WHAT COLOUR is YOUR BUILDING?

Measuring and reducing the energy and carbon footprint of buildings

David H. Clark

Appendix C

Energy consumption data

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Appendix C: Energy consumption data

He uses statistics as a drunken man uses lampposts – for support rather than illumination.

Andrew Lang, Scottish poet, novelist and literary critic.

Contents

This appendix provides additional information on energy consumption in buildings to support Chapter 2 (How much energy do buildings use?).

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C1. OPERATIONAL ENERGY BENCHMARKS

Source of data

A selection of operational energy benchmarks for different building types published since 1990 have been collated and converted into $kgCO_2e/m^2$ of GIA, the metric used in this book. The emissions factors ($kgCO_2e/kWh$) used were 0.6 for electricity and 0.2 for gas. The sources include:

- CIBSE publications:
  - Energy Benchmarks (TM46:2008).[1]
  - Guide F – Energy Efficiency in Buildings (2012).[2]
  - Technical Memoranda TM22: 1999 Annex.
- UK Government Energy Efficiency Best Practice guides:[3]
  - Energy use in offices (ECON 19).
  - Energy consumption in hospitals (ECG 072).
  - Saving energy in schools (ECG 073).
  - Energy use in Ministry of Defence establishments (ECG 075).
  - Energy use in sports and recreation buildings (ECG 078).
  - Benchmarking tool for industrial buildings (ECG 081).
  - Energy use in court buildings (ECG 082).
  - Energy use in Government laboratories (ECG 083).
  - Energy use in prisons (ECG 084).
  - Energy use in Local Authority buildings (ECG 087).
- Carbon Trust guides:
  - Carbon Trust online benchmarking tool for offices:[4]
  - Energy efficiency in retailing (CTL 84).
  - Saving energy - a whole school approach (GPG 343).
- PassivHaus PHPP software for UK (2011).

All benchmarks are for UK buildings unless noted otherwise. No attempt has been made to verify the accuracy of the benchmarks or to provide specific notes and exclusions for their correct use. The reader should seek this directly from the source material used.

C1.1 Offices

Table C.1 provides office energy benchmarks from a variety of sources.

	Tenant electricity	Landlord electricity	Gas	Total	Benchmark	Comments
	kWh/m² of GIA				$kgCO_2e/m^2$	
CIBSE Energy Benchmark (TM46: 2008)						
General office	95		120	215	**81**	
PassivHaus standard *						
Office	44		0	44	**27**	Primary energy factor = 2.7
ECON 19 Guide (2003)						TUFA to GIA conversion
Nat vent cellular (good)	5	27	75	106	**34**	0.95
Nat vent cellular (typical)	10	42	143	195	**59**	0.95
Nat vent open plan (good)	9	43	75	126	**46**	0.95
Nat vent open plan (typical)	14	67	143	224	**77**	0.95
Air con standard (good)	53	62	87	203	**87**	0.9
Air con standard (typical)	105	98	160	364	**154**	0.9
Air con prestige (good)	70	129	97	296	**139**	0.85
Air con prestige (typical)	124	180	179	483	**218**	0.85
Carbon Trust Office Benchmarking Tool (2011)						
Natural ventilation - good	84		99	183	**70**	Assumes open plan, 1 per 15m² of GIA
Natural ventilation - typical	132		188	320	**117**	
Mixed mode - good	103		124	227	**87**	
Mixed mode - typical	170		225	395	**147**	
Air conditioned - good	142		124	266	**110**	
Air conditioned - typical	252		225	477	**196**	

* The PassivHaus standard sets a Primary Energy target of 120 kWh/m² and also requires that heating and cooling energy does not exceed a total of 15 kWh/m² per annum. The standard was originally developed for houses but has been applied to other building types, including offices and schools.

Table C.1 Office energy benchmarks

Table C.3 shows the energy use indices (which have been converted to $kgCO_2e/m^2$ of GIA) used to develop the ECON 19 benchmarks.

	Heating and hot water	Cooling	Fans, pumps and controls	Humidification	Lighting	Office equipment	Catering (gas)	Catering (elec)	Other electric	Computer room
Nat vent cellular (good)	15	0	1	0	8	7	0	1	2	0
Nat vent cellular (typical)	29	0	3	0	13	10	0	2	2	0
Nat vent open plan (good)	15	1	2	0	13	11	0	2	2	0
Nat vent open plan (typical)	29	1	5	0	22	15	0	3	3	0
Air con standard (good)	17	8	16	4	15	12	0	3	4	8
Air con standard (typical)	32	17	32	10	29	17	0	3	4	10
Air con prestige (good)	18	11	18	6	15	12	4	7	7	44
Air con prestige (typical)	34	21	34	12	31	16	5	8	8	54

Table C.2 **ECON 19 office energy benchmark breakdown by end use ($kgCO_2e/m^2$ of GIA)**

The definitions for the buildings in ECON 19 are:

- **Nat vent cellular** – a simple building, often (but not always) relatively small and sometimes in converted residential accommodation. Typically 100 to 3,000 m^2.
- **Nat vent open plan** – largely open-plan but with some cellular offices and special areas. Typically 500 to 4,000 m^2.
- **Air con standard** – largely purpose-built and often speculatively developed. Typically 2,000 to 8,000 m^2.
- **Air con prestige** – a national or regional head office, or technical or administrative centre. Typically 4,000 to 20,000 m^2.

The factors used to convert between Gross Internal Area, Net Lettable Area and Treated Floor Area in ECON 19 are shown in Table C.3. In this book, unless noted otherwise a GIA to NLA factor of 80% (1.0 NLA to 1.25 GIA) has been typically used for general offices which is the factor used in CIBSE Energy Benchmarks (TM46:2008) and UK Display Energy Certificates.

Office type	Treated Floor Area % of Gross Internal Area	Net Lettable Area % of Treated Floor Area	Net Lettable Area % of Gross Internal Area
Naturally ventilated			
Cellular	95%	80%	76%
Open plan	95%	80%	76%
Air conditioned			
Standard	90%	80%	72%
Prestige	85%	80%	68%

Table C.3 **Floor conversion factors for UK offices (source: ECON 19)**

C1.2 Retail

Table C.4 provides energy benchmarks from a variety of sources for retail buildings.

	Electricity (kWh/m²)		Gas (kWh/m²)		**$kgCO_2e/m^2$ of GIA**		Comments
CIBSE Energy Benchmark (TM46: 2008)							
High street agency	140		0		**84**		
General retail	165		0		**99**		
Small food store	310		0		**186**		
Supermarket (or large food store)	400		105		**261**		
Large non-food store	70		170		**76**		
Shopping centre mall (circulation)	30		120		**42**		
Retail warehouse	70		170		**76**		
Energy benchmarking in the retail sector BMI Special Report SR 281 (2000)							
	Good	Typ	Good	Typ	**Good**	**Typ**	Converted from Sales Area to GIA using
Bank	71	101	63	98	**55**	**80**	-
Bank (all electric)	122	195	0	0	**73**	**117**	-
Clothes shop	157	192	44	72	**103**	**130**	0.67
Clothes shop (all electric)	181	217	-	-	**109**	**130**	0.67
Department store	121	150	99	126	**92**	**115**	0.51
Department store (all electric)	107	132	-	-	**64**	**79**	0.51
Distribution warehouse	53	67	103	169	**52**	**74**	-
Distribution warehouse (all electric)	55	101	-	-	**33**	**61**	-
DIY stores	85	107	100	129	**71**	**90**	0.67
Electrical goods retail	115	154	-	-	**69**	**92**	0.67
Frozen food centres	523	628	-	-	**314**	**377**	0.61
High street agency	39	53	105	161	**44**	**64**	0.7
High street agency (all electric)	63	112	-	-	**38**	**67**	0.7
Small food shop	280	350	56	70	**179**	**224**	0.7
Small food shop (all electric)	308	385	-	-	**185**	**231**	0.7
Supermarket	393	441	86	112	**253**	**287**	0.43
Supermarket (all electric)	445	497	-	-	**267**	**298**	0.43

Table C.4 Retail energy benchmarks

C1.3 Industrial

Table C.5 provides energy benchmarks from a variety of sources for industrial buildings.

	Electricity (kWh/m^2)		Gas (kWh/m^2)		**$kgCO_2e/m^2$ of GIA**		Comments
CIBSE Energy Benchmark (TM46: 2008)							
Workshop or open working area	35		180		**57**		
Storage warehouse or depot	35		160		**53**		
Refrigerated warehouse	145		80		**103**		
ECG 081 (2002)							
Lightweight Industrial	7		96		**23**		Post 1995 with general lighting
Lighting for open areas (300lux)	*7*						*Range of 6 to 7*
Lighting for open areas (500lux)	*9*						*Range of 8 to 10*
Lighting for racked storage (150lux)	*8*						*2.4m aisle width*
Lighting for racked storage (300lux)	*16*						*2.4m aisle width*
CIBSE TM22 Annex (1999) – from ECG 018 (1993)							
	Good	Typ	Good	Typ	**Good**	**Typ**	
General manufacturing	50	85	125	325	**55**	**116**	
Factory office	55	100	100	225	**53**	**105**	
Light manufacturing	31	70	90	300	**37**	**102**	
Storage and distribution	20	43	80	185	**28**	**63**	

Table C.5 Industrial energy benchmarks

C1.4 Hotels, pubs & restaurants

Table C.6 provides energy benchmarks from a variety of sources for hotels, pubs and restaurants.

