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NBSLM03E Low Carbon Technologies and Solutions (2010)

PART 2 of 3

Energy Conservation and Management in Buildings

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Copies of this handout and also the actual PowerPoint Presentations may be found on the WEB Site

http://www2.env.uea.ac.uk/gmmc/energy/nbslm03e/nbslm03e.htm

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10. ENERGY CONSERVATION IN BUILDINGS – Basic Considerations

10.1 Introduction

A significant amount of energy demand in a country is required for providing adequate thermal comfort within buildings. In many country is this will amount to 25-35% of the total energy demand. This has a consequential impact on the emissions of green house gases.

In all buildings no matter how well insulated they are there will always be heat loss in a cool/ climate and heat gain in a hot climate. The object of insulation in a building is to minimise heat losses/heat gains – insulation can never eliminate such heat transfers. Indeed it is just as important to ensure buildings are adequately insulated in a hot climate to minimise heat gain as it is to minimise heat loss in a cool climate.

This section introduces the physical basis of heat flow to provide an understanding of heat loss/heat gain in a building. In section 11 the use of these principles for actual heat loss / heat gain determination is covered. However, no matter how good the physical condition of a building is in terms of insulation effective energy management is critical and can result in significant savings for minimal cost outlay. Ideas of effective Energy Management are covered in section 12.

10.2 Heat Loss – Some basic definitions

SPECIFIC HEAT:- Quantity of ENERGY required to raise temperature of unit mass by 1 Kelvin. (Temperature Scale (K) - absolute zero at - 273.18°C).

UNITS:- $J\ kg^{-1}\ {}^{o}C^{-1}$

A knowledge of this is important when trying to determine how much energy is required to raise the temperature of water for hot water requirements in a building.

THERMAL CAPACITY:- Quantity of ENERGY required to heat a whole body by 1 K.

This is related to the specific heat but represents the total amount of heat (cool) stored in a body. It has important implications in the dynamic response of buildings. This is rather more technical, but will be covered only in passing in this course.

UNITS:- $J\ {}^{o}C^{-1}$

THERMAL CONDUCTIVITY:- a measurement of heat flow through a body. It is the heat transmitted in unit time, across a unit temperature difference, per unit distance.

UNITS:- $Wm^{-3o}C^{-1}$ or $Wm^{-3}K^{-1}$

(analogous to electrical conductivity or hydraulic permeability).

This is a measure of the intrinsic thermal properties of a material. Insulating material will have a low thermal conductivity, while materials like copper have a high thermal conductivity.

Thermal conductivity is usually given the symbol **k** or sometimes the Greek equivalent letter **κ** (kappa)

THERMAL RESISTIVITY:- this is the reciprocal of conductivity and is sometimes used as an alternative. This is usually given the symbol **ρ** (i.e. Greek letter rho).

i.e. $$\rho = \frac{1}{\kappa}$$

THERMAL RESISTANCE:- this is related to thermal resistivity but also takes in account the geometry (i.e. thickness and area) of the material. Many building materials are now specified with an R number.

$$R = \frac{\rho d}{A} = \frac{d}{\kappa A}$$

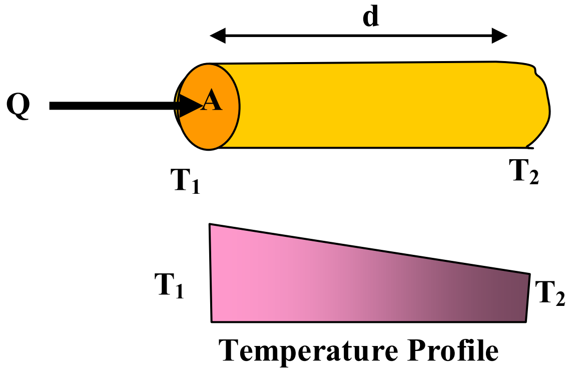
where R is the resistance
d is the thickness
A is the area
ρ is the resistivity
k is the conductivity

often we use the **UNIT AREA THERMAL RESISTANCE** - i.e. the thickness is included but not the area. This is now often used for many building materials which are specified by a R number i.e. the unit area thermal resistance

UNIT AREA THERMAL CONDUCTANCE or 'U' - Value is the reciprocal of **UNIT AREA THERMAL RESISTANCE. This parameter U is key to estimating heat losses/gains in a building.**

10.3 Heat Loss – Conduction

Figure 10.1 shows a simulation of heat flowing through a bar of uniform cross section. By convention, heat is given the symbol Q. It is noted that in a uniform material the temperature declines uniformly from one end to the other.



Fig, 10.1 Simulation of conductive Heat flow

Further more, the larger the area A is, the larger will be the heat flow and conversely the thicker the material (represented by d), the smaller will be the heat flow. .

Heat Flow, $$Q \propto \frac{A(T_1 - T_2)}{d}$$

$$Q = \frac{kA(T_1 - T_2)}{d} = \frac{A(T_1 - T_2)}{\rho d} = \frac{A(T_1 - T_2)}{R}$$

Direct analogy with electricity:-

$I = \frac{(V_1 - V_2)}{R}$ where I is the electric current and V is the voltage.

Water flow through soils is yet another analogy.

Surface Resistance

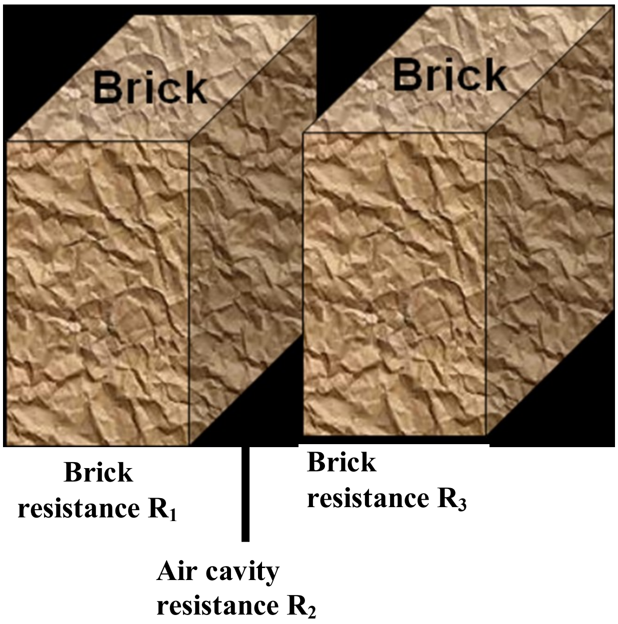


Fig. 10.2 Typical structure of buildings in UK constructed between 1945 and 1960.

A typical structure of a house built in the UK between 1945 and 1960 had an outer and inner leaf made of brick with a 50 mm cavity between. The purpose of the cavity was to minimise moisture ingress rather than minimise heat loss.

On both the outside surface and inside surface there is a boundary air layer which increases slightly the resistance to heat flow.

