In the name of God

An overview of energy management course

CH.1 Energy and the environment

1. Units of energy

Kilowatt-hour (kWh) : *1 kWh = 3.6 x 10^6 joule*

British thermal unit (Btu) : *1 Btu = 1.055 x 10^3 joule*

Therme : *1 therme = 1.055 x 10^8 joule*

Tonne of oil equivalent (toe): *1 toe = 4.5 x 10^{10} joule*

Barrel : *1 barrel = 6 x 10^9 joule*

Calorie : *1 calorie = 4.2 x 10^3 joule*

2. The laws of thermodynamics

3. Energy consumption and GDP

*The ratio of energy used to **GDP** is known as the **energy intensity** of an economy.*

4. Global warming

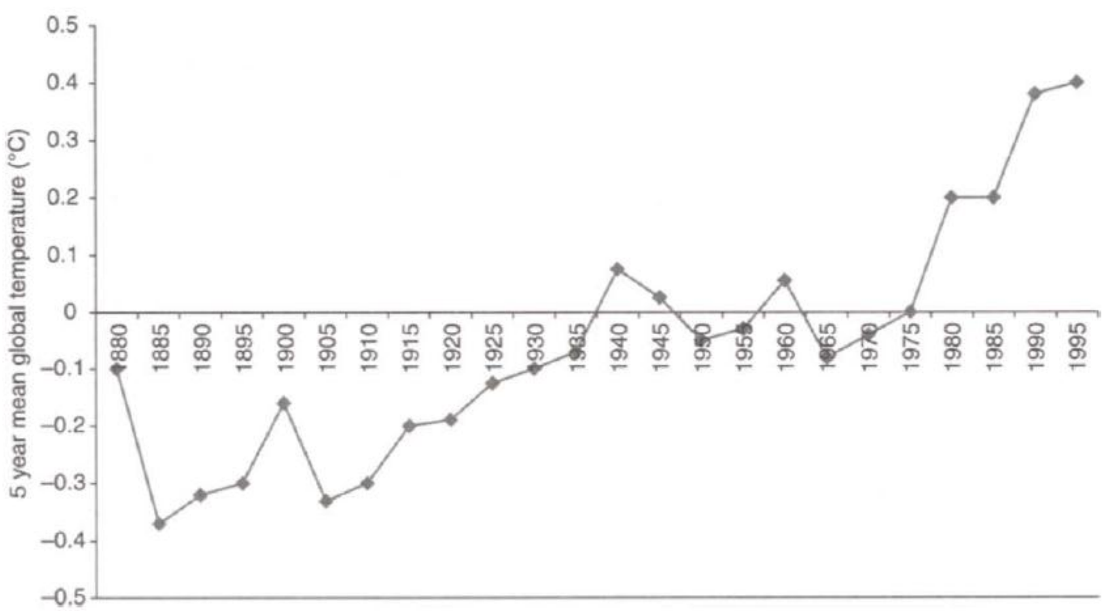


Figure 1.3 Global mean temperature change[9]

Table 1.2 Contribution to global warming of various gases [12]

Greenhouse gas	Carbon dioxide equivalent per molecule	Pre-1800 concen-tration	1990 Concen-tration	Growth rate (%/year)	Atmospheric life (years)
Carbon dioxide	1	280 ppmv	353 ppmv	0.50	50–200
Methane	21	0.8 ppmv	1.72 ppmv	0.90	10
CFC 12	7300	0.0 ppmv	484 pptv	4.00	130
CFC 11	3500	0.0 ppmv	280 pptv	4.00	65
Nitrous oxide	290	288 ppbv	310 ppbv	0.25	150

Table 1.3 CO_2 emissions per kWh of delivered electrical energy (compiled from Building Research Establishment data) [11]