	Electricity (kWh/m²)		Gas (kWh/m²)		**$kgCO_2e/m^2$ of GIA**		Comments
CIBSE Energy Benchmark (TM46: 2008)							
Restaurant	90		370		**128**		
Bar or pub	130		350		**148**		
Hotel	105		330		**129**		
ECG 036 (1993) / CIBSE TM22 Annex (1999)							
	Good	Typ	Good	Typ	**Good**	**Typ**	
Luxury hotel	90	150	300	460	**114**	**182**	Based on 58m² of GIA per bedroom
Additional for A/C	*40*	*70*	*30*	*40*	***30***	***50***	
Business or holiday hotel	80	140	260	400	**100**	**164**	
Additional for A/C	*30*	*60*	*30*	*40*	***24***	***44***	
Small hotel	80	120	240	360	**96**	**144**	
Additional for A/C	*20*	*50*	*20*	*30*	***16***	***36***	
Additional for leisure pool (all hotels)	10	20	30	50	**12**	**22**	
CIBSE Guide F (2012) – from Energy Efficiency Booklet EEB002 (1992)							
	Good	Typ	Good	Typ	**Good**	**Typ**	
Fast food restaurant	820	890	480	670	**588**	**668**	
Restaurant (with bar)	650	730	1100	1250	**610**	**688**	

Table C.6 Hotel, pub and restaurant energy benchmarks

C1.5 Education

Table C.7 provides energy benchmarks from a variety of sources for education buildings.

	Electricity (kWh/m²)		Gas (kWh/m²)		**$kgCO_2e/m^2$ of GIA**		Comments
CIBSE Energy Benchmark (TM46: 2008)							
School	40		150		**54**		
University campus	80		240		**96**		
ECG 073 (1998)							
	Good	Typ	Good	Typ	**Good**	**Typ**	
Primary school	20	28	126	173	**37**	**51**	
Secondary school	24	30	136	174	**42**	**53**	
Carbon Trust GPG 343 (2005)							
	Good	Typ	Good	Typ	**Good**	**Typ**	
Primary school	25	34	110	157	**37**	**52**	Heated floor area assumed to be same as GIA
Secondary school	28	36	117	160	**40**	**54**	
Secondary school with pool	29	36	142	187	**46**	**59**	
CIBSE Guide F (2012) – from 1996 Higher Education Funding Council publication							
	Good	Typ	Good	Typ	**Good**	**Typ**	
Lecture rooms - arts	67	76	100	120	**60**	**70**	
Lecture rooms - science	113	129	110	132	**90**	**104**	
Library - air conditioned	292	404	173	245	**210**	**291**	
Library - natural ventilation	46	64	115	161	**51**	**71**	
Science laboratory	155	175	110	132	**115**	**131**	
Halls of residence	85	100	240	290	**99**	**118**	
Self catering / flats	45	54	200	240	**67**	**80**	

Note: ECON 73 benchmarks are based on a 1997 survey with 'good' representing top 25% performance and 'typical' being the average. There has been a significant increase in IT use in schools since then so the electricity benchmarks are probably too low.

Table C.7 Education energy benchmarks

C1.6 Residential

Table C.8 provides energy benchmarks from a variety of sources for residential buildings.

	Electricity (kWh/m^2)		Gas (kWh/m^2)		**$kgCO_2e/m^2$ of GIA**		Comments
CIBSE Energy Benchmark (TM46: 2008)							
Long-term residential	65		420		**123**		
General accommodation	60		300		**96**		
PassivHaus Standard							
House / apartment	44		0		**27**		Refer Table C.1 note
ECG 087 (2004)							
	Good	Typ	Good	Typ	**Good**	**Typ**	
Residential care homes	59	75	492	555	**134**	**156**	
Sheltered housing	46	68	314	432	**90**	**127**	
CIBSE Guide F (2012) – from ECG 057 (1996)							
	Good	Typ	Good	Typ	**Good**	**Typ**	
Residential and nursing homes	44	79	247	417	**76**	**131**	
CIBSE Guide F (2012) – from 1996 Higher Education Funding Council publication							
	Good	Typ	Good	Typ	**Good**	**Typ**	
Halls of residence	85	100	240	290	**99**	**118**	
Self catering / flats	45	54	200	240	**67**	**80**	
ECG 084 (2004)							
	Electricity kWh/prisoner		Gas kWh/prisoner		**$kgCO_2e$/ prisoner**		
	Good	Typ	Good	Typ	**Good**	**Typ**	
High security prison	7,071	7,509	18,861	22,034	**8,015**	**8,912**	Excludes laundry & swimming pool
Other prison	3,736	4,460	18,861	22,034	**6,014**	**7,083**	

Table C.8 Residential energy benchmarks

C1.7 Healthcare

Table C.9 provides energy benchmarks from a variety of sources for healthcare buildings.

	Electricity (kWh/m²)		Gas (kWh/m²)		**$kgCO_2e/m^2$ of GIA**		Comments
CIBSE Energy Benchmark (TM46: 2008)							
Clinic	70		200		**82**		
Hospital (clinical & research)	90		420		**138**		
Laboratory or operating theatre	160		160		**128**		
ECG 072 (1996)							ECG 072 uses GJ/100m³ of heated volume. Converted to kWh/m² by multiplying by 8.06. This factor based on an average ceiling height of 2.9m.
	Good	Typ	Good	Typ	**Good**	**Typ**	
Teaching	86	122	339	411	**119**	**155**	
Acute	74	108	422	510	**129**	**167**	
Cottage	55	78	443	492	**122**	**145**	
Long stay	48	72	401	518	**109**	**147**	

Table C.9 Healthcare energy benchmarks

ALTERNATIVE BENCHMARKS

While floor area has become the de facto benchmark, it can be measured in a wide variety of different ways, such as Gross Internal Area (GIA), Net Internal Area (NIA), Net Lettable Area (NLA), Treated Useable Floor Area (TUFA), Retail Sales Area and so on. This can lead to differences of 25% in the benchmarks, so it is important to state which method of measurement is being used. In this book, m^2 of GIA is used throughout unless noted otherwise.

There is not a 'one size fits all' method to benchmarking. Alternatives to using floor area, which may better reflect the function of different types of building, include:

- Occupancy density – no. of workspaces, Full Time Equivalent (FTE) staff employed, daily headcount from security swipe cards, number of students, etc.
- Volume (m^3) – total volume of building heated or cooled (floor area x ceiling height).
- Activity – patient separations in hospitals, guest-nights in hotels, etc.

C1.8 Sport and leisure

Table C.10 provides energy benchmarks from a variety of sources for sport and leisure buildings.

	Electricity (kWh/m^2)		Gas (kWh/m^2)		**$kgCO_2e/m^2$ of GIA**		Comments
CIBSE Energy Benchmark (TM46: 2008)							
Entertainment halls	150		420		**174**		
Swimming pool centre	245		1130		**373**		
Fitness and health centre	160		440		**184**		
Dry sports and leisure centre	95		330		**123**		
ECON 78 (2001)							
	Good	Typ	Good	Typ	**Good**	**Typ**	
Local dry sports centre	64	105	158	343	**70**	**132**	
25m Swimming pool centre	152	237	573	1336	**206**	**409**	
Leisure pool centre	164	258	573	1321	**213**	**419**	
Combined centre	96	152	264	598	**110**	**211**	
Fitness centre	127	194	201	449	**116**	**206**	
Sports changing ground	93	164	141	216	**84**	**142**	
Ice rink	167	255	100	217	**120**	**196**	
CIBSE Guide F (2012)							
	Good	Typ	Good	Typ	**Good**	**Typ**	
Theatre	180	270	420	630	**192**	**288**	Area excludes balcony and circle areas
Cinema	135	160	515	620	**184**	**220**	
Social club	60	110	140	250	**64**	**116**	
Bingo club	190	230	440	540	**202**	**246**	

Table C.10 Sport and leisure Energy Benchmarks

C1.9 Public amenity and services

Table C.11 provides energy benchmarks from a variety of sources for public amenity and services buildings.

	Electricity (kWh/m²)		Gas (kWh/m²)		**$kgCO_2e/m^2$ of GIA**		Comments
CIBSE Energy Benchmark (TM46: 2008)							
Cultural (e.g. museum, art gallery)	70		200		**82**		
Public buildings with light usage	20		105		**33**		
Seasonal public buildings	40		150		**54**		
Public waiting (bus or train)	30		120		**42**		
Terminal (regional transport)	75		200		**85**		
ECG 082 (2002)							
	Good	Typ	Good	Typ	**Good**	**Typ**	
Magistrates court	33	47	132	204	**46**	**69**	Converted from Treated Floor Area to GIA. (TFA = 0.95 x GIA)
County court	55	63	132	200	**59**	**78**	
Crown court	72	78	146	192	**72**	**85**	
Combined court	60	75	117	167	**59**	**78**	
ECG 087 (2004)							
	Good	Typ	Good	Typ	**Good**	**Typ**	
Car park (open)	-	1	-	-	**-**	**1**	
Car park (enclosed)	-	15	-	-	**-**	**9**	
Community centre	22	33	125	187	**38**	**57**	
Day centre	51	68	203	349	**71**	**111**	
Museum and art gallery	57	70	96	142	**53**	**70**	
Library	32	46	133	210	**46**	**70**	
Town hall	84	111	138	205	**78**	**108**	
CIBSE Guide F - from EEB 012 (2002) and EEB 008 (1999)*							
	Good	Typ	Good	Typ	**Good**	**Typ**	
Ambulance station	48	67	333	437	**95**	**127**	Converted from Treated Floor Area to GIA. (TFA = 0.95 x GIA)
Fire station	52	76	366	513	**105**	**148**	
Police station	43	57	280	390	**82**	**112**	
Church *	10	19	76	143	**21**	**40**	

Table C.11 Public amenity and services energy benchmarks

C2. LOWEST ENEGY OFFICE CALCULATIONS

The rules and definitions of the UK's Zero Carbon Building and the European Union's Nearly Zero Energy Building targets are still to be resolved – refer to Appendix L for more details on this legislation. To determine the lowest practical energy consumption in a fully occupied UK office in 2012, a theoretical example was considered in Chapter 2. The annual energy consumption of the 'lowest energy office' described in Figure 2.1 is based on the following:

- Total hours per year = 24 hours x 365 days = 8,760 hours.
- Office hours per year = 10 hours x 5 days x 52 weeks = 2,600 hours (ignoring public holidays).
- Occupancy density = 1 person per 15 m^2 of GIA = 0.067 people per m^2.

Table C.12 shows the calculations summarised in Table 2.1 in Chapter 2.

