WHAT COLOUR is YOUR BUILDING?

Measuring and reducing the energy and carbon footprint of buildings

David H. Clark

Appendix B

CO_2e emission factors

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Appendix B: CO_2e emission factors

If it weren't for electricity, we'd all be watching television by candlelight.
George Gobel, American comedian and actor.

Contents

This appendix provides details and discussion on the CO_2e emission factors used or referred to in the book.

Published by RIBA Publishing, 15 Bonhill Street, London EC2P 2EA
www.ribaenterprises.com

Issue 1.1: 29 July 2013
Revision: figures B.2 and B.4, and section B11 updated for 200kg of waste per person instead of 500kg.

B1. SCOPES AND SUMMARY

Emission scopes

CO_2e emission factors are used to calculate greenhouse gas (GHG) emissions from a range of activities, including energy consumption, disposal of waste, and transportation. The factors convert activity data (e.g. litres of fuel used, number of miles driven, tonnes of waste sent to landfill) into kilograms of carbon dioxide equivalent (CO_2e).

CO_2e emission factors are published by the Intergovernmental Panel on Climate Change (IPCC) and also by governments in different countries. They can be used for different purposes including building regulations, corporate reporting (carbon footprinting), emissions trading and building rating tools. Factors often vary depending on the purpose that the factors are being used for. For example, in the UK in 2012 there were at least five different factors for grid electricity.[1]

The key purpose of this book is to define and reduce the energy consumption and carbon footprint of buildings. It is therefore essential to use a reliable and consistent set of factors so that emissions due to operating, embodied and transport energy can be compared on a level playing field.

The emission factors for operating energy and transport described in this Appendix are taken from the UK Government publication *2012 Guidelines to DEFRA/ DECC's GHG Conversion Factors for Company Reporting* unless noted otherwise.[2] These are consistent with IPCC guidelines and include:

- Emissions due to methane (CH_4) and Nitrous Oxide (N_2O).
- Direct and Indirect emissions (Scopes 1, 2 and 3)[3] – refer to Figure B.1.
- Emissions associated with the production and distribution of fuels (Scope 3).

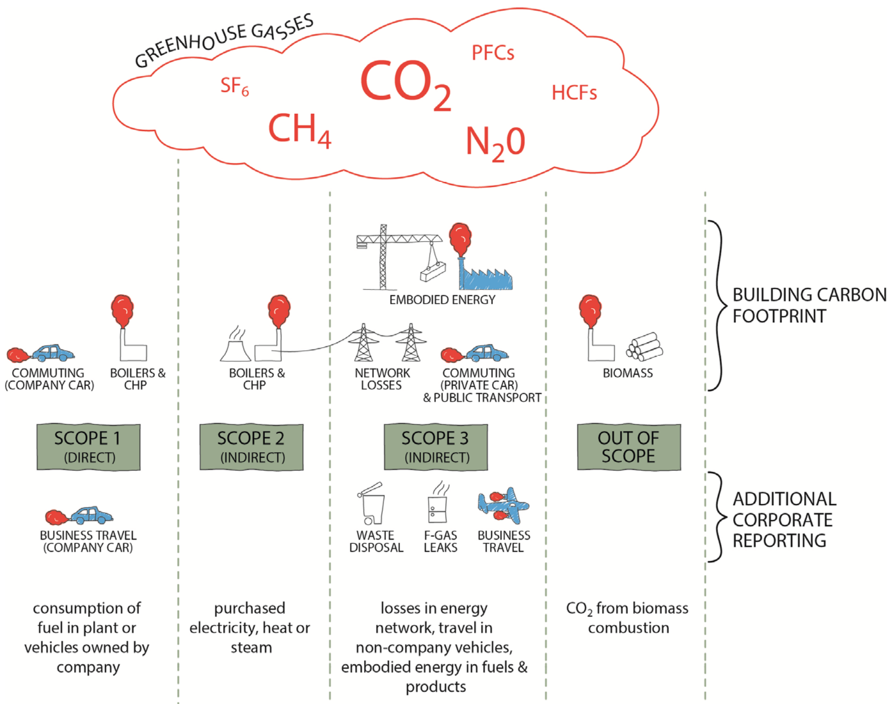

Fig B.1 Scopes typically used for greenhouse gas emissions reporting

Summary

Emission factors, in units of kilograms (kg) of carbon dioxide equivalent (CO_2e), are provided and discussed in this appendix for the following:

• Electricity • Natural gas • Fossil fuels (petrol, diesel, kerosene, LPG) • Biomass and biofuels	Main operating energy factors
• Cars and motorbikes • Public transport	Transport factors
• Black carbon • F-gases • Water consumption • Office consumables and waste disposal	Other factors*

The other factors (*) are not included in the whole carbon footprint defined in this book. Figure B.2 provides an indication of their potential CO_2e emissions in Building X, an example office building used in Chapter 7 of the book.[4] An option for 75% of heating from a wood pellet boiler, with the remainder from natural gas, is also shown to illustrate the 'CO_2 half-life' factor and provide context for the potential impact of black carbon.