The full heat flow path may be represented as

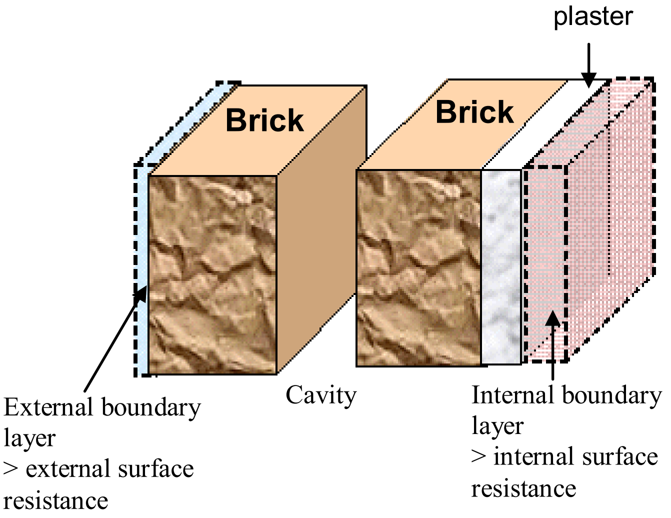


Fig. 10.3 Full heat flow path in a building built between 1945 – 1960 in UK.

10.3 Derivation of 'U'-values for 3 types of wall

The U-value is a measure of the heat loss through unit area of a particular component of a building for each 1°C between inside and out. It is the reciprocal of the sum of the resistances of the individual components o heat flow. For most standard types of wall construction, there are tables giving the appropriate U-value. However, any non-standard walls will require the U-value to be derived from first principles. The following give the derivation for three common types of wall.

Example 1

The resistance to heat flow in Fig. 10.3 arises from 6 components:-

1) external surface layer
2) outer brick layer
3) cavity
4) inner brick layer
5) plaster
6) internal surface layer

conductivity of brick = $\mathbf{1.0\ Wm^{-1}\ {}^{o}C^{-1}}$

conductivity of plaster = $\mathbf{0.7\ Wm^{-1}\ {}^{o}C^{-1}}$

$$\text{Now resistance} = \frac{l}{kA}$$

where k = conductivity
ℓ = length of heat flow paths (thickness in this case)
A = cross section Area (which we take as $1 m^2$)

$$\text{So resistance of brick} = \frac{\mathbf{0.11}}{\mathbf{1 \times 1}} = 0.11\ m^2\ {}^{o}C\ W^{-1}$$

$$\text{resistance of plaster} = \frac{\mathbf{0.013}}{\mathbf{0.7}} = 0.02\ m^2\ {}^{o}C\ W^{-1}$$

Now effective resistances of air spaces are:-

internal boundary	$0.123\ m^2\ {}^{o}C\ W^{-1}$
external boundary	$0.055\ m^2\ {}^{o}C\ W^{-1}$
air-cavity	$0.18\ m^2\ {}^{o}C\ W^{-1}$

So total resistance

= 0.055 + 0.11 + 0.18 + 0.11 + 0.02 + 0.123

= $\mathbf{0.598\ m^2\ {}^{o}C\ W^{-1}}$

and since $U = \frac{1}{\sum R}$, $\mathbf{U = 1.67\ W\ m^{-2}\ {}^{o}C^{-1}}$

[Note: that the external resistance is relatively small, and thus the U value for walls varies little with exposure normally only a few per cent at most].

Example 2

As example 1 except that the inner brick leaf is replaced by an aerated block wall i.e. construction used from mid-1960's.

conductivity for aerated block = 0.14 $Wm^{-1}\ {}^oC^{-1}$

and resistance of such a block $= \frac{0.11}{0.14} = 0.76\ m^2\ {}^oC\ W^{-1}$

and since this replaces the inner brick of 0.11 $m^2\ {}^oC\ W^{-1}$ of the original wall, the new resistance

$$= 0.598 + 0.76 - 0.11$$

$$= 1.248\ m^2\ {}^oC\ W^{-1}$$

$$\text{so U-value} = \frac{1}{\sum R} = \mathbf{0.80\ Wm^{-2}\ {}^oC^{-1}}$$

i.e. this is half the value of example 1 and represents a 50% saving in the heat lost through the walls of a house.

Example 3

- As example 2 except that cavity is filled with insulation
- As example 2 except that cavity is filled with polystyrene
- conductivity of polystyrene = 0.04 $Wm^{-1}\ {}^oC^{-1}$
- resistance of cavity fill = 0.05 /0.04 = 1.25 $m^2\ {}^oC\ W^{-1}$

and this replaces the resistance of 0.18 from the air-cavity

Thus the new resistance = 1.248 - 0.18 + 1.25

$$= 2.318\ m^2\ {}^oC\ W^{-1}$$

and U-value = $\mathbf{= 0.43\ Wm^{-2}\ {}^oC^{-1}}$

i.e. this is approximately half of the value in example 2 and one quarter of the value in example 1.

[the U-value for a wall with two brick leaves and cavity insulation is 0.60 $Wm^{-2}\ {}^oC^{-1}$. Thus the reduction in heat loss for this latter type of wall when cavity insulation is installed is much more noticeable for the wall in example 2].

11. HEAT LOSS/ GAIN CALCULATIONS

11.1 Introduction

There are five component parts to heat loss/heat gain calculations in a building:

- Losses/gains through the walls
- Losses/gains through the windows
- Losses/gains through the roof
- Losses/gains through the floor
- Ventilation losses/gains

The procedures are essentially the same whether for heating or cooling. Traditionally the term "Heat Loss" is used, but throughout this section "Heat Loss" is also taken to mean "Heat Gain". Some examples of cooling are given later in this section. The losses/gains other than those associated with ventilation are know as the fabric losses. In a poorly insulated building these fabric losses often dominate the total heat loss and it is thus important to tackle these through lofty insulation, cavity insulation, double glazing etc, However, as the insulation level become higher, the fabric losses will only amount to 20-25% of total losses and methods to control ventilation requirements become important.

11.1 U - values

To determine the heat losses/gain for the separate fabric components, the following equation is relevant:

$$\sum \mathbf{Area\ x\ U - value}$$

The total value obtained is the Fabric Heat Loss / Gain Coefficient which used previously to be known as the heat loss/gain Rate. This is the heat loss or gain per unit temperature difference.

This coefficient is an intrinsic factor which will be different for each particular building. The value of this coefficient may be changed by varying the insulation of one or more components.

While there will be typically 4 factors in the summation equation (one for roof, floor, wall, windows etc), more can be used (e.g. if there are walls of different construction, partial double glazing etc).

This fabric heat loss coefficient in units of (W / K) is a measure of the total losses through the fabric for every 1°C temperature difference between inside and out. It is thus a simple matter to estimate the total fabric heat losses by multiplying the fabric heat loss coefficient by the temperature difference.