System	Energy consumption calculation		Annual energy consumption (kWh/m^2)
Lighting	Ceiling:	Daylight dimming switches 50% off for 50% of the year 4 W/m^2 x 2600 hrs [1 – 0.5 x 0.5] = 7.8 kWh/m^2	8
	Task:	Assume on for 50% of the year 5 W/person x 2600 hrs x 50% x 0.067 = 0.4 kWh/m^2	
Equipment	Laptops:	30 W x 2600 hrs x 0.067 = 5.2 kWh/m^2	30
	Printers:	8 W/person x 2600 hrs x 0.067 = 1.4 kWh/m^2	
	Servers:	20 W/person x 8760 hrs x 0.067 = 11.7 kWh/m^2	
	Kettle:	2.5 kW x 1min to boil 1 cup x 4 cups/day x 260 days x 0.067 = 2.9 kWh/m^2	
	Fridge:	5 W/person x 8760 hrs x 0.067 = 2.9 kWh/m^2	
	Lifts:	Not used	
	Other stuff:	Phones, security, fire systems, exit signs, etc. 10 W/person x 8760 hrs x 0.067 = 5.8 kWh/m^2	
Air **C**ooling **H**eating	Adopt PassivHaus performance of heating, cooling and ventilation systems = 15 kWh/m^2 (refer to Table C.1). This assumes a well insulated building, heating/cooling via heat pump with air heat recovery on ventilation systems and openable windows for natural ventilation when heating/cooling not required.		15
Total annual energy consumption			**53**

Table C.12 Calculation of annual energy consumption for the 'lowest energy office'

Figure C.1 shows the percentage breakdown. The server accounts for 22% of the energy consumption which is almost as much as the heating, cooling and ventilation systems combined.

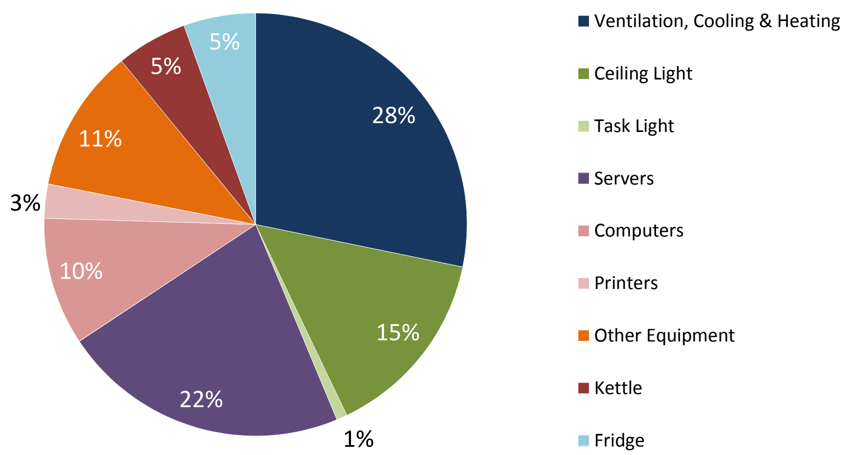


Fig C.1 **Energy consumption breakdown for the 'lowest energy office'**

To estimate the reduction in supplied energy and CO_2e emissions due to on-site renewables, a reasonably efficient photovoltaic (PV) panel was assumed with the following annual output:

- Solar irradiance in London = 1,048 kWh/m^2
- PV panel efficiency = 15.5%
- System losses = 28%
- Output per m^2 of panel = 1048 x 0.155 x (1 – 0.28) = **117 kWh/m^2**
- Emission factor = 0.6 kgCO_2e/kWh
- CO_2e emissions offset = 117 x 0.6 = **70 kgCO_2e/m^2 of panel**

Chapter 7 provides more details on renewable energy systems. Assuming the roof area is the same as a typical floor plate, and assuming the area of photovoltaic panels is equal to 50% of the total roof area, then the output from the panels (in kWh per m^2 of floor area (GIA) in a three-storey building) is as follows:

$$\text{PV Output} = \frac{\text{117 kWh/m}^2 \text{ x 50\% (of roof area)}}{\text{3no. floors}} = \text{19.5 kWh/m}^2 \text{ of GIA}$$

Table C.13 shows the output for a range of building heights. This data was used to produce Fig 2.2 in Chapter 2.

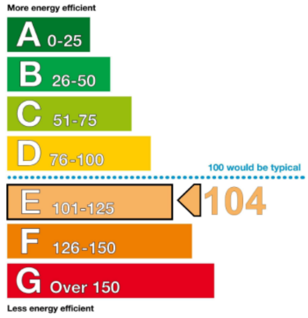
No. of stories	kWh/m^2 of floor	**kgCO_2e/m^2**		No. of stories	kWh/m^2 of floor	**kgCO_2e/m^2**
1	58	**35**		6	10	**6**
2	29	**18**		7	8	**5**
3	19	**12**		8	7	**4**
4	15	**9**		9	6	**4**
5	12	**7**		10	6	**4**

Table C.13 **PV output per m^2 of floor area based on roof with 50% PV panels**

C3. COMPARISON OF ENERGY RATING TOOLS

This section discusses and compares three widely used and established rating tools which benchmark the actual (metered) energy and carbon performance of office buildings in the UK, US and Australia.[5] Design energy rating tools, such as Energy Performance Certificates (EPC), are not covered as this book is about reducing the carbon footprint of buildings in operation.

Display Energy Certificates



DECs were introduced in 2008 in response to the EU's Energy Performance of Buildings Directive,[6] which required member countries to produce Energy Performance Certificates based on either computer modelling or actual energy consumption. The UK did both, calling the operational energy rating a Display Energy Certificate (DEC) and making these mandatory for all public buildings greater than 1,000m^2. The ratings range from A to G with the 'typical' performance benchmark set at the D/E rating boundary. Appendix D provides further details on the DEC methodology and limitations for its use in commercial office buildings.

NABERS

The energy component of the National Australian Building Environmental Rating Scheme (NABERS), originally called the Australian Building Greenhouse Rating (ABGR), was introduced in Australia in 1999 for offices. Other building types have since been added. Ratings of between 0 and 6 stars are available for base building (landlord services), tenancies and whole buildings. It was developed, and is maintained, by government in close consultation with industry. It was originally a voluntary tool, and was widely adopted by commercial landlords to attract large corporate and government tenants, who typically specified a minimum 4.5 star rating. The NABERS rating process is much more rigorous than DECs and consequently the assessment cost is higher. In 2010, a NABERS Energy rating became mandatory for the sale or lease of offices greater than 2,000m^2 under the Commercial Building Disclosure scheme.[7]

ENERGY STAR

ENERGY STAR is a U.S. Environmental Protection Agency (EPA) voluntary program for consumer products, buildings, industrial plants, and homes which started in the 1990s. Products carrying the ENERGY STAR logo, such as computer products and kitchen appliances, typically use 20 to 30% less energy than minimum U.S. federal government standards. A performance rating system for buildings was developed in 1999. Buildings that fall into any one of 18 categories can use the performance rating system to earn a score of between 0 to 100, with a score of 75 indicating top performance and eligibility for ENERGY STAR label status. The scheme applies to whole buildings only

Comparison of the tools

Table C.14 provides a summary of the key similarities and differences between the three tools.

	DEC	NABERS Energy	Energy Star
Country	UK	Australia	US
Rating scale	A to G	0 to 6 stars	0 to 100 points
Units used for benchmark	$kgCO_2/m^2$	$kgCO_2/m^2$	$kBtu/ft^2$ (primary energy)
Floor area used	Gross Internal Area	Net Lettable Area	Gross Floor Area
No. of building types covered	29	5	15
Office ratings available for	Occupants (part or whole buildings)	Base Building Tenant Whole Building	Whole Building
No. of office ratings in 2012	2,000+	1,235 (796 – base bldg, 280 – whole bldg, 159 – tenancy)	50,000+
Average rating	Refer Section C4	Not available	62
Green electricity allowed	No	Yes	No
Adjustments to benchmarks:			
Hours of use	Yes	Yes	Yes
Occupancy density	No	Yes*	Yes
Climate (location)	Yes	Yes	Yes
Heating degree days[8]	Yes	No	No

* In tenancy and whole building ratings only. Base building (landlord) rating based on area.

Table C.14 Overview of operational energy rating tools for offices

Figure 2.6 in Chapter 2 was produced by considering a typical office, Building X (refer to Appendix M), and then using its energy consumption, occupancy and hours of use to obtain ratings in the three tools. Hobart and Seattle were chosen as being the climates closest to London for heating and cooling degree days in Australia and the US respectively.[9]

Gross Internal Area	10,000 m^2
Net Lettable Area	8,000 m^2
No. of occupants & computers	665
Hours of occupancy per week	50
Area with heating & cooling	>80%
Electricity consumption	1,500,000 kWh
Gas consumption	750,000 kWh

The different rating levels in the tools were calculated by keeping the ratio of electricity to gas consumption constant in the building (i.e. 2:1), and adjusting the total energy consumption until the particular rating threshold was just reached (e.g. 4 star NABERS). For NABERS this was undertaken using the *NABERS Energy for Office Reverse Calculator version 10.0* and for Energy Star using the Target Finder website.[10]

The energy consumption for each rating level was then converted to primary energy using a factor of 3.0 for electricity and 1.1 for gas to enable comparison between the tools. This forms the horizontal axis in Figure 2.6. The electricity factor is slightly lower than the factor of 3.3 which is used in Energy Star. Table C.15 shows the indicative ratings for Building X for each tool.

Primary Energy (kWh/m^2)	DEC	NABERS Whole Building	Energy Star
533	F (score = 129)	3 stars	86 (an 'Energy Star')

Table C.15 Indicative ratings for Building X using DEC, NABERS and Energy Star

C4. ENERGY CONSUMPTION DATA FOR OFFICES

This section provides a summary of the data used to produce Figure 2.7 in Chapter 2 which was sourced from:

- Cundall UK office energy audits (2010)
- DEC rating database (2010)
- BBP sustainability benchmarking data (2011/12)
- US commercial building energy consumption survey (2003)
- Energy Star portfolio manager (2012)
- New York City office reporting (2011)
- Greenprint performance report (2011)

The author has used best endeavours to interpret the data correctly and convert it into the $kgCO_2e/m^2$ of GIA metric for the sole purpose of putting metered energy consumption of real offices into perspective. Readers are advised to go to the sources directly if they wish to use the data for any other purposes.