Primary fuel	Kg of CO_2 per GJ of primary energy (kg/GJ)	Average gross efficiency of power plant (%)	Kg of CO_2 per GJ of delivered electrical energy (kg/GJ)	Kg of CO_2 per kWh of delivered electrical energy (kg/kWh)
Coal	90.7	35	259.1	0.93
Oil	69.3	32	216.6	0.78
Gas (CCGT)	49.5	46	107.6	0.39

CH.2 Utility companies and energy supply

1. *Primary energy and Delivered energy*

   Primary energy : like Natural gas

   Delivered energy : like Electricity

CH.3 Competition in energy supply

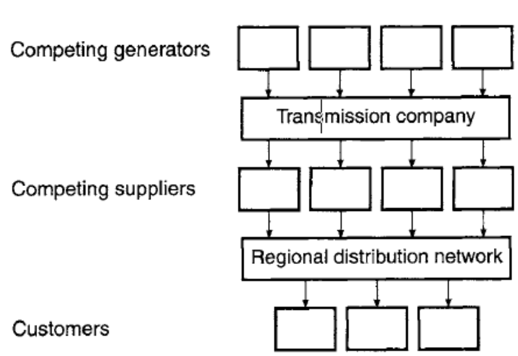


Figure 3.2 A horizontally integrated electricity supply industry

1. *Load management of electricity*

$$\text{Load factor} = \frac{\text{Energy consumed (kWh)}}{\text{Max. demand (kW)} \times \text{Time period (h)}} \times 100$$

Table 3.1 Typical load factors for a variety of applications [10]

Type of organization	*Load factor*
24 hour operation	0.7–0.85
2 shift system	0.45–0.6
Single shift system	0.25–0.4
Modern hotel complex	0.5–0.6
Hospital	0.6–0.75
Retailing	0.3–0.4
Catering business	0.3–0.5

CH.4 Energy analysis techniques

1. *Annual energy consumption*

(i) Convert all the energy consumption data into standard units (usually the kWh)

Table 4.1 Energy conversion factors

From	*Multiply by factor*	*To*
Therms	29.306	kWh
MJ	0.2778	kWh
GJ	277.778	kWh

Table 4.2 Typical gross calorific value of fuels [1]

Fuel type	*Typical gross calorific value*
Electricity	1 kWh
Natural gas	1.01 therms/100 ft^3
Gas oil (Class D)	38 MJ/litre
Heavy fuel oil (Class G)	42 MJ/litre
Coal	27–30 GJ/tonne
Propane	92.6 GJ/m^3
Butane	49.3 GJ/m^3

(ii) Produce percentage breakdowns of the total consumption and cost of each energy type, and determine the average unit cost per kWh for each.

(iii) Compile a table similar to the example shown in Table 4.3 showing the total annual energy consumption, cost and percentage breakdown of each fuel type.

Like:

Table 4.3 Table of annual energy input for 1998/99

Energy type	Purchased units	Consumption (kWh)	Consumption (%)	Cost (£)	Cost (%)	Cost (p/kWh)
Electricity	61 500 kWh	61 500.0	26.0	3075.00	52.58	5.00
Gas	146 800 kWh	146 800.0	62.0	2231.36	38.16	1.52
Oil-class D	2700 litres	28 500.0	12.0	541.52	9.26	1.90
Totals	–	236 800.0	100.0	5847.88	100.00	2.47 (av.)

(iv) Produce pie charts similar to those shown in Figure 4.1 to show graphically the energy and cost contributions of each energy type.

Like:

