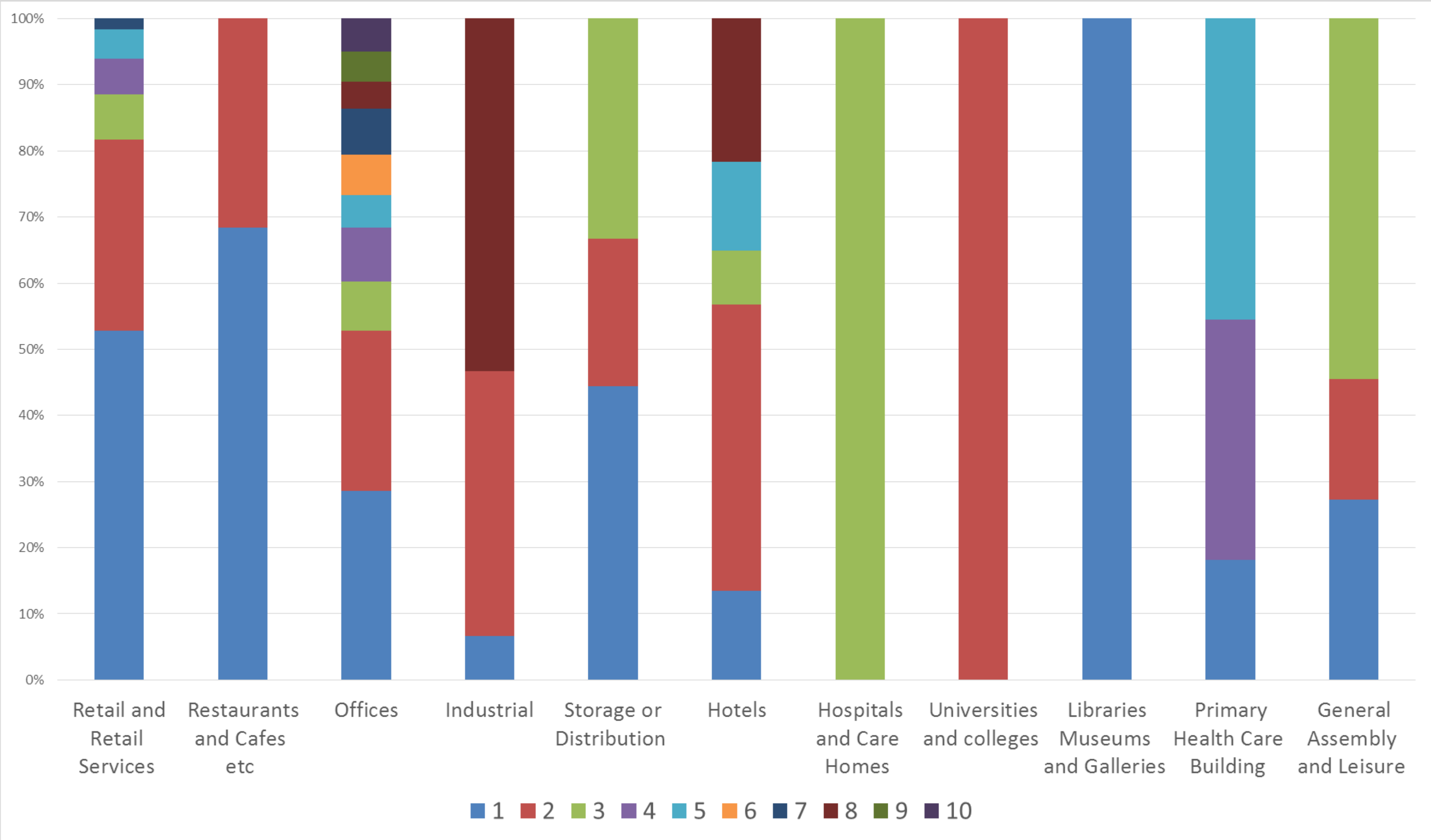


Figure C12: Percentage of buildings with one or more unique system type broken down by property type

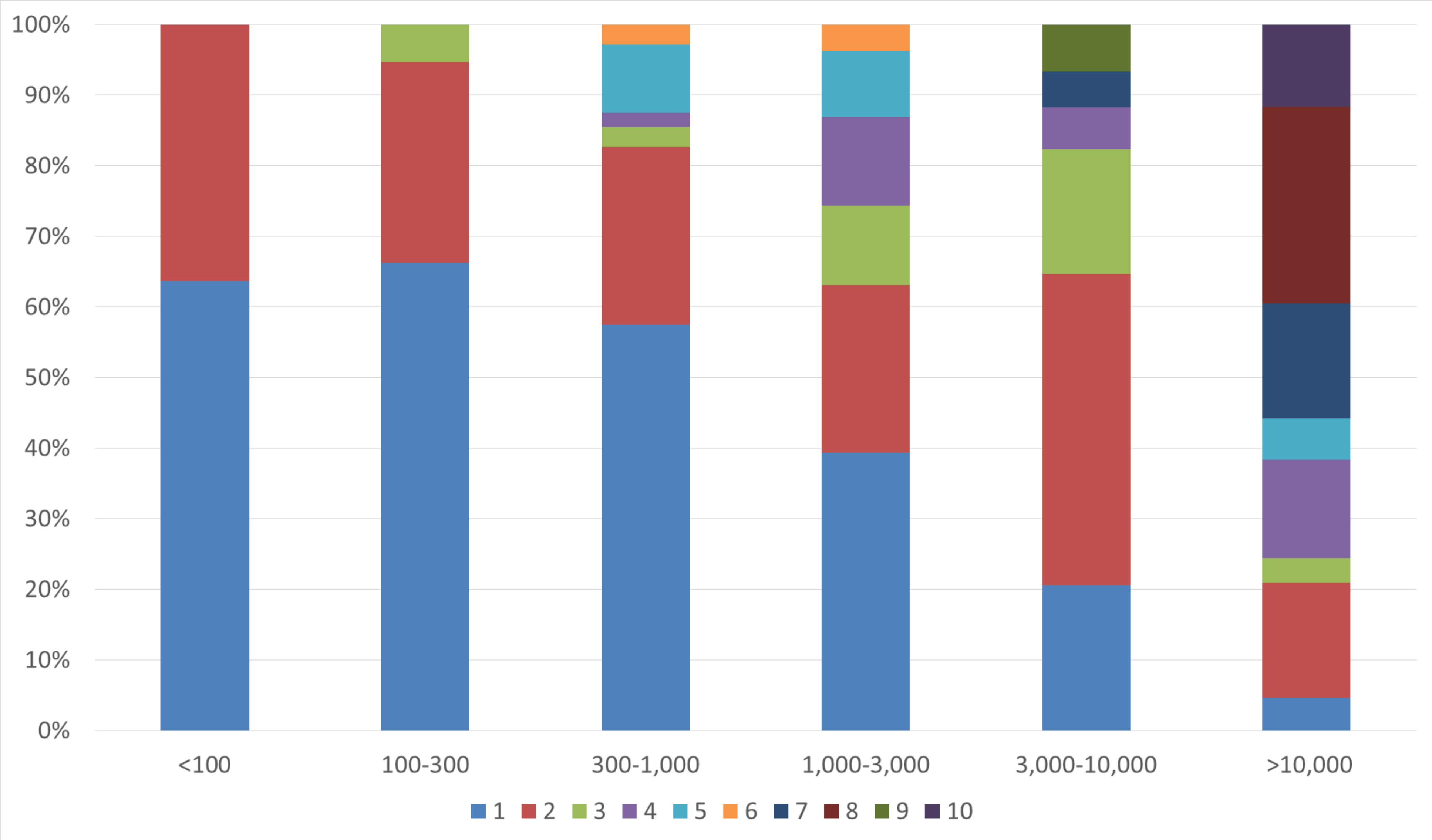


Figure C13: Percentage of buildings with one or more unique system type broken down by floor area size band

4.3.15 Table C14 shows the average percentage of the total building floor area that is treated by a cooling system within the EPC sample. This does not indicate any obvious relationship between building size and the percentage cooled area.