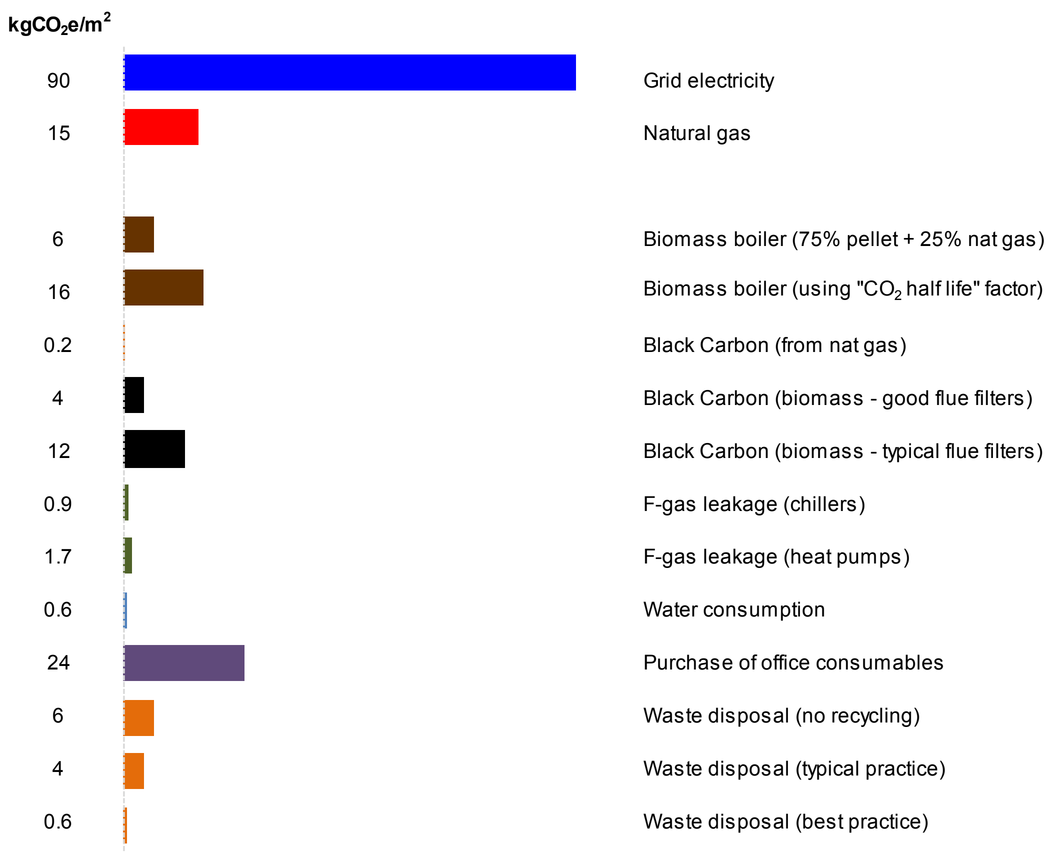

Fig B.2 **The $kgCO_2e$ emissions in Building X due to 'other factors'**

B2. EMISSION FACTORS FOR GRID ELECTRICITY

The electricity supplied to a building from the national grid is generated from a variety of energy sources which release different amounts of greenhouse gas per unit of electricity generated. Annual emission factors are used to determine the $kgCO_2e$ released for each kWh of grid electricity consumed at the point of final use. This factor varies for different countries and different years depending on the proportion of fossil fuels used to generate the electricity and the losses in the distribution network. The factors are typically based on a 5 year rolling average. Figure B.3 shows emissions from a typical black coal fired power station.

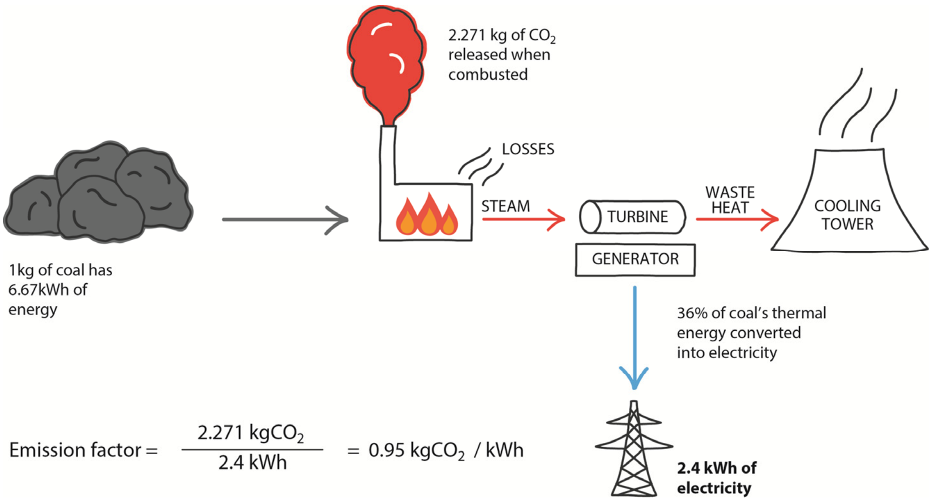

Fig B.3 Simplified calculation of scope 2 emission factor from a typical coal fired power station

The total CO_2e emissions of grid electricity comprise three components:

- **Generated emissions (Scope 2)** – these are the emissions due to the release of CO_2, CH_4 and N_2O from the combustion of fuel used in the generation of electricity.
- **Emissions from losses (Scope 3)** – this represents the emissions due to losses in the transmission and distribution grid between the power station and the building. In the UK the losses are around 8% of the total while in India losses are 30%.
- **Embodied emissions (scope 3)** – these are the emissions associated with the extraction and transport of primary fuels as well as the refining, distribution, storage and retail of finished fuels used in the generation of electricity (e.g. coal, oil, etc).