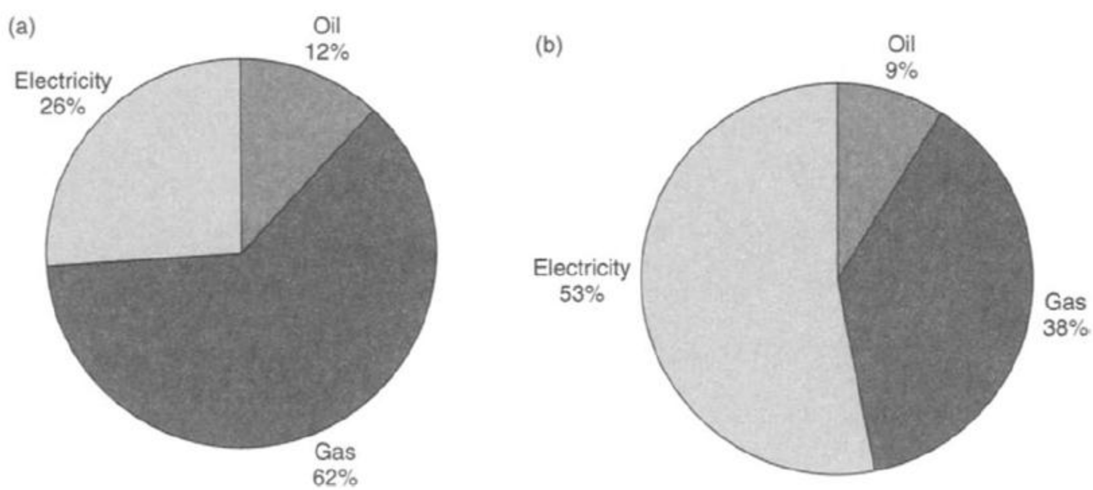


Figure 4.1 Energy consumption (a) and costs (b)

(v) Where historical energy data are available, comparisons should be made in order to identify any trends, as illustrated in Table 4.4.

Like:

Table 4.4 Changes in annual energy use

Year	Consumption (kWh)	Change (%)
1994/95 (base)	201 456.4	n.a.
1995/96	197 562.2	−1.9
1996/97	203 216.2	+0.9
1997/98	220 403.5	+9.4
1998/99	236 800.0	+17.5

2. *Normalized performance indicator (NPI)*

Good: Generally good controls and energy management procedures although further energy savings are often possible.

Fair: Reasonable controls and energy management procedures, but significant energy savings should be achievable.

Poor: Energy consumption is unnecessarily high and urgent action should be taken to remedy the situation.

Table 4.6 Yardsticks (kWh/m^2 per year) for annual energy consumption of various building types [1]

Building type	Standard hours of use per year	Fair performance range (kWh/m^2)
Nursery	2290	370–430
Primary school, no pool	1400	180–240
Primary school with pool	1480	230–310
Secondary school, no pool	1660	190–240
Secondary school, with pool	2000	250–310
Secondary school with sports centre	3690	250–280
Special school, non-residential	1570	250–340
Special school, residential	8760	380–500
Restaurants	–	410–430
Public houses	–	340–470
Fast-food outlets	–	1450–1750
Motorway service area	–	880–1200
Department/chain store (mechanically ventilated)	–	520–620
Other non-food shops*	–	280–320
Superstore/hypermarket (mechanically ventilated)*	–	720–830
Supermarket, no bakery (mechanically ventilated)*	–	1070–1270
Supermarket, with bakery (mechanically ventilated)*	–	1130–1350
Small food shop – general*	–	510–580
Small food shop – fruit & veg	–	400–450
University	4250	325–355
Colleges of Further Education	3200	230–280
Air conditioned offices, over 2000 m^2	2600	250–410
Air conditioned offices, under 2000 m^2	2400	220–310
Naturally ventilated offices, over 2000 m^2	2600	230–290
Naturally ventilated offices, under 2000 m^2	2400	200–250
Computer centres	8760	340–480
Swimming pool	4000	1050–1390
Sports centre with pool	5130	570–840
Sports centre, no pool	4910	200–340
Library	2540	200–280
Small hotel	–	240–330
Medium-sized hotel	–	310–420
Large hotel	–	290–420
Banks	2200	180–240
Museum, art gallery	2540	220–310
Cinema	3080	650–780
Theatre	1150	600–900

*Based on sales area

- ***CIBSE method***

✓ ***Heating degree days***

Nowadays, however, ***, degree days*** *are generally used to predict heating energy consumption in buildings.*

Base outside air temperature: above this *do not require any heating.*

In the UK this base temperature is generally taken to be 15.5°c.