11.2 Ventilation

Ventilation is treated differently in heat loss calculations. Fresh air is required for healthy living and in a cold climate, sold fresh air must be heated to the required air temperature.

It is convenient to specify the air requirements either in terms of litres per minute or more commonly in terms of an air-change rate (usually per hour). The requirements measure in litres per second, minute or hour are relevant for large buildings with large numbers of people in them – e.g. public buildings, shopping malls etc.

An air change rate of 1.0 means that the whole volume of air within a building is replaced each hour by cold air from outside which then has to be heated.

It is convenient to work in terms of an *equivalent U - value* i.e. to obtain a factor which is dependant on temperature difference.

The specific heat of air is about 1300 J m^{-3} $^{o}C^{-1}$ but varies with pressure and humity

So the total energy required to heat incoming air will be

volume x **air change rate** x **temperature difference** x **specific heat**

This will be energy required per hour, so dividing by 3600 to bring to Watts gives:-

$$\textbf{volume x (air change rate } \mathbf{x} \ \frac{\mathbf{1300}}{\mathbf{3600}} \textbf{) x temp diff.}$$

The quantity in brackets is *equivalent to a U - value.*

The factor 1300/3600 ~ 0.361 using an average value for the specific heat is.

11.3 Heat Loss/Gain Calculations

The total heat loss/gain requirements for a building for each 1°C temperature difference is given by.

$$\mathbf{H = \Sigma Area \ x \ U - Value \ + \ Volume \ x \ ach \ x \ 0.361}$$

H is thus the overall **heat loss coefficient.** A related term is the **heat loss parameter** which is the **heat loss coefficient per unit floor area.** This latter provides a useful approximate way of comparing one building with another irrespective of size or shape.

In a steady state condition, heat lost (gain) must be replaced by heat supplied (removed) by the heating (cooling) system. The sizing of system depends on

- the heat loss / coefficient e
- the design internal temperature
- the design external temperature

it should be noted that for a given building the overall heat loss coefficient should equal the overall heat gain coefficient.

Typically in UK the internal temperature is taken as 20 °C or 21°C for residential properties while external temperature may be varied according to external conditions - e.g. -1°C for UK.

e.g. for a house with a heat loss coefficient H = 250 W $^{o}C^{-1}$ which is a typical value, and a design internal temperature difference of 20 and external temperature of -1°C (i.e. a temperature difference of 21°C), the heating appliance must be able to supply 21 x 250 W = 5250 W.

The heating device must be capable of supplying at least this amount of heat.

An identical procedure is used to determine cooling requirements.

11.4 Notes on Sizing of Heating /Cooling Appliances

Within a building there will be many sources of incidental gain will help to reduce energy demand in a cold climate, but increase the demand in a hot climate. The sizing of the heating/cooling appliances must take into account several factors.

1) Even though incidental gains will reduce energy demand in a cool climate we cannot take these into account as at critical times such incidental gains may not be present. (However we take then into account when evaluating overall consumption.). In a warm climate where cooling is required the cooling demand will be in excess of that required purely for removing heat gain and sizing of appliances must include an allowance to remove heat from incidental gains.

2) Boiler sizes typically come in increments of 3 kW (some makes 6 kW), and size must also be capable of supplying not only space heating requirements but also hot water. The range of sizes for air-conditioners for use in hot climates will be comparable and in both cases the appliances size will be chosen so it it just larger than the predicted heat/cool requirement.

3) If the temperature falls below -1°C (typical UK design or relevant external design temperature elsewhere), heating system will not be capable of coping with heat demand and internal temperature will start to fall. Conversely in a warm climate, if the external temperature exceeds the maximum external design temperature then the system will not be able to cope and the internal temperature will rise slightly.

4) Basic heat loss / heat gain calculations assume a steady state and take no account of heat / cool stored in the fabric of a building. Most moderate – heavy weight buildings have significant heat / cool storage capacities, and this store can help when temperatures initially fall or rise above a set temperature and will help to smooth out temperature variations and also energy demand. .

6) Heat storage lags of 6 - 9 hours or more are not uncommon in houses – i.e. the first cool day after a warm spell will require noticeably less energy for heating than subsequent days even when the mean external temperature outside it the same. More examples or this dynamic effect are shown in section 11.6.

7) Hot water requirements can be significant at certain times of day, so boiler must be able to cope with this demand as well (additional 3 kW).

8) At times of low hot water demand, this additional capacity in a heating system can be used to boost heating supply.

11.5 Annual Consumption of Energy for Heating

Sections 11.3 and 11.4 considered the maximum heat/cool energy demand for a building as this is required to determine the size of the heating/cooling appliance.

It is also apparent that the energy used for space heating and cooling varies according to:

1) the external temperature
2) any incidental gains present
3) the dynamic performance of the building.

To determine overall energy requirements which will be needed in any financial model and also the extent of associated green house gas emissions it is important to evaluate overall annual consumption. There are basically two methods which can be used:

- a detailed way (sometimes known as the Mean Temperature Method). This requires preferably daily or weekly energy consumption together with information of the external temperature over the period. Energy consumption information over on a monthly basis is also possible, but the result is much less accurate. This approach can be time consuming depending on the level of detail

- an approximate method which uses Degree Day information. This formulation using Degree Days is discussed in the next sub-section. This method can give a rapid assessment of annual energy consumption for space heating or cooling from a knowledge of the heat loss coefficient. Energy requirements for other uses such as hot water etc must be added to the space heating / cooling requirements.

11.5.1 The Degree-Days Parameter

The Degree-Days Parameter is a numerical value which accounts for the temperature difference between inside and outside a building and also the duration of that difference. Since the external temperature is constantly changing the Degree-Days Parameter gives a weighted impact of the temperature difference across a given period. Such periods may be a week, month, quarter or year in length, but equally they could be for other special time intervals such as the heating or cooling season. There are separate Degree-Day Parameters for Heating and Cooling although the approach is essentially the same.

In many countries, but not all, Degree Day information is computed on a regular basis for a given region of the country. Thus in the UK Heating Degree-Day (HDD) information for monthly periods going back to 1995 at the following WEB Site.

www.vesma.com/ddd/regular.htm

This WEB site gives free information on a monthly basis for the following 18 regions of the UK and also provides 20 year average data

1) Thames Valley
2) South East
3) South
4) South West
5) Severn Valley
6) Midland
7) West Pennines
8) North West
9) Borders
10) North East
11) East Pennines
12) East Anglia
13) West Scotland
14) East Scotland
15) North East Scotland
16) Wales
17) Northern Ireland
18) North West Scotland.