UK grid electricity factor

The annual emission factor in the UK is based on a rolling 5 year average and a new value is published by DEFRA each year. The average factor between 2000 and 2010 was 0.6 $kgCO_2e$/kWh. This has been adopted as the factor for grid electricity in this book – refer to Table B.1. The UK's grid electricity factor has not varied by more than ±3% since 2000.[5]

Fuel	Unit	**Total**	Scope 1	Scope 2	Scope 3	Outside scope
		kgCO₂e per unit				
Grid electricity	kWh	**0.60**	-	0.50	0.10	-

Table B.1 **CO_2e emission factor for UK Grid Electricity (source: DEFRA, 2012)**

There is an argument that because on-site renewable energy displaces the need for coal power stations, different factors should be used for the displacement of grid electricity compared to the consumption of grid electricity. This all gets too complicated, so to keep it simple in this book, the same factor is used for both.

Grid electricity in other countries

Table B.2 shows the emission factors for grid electricity in various countries based on a 5 year rolling average between 2005 and 2009.

	Emission factors for 2009 (kgCO₂e / kWh)			
	Total (Scopes 2 & 3)	Generated (Scope 2)	Losses (Scope 3)	Embodied (Scope 3)
Austria	0.24	0.20	0.01	0.03
Belgium	0.30	0.25	0.01	0.03
Bulgaria	0.63	0.47	0.09	0.06
Cyprus	0.90	0.76	0.04	0.10
Czech Republic	0.67	0.53	0.07	0.07
Denmark	0.41	0.32	0.05	0.04
Estonia	0.95	0.71	0.14	0.10
Finland	0.25	0.21	0.01	0.03
France	0.11	0.09	0.01	0.01
Germany	0.52	0.43	0.03	0.06
Greece	0.92	0.74	0.07	0.10
Hungary	0.41	0.33	0.03	0.05
Ireland	0.63	0.51	0.05	0.07
Italy	0.52	0.43	0.03	0.06
Latvia	0.21	0.16	0.03	0.02
Lithuania	0.16	0.12	0.02	0.02
Luxembourg	0.44	0.38	0.01	0.05
Malta	1.24	0.94	0.17	0.13
Netherlands	0.48	0.39	0.03	0.05
Poland	0.79	0.65	0.05	0.09
Portugal	0.50	0.41	0.03	0.06
Romania	0.59	0.43	0.10	0.06
Slovak Republic	0.28	0.22	0.02	0.03
Slovenia	0.42	0.34	0.03	0.05
Spain	0.43	0.36	0.03	0.05

Sweden	0.05	0.04	0.00	0.01
United Kingdom	0.60	0.49	0.04	0.07
European Union - 27	0.44	0.36	0.03	0.05
Australia	1.09	0.88	0.08	0.12
Brazil	0.11	0.08	0.02	0.01
Canada	0.24	0.19	0.02	0.03
China, People's Republic of	0.92	0.76	0.05	0.10
Chinese Taipei	0.77	0.65	0.03	0.09
Croatia	0.42	0.33	0.05	0.04
Egypt	0.60	0.46	0.07	0.06
Gibraltar	0.86	0.76	0.00	0.10
Hong Kong (China)	0.97	0.76	0.10	0.10
Iceland	0.00	0.00	0.00	0.00
India	1.42	0.94	0.36	0.13
Indonesia	0.95	0.75	0.11	0.10
Israel	0.87	0.74	0.03	0.10
Japan	0.51	0.43	0.03	0.06
Korea, Republic of	0.59	0.50	0.02	0.07
Malaysia	0.73	0.63	0.02	0.09
Mexico	0.65	0.47	0.11	0.06
New Zealand	0.25	0.21	0.02	0.03
Norway	0.01	0.01	0.00	0.00
Pakistan	0.62	0.43	0.14	0.06
Philippines	0.61	0.47	0.08	0.06
Russian Federation	0.41	0.32	0.04	0.04
Saudi Arabia	0.93	0.74	0.09	0.10
Singapore	0.64	0.53	0.04	0.07
South Africa	1.10	0.88	0.11	0.12
Switzerland	0.05	0.04	0.00	0.01
Thailand	0.64	0.53	0.05	0.07
Turkey	0.61	0.46	0.09	0.06
Ukraine	0.51	0.36	0.10	0.05
United States	0.66	0.54	0.04	0.07
Africa	0.82	0.64	0.10	0.09
Latin America	0.24	0.18	0.04	0.02
Middle-East	0.91	0.69	0.13	0.09
Non-OECD Europe	0.45	0.35	0.05	0.05

Note: the data includes heat generated except for the UK figures.

Table B.2 **CO_2e emission factors for grid electricity in various countries in 2009 (source: DEFRA, 2012)**

To work out the carbon footprint of a building in a specific country, substitute the UK factor used in this book with an appropriate factor for the country in question.

Calculating a global average emission factor

It is difficult to get consistent figures for the carbon intensity of electricity globally as there are many different calculation methodologies. According to the *Factors underpinning future action – country fact sheets 2008 update* published by Ecofys,[6] the world average for electricity generation in 2007 was around 0.5 $kgCO_2/kWh$. This is similar to the UK emission factor in Table B.1.