Building Size Band	Average of % cooled floorarea
<100	82%
100-300	71%
300-1,000	69%
1,000-3,000	73%
3,000-10,000	78%
>10,000	77%
Grand Total	**72%**

Table C14: Average percentage cooled floor area broken down by size band (m^2)

4.3.16 Table C15 shows the average percentage cooled floor area for the EPC sample for each building type.

Building type	Average % cooled floor area	Min % cooled floor area	Max % cooled floor area
A1/A2 Retail	70%	6%	100%
A3/A4/A5 Restaurants & Cafes	69%	25%	100%
B1 Offices	81%	29%	100%
B2/B7 Industrial	75%	29%	100%
B8 Storage and Distribution	48%	10%	96%
C1 Hotels	70%	37%	100%
C2 Hospitals and Care Homes	45%	45%	45%
C2 Universities and Colleges	72%	72%	72%
D1 Libraries Museums and Art Galleries	69%	69%	69%
D1 Primary Health Care	56%	8%	100%
D2 General Assembly and Leisure	80%	62%	100%
Grand Total	**72%**	**6%**	**100%**

Table C15: Average percentage cooled floor area broken down by building type

5 Energy Analysis

This section describes how cooling energy use and cooling energy demands are calculated for EPCs and the procedures used for assessing cooling energy use. It reports results at both the building and system level.

5.1 The cooling energy use for EPC is calculated by SBEM based on the cooling demand of the building (which are based on the envelope details and activity areas entered by the EPC assessor and standard occupancy patterns for each activity area), the standard occupancy hours and internal gains (which relate to both the building type and the activity carried out within each zone serviced by a system) and the efficiency of the cooling equipment.

5.1.1 Figure C14 shows total calculated cooling energy use for the EPC sample (769 systems in 490 buildings) broken down by system type. This shows that split or multi- split systems account for a third of the total energy use, fan coil systems 19%, constant volume systems with variable fresh air rates account for 22% of the total and constant volume systems with fixed fresh air rates 15% of the total cooling energy use. Figure C15 shows cooling energy use broken down by system type and building type. This shows that split systems account for a greater proportion of energy use in retail and hotels compared to offices, where fan coil systems and constant volume systems account for a greater proportion of cooling energy use.