The web service above also gives a premium service for other time intervals – e.g. weeks

11.5.2. Heating Degree Days – Simple formulation

There are a number of methods for calculating the Degree-Day Parameter from the temperature information. The Degree Day Parameter is always related to a base temperature. Sometimes this base temperature is also know as the balance temperature or the neutral temperature and is the effective temperature at which no heating/cooling is required in a building. This base temperature will be several degree below the thermostat level during the heating level season as incidental gains from body heat, lighting and appliances, cooking ,hot water losses and solar gain will raise the temperature to the thermostat level. The base temperature is commonly taken as 15.5°C and this represents the average for most buildings. In reality the incidental gains in a specific building may be greater or less than average and this variation will thus affect the actual degree-Day Parameter for a building. For a first approximation it is adequate to assume that the building conforms to an average pattern. A more sophisticated approach would account for the actual gains and adjust the Degree-Day parameter accordingly.

The most basic method which gives a good indication of the basic method is as follows:

- For each day when there is a 1°C degree temperature difference between the base temperature (i.e. 15.5°C) and the mean outside temperature of a building we add 1, each day when there is a 2°C degrees temperature difference we add 2 and so on.

  i.e. Each day when there are ***n*** degrees temperature difference diff we add ***n***

- If the mean external temperature equals the base temperature then we add 0 (zero), and we also add 0 (zero) if the mean external temperature is above the base temperature.

- The Degree-Days parameter is them the sum of these daily values over the required period. Thus the 20 year average degree days and last 12 months for East Anglia based on 15.5°C are shown in Table 11.1

Table 11.1 Degree-Days East Anglia (15.5°C)

	Degree Days	
Month	Actual 2009-10	20 year Average
May-09	108	126
Jun-09	69	64
Jul-09	30	32
Aug-09	24	29
Sep-09	55	63
Oct-09	126	145
Nov-09	208	251
Dec-09	381	345
Jan-10	454	349
Feb-10	369	311
Mar-10	284	277
Apr-10	202	204
Annual Total	2310	2196
May-Aug-09	231	251
Sep-Dec-09	770	804
Jan-Apr-10	1309	1141

Despite December 2009 being noticeably colder than average, the degree-days over the four month period September – December were noticeably warmer as the degree-days were less.

Over the 8 month heating season – September 2009 to April 2010 the degree-days were 2079 compared to 1945 in an average year and thus one would expect energy consumption and associated carbon emissions to be 6.9% higher than in the same period in an average year.

11.5.3 Cooling Degree Days – Simple Formulation

The same procedure may be used for determining amount of energy used for cooling except in this case when the mean temperature is below the base cooling temperature zero is added, but if the mean external temperature is above the base value then the difference in temperature is counted. The base temperature for cooling will normally be set at a different level to the heating base temperature. There is less international agreement on this level, but in the UK the level is set as 22°C.

Approximate Formula

For each day work out the mean external temperature and the Degree-Day parameter for that day i.e.

$$\textbf{DegreeDays} = 0.5 * (T_{max} - T_{min}) - T_{neutral}$$
$$\text{if } 0.5 * (T_{max} - T_{min}) > T_{neutral}$$

$$\textbf{Or} = 0$$
$$\text{if } 0.5 * (T_{max} - T_{min}) <= T_{neutral}$$

As with the heating degree days, the values for each day are summed of the number of days in the period of interest – e.g. week, month, quarter etc.

11.5.4 Heating Degree Days – more exact formula

This formula was introduced as in spring and summer, there are many days when the temperature is partly above the balance temperature and partly below it. The consequence is often that a small amount of heating may be required, even though the balance temperature is below the mean daily external temperature.

It is not necessary to be able to replicate this only to appreciate there is a difference. The published degree days usually follow this more accurate approach. The improved method proceeds as follows.

During the Heating Period:

T_{max} - maximum external temperature
T_{min} - minimum external temperature
$T_{neutral}$ - neutral or base temperature.

For each day

If $\mathbf{T}_{neutral} < \mathbf{t}_{min}$

$$\textbf{DegreeDays} = 0$$

If $\mathbf{T}_{neutral} > \mathbf{t}_{max}$

$$\textbf{DegreeDays} = T_{neutral} - 0.5 * (T_{max} + T_{min})$$

If $\mathbf{T}_{neutral} < \mathbf{t}_{max}$

Then if $T_{neutral} > 0.5 * (T_{max} + T_{min})$

$$\textbf{DegreeDays} = 0.5 * (T_{neutral} - T_{min}) - 0.25 * (T_{max} - T_{neutral})$$

Or if $T_{neutral} < 0.5 * (T_{max} + T_{min})$

$$\textbf{DegreeDays} = 0.25 * (T_{neutral} - T_{min})$$

As with the approximate method, the Degree Days are summed over number of days in period = e.g. week, month, quarter, year.

There is a comparable method to determine the Cooling degree Days more accurately.

11.5.4 Degree Day Tables

20-year average heat degree-day tables for the eighteen different regions of the UK are shown in Tables 11.2 and 11.3 for 1979 – 1998 and 1988-2007 respectively It is interesting to note that in only 4incidences were the degree days greater in the latter period – clearly indicating the impact of global warming. The four incidences are February and November in NW Scotland and December in the Severn Valley and the North West. It is also noteworthy that in August in the South East the number of Degree Days is 35% lower in the latter period.

Table 11.2 20-year average heating degree days for the UK 1979 - 1998

		Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
1	Thames Valley	337	303	256	190	111	47	19	22	51	130	234	302
2	South Eastern	356	323	280	217	136	66	32	38	75	155	255	321
3	Southern	342	310	277	221	138	68	37	42	77	150	244	309
4	South Western	289	268	250	198	124	59	24	26	51	116	199	255
5	Severn Valley	320	288	250	190	114	47	18	20	47	128	215	284
6	Midlands	373	333	290	230	152	76	39	43	83	176	269	342
7	West Pennines	360	317	286	219	139	73	35	40	78	165	259	330
8	North Western	370	323	303	239	162	90	47	53	98	183	272	346
9	Borders	363	319	306	258	199	112	58	60	101	182	267	333
10	North Eastern	380	328	298	234	163	83	41	46	87	178	274	346
11	East Pennines	371	327	287	225	152	77	39	41	80	170	267	340
12	East Anglia	374	336	291	228	145	72	36	36	69	157	266	341
13	West Scotland	376	327	311	239	164	92	54	62	111	200	285	358
14	East Scotland	386	332	314	252	189	103	57	63	110	199	289	362
15	NE Scotland	389	336	324	264	197	115	63	70	119	211	294	364
16	Wales	329	303	285	232	159	88	44	43	74	150	230	294
17	Northern Ireland	358	314	298	234	162	88	47	54	98	179	268	329
18	NW Scotland	323	291	313	256	208	129	84	77	118	206	254	328