The Scope 3 emissions due to losses and embodied emissions vary significantly between countries. A factor of 0.10 $kgCO_2/kWh$ is assumed, comprising:

0.05	distribution losses of 10%
0.05	embodied energy in fuel production and transportation*

** This is probably an underestimate given the two largest energy consumers in the world, the US and China, have factors of 0.07 and 0.10 respectively. The average in Europe is 0.05.*

Annex E of the EU standard EN15603:2008 suggests an average grid electricity factor of 0.617 $kgCO_2e/kWh$, although this is based on data from 1996 and is provided for information only. Based on the available data, it therefore appears reasonable to assume that the global average emission factor for grid electricity is around 0.6 $kgCO_2e/kWh$ – which is the same as the UK.

B3. NATURAL GAS

Natural gas use in buildings is metered by volume, typically in m^3 or $100ft^3$ units. To convert $100ft^3$ into m^3 multiply by 2.83. To convert metered volume (m^3) into energy (kWh) the following formula is used:

$$\text{Energy (kWh)} = \text{Volume } (m^3) \times \text{Conversion Constant } (1.022) \times \text{Calorific Value } (MJ/m^3) \times 1/3.6$$

Note: different units for the energy content of natural gas are used in different countries: kWh in UK, MJ in Australia (3.6 MJ = 1 kWh) and BTU in United States (3409 BTU = 1 kWh).

Natural gas energy is typically based on a gross calorific value (CV).[7] This is a measure of energy content (or heating power) and is dependent upon the composition of the gas passing through the National Grid pipeline system in the UK. It typically fluctuates between 37 and 43 MJ/m^3.

Fuel	Unit	**TOTAL**	Scope 1	Scope 2	Scope 3	Outside scope
		$kgCO_2e$ per unit				
Natural gas	kWh	**0.20**	0.18	-	0.02	-

Table B.3 **CO_2e emission factor for natural gas on gross CV basis (source: DEFRA, 2012)**

IS GAS GETTING DIRTIER?

As current natural gas fields, (such as the North Sea) become depleted, gas must be found from other sources. This means exploiting more difficult and remote reserves (and transporting the gas by ship) or using fracking techniques to extract shale gas. A concern with fracking is the potential for significant fugitive emissions of methane which could, in some cases, make gas dirtier than coal.[8] The likely outcome is that the CO_2e emission factors for the consumption of natural gas will increase in the future, possibly by up to 2% per annum.

B4. FOSSIL FUELS

The fossil fuels commonly used in buildings for heating and emergency electricity generators are shown in Table B.4. The factors for kWh are expressed as a net calorific value basis. The factors for diesel and petrol purchased at UK retail outlets include a proportion of biofuel blended with the mineral fuel (3.3% for diesel, 1.9% for petrol).

Fuel	Unit	TOTAL	Scope 1	Scope 2	Scope 3	Outside scope
		kgCO_2e per unit				
Heating Oil (kerosene)	litres	**3.10**	2.54		0.53	
Diesel	litres	**3.17**	2.58		0.58	
Petrol	litres	**2.72**	2.24		0.48	
LPG	litres	**1.72**	1.53		0.19	
Heating Oil (kerosene)	kWh	**0.31**	0.26		0.05	
Diesel	kWh	**0.32**	0.26		0.06	
Petrol	kWh	**0.30**	0.25		0.05	
LPG	kWh	**0.26**	0.23		0.03	

Table B.4 **CO_2e emission factors for fossil fuels (Net CV basis) (source: DEFRA, 2012)**

B5. BIOMASS AND BIOFUELS

Biomass in this book means solid fuels – wood pellets, wood logs and wood chips. Biofuels are liquid or gas fuels which are derived from organic materials such as crops, anaerobic digesters and recycled vegetable oils.

Determining emission factors for biofuels and biomass becomes complicated due to the issue of carbon sequestration (or storage):

- should the factor assume zero CO_2 emissions because when the fuel is combusted the new feedstock (trees and plants) planted to replace the fuel will reabsorb these, or
- should the factor reflect that there is a time lag (< 1 year for crops, 5 years for coppicing and more than 20 years for trees) before the replacement feedstock has reabsorbed the CO_2 that was released into the atmosphere at combustion?

Table B.5 shows the average emission factors from the DEFRA guidelines assuming CO_2 is absorbed immediately (the 'biomass is carbon neutral' argument). The table also shows a 'CO_2 half-life' factor which includes half of the CO_2 emissions released at the time of combustion. This is not an officially recognised factor and has been included by the author to promote debate about how to deal with the time lag issue.[9]

Fuel	**Standard factor**	CO_2 half life *
	kgCO_2e/kWh	
Wood logs	**0.02**	0.19
Wood chips	**0.02**	0.19
Wood pellets	**0.04**	0.21
Biogas	**0.00**	-
Recycled cooking oil	**0.06**	-
Biodiesel	**0.12**	-
Bioethanol	**0.16**	-
Biomethane	**0.10**	-

* This is an unofficial factor created by the author to promote debate on CO_2 emissions from biomass

Table B.5 **CO_2e emission factors for biomass and biofuel (source: DEFRA 2012 and RFA 2009)**

The biofuel factors given in Table B.5 are average factors for biofuels used in the UK. The range in actual emissions can vary between 0.05 and 0.4 kgCO_2e/kWh depending on the type of fuel, the crop used, and the country of origin. The majority of biofuels globally, while renewable, are not low carbon, and some have higher emission factors than petrol.[10] When using biofuels it is essential to consider where they are being sourced from.