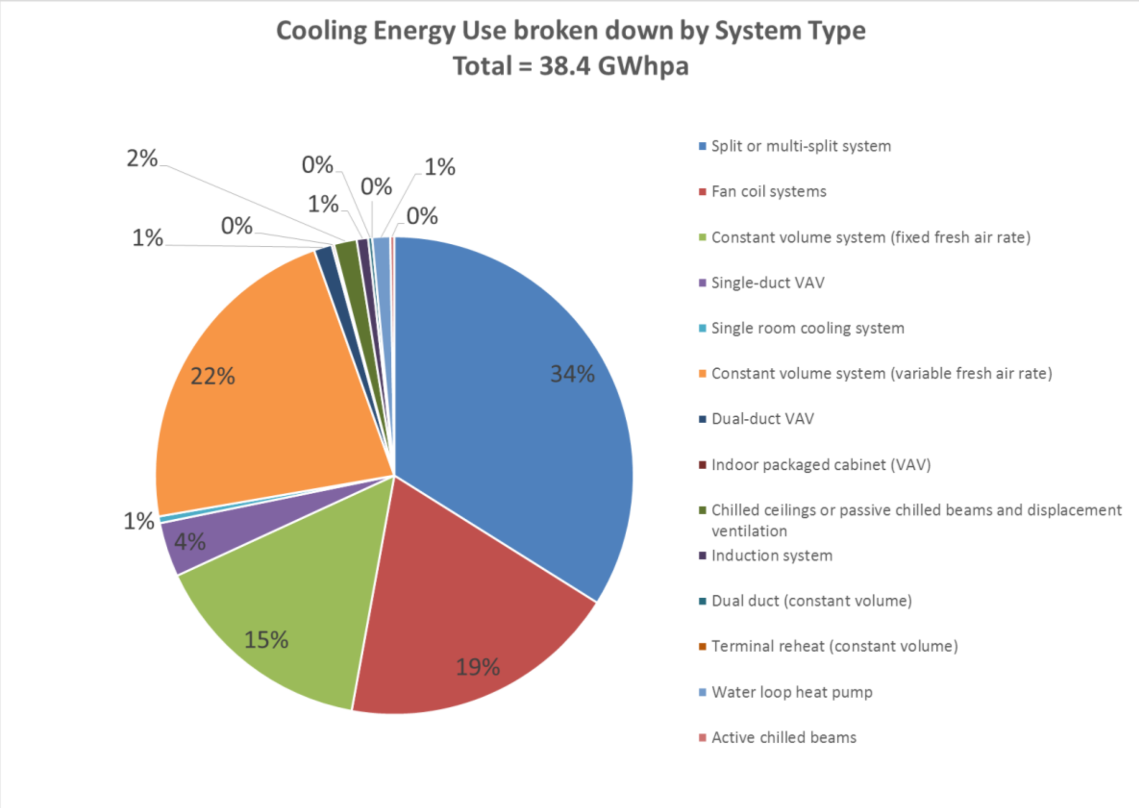


Figure C14: Cooling energy use broken down by system type

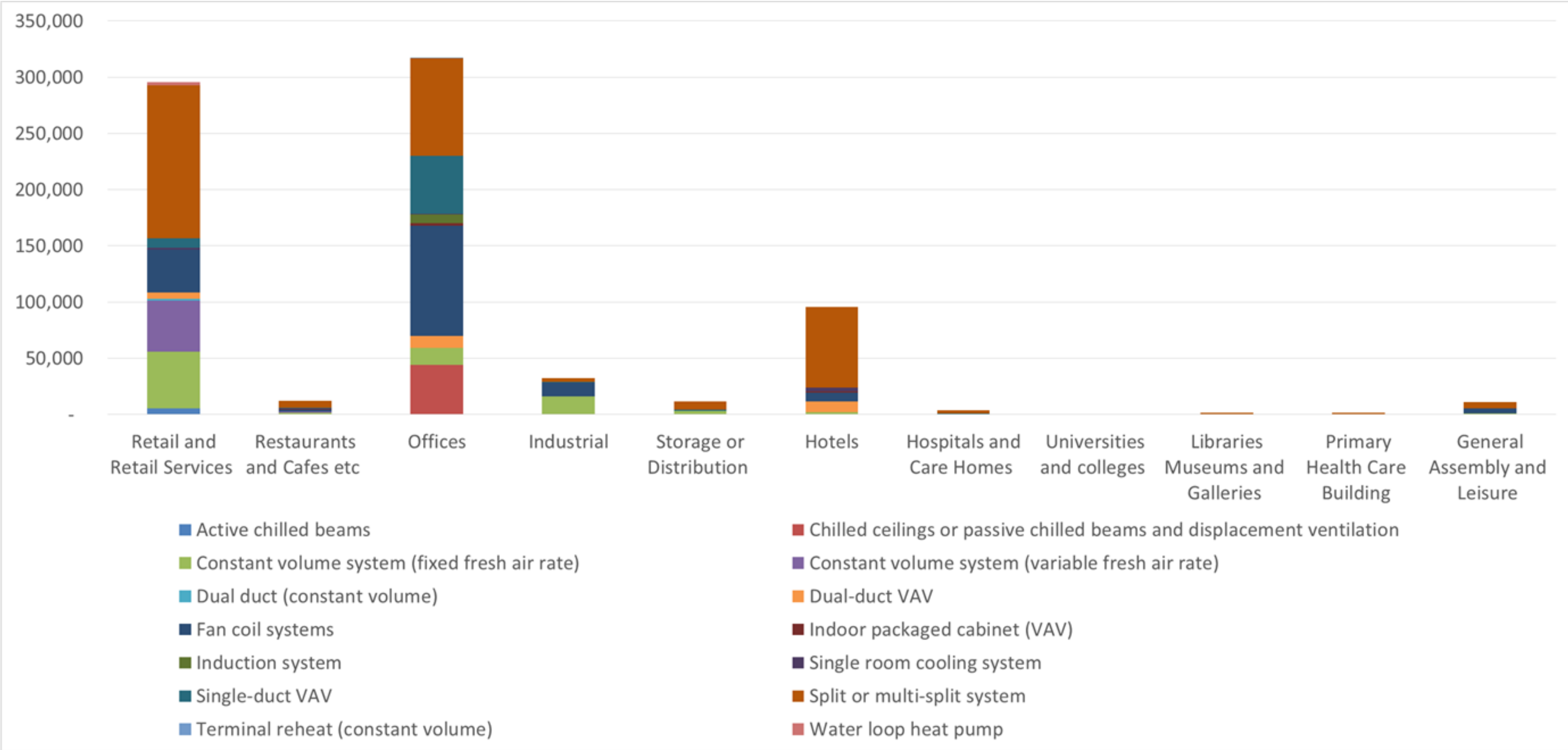


Figure C15: Calculated cooling electricity use (kWh) for each building type broken down by system type

5.1.2 Table C17 shows the average annual cooling energy use per unit of cooled floor area broken down by system type and building type. Hospitals and care homes have the highest energy intensity for all building types. This is likely to be due to factors such as long occupancy hours, high internal gains and more stringent temperature requirements, whilst hotels have the lowest energy intensity. Water loop heat pumps and constant volume air distribution cooling systems have the highest energy intensities whilst those for chilled ceilings and active chilled beams are an order of magnitude lower. Table C18 shows the average annual cooling demands broken down by system type and building type.

5.1.3 The ratio of cooling energy demand to cooling energy use is shown in Table C19 and provides an indication of the overall system efficiency, with lower ratios being more efficient. However, it should be remembered that these results partly reflect the relationships within the SBEM modelling process, specifically the way in which the different system types are modelled and the standard occupancy patterns associated with the activity areas within the buildings. However, they do reflect the performance of the building envelope, the approximate building location and mix of activity areas within the actual building.

Building Types	Split or multi-split system	Fan coil systems	Constant volume system (fixed fresh air rate)	Single-duct VAV	Single room cooling system	Constant volume system (variable fresh air rate)	Dual-duct VAV	Indoor packaged cabinet (VAV)	Chilled ceilings or passive chilled beams and displacement ventilation	Induction system	Dual duct (constant volume)	Terminal reheat (constant volume)	Water loop heat pump	Active chilled beams	All System Types
A1/A2 Retail and Retail services	50	66	97	66	57	152	26				55		151	20	55
A3/A4/A5 Restaurant and Cafes etc.	88	67	181	194	35	137		48		119					99
B1 Offices and Workshop businesses	43	36	24	13	29		13	15	14	36		16			37
B2 to B7 Industrial	56	21	21	21	88										46
B8 Storage or Distribution	23		74	61											33
C1 Hotels	25	46	173		9		35	11							29
C2 Hospitals and Care Homes	115			483											238
C2 Universities and colleges	39														39
D1 Libraries Museums and Galleries	27														27
D1 Primary Health Care Building	46	9													43
D2 General Assembly and Leisure	38	18	122		12										47
All Buiding Types	**49**	**42**	**99**	**52**	**44**	**148**	**27**	**19**	**14**	**63**	**55**	**16**	**151**	**20**	**51**

Table C16: Average annual kWhe/m^2(cooled) calculated cooling electricity use (from EPCs) broken down by building type and system type

Building Types	Split or multi-split system	Fan coil systems	Constant volume system (fixed fresh air rate)	Single-duct VAV	Single room cooling system	Constant volume system (variable fresh air rate)	Dual-duct VAV	Indoor packaged cabinet (VAV)	Chilled ceilings or passive chilled beams and displacement ventilation	Induction system	Dual duct (constant volume)	Terminal reheat (constant volume)	Water loop heat pump	Active chilled beams	All System Types
A1/A2 Retail and Retail services	86	102	84	64	82	137	33	-	-	-	34	-	211	35	87
A3/A4/A5 Restaurant and Cafes etc.	136	91	121	215	50	125	-	81	-	142	-	-	-	-	125
B1 Offices and Workshop businesses	83	78	23	15	82	-	42	40	41	44	-	33	-	-	73
B2 to B7 Industrial	80	39	34	54	125	-	-	-	-	-	-	-	-	-	70
B8 Storage or Distribution	42	-	54	73	-	-	-	-	-	-	-	-	-	-	46
C1 Hotels	49	64	126	-	15	-	35	15	-	-	-	-	-	-	47
C2 Hospitals and Care Homes	262	-	-	536	-	-	-	-	-	-	-	-	-	-	353
C2 Universities and colleges	159	-	-	-	-	-	-	-	-	-	-	-	-	-	159
D1 Libraries Museums and Galleries	62	-	-	-	-	-	-	-	-	-	-	-	-	-	62
D1 Primary Health Care Building	96	12	-	-	-	-	-	-	-	-	-	-	-	-	89
D2 General Assembly and Leisure	58	24	88	-	18	-	-	-	-	-	-	-	-	-	54
All Buiding Types	**86**	**78**	**80**	**58**	**74**	**135**	**35**	**35**	**41**	**77**	**34**	**33**	**211**	**35**	**83**