Table 11.3 20-year average heating degree days for the UK 1988 - 2007

		Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
1	Thames Valley	297	267	231	172	91	38	17	17	43	113	219	295
2	South Eastern	324	293	258	198	116	57	28	28	64	141	246	321
3	Southern	307	278	256	203	118	60	33	34	64	130	229	306
4	South Western	263	245	230	187	109	53	23	21	45	102	187	253
5	Severn Valley	289	258	231	180	97	41	18	17	43	118	210	288
6	Midland	335	298	268	213	129	63	33	33	69	157	256	334
7	West Pennines	325	287	264	206	125	64	34	35	69	150	247	330
8	North Western	336	301	286	226	145	81	45	46	88	170	259	348
9	Borders	328	292	287	240	176	99	55	50	89	164	252	327
10	North Eastern	342	296	279	220	146	76	40	43	80	165	265	345
11	East Pennines	335	293	266	207	131	65	34	32	66	149	256	335
12	East Anglia	337	303	272	212	128	65	33	31	62	143	258	338
13	West Scotland	338	302	291	227	154	85	51	54	96	181	267	347
14	East Scotland	352	309	296	239	175	93	56	56	97	180	274	356
15	N E Scotland	349	315	305	248	183	104	60	61	105	191	275	355
16	Wales	301	275	262	218	142	77	40	35	63	135	216	290
17	N. Ireland	327	294	278	221	147	78	45	47	85	165	251	321
18	N W Scotland	316	295	297	242	189	121	79	72	111	184	256	316

Neutral/Base Temperature in above table taken as 15.5^{o}C.

11.5.5 A worked example using Degree-days

A house has a heat loss coefficient of 450 W m^{-2} $^{o}C^{-1}$. If there are 1100 Degree-Days in a four month winter period, estimate the energy demand for space heating over that period and also the total demand for gas if the efficiency of the gas heating system is 90%.

The energy demand for space heating over the period is

450 * 1100 *86400 **= 42.8 GJ = 11880 kWh**

[the 86400 represents the number of seconds in a day]

Allowing for the efficiency of the heating appliance gives a total gas consumption of:

42.8/0.9 = 47.5 GJ = 13200 kWh

The above estimate assumes that the base temperature in the building is indeed 15.5^{o}C. If information is available relating to incidental gains – e.g. almost all electrical energy consumption apart from that used outside will end up as incidental heat gain. Equally typically each person will emit around 1 GJ per annum of body heat (or around 60W) which will also be useful incidental heat gain. Other gains will come from cooking – much but not all will result in useful incidental gains as will typically 20% of hot water use – through losses from hot water pipes, losses from when hot water is used etc. Finally a significant amount of incidental gain can come from passive solar gain and it is possible to estimate such gain from a knowledge of the area and orientation of each window in the building.

In a house the incidental gains overall might amount to 2000 W. If we assume a value of 2025 W, the we can evaluate the free temperature rise As follows:

Free temperature rise is 2025/450 = 4.5 ^{O}C

If the internal thermostat setting is 20^{o}C then the base temperature will be:

Base temperature = 20 - 4.5 = 15.5 ^{O}C (i.e. the standard value)

If on the other hand, the incidental gains amounted to 2250W, the free temperature rise would be:

20 – 2250/450 = 15^{o}C

and a correction to the degree day parameter must be made. If the period actually covered is the months of January – April = 120 days, then an approximate correction to the Degree-days parameter will be

1100 - (15.5 – 15) * 120 = 1040

And the overall gas consumption will be

450 * 1040 * 8640 / 0.9 = 12480 a reduction of **5.45%.** compared to a house with a standard base temperature of 15.5^{o}C.

It would, at first sight appear that if incidental gains can be increased then there will be savings in space heating requirement. \However, this must be treated with caution. Firstly electrical use for appliances, lighting is a significant factor in the incidental gains and increasing this will (except in electrically heated buildings) lead to a greater amount of energy being consumed because of the relative inefficiency of the power stations. Equally the carbon factors for electricity in the UK are much higher than for gas and this is not an effective policy to promote a low carbon environment.

Enhancing passive solar gain will of course be beneficial and good architectural design can be important. However, unless designs are made carefully, attempts to optimise solar gain in winter and thereby reduce heating demand will be offset by overheating in summer and an increased requirement for cooling.

11.6 Dynamic Heating

11.6.1 Thermal Lag in Buildings

Basic assessments of space heating /cooling requirements are based on steady state conditions. In reality, energy stored in the fabric of a building (either as heat or cool) can be significant and can help to smooth out the demand for energy.

In a cool climate, heat stored in the fabric during the day time will be slowly released after the heating has been switched off at night keeping the building relatively warm in the overnight period.

The consequence of the thermal store in the absence of any heating or cooling is that the peak internal temperature will lag the peak external temperature by a number of hours and conversely the minimum temperature will be after the minimum external temperature. Figure 11.1 shows a simplified response of a building to an sinusoidally varying external temperature variation from a peak of 25°C at midday to a minimum of 15°C at midnight. The peak internal temperature is around 6 hours later in both cases. Furthermore the variation in internal temperature is much less. The greater the size of the thermal store, the greater will be the lag and the less will be the internal variation.

In a lightweight structure the response lag may be a short as 1 hour. For most buildings which are occupied for significant periods each day it makes sense to make use of the storage aspect to optimise performance whether it be in a warm or cool climate. However, aq consequence of this is the surface temperature of the fabric will take some time to adjust to the temperature when heating/cooling is applied and this can affect the perception of thermal comfort. It will be common practice to have the heating/cooling to start a period before the start of the working day to ensure adequate thermal comfort throughout the working day. However, each building will be different and the optimum pre-heat time must be explored through experimentation.

For an office building not used at weekends, the heating/cooling may be at a low level over the weekend period and an increased pre-heating time will be required on a Monday morning to compensate.