B6. PRIVATE TRANSPORT

Table B.6 shows the emission factors for cars and motorbikes in the UK in 2010.

	Engine size	kgCO_2e per km		
		Total	Direct (Scope 1 or 3)	Indirect (Scope 3)
Petrol cars				
Small car	<1.4 litres	**0.198**	0.165	0.033
Medium car	1.4 to 2.0 litres	**0.249**	0.208	0.041
Large cars	> 2.0 litres	**0.358**	0.298	0.060
Average car		**0.242**	0.202	0.040
Diesel cars				
Small car	<1.7 litres	**0.171**	0.143	0.028
Medium car	1.7 to 2.0 litres	**0.213**	0.178	0.035
Large cars	> 2.0 litres	**0.283**	0.234	0.047
Average car		**0.224**	0.187	0.037
Average all fuels				
Small car		**0.191**	0.160	0.032
Medium car		**0.234**	0.194	0.039
Large cars		**0.310**	0.257	0.052
Average car		**0.234**	0.195	0.039
Petrol motorbikes				
Small	up to 125cc	**0.105**	0.088	0.017
Medium	125-500cc	**0.127**	0.106	0.021
Large	over 500cc	**0.167**	0.140	0.028
Average		**0.142**	0.119	0.023

Table B.6 **CO_2e emission factors for cars and motorbikes (source: DEFRA, 2012)**

B7. PUBLIC TRANSPORT

Table B.7 shows the emission factors for public transport in the UK in 2010.

	kgCO_2e per passenger km		
	Total	Direct (Scope 3)	Indirect (Scope 3)
Taxi			
Regular taxi	**0.177**	0.148	0.029
Black cab	**0.188**	0.157	0.031
Bus			
Local bus (not London)	**0.150**	0.124	0.026
Local London bus	**0.100**	0.083	0.017
Average local bus	**0.136**	0.112	0.024
Coach	**0.035**	0.029	0.006
Rail			
National rail	**0.067**	0.058	0.009
International rail (Eurostar)	**0.017**	0.015	0.002
Light rail and tram	**0.077**	0.068	0.009
London Underground	**0.082**	0.072	0.010

Table B.7 **CO_2e emission factors for taxis, buses and trains (source: DEFRA, 2012)**

B8. BLACK CARBON

Black carbon is basically soot from the incomplete combustion of fossil fuels and biomass. It contributes to global warming in two ways: it absorbs heat in the atmosphere (direct effect) while deposits on snow and ice reduce the ability to reflect sunlight. The science of how much black carbon contributes is still developing.[11]

Black carbon is currently not included in the whole carbon footprint of buildings because there is no agreed emission factor for it. This is because:

- It behaves very differently to the six Kyoto greenhouse gases (CO_2, CH_4, N_2O and F-gases) as it is so short lived (days to weeks rather than years).
- There is little consensus on the level of past, current and future emissions of black carbon.
- Concentrations in the atmosphere vary regionally.
- The albedo effect (soot on snow) varies regionally.

The author has undertaken a crude calculation to estimate the equivalent $kgCO_2e/m^2$ due to black carbon emissions in Building X.[12] This shows that for natural gas boilers it may add around 1% to the heating CO_2e emissions, but for biomass boilers it could add more than 66% depending on the type of flue filters fitted.

An approximation of the equivalent emission factors for black carbon is shown in Table B.8. These are for discussion purposes only and further research in this area is required.

	Particulate emissions g/GJ	Global average $kgCO_2e/kWh$	Upper Europe estimate $kgCO_2e/kWh$
Natural Gas	1	0.002	0.005
Biomass (efficient flue filter)	20	0.05	0.11
Biomass (average flue filter)	60	0.15	0.35

Table B.8 Indicative CO_2e emission factors for black carbon (for discussion purposes only)

B9. F-GASES

The fluorinated gases (F-gases), which are included in the United Nation's Framework Convention on Climate Change, are Hydrofluorocarbons (HFC), Perfluorocarbons (PFCs) and Sulphur hexafluoride (SF_6). Table B.9 summarises key information on these gases which have significantly higher Global Warming Potential (GWP) compared to CO_2, which has a GWP of 1.

	Global Warming Potential (GWP)	Atmospheric lifetime (years)	% of UK GHG emissions	Typical uses
HFC	97 to 12,000	10's to 100's	2.6%	Commonly used in refrigerants in fridges, air-conditioning and heat pumps. Other uses include aerosols, insulating foam, solvent cleaning and fire protection.
PFC	5,700 to 11,900	1000+	0.1%	Used in semi-conductor manufacture.
SF_6	22,000	1000+	0.1%	Used in high voltage switch gear and for magnesium smelting processes.