Cundall UK offices

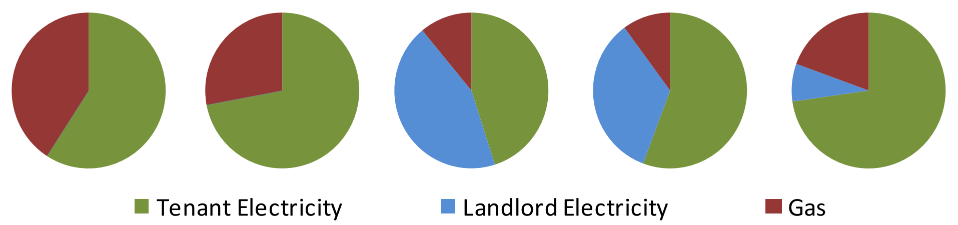
The average and median consumption for Cundall's five UK offices is shown in Table C.16. This data was used in Figure 2.7 in Chapter 2.

	Median	Average		
	ALL	ALL	Nat vent	Mechanical
$kgCO_2e$ / m^2	75	91	63	107
tCO_2e / person	1.6	1.5	1.5	1.4

Table C.16 Summary of Cundall's UK median and average office energy consumption in 2010

Table C.17 shows the energy consumption in each office in 2010. This includes the direct metered electrical energy used in each tenancy, plus a proportion of the landlord's energy based on the floor area occupied in the building.

The London office has the newest building services (multi-service active chilled beams) and no openable windows. It also has the highest energy consumption by area and second highest per person. The three buildings with openable windows have, on average, 30 to 40% lower energy consumption than larger offices with air conditioning. However, these offices are also less densely occupied and have higher CO_2e emissions per person on average.

Location	Birmingham	Edinburgh	London	Manchester	Newcastle
GIA (m^2)	649 [a]	473	1439	526	1481
People (FTE/year)	26	19	106	22	112
Occupancy density	25	25	14	24	13
Energy consumption (kWh/m2)					
Direct electricity	46	77	94	68	104
Landlord electricity	n/a	n/a	92	42	11
Landlord gas	110	91	69	37	85
Total energy	154	168	255	148	200
Primary energy	249	308	578	339	404
Carbon benchmarks					
kgCO_2e/m^2	51	64	125	74	86
tCO_2e/person	1.3	1.6	1.7	1.8	1.2
Split in kgCO_2 between landlord and tenant					
DEC rating [b]	B	D [c]	G	D	E
Ranking by area	1	2	5	3	4
Ranking by people	2	3	4	5	1
Features					
Lighting	Manual	Manual	Sensor	Manual & sensors	Manual
Air	Nat vent	Nat vent	Mechanical	Nat Vent	Mechanical
Cooling [d]	None	None	Active chilled beams	Heat pump	Heat pump
Heating	Gas boiler & radiators	Gas boiler & radiators	Active chilled beams	Gas boiler & rads + heat pump	Gas boiler & radiators

(a) - based on occupied floor area. Empty second floor not included (although its energy consumption is). DEC rating is based on total GIA of 972m^2 in accordance with the rating rules. Would be a C if restricted to occupied floor only.

(b) - note the DEC rating is based on different emission factors (0.551kgCO_2/kWh and 0.194kgCO_2/kWh).

(c) - Scotland doesn't have DEC ratings. If it did, this is the rating the Edinburgh office would achieve.

(d) - all offices have an A/C unit for the server room.

Table C.17 Summary of energy consumption in Cundall UK offices in 2010

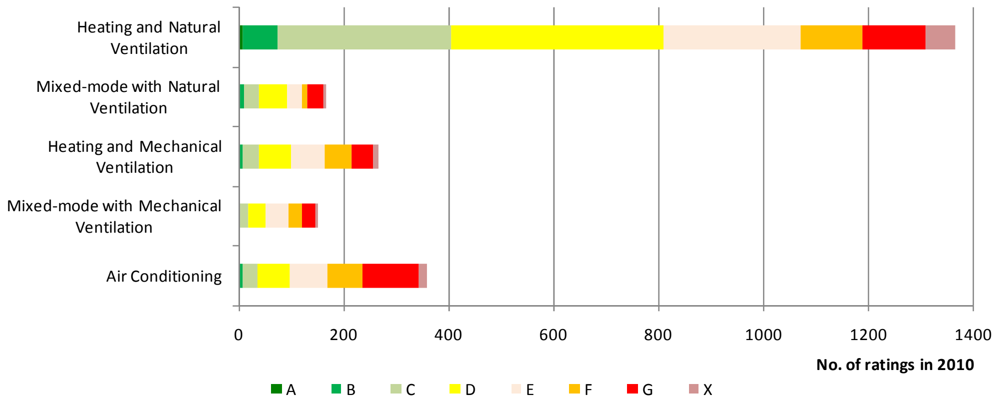
This brief sample illustrates a number of issues when it comes to benchmarking energy, which are discussed further in Appendix D:

- Unoccupied floors can give a false impression of energy efficiency if the floor area is not excluded from the benchmarking calculation.

- Benchmarks for landlords and tenants need to be adjusted to reflect how the services are connected. For example, London has central plant connected to the landlord meter, while in Manchester the VRF heat pumps are connected to the tenant meter.
- The ranking of offices by $kgCO_2e/m^2$ is quite different to that by tCO_2e/person – occupancy density is clearly an important factor, which must be considered when making comparisons between buildings.

Display Energy Certificates (DEC)

The DEC database contains ratings for over 30,000 buildings rated in 2010. Over 95% of the ratings are for public sector buildings and half are for schools. The database is currently not made publicly available by the government, but via a freedom of information request, components of the database have been put in the public domain. Figure C.2 shows a summary of the author's analysis of 2,311 'office' buildings in 2010 by HVAC type.[11]



DEC rating	Ave score	$kgCO_2e/m^2$ *
D	99	81
E	106	87
E	117	96
F	133	109
F	138	113

* calculated from average DEC rating score multiplied by a benchmark of 81 $kgCO_2e/m^2$ (based on emission factors used in this book)

Fig C.2 **Number of ratings by HVAC type for 'offices' from the 2010 DEC database**

About 60% of the ratings were for buildings with natural ventilation and heating only systems, with only 16% being fully air conditioned. The analysis indicates that naturally ventilated buildings had around 30% lower energy consumption by area than air conditioned buildings. The distribution of ratings within each category is shown in Figure C.3.

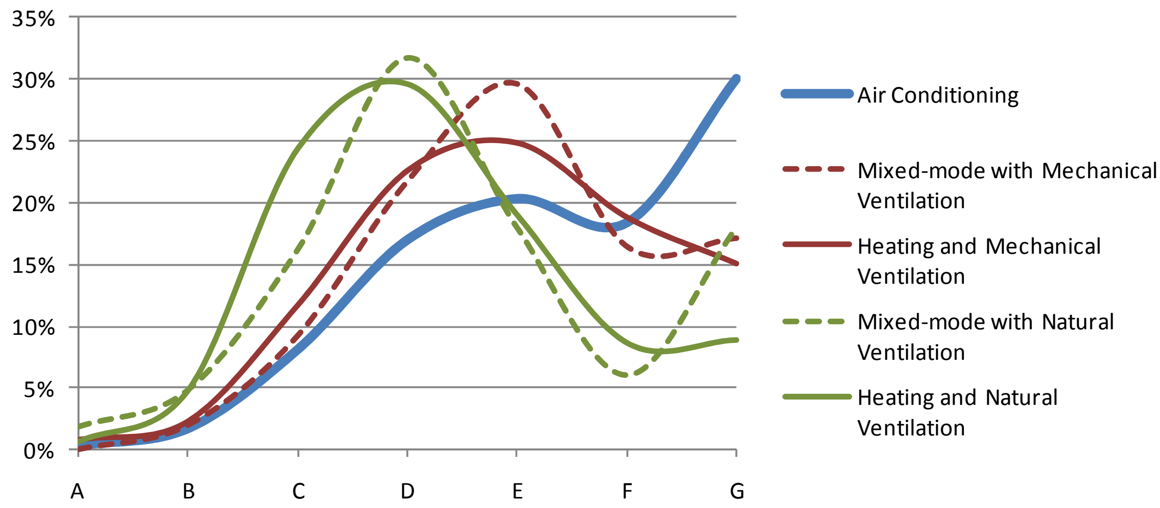


Fig C.3 **Distribution of ratings by HVAC type for 2,311 'offices' from the 2010 DEC database**

Better Buildings Partnership, London

The Better Buildings Partnership (BBP) is a collaboration of the UK's leading commercial property owners and allied organisations whose aim is to develop solutions to improve the sustainability of existing commercial buildings. Since 2007 the BBP and Jones Lang LaSalle have been measuring the actual energy performance of over 200 large commercial buildings in London.

The 2010/11 database included 225 buildings with an average office size of 9,203 m^2 of NLA with total emissions of 348,831 tCO_2.[12] Figure C.4 shows the whole energy performance (landlord and tenant) of 138 offices with a vacancy rate less than 25%. The DEC rating scale has been added by the author, based on a GIA to NLA ratio of 1.25 and suggests that more than half of commercial office buildings in London will probably get a G rating. The median of the DEC rating scale (75 $kgCO_2/m^2$ of GIA = 94 $kgCO_2/m^2$ of NLA) is clearly not representative of the median of commercial office buildings in London.