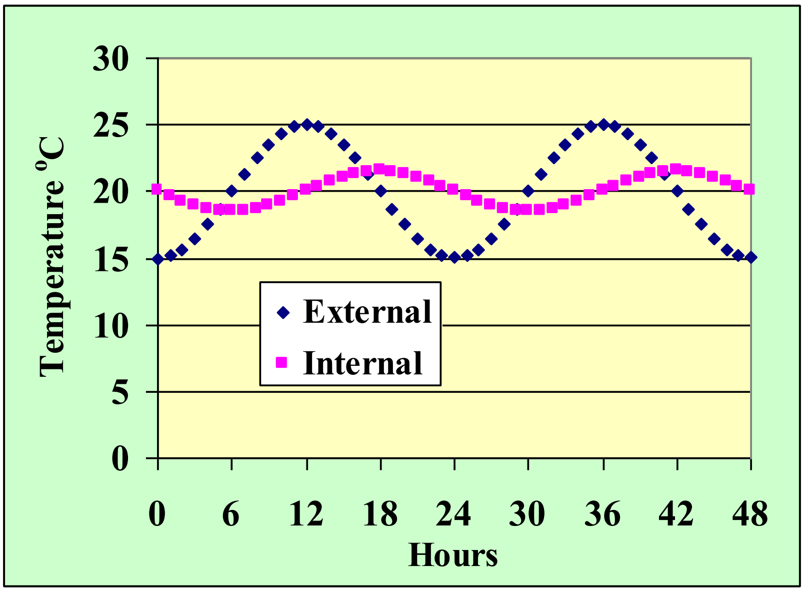


Fig. 11.1 Internal and external temperature variations in an unheated house

11.6.2. Thermal performance in respect of varying external temperature.

- It is possible to estimate the dynamic performance of a building, but the theoretical basis of the methods are beyond the scope of this course. However, it is sufficient to note that in addition to the normal steady state heat losses/ gains, a knowledge of the thermal capacity of the heat store is needed. In an given time period such as an hour, when the heating is switched off, heat will be withdrawn from the thermal mass of the building and it is possible to estimate the reduction in temperature within the building at the end of the given period when the same procedure is repeated for the next time interval. Need to account for heat stored and work out loss/gain of heat from/to heat store during a specific time period (e.g. each hour) as well as the normal calculations.
- In such a dynamic situation, the internal temperature will start to fall once the boiler is turned off. The trend is one of exponential decay. Alternatively if the internal temperature is constant and the boiler is kept on, then the heat output from the boiler will moderate in response of changes in the external temperature (see figure 11.2)
- In a heavy weight house, the heat flows will lag the changes in temperature by many hours - typically up to 6 - 9 house in a typical brick construction. In a lightweight insulated structure of timber, the lag can be a short as 1 hour. As noted in Figure 11.1, the amplitude of the internal temperature is less than the external variations. In a heavy weight building the internal amplitude variation will be quite small but moderately large in a lightweight building.

There is an interesting conflict in that heavy weight buildings will normally have a higher embedded energy, but once built will have a low energy requirement and in any life cycle analysis, the overall performance should be considered. The ZICER building at UEA is such a heavy weight building and despite the higher embedded energy certainly saves energy over its lifespan.

A heavy weight building can be particularly beneficial in a warm climate as it is possible to pre-cool the building overnight. In the ZICER Building, cool night air is circulated through the structure which pre-cools the building by 2 – 3°C and this thermal cool store then absorbs heat from activities within the building during the summer day time thereby obviating the need for air-conditioning.

In warm climates where air-conditioning is definitely required, there is a further benefit from heavy weight buildings in that the air-conditioning can be run over night when

a) The external temperature is a little cooler and thus the coefficient of performance will be higher (see section 5.5 in the 1st handout for the course).
b) The electricity tariffs will usually be less therefore resulting in financial savings,
c) The carbon emission factors for overnight and weeked generation of electricity are frequently lower as the less efficient high carbon emitting sources of generation are used les at such times (see Fig 13.1).

Such overnight operation can thus result in significant reductions in CO_2 emissions compared to normal operation in the middle of the day.

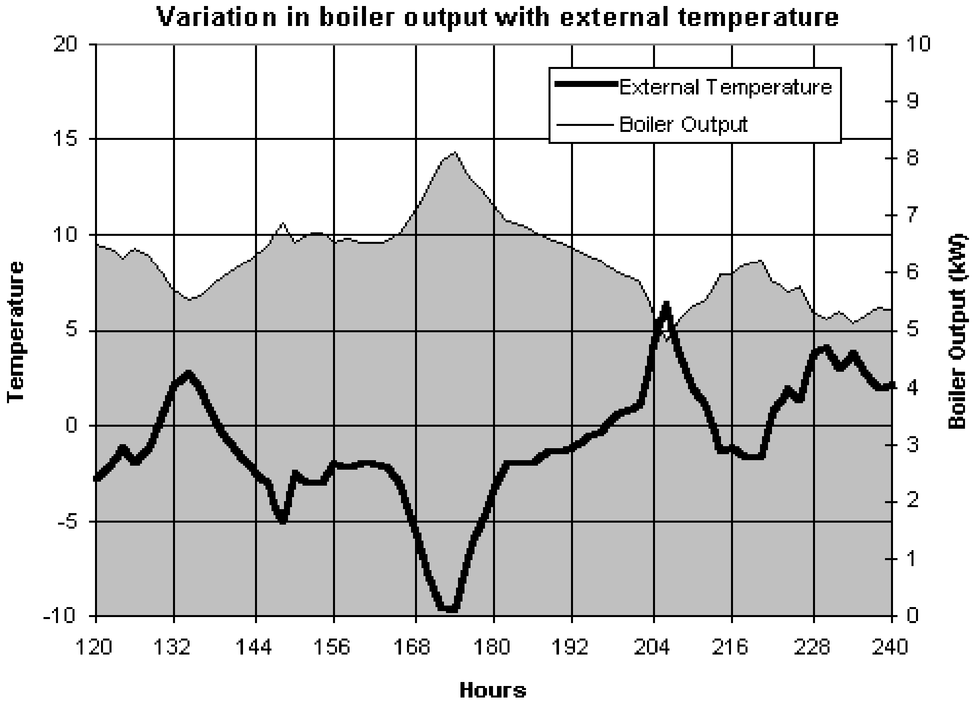


Fig. 11.2 Variation in Boiler Output with external temperature for a house. The thermostat temperature is 20°C. The climatic data refer to the period 5th - 10th January 1985 in Norwich which recorded the coldest overnight Temperature in the last 30 years.

In a cool climate in winter, the temperature will always be below the thermostat setting and the boiler will cut in to supply heat as required. Fig. 11.2 shows the situation for a non-time switched case for a house in Norwich in a particularly cold spell in January 1985. It is noticed that the boiler output peaks when the temperature is at its lowest and is at a minimum when the temperature is a maximum. Note though, because of the storage of the building the amplitude of variation in the boiler output is once again much less than the temperature variation. The temperature ranges from +7°C to -10°C, a range of 17°C compared to a range from 5 – 8 kW in the case of boiler output.

The shaded area beneath the boiler curve represents the total energy consumed during the period. If the outside temperature had been constant at 0°C, the output of the boiler would have been constant at around 5.9 kW through out.

11.6.3. Example of internal temperature variations with a constant external temperature but with time switching.

Figure 11.3 shows the internal temperature variations when the boiler is time switched so that it is on between 07:00 and 11:00 and again between 17:00 and 24:00, but off at other times.