Table B.9 Summary of Global Warming Potential of F-gases[13]

The calculation of the greenhouse gas emissions due to refrigerants released to the atmosphere is:

GHG Emissions ($kgCO_2e$) = kg of refrigerant released x GWP of refrigerant

Leakage of refrigerants can occur during installation, operation and disposal. Table B.10 shows the typical charge capacity (kg of refrigerant) and leakage rates (as a percentage) for different types of equipment.[14]

Type of equipment	Typical range in charge capacity (kg)	Lifetime (years) *	Installation leakage	Annual leak rate	Capacity remaining at disposal (%)	Refrigerant recovered at disposal (%)
Domestic Refrigeration	0.05 - 0.5	12 - 20	-	0%	80%	65%
Heat Pumps	0.5 - 100	10 - 20	2%	6%	80%	65%
Chillers	10 - 2,000	15 - 30	0.5%	3.0%	80%	80%

* Lower value for developed countries and higher value for developing countries

Table B.10 Typical refrigerant charge capacity and leakage in different types of equipment (source: DEFRA 2012)

R22 refrigerants were widely used in fridges and air conditioning systems until the discovery of the hole in the ozone layer and the introduction of the Montreal Protocol in 1987 started to see the phasing out of CFCs and HCFCs. A popular alternative for heat pumps and chillers was the HFC based R134a refrigerant which has an Ozone Depletion Potential (ODP) of zero but is a potent greenhouse gas. The European Union is currently phasing out the use of F-gases. Alternatives include Hydrocarbons (HC) and natural refrigerants (such as CO_2, ammonia and isobutene). Table B.11 shows typical ODP and GWP values for different types of refrigerants.

Refrigerant	Type	ODP	GWP	Comments & uses
R11	CFC	1	4750	Old chillers (now banned in EU)
R22	HCFC	0.055	1810	Package AC (no longer manufactured in EU)
R134a	HFC	0	1300	Chillers & heat pumps
R290 (Propane)	HC	0	3	
R404a	HFC	0	3260	
R407C	HFC	0	1525	Chillers & heat pumps
R600a (Isobutane)	HC	0	0	New fridges
Ammonia		0	0	

Table B.11 ODP and GWP for different refrigerants

Fortunately, the volumes of F-gases are relatively small and only become a greenhouse gas issue if they leak to atmosphere. To put F-gas emissions into context consider Building X with operating carbon emissions of 105 $kgCO_2e/m^2$. The building has two 400 kW chillers each using R407C refrigerant with a charge of 80 kg. Assuming an expected chiller life of 20 years, the estimated greenhouse gas emissions from refrigerant leakage are:

- Percentage leakage = 0.5% + 20 years x 3% + 80% x (1 – 80%) = 77%
- Emissions over life = 2 x 80 kg x 1525 x 77% = 187,880 $kgCO_2e$
- Emissions per year = 187,880 / 20 = 9,394 $kgCO_2e$ = **0.9 $kgCO_2e/m^2$**

This represents approximately 1% of the operating emissions of the building. If individual heat pumps were used instead, with R134a refrigerant, a life of 15 years and a total charge of 160kg, then the percentage of leakage increases to 120% and the emissions per year are 16,640 $kgCO_2e$ (**1.7 $kgCO_2e/m^2$**). This highlights both the importance of regular maintenance to reduce refrigerant leakage, and the commitment of the EU to phase out refrigerants with high global warming potential.

B10. EMISSIONS DUE TO WATER CONSUMPTION

The consumption and disposal of water requires energy. The DEFRA emission factors for 2010/11 in the UK were:

- Potable water supply   0.34 $kgCO_2e$ per m^3
- Sewage treatment   0.71 $kgCO_2e$ per m^3

To put this into context, consider the typical UK office water consumption of 0.6 kL/m^2 per year.[15] Table B.12 shows the CO_2e emissions assuming 90% of the potable water ends up going to sewer.

	Emission factor ($kgCO_2e/m^3$)	Annual water consumption (m^3/m^2)	Carbon emissions ($kgCO_2e/m^2$)
Potable Water Supply	0.34	0.6	0.2
Sewage Water Treatment	0.71	0.54	0.4
Total Emissions			**0.6**

Table B.12 **CO_2e emissions due to water use in a typical UK office building**

The carbon emissions due to water consumption and disposal in an office building represent 0.5% of the total operating energy emissions in Building X (105 $kgCO_2e/m^2$). In buildings with a much higher demand for water, such as hospitals or leisure centres, then the energy due to water could be more significant.

EMBODIED WATER

According to Waterwise the average resident in the UK uses about 150 litres of tap water a day (for cooking, cleaning, washing and flushing), but if you include the amount of water embedded within products, the water consumption is around 3400 litres every day.[16] The breakdown is roughly:

- 0.2% drinking water
- 4.2% water used for domestic purposes such as cooking, washing and flushing
- 30.6% water embedded in industrial goods
- 65% water embedded in food.

About 70% of the water footprint is in the goods and services imported from overseas. According to Waterwise: '*a tomato has about 13 litres of water embedded in it, an apple has about 70 litres, a pint of beer about 170 litres, a glass of milk about 200 litres, and a hamburger about 2400 litres.*'

As global water consumption increases more parts of the world will face water stress – and the effects of climate change are unlikely to make the situation any better. Embodied water is an issue that will become increasingly more prominent in the next few years.

B11. EMISSIONS FROM MATERIAL CONSUMPTION AND WASTE DISPOSAL

Table B.13 shows emission factors for consumption of materials typically used in offices and their disposal in the UK. Waste factors vary depending on whether the waste is recycled, used in waste to energy plant, composted or sent to landfill.