For example, if an outside air temperature of 10.5°c is maintained for 1 week then 35 ***degree days*** *will be accumulated.*

Table A1.1 UK 20-year average heating degree day data to base 15.5 °C [2]

Region	Jan	Feb	Mar	April	May	June	July	Aug	Sept	Oct	Nov	Dec	Average
Thames valley	346	322	286	205	120	51	22	25	54	130	242	312	2115
South eastern	368	344	312	233	150	74	39	44	82	160	267	334	2407
Southern	345	327	301	229	148	72	39	43	79	150	251	312	2296
South western	293	285	271	207	137	63	28	28	55	116	206	258	1947
Severn valley	321	305	280	201	128	56	24	27	61	138	237	300	2078
Midland	376	359	322	243	162	83	44	48	90	178	275	343	2523
West Pennines	361	340	312	230	144	75	38	39	78	157	267	328	2369
North western	375	345	323	245	167	90	50	56	96	171	284	341	2543
Borders	376	349	330	271	206	117	66	68	104	182	282	339	2690
North eastern	381	358	322	247	168	87	46	49	88	175	281	346	2548
East Pennines	372	352	313	232	154	78	42	44	81	165	272	341	2446
East Anglia	378	349	317	239	149	73	40	39	71	154	269	341	2419
West Scotland	383	352	328	246	170	94	58	64	111	188	299	352	2645
East Scotland	388	357	332	263	197	109	62	67	109	192	301	354	2731
North East Scotland	401	368	346	277	206	120	74	78	127	203	311	362	2873
Wales	330	320	307	240	170	92	49	45	77	145	235	294	2304
Northern Ireland	365	334	320	242	171	92	53	59	99	173	282	329	2519

✓ ***Cooling degree days***

Example 4.1

A library building is situated in an urban location, which experiences 2115 heating degree days per year. It is in use for 2400 hours per year, and consumes 940 000 kWh of natural gas and 28 000 kWh of electricity. If the floor area of the school is 4800 m², calculate its NPI and assess its energy performance.

Solution:

Electrical energy used = 28 000 kWh

Gas used = 940 000 kWh

Total energy consumed = 28 000 + 940 000 = 968 000 kWh

Table 4.5 shows that 70% of the gas used can be attributed directly to space heating.

Table 4.5 Proportion of fuel used for space heating and hot water production which is assumed to be attributable to space heating [1]

Building type	*Proportion of fuel used for space heating and hot water attributable to space heating (%)*
School	75
Hospital, nursing home	50
Other health care	75
Further/higher education	75
Office	75
Sports centre, no pool	75
Sports centre, with pool	65
Swimming pool	55
Library, museum, gallery	70
Church	90
Hotel	60
Bank, agency	75
Entertainment	75
Prison	60
Court, depot, emergency services building	75
Factory	80

$$\text{Weather coefficient} = \frac{\text{Standard annual heating degree days}}{\text{Annual heating degree days experienced by building}}$$

In the UK the standard annual number heating degree days is considered to be ***2462****. This value will vary with the particular country or region under consideration.*

Exposure coefficients *are as follows:*

Exposure	*Exposure coefficient*
Sheltered (city centre)	1.1
Normal (urban/rural)	1.0
Exposed (coastal/hilly site)	0.9

Therefore:

$$\text{Space heating energy consumption} = 940\,000 \times 0.70 = 658\,000 \text{ kWh}$$

By applying weather and exposure coefficients:

$$\text{Corrected space heating energy consumption} = 658\,000 \times \frac{2462}{2115} \times 1.0$$
$$= 765\,955.6 \text{ kWh}$$

$$\text{Non-heating energy consumption} = 968\,000 - 658\,000 = 310\,000 \text{ kWh}$$

$$\text{Hours of use coefficient} = \frac{\text{Standard annual hours of use}}{\text{Actual annual hours of use}}$$