Table C17: Average annual calculated cooling demand (kWhc/m^{2}cooled) broken down by property type and system

Building Types	Split or multi-split system	Fan coil systems	Constant volume system (fixed fresh air rate)	Single-duct VAV	Single room cooling system	Constant volume system (variable fresh air rate)	Dual-duct VAV	Indoor packaged cabinet (VAV)	Chilled ceilings or passive chilled beams and displacement ventilation	Induction system	Dual duct (constant volume)	Terminal reheat (constant volume)	Water loop heat pump	Active chilled beams	All System Types
A1/A2 Retail and Retail services	0.58	0.65	1.16	1.03	0.70	1.10	0.79				1.61		0.71	0.57	0.64
A3/A4/A5 Restaurant and Cafes etc.	0.65	0.74	1.49	0.90	0.70	1.10		0.59		0.84					0.79
B1 Offices and Workshop businesses	0.51	0.47	1.08	0.84	0.35		0.32	0.38	0.34	0.81		0.50			0.51
B2 to B7 Industrial	0.70	0.55	0.61	0.40	0.70										0.66
B8 Storage or Distribution	0.56		1.38	0.84											0.71
C1 Hotels	0.52	0.73	1.38		0.56		1.02	0.74							0.62
C2 Hospitals and Care Homes	0.44			0.90											0.67
C2 Universities and colleges	0.24														0.24
D1 Libraries Museums and Galleries	0.44														0.44
D1 Primary Health Care Building	0.48	0.74													0.49
D2 General Assembly and Leisure	0.66	0.73	1.38		0.70										0.88
All Buiding Types	**0.57**	**0.54**	**1.24**	**0.90**	**0.60**	**1.10**	**0.78**	**0.54**	**0.34**	**0.82**	**1.61**	**0.50**	**0.71**	**0.57**	**0.62**

Table C18: Ratio of calculated cooling electricity consumption: calculated cooling demand use (kWhe/kWhc) broken down by builidng type and system type

5.1.4 As well as using energy use to generate cooling e.g., chiller energy use, HVAC systems also use energy to power fans pumps and controls. This is referred to as auxiliary energy use in the EPC data files. For systems which provide heating and/or ventilation in addition to cooling, the auxiliary energy use relates to all the energy services provided, not just the cooling function. For the purpose of this analysis auxiliary energy use had been allocated between heating and cooling based on the ratio of heating and cooling demand in the building. The demand for ventilation is not provided in the EPC outputs and, even if it were, it would be difficult to allocate energy use to ventilation alone; because thermal and ventilation demands are met simultaneously and interact. (Ventilation demand may require additional energy to heat incoming outdoor air during the heating season and benefit from free cooling from incoming air when cooling.)

5.1.5 The cooling energy use and cooling share of auxiliary energy use therefore provide an indication of the total energy used to provide the cooling service for the building; acknowledging that this is likely to overestimate the auxiliary energy use associated with distributing and controlling the distribution of cooling for the reasons outlined above.

5.1.6 Figure C16 shows estimated energy consumption for cooling plus cooling allocation of auxiliary energy use for the EPC sample, broken down by system type. Here the share of energy use, compared to cooling only, is increased for systems which include air distribution systems. Single split systems still accounting for the largest proportion at 25% of the total, compared to 34% for cooling only systems.

5.1.7 Table C20 shows the average energy intensity for cooling and auxiliary energy use compared to the energy intensity for cooling only for different system types across the EPC sample. This shows auxiliary energy use accounts for around a quarter of total air conditioning energy use, and that for system types which include air distribution, auxiliary energy use can be higher than cooling only energy use.

5.1.8 Table C21 shows similar energy intensity information broken down by building type. Here the variations are generally much smaller and largely reflect the mix of systems found in each building type.

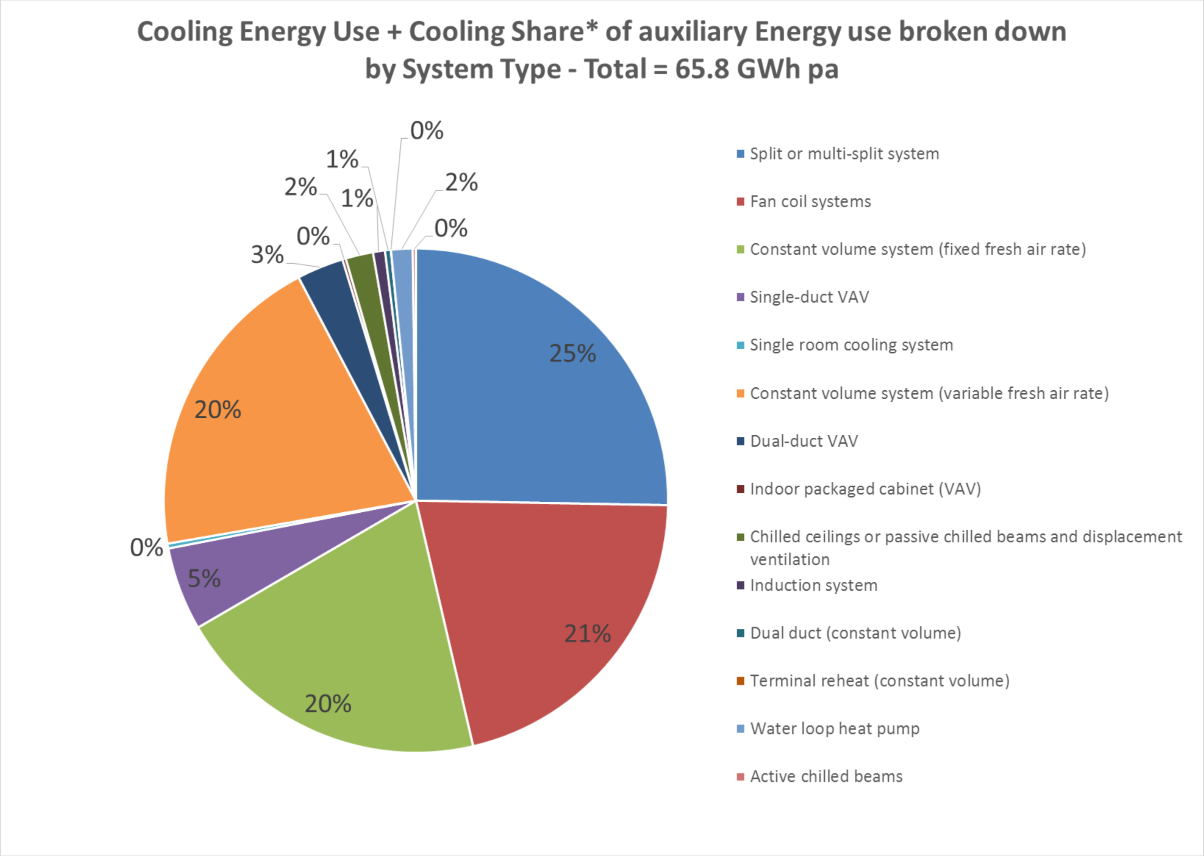


Figure C16: Calculated cooling electricity use, including estimated auxiliary electricity use, broken down by system type

*Auxiliary energy use has been allocated between cooling and heating based on the ratio of the demand for cooling and heating.