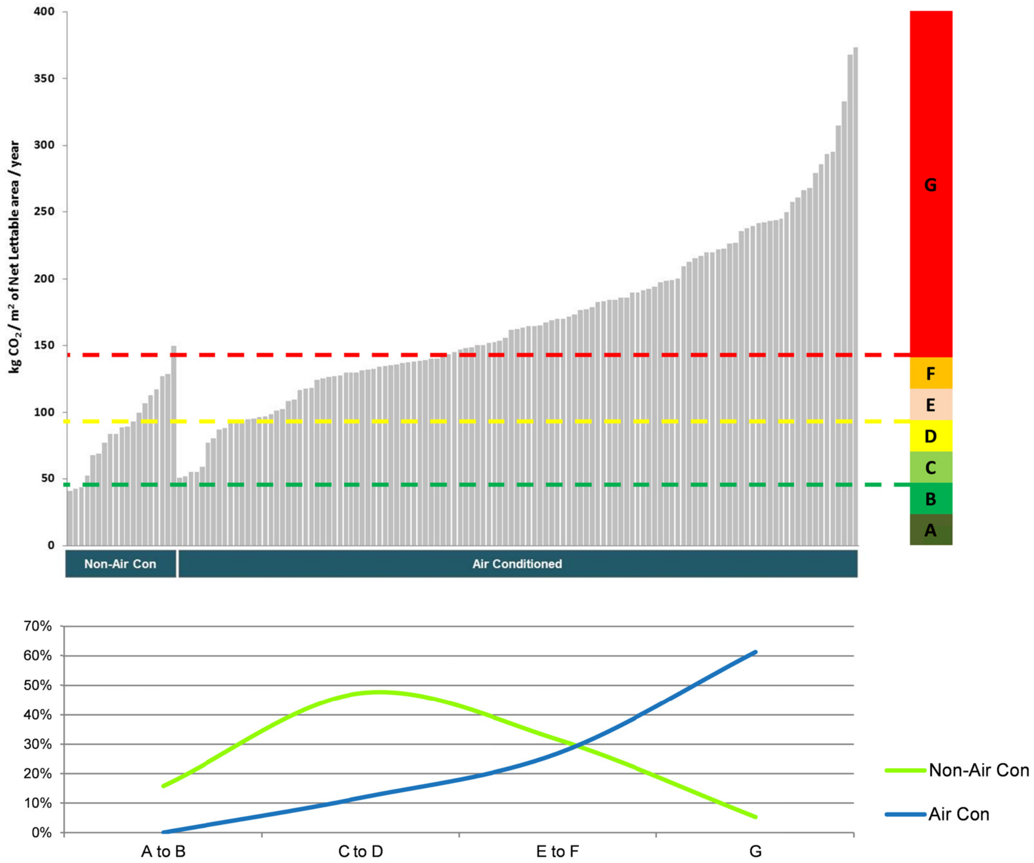


Fig C.4 **Energy intensity of whole building offices in 2011/12 with approximated DEC scale and rating distribution chart added by author**
(source: Jones Lang LaSalle / Better Buildings Partnership, 2012)

Table C.18 summarises the median energy performance of the offices in Figure C.4. The author has converted this to $kgCO_2e/m^2$ of GIA using the following adjustments:

- NLA to GIA ratios as shown in Table C.18.
- The average $kgCO_2e$ emissions factor is 9% higher than the DEC $kgCO_2$ factor (based on a ratio of 90% electricity and 10% gas in the operating carbon total).

	No. of buildings	Median $kgCO_2/m^2$ of NLA	NLA/GIA ratio assumed	Median $kgCO_2/m^2$ of GIA	**Median $kgCO_2e/m^2$ of GIA**
Non-Air Conditioned	19	88	0.8	70	**77**
Air Conditioned - Standard	64	150	0.8	120	**131**
Air Conditioned - Prestige	55	186	0.75	140	**152**
ALL BUILDINGS	**138**	**157**	**0.78**	**122**	**133**

Table C.18 **BBP energy performance data for 2011-12**

Commercial buildings in the US

The US Energy Information Administration (EIA) conducts a Commercial Building Energy Consumption Survey (CBECS) every 4 years. The latest data available is from a survey of 6,000 buildings in 2003. This data is used to inform the energy benchmarks in the Energy Star rating scheme. Figure C.5 shows the survey data by building type, converted to the $kgCO_2e/m^2$ of GIA metric used in this book.[13]

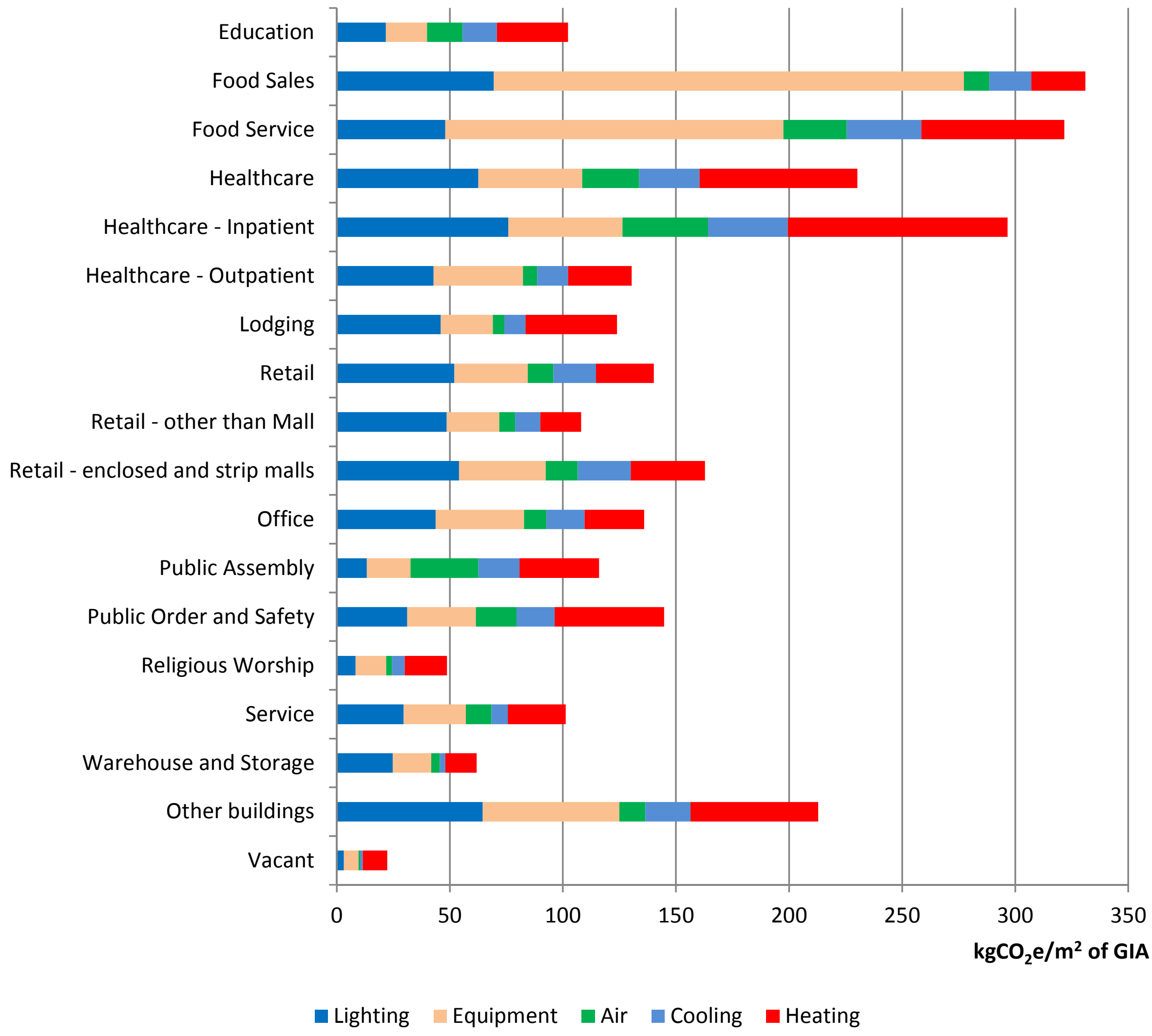


Fig C.5 **Summary of US Commercial Building Energy Consumption Survey 2003 by building type**

The average for offices in the US in 2003 was 136 $kgCO_2e/m^2$. This includes private sector and public sector buildings and is much higher than the DEC benchmark in the UK of 82 $kgCO_2e/m^2$ (based mainly on public sector buildings), but is similar to the BBP commercial office median of 133 $kgCO_2e/m^2$.

Energy Star Portfolio Manager

The US Environment Protection Agency's (EPA) Energy Star Portfolio Manager system was used by 57,247 office properties in 2012, with a total floor area of 900 million m^2. The average energy star score was 62.[14] Table C.19 summarises the data and includes the author's conversion of primary energy consumption into $kgCO_2e/m^2$ for comparative purposes in this book.

		5th percentile	Median	95th percentile
Primary energy use intensity (EUI)	kWh/m^2	224	653	1,489
Site energy use	kWh/m^2	117	341	778
Carbon emissions	**$kgCO_2e/m^2$**	**41**	**120**	**273**
Area	m^2	670	6,469	51,065
Operating hours	hours/week	40	60	120
Occupancy density	m^2 per person	133	39	17

Assumptions to calculate carbon emissions:

1 kWh/m^2 = 317 Btu/ft^2

66% of primary energy is electricity and 34% is gas

Primary energy conversion factors are 3.34 for electricity and 1.047 for gas (refer Table A.2 in Appendix A)

Emission factors of 0.6 $kgCO_2e/kWh$ for electricity and 0.2 $kgCO_2e/kWh$ for gas

Table C.19 Energy Star Portfolio Manager data for offices in 2012

New York City energy benchmarking 2011

In September 2012, New York City publicly posted the 2011 energy and water benchmarking results for non-residential properties covered under the benchmarking ordinance Local Law 84.[15] The law targets the largest properties because while the city's 15,000 private and public sector properties over 50,000 square feet (4,650m^2) constitute less than 2% of the number of properties, they contain half of the city's total floor area. Large buildings account for 45% of New York City's energy use.