Therefore:

$$\text{Corrected total energy consumption} = 310\,000 + 765\,955.6 = 1075\,955.6 \text{ kWh}$$

and correcting for occupancy (using data from Table 4.6):

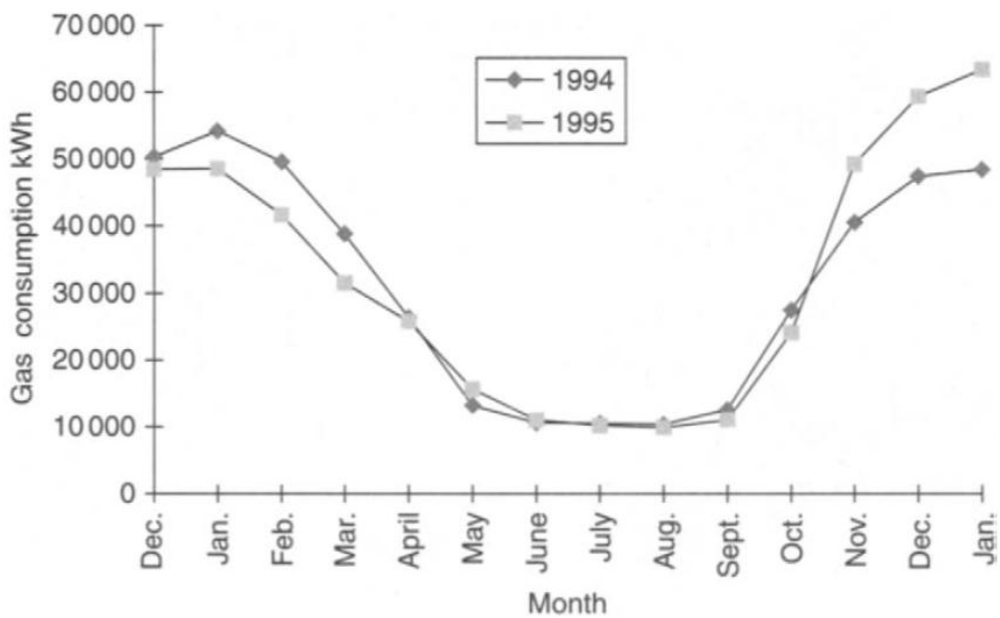
$$\text{Normalized annual energy consumption} = 1075\,955.6 \times \frac{2540}{2400} = 1138\,719.7 \text{ kWh}$$

Therefore:

$$\text{NPI} = \frac{1138\,719.7}{4800} = 237.2 \text{ kWh/m}^2$$

According to Table 4.6 the assessed energy performance of the library building is 'fair'. In other words, the building is performing reasonably well, but significant energy saving could still be made.

3. Time-dependent energy analysis



4. Linear regression analysis

- ***Single independent variable***
  This linear equation can be used to predict future energy consumption.

The generic equation for a straight-line graph can be represented as:

y = c + mx

Where y is the dependent variable (e.g. energy consumption), x is the independent variable (e.g. number of degree days), c is the value at which the straight-line curve intersects the 'y' axis, andm is the gradient of the straight-line curve.

If the straight line y = c + mx is best fitted to a set of data sample points;

$$(x_1, y_1)\cdot(x_2, y_2)\cdots(x_n, y_n)$$

it can be shown that

$$cn + m\Sigma x = \Sigma y$$

and

$$c\Sigma x + m\Sigma x^2 = \Sigma xy$$

Example 4.2

Consider a hospital building which during a monitoring programme produces the following sample data:

Degree days experienced per month (x)	72	88	95	106	169	204	244	265	290	298	332	345
Gas consumption per month (y) (GJ)	482	520	634	570	671	860	903	940	1007	1210	1020	1131