	Material consumption ($kgCO_2e$/tonne)			Waste disposal ($kgCO_2e$/tonne)				
	Primary material	Recycled open loop	Recycled closed loop	Recycled open loop	Recycled closed loop	Waste to energy	Compost	Landfill
Paper	955		680		21	21	21	553
Cardboard	1038		680		21	21	21	553
Food and drink	3590					21	6	570
Metal cans (mixed)	4964		1,054		21	21		21
Glass	895		508	21	21	21		26
Plastic (average)	3179	693	1,977	21	21	21		34
Plastic - Film	2591	599	1,528	21	21	21		34
Plastic - Rigid	3281	599	2,138	21	21	21		34
Mixed Electrical	1149			21		21		17

Table B.13 **CO_2e emission factors for material consumption and waste disposal (source: DEFRA, 2012)**

Figure B.4 shows the CO_2e emissions due to waste disposal in an office building, generating 200 kg of waste per person each year, based on three scenarios:[17]

- No recycling – all waste goes to landfill.
- Typical practice – 50% of paper, cardboard, plastics, glass and cans are recycled, the remainder goes to landfill.
- Best practice – 100% of paper, cardboard, glass and cans are recycled, 75% of plastic is recycled and 75% of food waste is composted.

Figure 1.5 in Chapter 1 shows higher values for waste CO_2e emissions than Figure B.4. The values in Figure 1.5 were based on 500 kg of waste per person per year, which was the waste generated by large financial sector companies in 2000.[18] Figure B.4 is based on a less wasteful office.

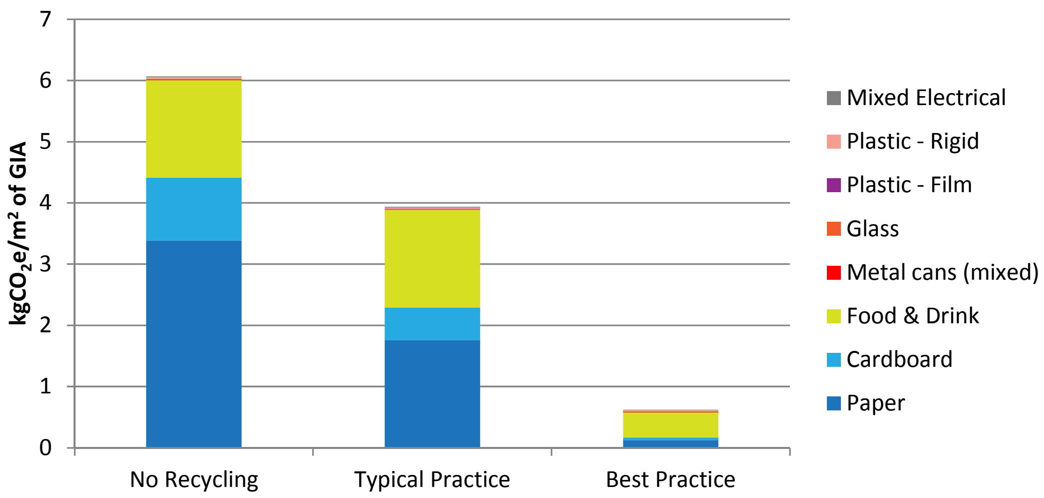

Fig B.4 CO_2e **emissions in a typical office (200 kg of waste per person) for different waste recycling scenarios**

Since the total and type of waste generated, and how this is disposed of, can vary so widely between different occupants of the same building, it is not practical to include emissions from waste in the whole carbon footprint. However, this simple analysis does show the importance of reducing the amount of materials consumed, and then diverting as much of the waste as possible away from landfill to reduce total greenhouse gas emissions. If all the waste is sent to landfill, the CO_2e emissions in Building X due to waste are the same as the natural gas consumption for heating.

The emissions due to producing the materials before throwing them away are much larger than the emissions associated with disposal of them. Using the same assumptions above (200 kg per person), if all the materials were purchased using primary materials (i.e. no recycled content) then the emissions per annum are 24 $kgCO_2e/m^2$. Paper with no recycled content accounts for 6 $kgCO_2e/m^2$. Purchasing 100% recycled paper reduces this to 4 $kgCO_2e/m^2$.

Notes

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

1. Examples of grid electricity and natural gas emission factors used in the UK in the last five years (noting that the rolling five year average has remained fairly constant over this period) are shown in the table below. Different factors lead to different technologies gaining favour over others in carbon calculations.

Source	electricity	gas
Part L 2006 – consumption	0.422	0.194
Part L 2006 – electricity displaced from grid	0.568	n/a
Part L 2010 – consumption	0.517	0.198
Part L 2010 – electricity displaced from grid	0.529	n/a
CRC Energy Efficiency Scheme	0.541	0.184
Display Energy Certificate (DEC)	0.551	0.190
2012 DEFRA Guidelines – generation & losses in 2010	0.520	0.185
2012 DEFRA Guidelines – generation, losses & embodied in 2010	0.590	0.204

2. *2012 Guidelines to DEFRA / DECC's GHG Conversion Factors for Company Reporting* (Version 1 Updated: 28/5/2012). Produced by AEA for the Department of Energy and Climate Change (DECC) and the Department for Environment, Food and Rural Affairs (DEFRA).

   The *2012 Methodology Paper for Emission Factors* provides background to how all the emission factors were calculated. Values for methane (CH_4) and nitrous oxide (N_2O) are presented as CO_2 equivalents (CO_2e) using GWP factors from the IPCC 2nd assessment report (GWP for CH_4 = 21, GWP for N_2O = 310). Indirect emissions include extracting, processing and delivering energy and fuels to end users. www.gov.uk/government/publications/2012-greenhouse-gas-conversion-factors-for-company-reporting

3. The GHG Protocol defines direct and indirect emissions as follows:
   - Direct GHG emissions are emissions from sources that are owned or controlled by the reporting entity.
   - Indirect GHG emissions are emissions that are a consequence of the activities of the reporting entity, but occur at sources owned or controlled by another entity.