System Type	**Cooling System kWh/m²**	**Cooling only kWh/m²**	**% Auxiliary energy**
Split or multi-split system	55	49	9%
Fan coil systems	77	43	45%
Constant volume system (fixed fresh air rate)	210	99	53%
Single-duct VAV	233	92	60%
Single room cooling system	56	49	12%
Constant volume system (variable fresh air rate)	261	148	43%
Dual-duct VAV	91	27	70%
Indoor packaged cabinet (VAV)	39	19	52%
Chilled ceilings or passive chilled beams and displacement ventilation	29	14	52%
Induction system	100	63	37%
Dual duct (constant volume)	130	55	58%
Terminal reheat (constant volume)	16	16	0%
Water loop heat pump	295	151	49%
Active chilled beams	26	20	22%
All System Types	**71**	**53**	**25%**

Table C20: Average energy intensities for cooling and overall cooling system and the proportion of auxiliary energy use for different systems type for the EPC sample.

Building Type	Cooling System kWh/m^2	Cooling only kWh/m^2	% Auxiliary energy
A1/A2 Retail and Retail services	68	56	19%
A3/A4/A5 Restaurants and Cafes etc.	164	102	38%
B1 Offices and Workshop businesses	55	41	26%
B2 to B7 Industrial	72	46	35%
B8 Storage or Distribution	60	33	45%
C1 Hotels	54	29	45%
C2 Hospitals and Care Homes	495	238	52%
C2 Universities and Colleges	39	39	0%
D1 Libraries Museums and Galleries	27	27	0%
D1 Primary Health Care Buildings	50	47	6%
D2 General Assembly and Leisure	77	47	39%
Grand Total	**71**	**53**	25%

Table C21: Average energy intensities for cooling and overall cooling system and the proportion of auxiliary energy use for different building type for the EPC sample.

5.2 The distribution of (calculated) floor area normalised energy consumption for cooling for four main building types in the EPC sample was examined and compared to relevant benchmark values where they are available (See 5.1.12).

5.2.1 Because these energy consumptions are based on standard occupancy patterns and equipment usage, the actual distribution is likely to be wider than that indicated here. The observed variations in energy consumption calculated on the basis of information collected during an EPC assessment therefore reflect differences in building design, system type, and the mix of activity areas within each building type, its location, and the lighting and system efficiencies.

5.2.2 More detailed analysis of the EPC data showed that around 10% of the observed variance is attributable to cooling system efficiencies, most of it relating to chiller efficiency. This means that the remainder of the observed variance reflects differences in building design, system type, and the mix of activity areas within each building type, its location, and lighting efficiencies.

5.2.3 Figure C17 shows the energy weighted distribution of calculated cooling energy consumption for offices from the EPC sample. The majority of energy intensity values falls within the range 15-55 kWh/m^2. This compares favourably to actual energy performance benchmarks from ECON 19[B] of 31 to 41 kWh/m^2 for good practice, 14 to 21 for best practice and a cost-optimal energy efficiency value of 9 kWh/m^2 for new offices. This indicates that EPC calculated values are in reasonable agreement with actual consumption values.

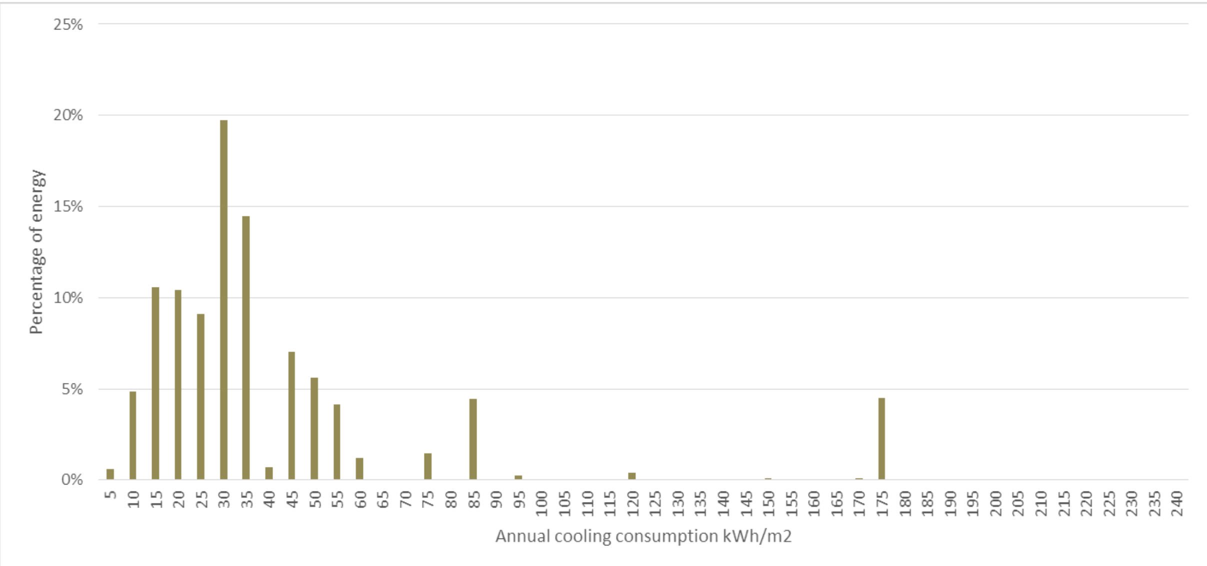


Figure C17: Energy Weighted distribution of Normalised Cooling Energy Consumption for Offices from EPCs

5.2.4 Figure C18 shows the energy weighted distribution of cooling energy consumption for Restaurants from the EPC sample. The majority of energy intensity values falls within the range 15-55 kWh/m2. The variance in cooling energy consumption is larger than for offices and system efficiency (which is mostly split systems) accounts for around 50% of the observed variance.