Therefore:

	x	y	x^2	xy
	72	482	5184	34 704
	88	520	7744	45 760
	95	634	9025	60 230
	106	570	11 236	60 420
	169	671	28 561	113 399
	204	860	41 616	175 440
	244	903	59 536	220 332
	265	940	70 225	249 100
	290	1007	84 100	292 030
	298	1210	88 804	360 580
	332	1020	110 224	338 640
	345	1131	119 025	390 195
Σ	2508	9948	635 280	2340 830

Therefore, the normal equations become:

$$12c + 2508m = 9948$$

and

$$2508c + 635\,280m = 2340\,830$$

therefore

$$c = \frac{9948 - 2508m}{12}$$

therefore

$$2508\,\frac{(9948 - 2508m)}{12} + 635\,280m = 2340\,830$$

therefore

$$m = 2.355$$

and

$$c = 336.73$$

The best fit straight line curve equation is therefore:

$$y = 336.73 + 2.355x$$

a best-fit straight line

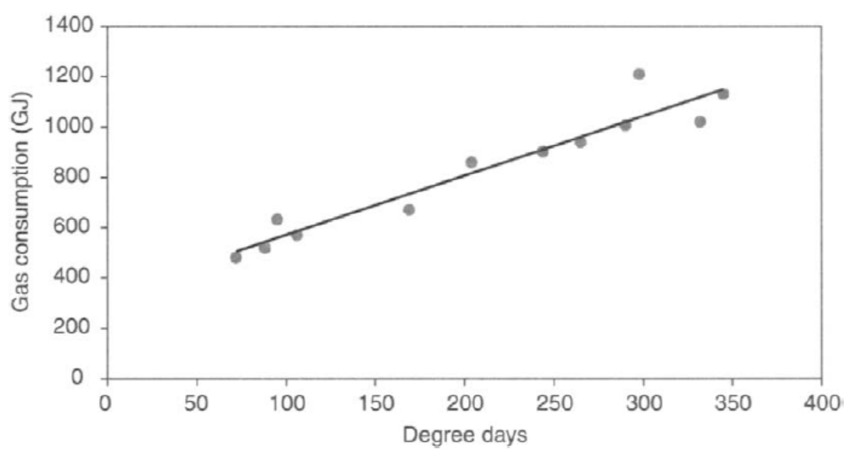


Figure 4.4 Regression analysis for hospital building

*Figure 4.4 shows that even when zero degree days are experienced in a particular month, the building still consumes **336.7 GJ** of gas.*

Pearson correlation coefficient *which gives an indication of the reliability of the line drawn*

$$r = \frac{\Sigma(x - \bar{x})(y - \bar{y})}{\sqrt{[\Sigma(x - \bar{x})^2\Sigma(y - \bar{y})^2]}}$$

The Pearson correlation coefficient is a value between 1 and 0, with a value of 1 representing 100% correlation.

Example 4.3

For the data presented in Example 4.2 determine the correlation coefficient.
Therefore:

	x	y	$(x-\overline{x})$	$(y-\overline{y})$	$(x-\overline{x})(y-\overline{y})$	$(x-\overline{x})^2$	$(y-\overline{y})^2$
	72	482	−137	−347	47 539	18 769	120 409
	88	520	−121	−309	37 389	14 641	95 481
	95	634	−114	−195	22 230	12 996	38 025
	106	570	−103	−259	26 677	10 609	67 081
	169	671	−40	−158	6 320	1 600	24 964
	204	860	−5	31	−155	25	961
	244	903	35	74	2 590	1 225	5 476
	265	940	56	111	6 216	3 136	12 321
	290	1007	81	178	14 418	6 561	31 684
	298	1210	89	381	33 909	7 921	145 161
	332	1020	123	191	23 493	15 129	36 481
	345	1131	136	302	41 072	18 496	91 204
Σ	2508	9948	0	0	261 698	111 108	669 248

Therefore:

$$r = \frac{261\,698}{\sqrt{(111\,108 \times 669\,248)}} = 0.96$$

Table 4.8 Minimum correlation coefficients [4]

Number of data samples	*Minimum correlation coefficient*
10	0.767
15	0.641
20	0.561
25	0.506
30	0.464
35	0.425
40	0.402
45	0.380
50	0.362

It can be seen from Table 4.8 that the correlation coefficient in Example 4.3 is very good.