The benchmarking report stated: *'Though many factors are at play, newer office buildings in New York City tend to use more energy per square foot than older ones. This trend is generally true for buildings dating back to the early 1900s, with each 20-year group using more energy per square foot than the prior group. However, measurement per square foot does not necessarily reflect efficiency in terms of energy per unit of economic activity happening in buildings.'*

The report also noted that higher asthma rates occurred in neighbourhoods with less energy efficient buildings – a finding which may be a statistical quirk but could warrant further research. The published energy database included 4,081 properties, of which 1,145 were offices. After filtering out offices with zero energy consumption and 17 with an energy intensity greater than 1,500 kWh/m^2 there are 1,023 left, of which 897 have an Energy Star rating. Figure C.6 shows the energy intensity distribution of these offices. Table C.20 summarises the average energy performance of the buildings. The average carbon intensity is estimated by dividing the total tCO_2 by the total building area.

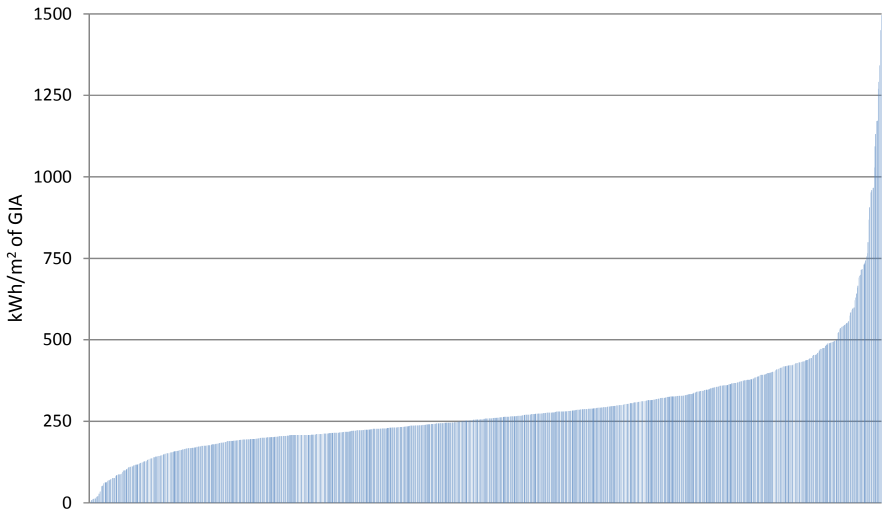


Fig C.6 **Site energy intensity of 1,023 New York City office buildings in 2011**

	No. of	Area (m^2)	Site energy kWh/m^2	Primary energy kWh/m^2	tCO_2	**$kgCO_2/m^2$**
All offices	1023	29,673,988	288	699	2,746,439	**93**
Energy Star rated	897	26,738,270	285	694	2,435,675	**91**

Table C.20 **Summary of New York City energy performance data 2011**

Greenprint performance report 2011

The Greenprint Performance Report 2011[16] contains energy and carbon data collated from 2,703 properties in 46 countries, comprising 65 million m^2 of commercial space, of which 29.9 million m^2 (46%) was offices.

The report includes energy intensity by region, country, city and age of building. Table C.21 summarises the data by location, with a factor of 1.25 used to convert net lettable area into gross internal area. The energy intensity includes electricity and gas combined and is therefore difficult to compare across countries – buildings with higher heating demands met by gas will have higher metered energy consumption, but not necessarily higher CO_2 emissions or higher primary energy.

The median energy value for London is 318 kWh/m^2 of GIA. If 70% is assumed to be electricity and 30% is gas, then applying the CO_2e emission factors used in this book [222 x 0.6 + 95 x 0.2] gives 152 $kgCO_2e/m^2$. This is the same as the median values for prestige air conditioned buildings in London from the BBP benchmarking data (152 $kgCO_2e/m^2$).

The Greenprint Index provides some data on CO_2 emissions and Table C.22 summarises the absolute emissions from pages 15 to 17 of the report.

	No. of office properties	Median energy intensity (kWh/m^2 NLA)	Median energy intensity (kWh/m^2 GIA)
Americas	715	212	170
EMEA	284	344	275
Asia Pacific	52	251	201
Total	**1,051**		
United States	706	211	169
United Kingdom	193	372	298
Germany	22	250	200
France	19	213	170
Poland	15	383	306
Japan	10	192	154
Hungary	8	196	157
India	7	352	282
Australia	4	237	190
London	165	398	318
San Francisco	65	200	160
Washington DC	44	235	188
New York	31	275	220
Tokyo	21	190	152
Paris	18	236	189
Frankfurt	10	345	276
Seoul	4	420	336

Table C.21 Greenprint median energy use intensity in offices 2011

	No. of properties	Floor area (million m^2)	1,000 tCO_2
Americas	1,247	34.2	4,536
EMEA	269	5.8	410
Asia Pacific	112	1.2	119
Total	**1,628**	**41.2**	**5,065**
Offices	990		4,707
Industrial	141		63
Retail	124		149
Multifamily	371		144
Hotel	2		1.5
Total	**1,628**		**5,065**

Table C.22 Greenprint CO_2 emissions data 2011

Over 90% of the CO_2 emissions stated (4.7 million tCO_2) were from 990 office buildings. The total floor area of these offices was not stated. If a crude estimate of 25 million m^2 is assumed (41.2 million m^2 x 990 / 1628) then the average carbon intensity for office buildings is approximately 188 $kgCO_2e/m^2$ of GIA.

On page 27 of the Greenprint Office Carbon Index™ the average carbon intensity was given as 196 $kgCO_2e/m^2$ based on 1,074 properties with a total area of 24 million m^2. Assuming a gross to net area ratio of 1.25, this becomes approximately **157 $kgCO_2/m^2$ of GIA.**

The emission factors used in the Greenprint Index are different to those adopted in this book. The value of 157 above has been shown in Figure 2.7 in Chapter 2 but this is likely to be lower than the value if calculated using this book's emission factors.

C5. ENERGY CONSUMPTION OF GREEN BUILDINGS

Figure 2.8 in Chapter 2 shows the energy performance of a range of green buildings based on the data shown in Table C.23. A building was considered 'green' if it has a BREEAM rating, has won a sustainability award, or has been published in journals or books as an exemplar of sustainable design. Operational energy consumption for these buildings was obtained from a variety of sources:

- Display Energy Certificate database.[17]
- Carbon Buzz website (www.carbonbuzz.org).
- Articles in CIBSE Journal.
- Case studies in Sustainable Architecture, David Turrent, RIBA Publishing 2007.
- Probe studies from Useable Building Trust website (www.usablebuildings.co.uk).
- Project websites.
- Presentations by building owners / tenants at conferences and seminars.
- Building owners supplying data directly to the author.

The data was supplied in different formats and has been converted to the standard $kgCO_2e/m^2$ of GIA used in this book by the author. There are many other green buildings around but actual consumption data is not publicly available. Too many developers and building owners have made promises about energy performance, garnering sustainability awards and publicity, and have then not published any data to demonstrate actual performance – you may draw your own conclusions from this oversight. The buildings in Table C.23 stand out because they have made this data available and should be applauded for this.

Building	Location	Year opened	BREEAM rating	GIA (TUFA)	Storeys	Openable windows	HVAC type
Beaufort Court, Kings Langley	Rural	2003		3000 (2670)	2	Yes	Mixed Mode
Pool Innovation Centre, Pool	Out-of-town	2008	Excellent	3400	3	Yes	Heating & Nat Vent
Powys County Council Learning Centre, Powys	Town	2009	Excellent	391	2	Yes	Nat Vent (PassivHaus)
60L Green Building, Melbourne	City centre	2002	n/a	3900	4	Yes	Mixed Mode
Wessex Water, Bath	Rural	2000	none	10000 (9360)	2	Yes	Nat Vent / Mech Vent
Lion House (ZEBRA), Alnwick	Rural	2008	Excellent	(1894)	2	Yes	Nat Vent
BRE Environment Building, Garston	Out-of-town	1997	Excellent	2040	3	Yes	Nat Vent
Elizabeth II Court, Winchester	Town	2009	Excellent	13600	5	Yes	Mixed Mode
Eden Foundation, St Austel	Rural	2001	Excellent	1800	2	Yes	Nat Vent
Woodland Trust, Grantham	Town	2010	Excellent	2850	3	Yes	Nat Vent
South Cambridge District Offices, Cambourne	Out-of-town	2005	Excellent	7246	3	Yes	Mixed Mode
Environment Agency, Wallingford	Out-of-town	2005	Excellent	3056	3	Yes	Nat Vent
Commerzbank HQ, Frankfurt	City centre	1998		100000	56	Yes	Mixed Mode
Heelis, NT HQ, Swindon	Town	2006	Excellent	7110 (6481)	2	Yes	Nat Vent / Mech Vent
Mid Beds Council Offices, Shefford	Out-of-town	2006	Very Good	(6009)	2	Yes	Nat Vent
Centre for Mathematical Sciences, Cambridge	Campus	2003		(20135)	3	Yes	Nat Vent
Arup Campus, Solihull	Rural	2001	Very Good	9058	2	Yes	Nat Vent
Barclaycard HQ, Northampton	City centre	1996	Excellent	35,000	4	Yes	Mixed mode
Eland House, London	City centre	1998		(37962)		No	Air Conditioned
St Pauls Place, Sheffield	City centre	2009		10483 (6980)	7	No	Air Conditioned
7 More London	City centre	2011	Outstandi ng	60000	9	No	Air Conditioned
50 Queen Anne's Gate, London	City centre	2008	Excellent (refurb)	(49889)	14	No	Air Conditioned
One First Street, Manchester	City centre	2008	Excellent (refurb)	20400	6	No	Air Conditioned
Vulcan House, Sheffield	City centre	2008	Excellent	(13859)	6	No	Air Conditioned
201 Bishopsgate, London	City centre	2008	Excellent	37,000	14	No	Air Conditioned