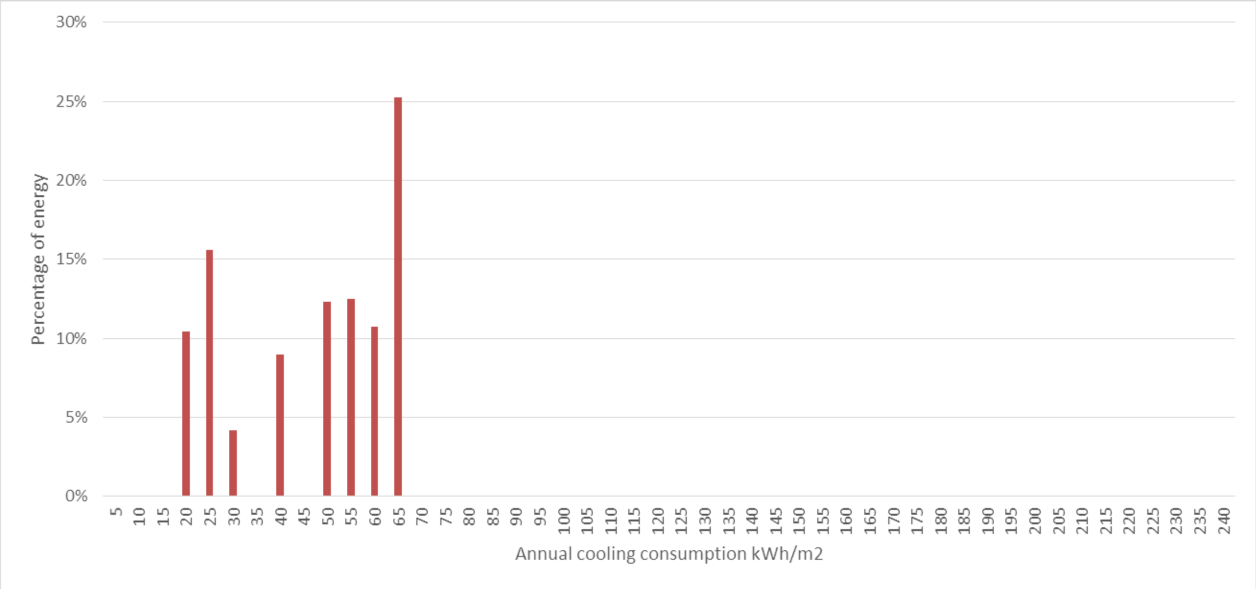


Figure C18: Energy Weighted distribution of Normalised Cooling Energy Consumption for Restaurants from EPCs

5.2.5 Figure C19 shows the energy weighted distribution of cooling energy consumption for Hotels from the EPC sample. The majority of energy intensity values falls within the range 15-45 kWh/m^2, and so is broadly similar to that for offices but with greater variance. This may reflect the wider range of activity areas within hotels. There are no published benchmarks for cooling energy use in hotels, but the cost optimal values for a new hotel has been calculated at 7 kWh/m^2, which is at the lower end of the observed range. System efficiency accounts for nearly 60% of the observed variance and the system types are mostly split or VRF systems.

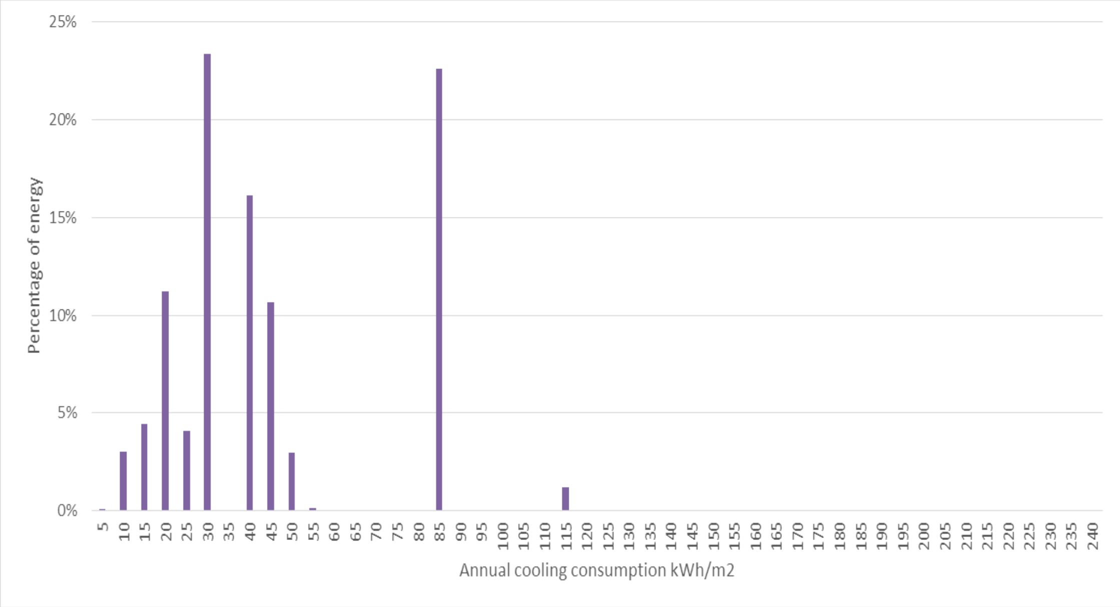


Figure C19: Energy Weighted distribution of Normalised Cooling Energy Consumption for Hotels from EPCs

5.2.6 Figure C20 shows the energy weighted distribution of cooling energy consumption for Retail buildings from the EPC sample. The typical energy consumption is considerably higher than that observed for the other building types and there is a much wider range of energy intensities. High levels of heat gains from display lighting are probably a significant contributor to the cooling energy demand. This is supported by a breakdown of typical electricity consumption in a hypermarket comprising 23% lighting and 9% air conditioning[c].

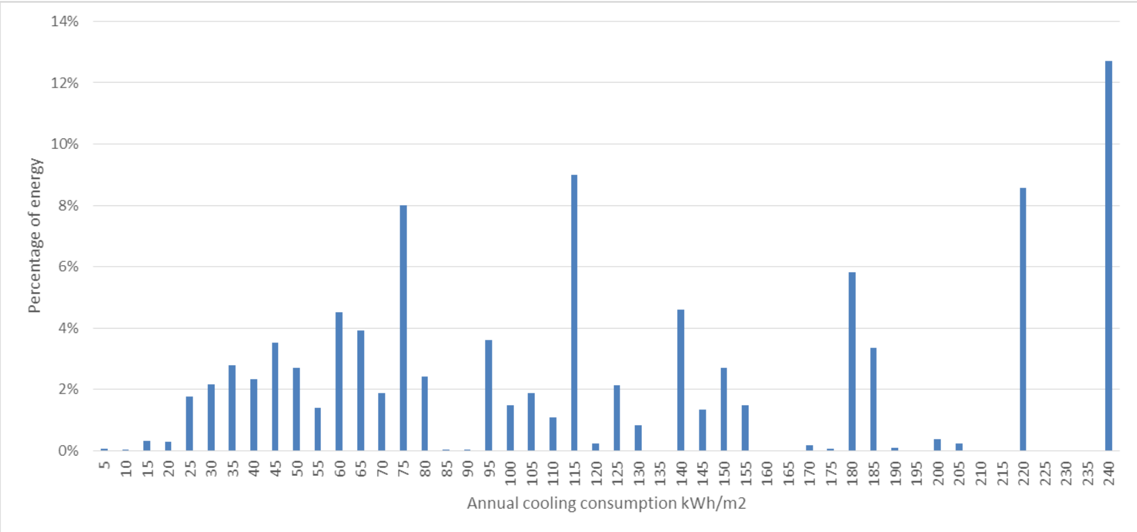


Figure C20: Energy weighted distribution of normalised cooling energy consumption of Retail Buildings from EPCs

6 Analysis of Cooling related recommendations from EPCs

This Section describes the procedure for generating cooling related EPC recommendations and presents the results of an analysis of cooling related recommendations contained in the EPC data.