CH.5 Energy audits and survey

1. Types of energy audit

- ✓ *Preliminary*
- ✓ *targeted*
- ✓ *comprehensive*
    - *Preliminary energy audits:*
        1. *Collecting data*
        2. *Analysing data*
        3. *Presenting data*
        4. *Establishing priorities and making recommendations.*

Example 5.1

A preliminary energy audit of a 5000 m^2 air conditioned office building has yielded the following energy data:

Month	Heating degree days	Gas consumption (kWh)	Gas cost (£)	Electricity consumption (kWh)	Electricity cost (£)
January	267	90 010	1080.12	68 214	3956.41
February	298	97 160	1165.92	60 312	3437.78
March	250	87 058	1044.70	59 645	3280.48
April	176	71 320	855.84	65 045	3382.34
May	69	47 200	566.40	89 234	4550.93
June	30	38 645	463.74	105 932	5296.60
July	12	33 840	406.08	119 237	5961.85
August	20	34 400	412.80	103 247	5265.60
September	50	44 050	528.60	88 235	4588.22
October	208	75 920	911.04	65 023	3446.22
November	215	78 580	942.96	61 567	3447.75
December	337	106 640	1279.68	70 124	4137.32
Totals	1932	804 823	9657.88	955 815	50 751.50

Given that the office building is located in a city centre and is occupied for 2560 hours per year, perform an analysis which characterizes the building's energy consumption.

Solution

The annual energy consumption and energy cost breakdowns are shown in Figure 5.3. It can be seen from the pie charts that although approximately 46% of the energy consumed is natural gas, it only accounts for 16% of the energy costs.

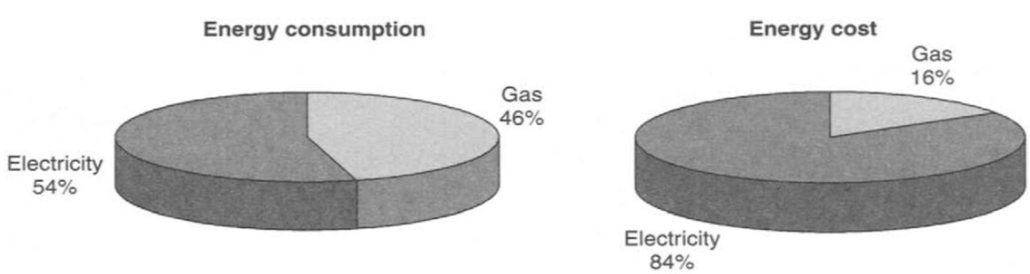


Figure 5.3 Energy consumption and cost breakdowns

The raw energy consumption and cost figures per m^2 are as follows:

Fuel	*Annual energy consumption per* m^2	*Annual energy cost per* m^2
Natural gas	160.965 kWh per m^2	£1.93 per m^2
Electricity	191.163 kWh per m^2	£10.15 per m^2

Using the methodology explained in Section 4.3, the NPI can be established as follows:

Electrical energy used = 955 815 kWh

Gas used = 804 823 kWh

$$\text{Total energy consumed} = 955\,815 + 804\,823 = 1760\,638 \text{ kWh}$$

From Table 4.5 it can be seen that 75% of the gas consumed can be attributed directly to space heating. Therefore:

$$\text{Space heating energy consumption} = 1760\,638 \times 0.75 = 1320\,478.5 \text{ kWh}$$

By applying weather and exposure coefficients:

$$\text{Corrected space heating energy consumption} = \frac{1320478.5 \times 2462 \times 1.0}{1932} = 1682\,721.6 \text{ kWh}$$

$$\text{Non-heating energy consumption kWh} = 1760\,638 - 1320\,478.5 = 440\,159.5 \text{ kWh}$$