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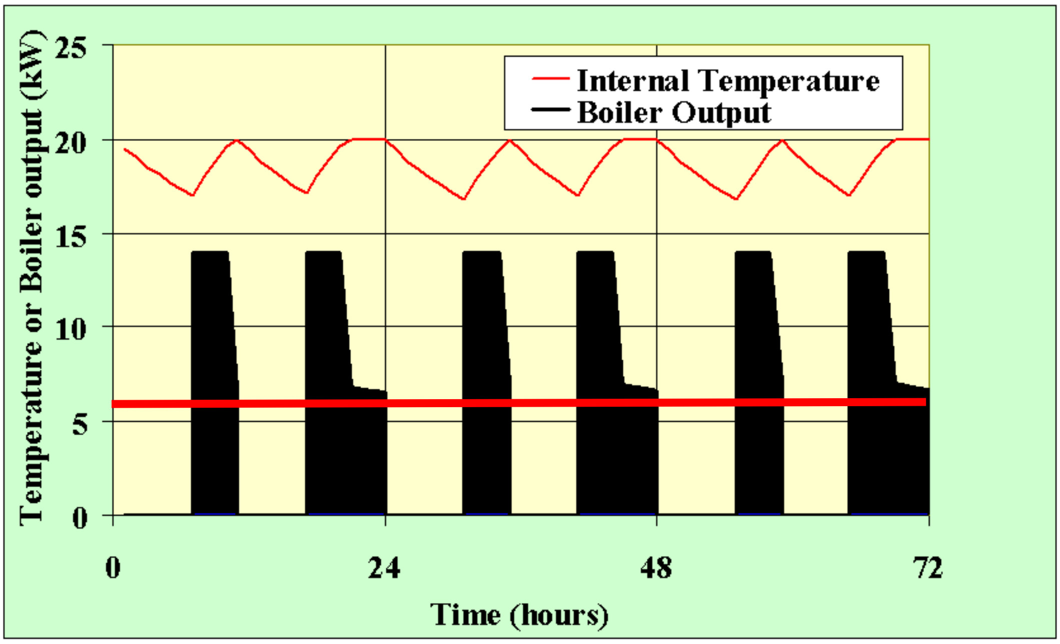

Fig. 11.3 Effect of time switching - constant external temperature. on periods 07:00 - 11:00 and 17:00 - 24:00.

Figure 11.3 shows the performance of the house with a 14kW boiler even though the steady state calculations indicate that a 5.9kW boiler would be sufficient. The issue is that overnight heat will be withdrawn from the thermal store and extra capacity will be required to bring the temperature up again in the morning.

Overnight the temperature falls exponentially from 20^{o}C at midnight to around 17^{o}C when the boiler switches on again at 7am. The boiler operates under full power as the temperature rises - eventually reaching the thermostat level shortly before it cuts out in the late morning.

During the middle of the day when the boiler is off, the temperature falls again and at 17:00, the boiler once again operates under full output until the temperature reaches the thermostat level at 20^{o}C after about four hours after which the boiler throttles back as the thermostat level is reached and the boiler output continues to fall with time as the heat storage of the house is replenished. The solid line show the situation had the boiler been on constantly - with an output of 5.9 kW. Thus even at the end of the day, the boiler output in the time-switched mode is still significantly above the steady state level.

A consequence of time switching is thus to require a larger boiler. If an even larger boiler than the 154 kW shown had been used then the temperature would have risen more quickly to the thermostat level both in the morning and evening and its output would have also declined earlier in the evening.

If the boiler had been on constantly, then the total energy consumed could be estimated from the total area beneath the solid line. With time switching the total energy requirement is as shown shaded, and in this case represents a saving of just over 13%. even though the heating was on for only 11 hours in the period of 24 not the 13/24 = 54% that might be expected because of the ratio of the time that the boiler is on to the time that it is off. With a larger boiler, the saving would have been less because the temperature reaches thermostat level more quickly and the mean internal temperature is effectively higher.

The key thing to remember about saving with time switching is that the energy required is directly proportional to the mean internal temperature, If this is kept higher – i.e. with a larger boiler or better insulation, then the saving will be proportionally less. Obviously one consequence of too small a boiler is the fact that the temperature may never quite make thermostat level and will continue to decline with time. This is illustrated in Fig. 11.4. Though the temperature rises slightly each time the boiler comes on it never actually reaches the thermostat level, and consequently each day the temperature will fall progressives until a mean temperature of around 12.5^{o}C is reached. In this example there is a theoretical energy saving of 50%, but this is meaningless as the temperature never reaches the desired comfort level.

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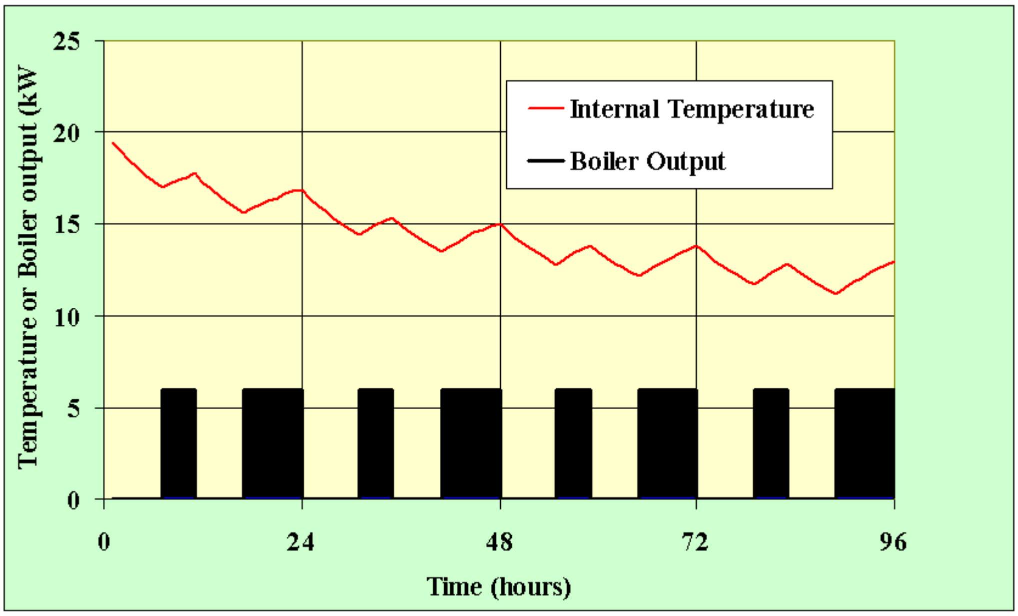


Fig. 11.4 Effect of time switching with an under-sized boiler.

While the above graphs illustrate the situation with "idealised" boilers, i.e. the boilers throttle back in output once the thermostat temperature is reached, this is not how many domestic boiler work. Large industrial boilers, e.g. the UEA boilers have some scope in reducing output to a certain level, but many domestic boilers are either on or off. Some of the latest designs do have modulating output facilities. In many cases, the actual mode of operation of a domestic boiler is to see it firing continuously for a period when it first comes on. Then when it reaches temperature it will cut out - perhaps for just a minute or so, and then cut back in again. As the internal temperature solely rises, the on period to off period decreases so that even on a cold winters day, the boiler will be on for perhaps 50% - 60% of the time. The longer the boiler has been switched on in any one period the shorter will be the on periods, and the longer the off periods. If the output of the boiler during this oscillating phases is average from the zero output in off periods and rated output during the on periods, then the computed result will be as indicated in the graphs such as 11.3 and 11.4.