6.1 Energy Performance Certificates include recommendations for improving the energy performance of the building. A number of standard recommendations are automatically generated within the software tool. For cooling these are:

- EPC-C1 - The default chiller efficiency is chosen. It is recommended that the chiller system be investigated to gain an understanding of its efficiency and possible improvements.
- EPC-C2 - Chiller efficiency is low. Consider upgrading chiller plant.
- EPC-C3 - Ductwork leakage is high. Inspect and seal ductwork.

A high, medium or low potential CO_2 saving is assigned to each recommendation.

6.1.1 The criteria used to assign the three standard cooling recommendations are described in the following extract from the iSBEM Technical Manual[D] In addition to the three standard cooling recommendations EPC assessors may also provide recommendations that are specific to that building.

EPC-C1

- Check if using default cooling efficiency – if yes trigger EPC-C1

Note: Assessing impact of recommendation EPC-C1 is done similarly to that for recommendation EPC-C2 shown below.

EPC-C2

- Find cold generator efficiency
  - If cold generator efficiency > 2.4, classify cold generator efficiency as "good"
  - If 2.4 > = cold generator efficiency > 2.0 , classify cold generator efficiency as "fair"
    - Trigger recommendation EPC-C2
    - Assess likely scale of energy impact from proportion of total "energy" (assumed to be price-weighted using factor from fuel price ratios).
      - Calculate new cooling energy as ratio between actual efficiency and 2.5.
      - Determine % change in total building energy
        - If change in total energy is > 4% potential impact is "high"
        - If 4% > = change in total energy > 0.5%, potential impact is "medium"
        - Otherwise change in total energy potential impact is "low"
    - Assess likely scale of carbon impact from proportion of total carbon.
    - Calculate new cooling carbon emissions as ratio between actual efficiency and 2.5. Determine % change in total building carbon emissions
      - If change in total carbon is > 4% potential impact is "high"
      - If 4% > = change in total carbon > 0.5%, potential impact is "medium"
      - Otherwise change in total carbon, potential impact is "low"
  - If 2.0 > cold generator efficiency, classify cold generator efficiency as "poor"
    - § Trigger recommendation EPC-C2 as above

EPC-C3

- If the HVAC system is VAV (including packaged cabinet), fan coil, induction, constant volume, multizone, terminal reheat, dual duct, chilled ceiling or chilled beam (with displacement ventilation), or active chilled beams,
- Extract duct and AHU leakage for Actual Building
- If duct and AHU leakage < 5% classify duct leakage as "good"
- If 5% < = duct and AHU leakage < 10% , classify duct leakage as "fair"
  - Trigger recommendation EPC-C3 and calculate impact
  - Reduce cooling energy by P% where P is · VAV, constant volume, multizone, terminal reheat, dual duct P=5%
  - Fan coil, induction P = 2%
  - Chilled ceiling, chilled beam P= 0.5%
- Assess likely scale of energy impact from proportion of total "energy" (assumed to be price-weighted using factor from relative fuel prices),
  - If total energy cost for building changes by more than 4%, impact is "high"
  - If total energy cost for building changes by less than or equal to 4% but more than 0.5%, impact is "medium"
  - Otherwise impact is "low"
- Assess likely scale of carbon impact from proportion of total carbon
  - If total carbon emissions from the building change by more than 4%, impact is "high"
  - If total carbon emissions from the building change by less than or equal to 4% but more than 0.5%, impact is "medium"
  - Otherwise impact is "low"
- If 10% < = duct and AHU leakage , classify duct leakage as "poor"
  - Trigger recommendation EPC-C3 – as above and calculate impact – this time reducing cooling energy by P% where P is
    - VAV, constant volume, multizone, terminal reheat, dual duct P=10%
    - Fan coil, induction P = 4%
    - Chilled ceiling, chilled beam P= 1%

6.1.2 Table C22 shows an analysis of the prevalence of the three standard cooling recommendations broken down by building type, of the three standard recommendations across the 490 buildings included in the sample.

Building Type	EPC-C1 Default Chiller Efficiency	EPC_C2 Low Chiller Efficiency	EPC_C3 Ductwork leakage is high	Total Number Recommendations
A1/A2 Retail and Financial/Professional services	126	5	9	140
A3/A4/A5 Restaurant and Cafes/Drinking Establishments and Hot Food takeaways	14	2	3	19
B1 Offices and Workshop businesses	26	2	7	35
B2 to B7 General Industrial and Special Industrial Groups	3		2	5
B8 Storage or Distribution	1			1
C1 Hotels	4			4
D1 Non-residential Institutions - Primary Health Care Building	1		1	2
D2 General Assembly and Leisure plus Night Clubs and Theatres	4	1		5
All Building type	**179**	**10**	**22**	**211**

Table C22: Standard cooling recommendations appearing on EPC broken down by building type

6.1.3 The vast majority of the standard recommendations arise because a default efficiency value was selected in the software, and this recommendation is just flagging up that the actual energy efficiency value is unknown. The number of instances where low chiller efficiency is flagged when a value has been entered for the chiller efficiency is only 3%. The incidence of high ductwork leakage is also relatively low at around 4%, however, most systems don’t have air distribution systems so this recommendation is only relevant for some system types. There are no obvious trends in relation to the standard recommendations provided by property type.

6.1.4 Eighteen non-standard recommendations were identified in the sample. Of these, 7 were concerned with replacing components other than chillers, 4 related to monitoring, 3 related to controls, 2 to reducing ductwork leakage with one recommendation for system replacement and another for system reconfiguration. The non-standard recommendations are shown in Table C23.

Non-Standard Recommendations	A1/A2 Retail and Retail Services	B1 Offices and Workshops	Grand Total
Consider installing independent monitoring systems for the various building services, such as heating, cooling and lighting. Monitoring procedures should also be implemented to highlight any 'out-of-range' events and values	4		4
Consider installing sensors where appropriate in rooms with intermittent occupation to ensure that the heating/air conditioning is switched off during periods of extended non-occupation.	2		2
Consider reconfiguring AHU dampers to enable re-circulation of extract air.	1		1
Consider replacing the VAV system with fancoils. Due to the way VAV systems operate they are much less efficient. Replacing with a fancoil system would reduce heating, cooling and fan energy.		1	1
Consider upgrading any Direct Drive pumps and fans to Variable Speed Drive (VSD) types. Savings will depend on hours of use, but typically 20-40% savings are achievable	4		4
Consider upgrading the air-conditioning plant with new inverter driven condensers running R410A refrigerant	1		1
Inspect ductwork for leakage and seal as required		1	1
Investigate specific fan powers on all air handling plant. Consider adjusting the volumes or replacing the motors to current standards as set out in the Non-domestic HVAC guide (1.8 W(l/s))		1	1
Test AHUs for air leakage and seal them to Class L1.	1		1
The specific fan power of the AHUs is below the recommended amount of 1.8	1		1
Use inverter on AHU to reduce fan power by 10%.	1		1
Grand Total	**15**	**3**	**18**

Table C23: Non- standard cooling recommendations appearing on EPCs.