Therefore

$$\text{Corrected total energy consumption} = 440\,159.5 + 1682\,721.6 = 2122\,881.1 \text{ kWh}$$

and correcting for occupancy (using data from Table 4.6):

$$\text{Normalized annual energy consumption} = 2122\,881.1 \times \frac{2600}{2560} = 2156\,051.1 \text{ kWh}$$

Therefore

$$\text{NPI} = \frac{2156\,051.1}{5000} = 431.21 \text{ kWh/m}^2$$

- *Because the calculated NPI of* ***431.21 kWh/m²*** *is above the upper limit of the 'fair' range (i.e.* ***410 kWh/m²*** *in Table 5.2), for an air conditioned office building, it can be assumed that the energy performance of the office building is poor.*
- ***Monthly gas consumption (kWh) = 31 521.75 + (220.788 x Degree days)***
- *This equation shows that the monthly gas base-load consumption is* ***31 521.75 kWh****.*

- *Comprehensive energy audits*

  Comprehensive audits require detailed energy surveys to be undertaken, and they often require the installation of additional sub metering in order to determine accurately component energy flows.

Example 5.2

Through the installation of sub-meters in the office building in Example 5.1, it has been possible to establish the following data:

Month	*Space heating* (kWh)	*Domestic hot water* (kWh)	*Catering* (kWh)	*Lifts* (kWh)	*Lighting* (kWh)	*Air conditioning* (kWh)	*Other* (kWh)
January	54 075	13 239	22 696	620	44 016	21 231	2 348
February	61 856	12 924	22 380	610	41 082	16 566	2 054
March	52 888	11 978	22 191	627	33 746	23 659	1 614
April	38 537	11 348	21 435	631	24 942	27 734	11 738
May	12 841	11 663	22 696	636	19 074	68 013	1 511
June	2395	12 293	23 957	640	14 672	88 713	1 907
July	427	11 663	21 750	625	15 112	1011 681	1 819
August	672	10 717	23 011	621	19 074	81 909	1 643
September	14 420	94 57	20 174	615	26 410	59 655	1 555
October	42 507	11 348	22 065	630	32 719	30 134	1 541
November	43 591	11 978	23 011	632	42 549	16 611	1 775
December	67 868	13 554	25 217	628	45 483	21 929	2 083
Totals	392 077	142 163	270 583	7515	358 877	557 835	31 589

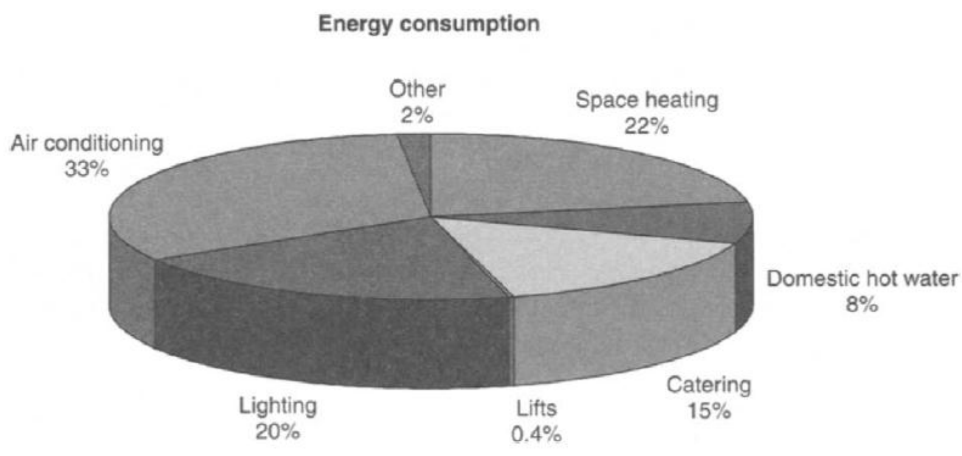


Figure 5.4 Energy consumption breakdown for the office building