   The GHG Protocol further categorizes these direct and indirect emissions into three broad scopes:
   - Scope 1: All direct GHG emissions.
   - Scope 2: Indirect GHG emissions from consumption of purchased electricity, heat or steam.
   - Scope 3: Other indirect emissions, such as the extraction and production of purchased materials and fuels, transport-related activities in vehicles not owned or controlled by the reporting entity, electricity-related activities (e.g. T&D losses) not covered in Scope 2, outsourced activities, waste disposal, etc.

   For further details refer to www.ghgprotocol.org.

4. Building X is an example office building described in Appendix M and primarily used as a guinea pig in Chapter 7 to test the contribution that renewable energy systems can make to reducing the operating carbon footprint of office buildings.

5. Refer to Information Paper 3 – Fuel mix in grid electricity for UK emission factors since 1990, and examples of fuel mixes for different countries.

6. The world average is taken from *Factors underpinning future action – country fact sheets 2008 update* prepared by ECOFYS for the UK Department of Energy and Climate Change (DECC). www.ecofys.com/en/publication/factors-underpinning-future-action-update-2008.

   The generated emission values in the tables differ slightly from the energy intensity values stated in the fact sheets as they are based on a five year rolling average and not the 2006 values. However, all of the emission data is ultimately from the same source - the International Energy Agency's Data Services 2006 and 2008.

7. The gross calorific value (CV) or higher heating value (HHV) is the CV under laboratory conditions. Net CV or lower heating value (LHV) is the useful calorific value in typical real world conditions (e.g. boiler plant). The difference is

essentially the latent heat of the water vapour produced (which can be recovered in laboratory conditions). The daily gross CV of natural gas passing through the UK National Grid pipeline system is determined by measurement at various locations using process gas chromatographs. The monthly or quarterly weighted average of gross CV is shown on UK gas bills and is used to convert metered gas consumption by volume (m^3 or ft^3) into energy consumption (kWh). Users pay for gas by energy, not volume.

8. *Methane and the greenhouse-gas footprint of natural gas from shale formations: A letter* by Robert W. Howarth, Renee Santoro & Anthony Ingraffea, published in Climatic Change Letters (105:5), May 2011. Also refer to http://news.cornell.edu/stories/2011/04/fracking-leaks-may-make-gas-dirtier-coal.

9. Refer to Information Paper 4 – CO_2e emissions from biomass and biofuels for more background to the biomass and biofuel factors.

10. As note 9.

11. In the IPCC Fourth Assessment Report (AR4): *Climate Change 2007 – The Physical Science Basis*, the radiative forcing of black carbon was estimated to be 0.3 W/m^2 ± 0.25, with two thirds due to direct atmospheric effect (section 2.4.4.3) and one third due to black carbon on snow (section 2.5.4). This makes it the third largest contributor to positive radiative forcing after greenhouse gases and tropospheric ozone.

12. Refer to Information Paper 5 – Global warming due to black carbon for assumptions made and calculations for Building X.

13. Data on F-gases from: Regulation (EC) no. 842/2006 of the European Parliament and of the council of 17 may 2006 on certain fluorinated greenhouse gases; F-Gas Support Information Sheet *GEN 2 - Fluid Uses*, August 2011, and 2012 *UK greenhouse gas emissions, provisional figures and 2011 UK greenhouse gas emissions, final figures by fuel type and end-user*, a statistical release by Department of Energy and Climate Change dated 28th March 2013.

14. Data taken from Table 36 of *2012 Guidelines to Defra / DECC's GHG Conversion Factors for Company Reporting: Methodology Paper for Emission Factors*.

15. In 2006 the government set a target for water consumption in the public sector of 9.3 m^3 per person per year with a best practice target of 6.4 m^3 per person per year. Assuming an average occupancy of 1 person per 15 m^2 of GIA then this converts to 0.62 kL/m^2 and 0.43 kL/m^2 respectively. Source: the now defunct website www.watermark.gov.uk accessed via http://web.archive.org/web/20050409212425/www.watermark.gov.uk/w_Events.asp?SectionID=1&SubSectionID=1&StoryID=272.

    The *Australian Water Efficiency Guide* published by the Federal Government in October 2006 gives the average water consumption as 1.125 kL/m^2 although this varies depending on the climate (0.7 to 1.56) and whether cooling towers are used (which typically account for a third of the total).

16. The Waterwise website (www.waterwise.org.uk) states: '*Each person in the UK uses 150 litres of water a day. This takes into account cooking, cleaning, washing and flushing. This has been rising by 1% a year since 1930. This consumption level is not sustainable in the long-term.*' In 2007 they published a report on embodied water called *Hidden Waters*.

17. For calculation and assumptions refer to Information Paper 6 – CO_2e emissions due to office waste.

18. Breakdown of waste in financial sector offices from the Waste Watch report *Rethinking waste management to reap rewards - minimising waste for business benefit* published in 2004 based on a site audit of 14 office buildings in 2000. www.massbalance.org/downloads/projectfiles/1536a-00282.pdf