6.1.5 Table C24 shows the standard recommendation broken down by system type for buildings which only have one cooling system[5] . This shows that the vast majority of recommendations relate to the chiller efficiency of split systems being unknown. This is not surprising given that split system are the most prevalent system type in the sample and, because the chiller is part of the packaged unit, information on the efficiency of the chiller is less likely to be easily identified from either the installation or from technical manuals.

System Type	**EPC_C2 Low Chiller Efficiency.**	**EPC_C3 Ductwork leakage is high**	**EPC-C1 Default Chiller Efficiency**	**Total**
Constant volume system (fixed fresh air rate)	1	1	3	5
Constant volume system (variable fresh air rate)		2	1	3
Dual duct (constant volume)		1	1	2
Dual-duct VAV		1		1
Fan coil systems		2	3	5
Induction system			1	1
Single room cooling system			2	2
Single-duct VAV			3	3
Split or multi-split system	4	1	119	124
Grand Total	**5**	**8**	**133**	**146**

Table C20: Standard cooling recommendations appearing on EPC broken down by building type (for buildings with one cooling system)

6.1.6 The estimated CO_2 impacts for the standard measures (calculated within SBEM) are shown in Table C21. In general not knowing the actual chiller efficiency and selecting the default value is associated with a low carbon impact, whilst the other measures tend to be associated with medium and high CO_2 impacts.

[5] Where a building includes more than one system it is not possible to allocate the recommendations to a specific system type

CO_2 Impact Rating	EPC_C2 Low Chiller Efficiency.	EPC_C3 Ductwork leakage is high	EPC-C1 Default Chiller Efficiency	Total
HIGH	3	8	3	14
MEDIUM	6	13		19
LOW	1	1	176	178
Grand Total	**10**	**22**	**179**	**211**

Table C21: CO_2 impacts for standard cooling recommendations appearing in EPC sample

7 Results and Conclusions

This Section summarises the main results and conclusions of the EPC analysis

7.1 Comparison of the floor area and system types identified in the corresponding EPC data and ACIR identified significant differences in the floor area and system type for around 50% of the sample and for this reason analysis of the combined data set was not attempted. These discrepancies are likely to have arisen from differences in the way in which property boundaries were defined for the different assessments.

7.2 In terms of the number of buildings, 65% of the sample were retail, 20% offices, with hotels, restaurants and cafes accounting for the majority of the remainder. These EPC sample covers approximately 1 million m2 of floor area. In terms of floor area, retail premises represent 38% of the sample, offices 37% of the total, and hotels, restaurants and cafes accounting for the majority of the remainder. Analysis shows that the data are representative in each Government Office Region.

7.3 There appears to be no relation between property size and proportion of cooled area, although there are discernible variations in the proportion of cooled area between building types. Most building types have around 70-80% of their floor area cooled, but in primary health care, hospitals and warehouses, this proportion falls to around 50%.

7.4 In terms of system type over three quarters of the systems in the sample were split or multisplit systems and these also cooled the largest proportion of floor area (41%). The next largest floor area was cooled by fan coil systems (21%).

7.5 The EPC methodology combine data on the actual building geometry, construction, and the air conditioning system type and its efficiency to calculate the expected electricity demand for cooling based on a standardised occupancy patterns for the relevant building type and the mix of activity areas within it. For existing buildings it is not always possible for assessors to obtain information on the efficiency of the installed equipment and in these instances default values are entered (these are deliberately conservative, but reasonable). The efficiency of the cooling equipment is defined by the SEER (Seasonal Energy Efficiency Ratio) and is entered by the EPC Assessor. In addition the SSSEER (System Seasonal Energy Efficiency Ratio) is calculated based on the system type and other information on the air conditioning system and takes account of energy use by fans pumps and controls and any distribution losses.

7.6 60% of SEER values in the EPC data sample were shown to correspond to defaults value. Where non-default values have been entered these are on average around 50% more efficient compared to a weighted average of the (conservative) default values .The non-default SEER values should therefore provide a good indication of SEER values found in this sample of buildings and it should be possible to extrapolate these results to the UK building stock.

7.7 Of the total 38 GWh per year of calculated energy used for cooling by all the buildings in the EPC data sample, split or multi- split systems account for a third of the total cooling energy use (which is unsurprising given that they account for 77% of all systems and serve 40% of the total floor area in the sample), fan coil systems 19%, constant volume systems with variable fresh air rates account for 22% of the total and constant volume systems with fixed fresh air rates 15% of the total cooling energy use.

7.8 In terms of sectors, offices and retail have the highest electricity use for cooling. Despite the hospitals and primary health care sector only having around 50% of the surface area cooled, they are the heaviest users of electricity for cooling with an average of 238 kWh/m^2 providing an average cooling demand of 353 kWh/m^2. This is at least in part due to the longer occupancy rates for hospitals and accordingly improving energy efficiency in this sector may have greater scope for energy savings.

7.9 In addition to energy use for cooling air conditioning systems also use energy for fans pumps and controls and cooling can also be lost in the distribution process via conductive heat transfer and duct leakage. This additional energy use included in the EPC data as auxiliary energy use, but this also includes auxiliary energy use for heating and ventilation factions as well as for the cooling function. In order to provide an estimate of the auxiliary energy use associated with the cooling function the auxiliary energy use was split between heating and cooling based on the annual average demand for these two services for each system. This analysis showed that the share of auxiliary energy use for cooling accounted for an additional 17 GWh per year for the EPC data sample, giving an estimated total of 65 GWh a year attributable to providing the cooling function.

7.10 The energy weighted distribution cooling energy use per m^2 for office buildings shows a relative wide distribution and that the calculated energy intensities are broadly in line with benchmarks values. The energy weighted distribution of cooling energy use per m^2 retail buildings show a much wider spread for the energy weighted distribution of normalised cooling energy consumption of Retail Buildings from EPCs (much wider than for hotels or offices). Analysis was not carried out for the primary health care and hospital sectors due to the small number of buildings included in the sample.

7.11 As well as the building efficiency rating outputs, an EPC also includes report of recommendations to improve efficiency from SBEM. Cooling energy-related recommendations from EPC's - highest number is for retail. But the most common recommendation is to find out the real chiller efficiency instead of using the default. After that, the most common recommendation is to fix leaks in the ductwork - but this only applies for some system types. A range of non-standard recommendations were given, the most common being to install variable speed drives and monitoring.

8 References

[A]NCM Modelling Guide and SBEM User Guide and SBEM Technical Manual can be downloaded from the UK NCM website here: http:/www.uk-ncm.org.uk/

[B] Energy efficiency in offices Energy Consumption Guide ECG 19 Action Energy, 2000.

[C]Tassou SA, Ge YT, Hadewey A and Marriott D (2001) energy consumption and conservation in food retailing. Applied Thermal Engineering 31 147-156

[D]SBEM: Simplified Building Energy Model - Part of the National Calculation Methodology: SBEM for assessing the Energy Performance of Buildings. A Technical Manual for SBEM, UK Volume 31 July 2014.