Building	On Site Renewables	Electricity (kWh/m²)	Natural Gas (kWh/m²)	Renewable Thermal (kWh/m²)	Renewable Electricity (kWh/m²)	TOTAL ENERGY (kWh/m²)	**kgCO2e/m² *(excl renewables)***	kgCO2e/m² *(incl. all on-site renew)*
Beaufort Court, Kings Langley	wind, solar, biomass, SHW	68	101	30	65	199	**67**	22
Pool Innovation Centre, Pool	Biomass	38	35	45		118	**39**	31
Powys County Council Learning Centre, Powys	7kW PV	69	13		17	82	**44**	34
60L Green Building, Melbourne		65	0		3	65	**39**	37
Wessex Water, Bath		52	45			97	**40**	
Lion House (ZEBRA), Alnwick	wind, solar, biomass, SHW	57	36			93	**41**	
BRE Environment Building, Garston		48	77			125	**44**	
Elizabeth II Court, Winchester		77	54			131	**57**	
Eden Foundation, St Austel		86	30			116	**58**	
Woodland Trust, Grantham		107	32			139	**71**	
South Cambridge District Offices, Cambourne		106	63			169	**76**	
Environment Agency, Wallingford	200m² of PV	139	26		3	165	**89**	87
Commerzbank HQ, Frankfurt		110	115			225	**89**	
Heelis, NT HQ, Swindon	83kW of PV	128	114		12.2	242	**100**	92
Mid Beds Council Offices, Shefford		146	100			246	**108**	
Centre for Mathematical Sciences, Cambridge		150	113			263	**113**	
Arup Campus, Solihull		167	76			243	**115**	
Barclaycard HQ, Northampton		204	113			317	**145**	
Eland House, London		113	27			140	**73**	
St Pauls Place, Sheffield	20kW PV	111	61			172	**79**	79
7 More London	Biofuel CHP	128	29	9	16	198	**94**	85
50 Queen Anne's Gate, London		150	38			188	**98**	
One First Street, Manchester		177	0			177	**106**	
Vulcan House, Sheffield		155	69			224	**107**	
201 Bishopsgate, London		341	14			355	**207**	

Building	Source of data	Comments / Awards
Beaufort Court, Kings Langley	www.beaufortcourt.com - report (sep04-aug05)	In 2012 renewables = 55 kWh/m^2 of electricity, 26 kWh/m^2 of heating and 6 kWh/m^2 of cooling, a total saving of 40 kgCO_2e/m^2. Consumption data for 2012 not available.
Pool Innovation Centre, Pool	Carbon Buzz (Nov 2012)	Occupancy of 1 per 25 m^2
Powys County Council Learning Centre, Powys	CIBSE Journal (April 2011)	The first certified PassivHaus office in the UK.
60L Green Building, Melbourne	Refer Table C.23	Pioneering green building in Melbourne and recipient of numerous awards. Tours available.
Wessex Water, Bath	RIBA book (2007)	
Lion House (ZEBRA), Alnwick	DEC (Aug 2009)	The energy data is from the DEC certificate which does not record the renewable energy generated. Actual CO_2 emissions are likely to be lower.
BRE Environment Building, Garston	Carbon Buzz (Nov 2012)	
Elizabeth II Court, Winchester	Building Magazine (Oct 2011)	The source article states 43 kgCO_2/m^2 which is based on lower emission factors.
Eden Foundation, St Austel	RIBA book (2007)	
Woodland Trust, Grantham	BuroFour (2013)	60% of electricity is for the trust's UK server room. Excluding 50% of this, the building energy is around 50 kgCO_2e/m^2.
South Cambridge District Offices, Cambourne	DEC (July 2011)	
Environment Agency, Wallingford	DEC (Aug 2012)	
Commerzbank HQ, Frankfurt	CIBSE Journal (Dec 2010)	Thermal heating & cooling is from district heating - assumed to be from natural gas source for benchmarking.
Heelis, NT HQ, Swindon	Carbon Buzz (Nov 2012)	The server accounts for 70 kWh/m^2 (> 50% of total). Design: 87 kWh/m^2 elec + 36 kWh/m^2 gas = 59kgCO_2e/m^2
Mid Beds Council Offices, Shefford	DEC (Jan 2012)	Design: 86 kWh/m^2 elec + 60 kWh/m^2 of gas = 64 kgCO_2e/m^2
Centre for Mathematical Sciences, Cambridge	DEC (Dec 2010)	
Arup Campus, Solihull	RIBA book (2007)	
Barclaycard HQ, Northampton	Probe study (1998)	The data is 15 years old. A lake (plus ammonia chillers) used for cooling via active chilled beams.
Eland House, London	DEC (Jun 2012)	EPC of the Year, CIBSE Low Carbon Awards 2010
St Pauls Place, Sheffield	CIBSE Journal (Mar 2013)	PV output included in total. Data centre of 150 kWh/m^2 (90 kgCO_2e/m^2) excluded from Fig 2.8.
7 More London	BCO Conference, PwC, May 2012.	41 kWh/m^2 of recycled cooking oil. Refer next page for estimate of energy consumption without biofuel CHP.
50 Queen Anne's Gate, London	DEC (Sep 2012)	
One First Street, Manchester	Ask Developments (2011)	
Vulcan House, Sheffield	DEC (Sep 2009)	
201 Bishopsgate, London	Carbon Buzz (Nov 2012)	C rated EPC. Design regulated electricity 69 kWh/m^2 is 5 times less than actual. Building has extended out-of-hours use.

Table C.23 Green building energy consumption data

IMPORTANT NOTE ON GREEN BUILDING DATA

No attempt has been made to independently verify the data in Table C.23 or make adjustments for occupancy levels, hours of occupancy or heating/cooling degree days. The author has used best endeavours to ensure the interpretation of data reflects the performance of the building in the year stated, but due to the diversity of how data is reported, and assumptions made to convert the data to the format used in this book, there will inevitably be some errors.

This is why Figure 2.8 in Chapter 2 and Table C.23 above *must not* be used to compare or rank the performance of one building against another. Instead, the aim is to put the 100 $kgCO_2e/m^2$ benchmark proposed in the book into perspective by comparing against a variety of green buildings. If you are aware of any errors, or have data on other buildings, please contact the author so that this can be updated on the website (www.whatcolourisyourbuilding.com) and included in future editions of the book. Please also share your UK building energy consumption data on the CarbonBuzz website (www.carbonbuzz.org).

Energy data in Table C.22 for 7 More London

7 More London is the headquarters of PriceWaterhouseCoopers (PwC). The building, opened in 2010, has a GIA of approximately 60,000 m^2 and the use of a 770 kWe packaged biodiesel CCHP (trigeneration) system saved 550 tCO2 over a 12 month period, which is equivalent to 9 $kgCO_2/m^2$ of GIA.[18] As detailed data for the system was not available to the author, to estimate the performance of the building without the CCHP system (for inclusion in Figure 2.8 in Chapter 2) some assumptions have been made. The breakdown in energy consumption is shown in Table C.24 and has been converted to GIA using a factor of 0.85 given in ECON19.

	kWh/m^2 of TUFA (from PwC data)	kWh/m^2 of GIA (estimate)	$kgCO_2e/kWh$	$kgCO_2e/m^2$ of GIA
Electricity	150	128	0.6	77
Natural gas	34	29	0.2	6
Biofuel (recycled cooking oil)	48	41	0.06 *	2
Total	**232**	**198**		**85**

* In the PwC presentation the biofuel is referred to as ‘carbon free’ and ‘zero carbon’

Table C.24 Energy consumption in 7 More London

The outputs from the biodiesel CCHP system are assumed to be 35% of electricity and 37% of heat with the heat output assumed to be split roughly equally between heating and cooling (provided via an absorption chiller with a CoP of 1.05). Using the same assumptions regarding standard chiller and boiler efficiencies as used in Figure 7.19 in Chapter 7, a crude estimate of the performance of the building without the biofuel CCHP system is 94 $kgCO_2e/m^2$ – refer to Figure

C.7. This gives a saving of 9 $kgCO_2e/m^2$, which is similar to the savings published by PwC (although different CO_2e emission factors may have been used).

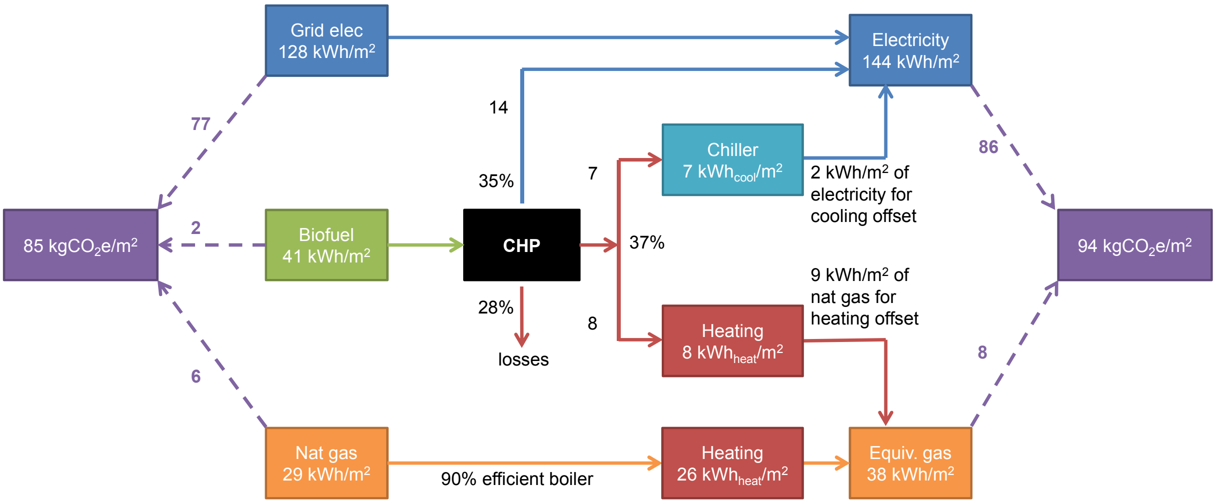


Fig C.7 **Crude estimate of biofuel CHP energy flows and CO_2e emissions in 7 More London (made by the author)**

The manufacturer's case study data sheet suggests savings of 3,784 tCO_2 per annum (63 $kgCO_2e/m^2$ of GIA) are possible based on 19 hours operation, 7 days per week (approximately 6,900 hours per annum). This assumes that all the heating and cooling outputs would be able to be used effectively. The standard annual operating hours for an office building are 2,600 hours and it is typically uneconomic to operate CHP outside of these hours or in periods of off-peak electricity tariffs.

To operate the CCHP for 6,900 hours would require an annual biofuel input of around 15 million kWh (1.5 million litres). In 2012 the building used 310,000 litres which suggests operating hours of around 20% x 6,900 = 1,380 hours / annum.

Based on the assumptions above, a system operating for 2,600 hours per year would have a biofuel input of approximately 41 x 2,600 / 1,380 = 77 kWh/m^2. The grid electricity and natural gas consumption shown in Figure C.7 would reduce to approximately 113 kWh/m^2 and 22 kWh/m^2 respectively. This would reduce CO_2e emissions to approximately 77 $kgCO_2e/m^2$, a potential annual saving of 17 $kgCO_2e/m^2$ of GIA. Refer to Chapter 7 for more discussion on biofuel CHP in buildings.

60L Green Building, Melbourne

The Australian Conservation Foundation (ACF) partnered with ethical investment consortium the Green Building Partnership to create a headquarters building that would demonstrate best practice sustainable commercial building. The 3,900 m^2 building, part new, part refurbishment, opened in October 2002.

This building was a key project in inspiring the author to start designing green buildings. The building's manager generously provided all sub-metering data for the whole building[19] – very few green buildings will share this amount of data.

The building is surrounded on three sides by other buildings, and so light wells and a large central atrium were incorporated to provide natural light and natural ventilation into the tenancies. Four thermal chimneys on the roof provide the stack effect – refer Figure C.8. When outside temperatures are very hot or cold, tenants can use small domestic-sized reverse-cycle heat pumps for heating or cooling their space.

Fig C.8 **Front façade and thermal chimneys of 60L Green Building (Source: ACF)**

The building also includes a rainwater collection, a black water treatment plant, photovoltaics, a roof garden and substantial use of recycled materials. A detailed report on the building is available from the ACF website.

The energy consumption data for the first 7 years of operation is summarised in Figure C.9.

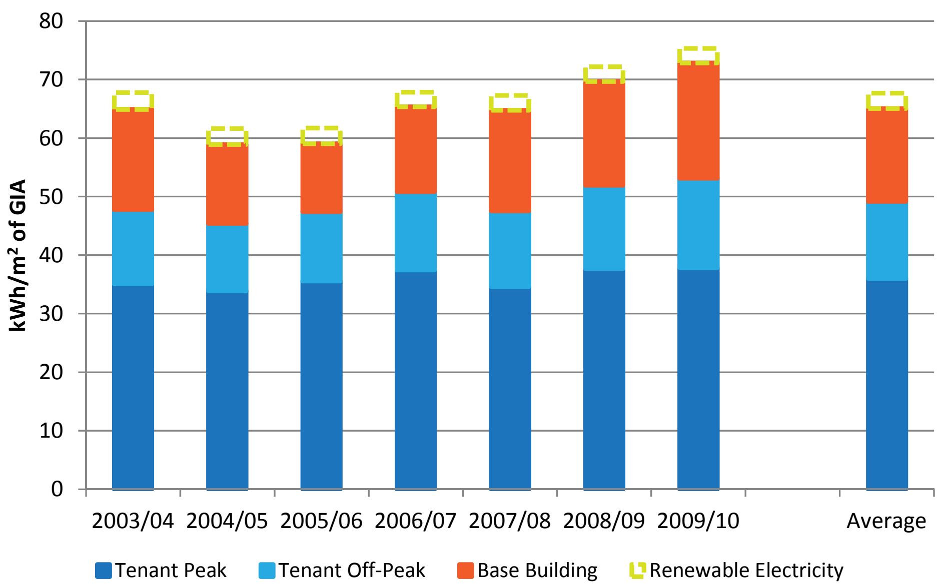


Fig C.9 Electricity consumption in 60L Green Building 2003 to 2010 (source: ACF)

The average annual energy consumption between 2003 and 2010 is shown in Table C.25. The $kgCO_2e/m^2$ is based on the electricity emission factor of 0.6 $kgCO_2e/kWh$ used throughout this book. In Melbourne the electricity factor is typically over twice this, although certified green power (from new wind and solar systems) can be purchased.[20]

	Tenant peak	Tenant off-peak	Tenant total	Base building	**Building total**	Renewable electricity from PV	Net imported energy
kWh/m^2	36	13	49	16	**65**	3	62
$kgCO_2e/m^2$	22	8	30	10	**39**	2	37

Table C.25 Summary of whole building energy consumption (kWh) for 60L Green Building between 2003 to 2010 (source: ACF)

Notes

All websites were accessed on 6 May 2013 unless noted otherwise. Information papers referenced are available to download from www.wholecarbonfootprint.com.

1. *Energy Benchmarks*, TM46:2008 published by CIBSE provides the benchmarks used for DECs in England, Wales and Northern Ireland and explains the approach to their development and use.

2. *CIBSE Guide F: Energy Efficiency in Buildings* (2012) includes a good section on energy benchmarks for many different building types, many of which are based on the government guides described in note 3. Detailed end-use benchmarks for offices, banks & agencies, hotels, mixed use buildings, sports & recreation and hospitals are provided.

3. A series of guides were produced under the Government's Energy Efficiency Best Practice Programme in the late 1990s and early 2000s. ECON 19 for offices was published in 2000 (with minor revisions in March 2003) and its values are based on understanding what causes energy to be used in offices, supported by evaluation of over 100 building case studies (including numerous Probe studies from 1995 – 2002: refer www.usablebuildings.co.uk). The whole building benchmarks in ECON 19 are primarily based on benchmarks for each end use (heating, hot water, pumps, ventilation fans, cooling, lighting, PCs, catering, controls, etc.).

4. The Carbon Trust benchmarking tools were downloaded from www.carbontrust.co.uk/cut-carbon-reduce-costs/calculate/energy-metering-monitoring/pages/industry-benchmarks.aspx#onlinetools in 2011.

5. Further details on the tools can be found at:
   - DEC: There is no DECs website. Refer to www.gov.uk/government/publications/display-energy-certificates-and-advisory-reports-for-public-buildings and www.ndepcregister.com/.
   - NABERS: www.nabers.gov.au. Versions for energy, water, waste and indoor environment also available.
   - Energy Star: www.energystar.gov. Run by US Environment Protection Agency (covers appliances, buildings, computers, etc).

6. The European Union's first Energy Performance of Buildings Directive (EPBD-1) was legislated in 2002, and led to the introduction of Energy Performance Certificates (EPCs) in member countries. In 2010 this was recast (EPBD-2) to strengthen the provisions and to provide a more consistent approach to the EPC methodology adopted in each country. Refer to Appendix L for further details.

7. Commercial Building Disclosure (CBD) is a national programme designed to improve the energy efficiency of Australia's large office buildings. www.cbd.gov.au.

8. Heating degree days (HDD) are used to adjust annual heating energy benchmarks to reflect the severity or mildness of the heating period in the year of the rating. Refer to Information Paper 16 – Heating degree days for more information.

9. Using the www.degreedays.net website, heating degree days and cooling degree days were obtained for London, Hobart and Seattle for 3 years between September 2009 and August 2012. These provided reasonably close correlations with London and were used as the locations to compare DECs with NABERS and Energy Star ratings respectively.

	Base Temp	Degree Days		
		London	Hobart	Seattle
Heating	15.5°C	5667	3874	5791
Cooling	20°C	216	250	303

10. https://www.energystar.gov/index.cfm?fuseaction=target_finder accessed on 16 September 2012.

11. In March 2011, the Centre for Sustainable Energy obtained the DEC dataset for all ratings undertaken in 2008, 2009 and 2010 and published these in Excel spreadsheet format in March 2011. The author has analysed the database (which doesn't specifically identify buildings by type) and made interpretations to identify 2,311 buildings which are likely to be office buildings. Refer to Information Paper 7 – Analysis of Display Energy Certificates 2008-10 for further information and more details on the analysis.

12. The BBP 2011/12 data was supplied to the author by the BBP in November 2012. This data is summarised in *A Tale of Two Buildings: Are EPCs a true indicator of energy efficiency?* published by JLL and BBP in 2012. A summary of BBP data for 2009/10 can be found in the BBP Sustainability Benchmarking Toolkit published in 2010. www.betterbuildingspartnership.co.uk.

13. This is the latest survey – the 2007 survey was deemed unsatisfactory and the 2011 survey was put on hold due to funding cuts. In April 2013 work started on a new survey. For more details of the 2003 survey, including a breakdown of energy by end use in the buildings, refer to Information Paper 8 – US Office energy data.

14. *Energy Use in Office Buildings*, Energy Star Portfolio Manager Data Trends, EPA, October 2012. www.energystar.gov/index.cfm?c=business.bus_energy_star_snapshot.

15. The *New York City Local Law 84 Benchmarking Report* (August 2012) and database of energy performance was downloaded from www.nyc.gov/html/gbee/html/plan/ll84_scores.shtml on 13 Jan 2012.

16. The data was based on rentable area. To convert to GIA, a factor of 1.25 was applied. http://greenprintfoundation.org/gci/carbonindex.aspx.

17. The Non-Domestic Energy Performance Register contains the latest EPC and DEC certificates for rated buildings in the UK. These can be accessed at www.ndepcregister.com provided the building's 20 digit certificate number is known. The DECs in Table C.22 were the latest available on 30 November 2012 – a number of public buildings haven't updated their DEC ratings annually despite this being a legislative requirement.

18. The performance of the biofuel CHP is taken from *Building Wealth – Are Sustainable Buildings Worth It? An Occupiers Perspective* by Chris Richmond of PwC at the BCO Conference in May 2012. The size of the biofuel CHP system was taken from Dresser-Rand case study 12 (www.dresser-rand.com/literature/CHP/2259_CHP_CS12.pdf).

19. The energy data was supplied to the author by Andrew Gemmell, Building Manager, 60L Green Building, Melbourne in May 2011. Extensive information on 60L can be downloaded from the ACF website, including detailed reports and plans. www.acfonline.org.au/about-us/our-home-60l.

20. GreenPower is a Government accredited programme aimed at increasing the generation of renewable energy in Australia. www.greenpower.gov.au.