A further complication during actual operation arises from the fact there is no single thermostat level. A setting of 20^{o}C implies a range of temperatures which may in reality be 19^{o}C to 21^{o}C. When the boiler reaches the upper thermostat level it will cut out and the temperature will slowly drop until it falls below the lower set point at which time the boiler will cut back in again

As a result the actual temperature profile will show a slight saw tooth form even in the apparently flat sections of the curve in the late evening shown in Figure 11.3.

Because of the thermal lag in buildings as shown in Figure 11.1, the actual energy supplied by the boiler will reflect the external temperature some hours before hand. If the external temperature rises rapidly, the control on the boiler will not be aware of this and will continue to pump out heat relevant to the temperature a few hours beforehand, and this is potentially wasteful. The most sophisticated controls provide for a boiler energy manager which monitors outside temperature as well as inside, and will prematurely throttle back the boiler in such cases. Equally, it will temporarily increase the water flow temperature when the external temperature falls to ensure the boiler is working at its optimum efficiency for as long as possible, and avoid unnecessary cycling of the thermostat.

Few domestic properties has such systems installed, although they are common in commercial and industrial premises. Indeed the installers of central heating systems have little experience of them - and are prone to install them incorrectly – experience by N.K. Tovey.

11.7 Two Examples: Energy Conservation

This section explores two examples of energy conservation and indicate how the potential energy and carbon savings can be predicted. Both examples explore the use of heat pumps – the first to provide cooling in a hot climate and the second to provide heating in a cool climate. Similar approaches can be used to explore the benefits of other energy conservation measures.

11.7.1. Example 1: Energy Conservation in a large commercial building in a hot climate.

A large hotel in a tropical climate has a window are of 12 000 sq m which is single glazed. It is air conditioned using a heat pump with an average coefficient of performance of 2.5. What would be the saving in energy and carbon if double glazing were installed which reduced the U-value of the windows from

5.0 W m^{-1} ^{o}C^{-1} to 2.5 W m^{-1} ^{o}C^{-1}.

Data for initial electricity consumption are shown in Table1 , while the cooling Degree-Days in the area are 3000.

Table 1. Electricity Consumption Data.

Mean daily external temperature (^{o}C)	Mean Electricity Consumption (kW)
10	320
15	319
20	320
25	695
30	1070
35	1445
40	1820

Figure 11.5 shows a plot of electricity consumption against mean external temperature. There are two distinct trends. One trend covers temperature below 20^{o}C covering the winter period during which time no cooling is required. This energy consumption represents the functional energy use within the building, i.e. that use not associated with cooling. The second trend relates to temperatures above 20^{o}C when cooling is required and the gradient of the line is related to the heat gain rate in the building. The gradient of this line reflects the actual electricity consumption for cooling but this will include the performance of the heat pump through its coefficient of performance.

Thus the gradient of the lines is 75kW^{o}C^{-1} but as the coefficient of performance of the heat pump is 2.5 this will reflect a heat gain coefficient of 75 * 2.5 = 225 kW ^{o}C^{-1}.

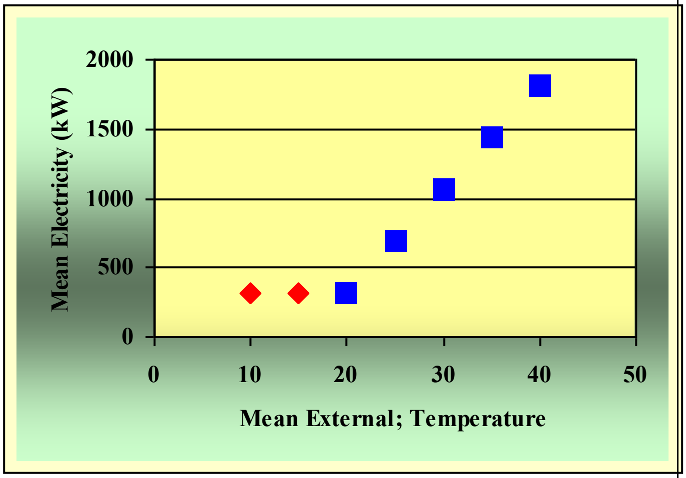


Fig. 11.5 Electricity consumption

1) What is the electrical energy required in cooling?
2) What would be the carbon emissions if the carbon factor is 800 kg / MWh?

Actual Electrical Energy Consumed

= 75 * 3000 * 24 = 5400000 kWh **= 5400 MWh**

The carbon emission will be 5400 * 800/ 1000 **= 4320 tonnes**

3) Saving in heat gain coefficient from double glazing

$$= \underbrace{12\,000}_{\text{Area}} * \underbrace{(5-2.5)}_{\text{change in U-value}} = \mathbf{30\ kW\ ^{o}C^{-1}}$$

However, this does not take account of COP of heat pump
So actual electrical saving will be **30 / 2.5 = 12 kW^{o}C^{-1}**

Saving in electricity consumed
= 12 * 3000 * 24 = 864 MWH

Saving in carbon = 864 * 800 = **691.2 tonnes**

11.7.2. Example 2: Energy Conservation in a house in a cool climate.

In this example the competing aspects of using a heat pump or oil boiler are explored.

A new house is designed to have a heat loss rate of 100 W ^{o}C^{-1} and a base temperature of 15.5^{o}C. The householder is considering whether to use a heating system based on an oil condensing boiler (efficiency 90%), or a heat pump, the performance of which is shown in the following Table 2.

Table 2. Coefficient of Performance of Heat Pump

External Temperature (^{o}C)	Coefficient of Performance
0	1.7
4	2.5
8	3.3
12	3.88
16	4.2

The mean external temperature is as shown in Table 3.

Table 3. Mean External Temperature at location of Building

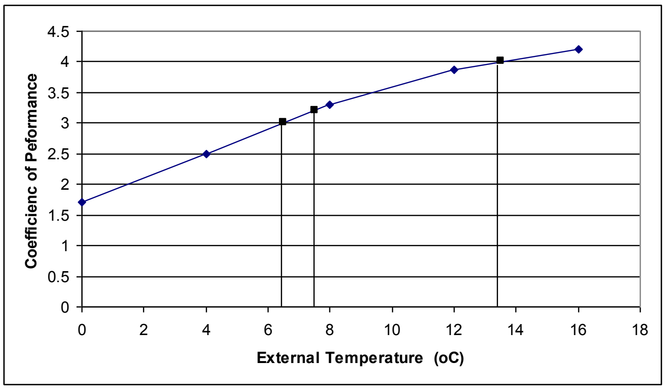
Months	Mean Temperature (°C)
January - March	6.5
April - June	12.5
July - September	16
October - December	8

If the oil boiler cost £2000 and the heat pump costs £4000 after relevant grants, which system would you recommend the householder should choose assuming a discount rate of 5%.

Calorific Value of oil	37 MJ/litre
Cost of oil	45 per litre
Cost of electricity average of day/night tariffs	4.5 p per kWh

Solution:

First plot the COP against mean temperature



The solution is best done in tabular form as illustrated by Table 4. As the balance temperature is 15.5 °C no heating will be required in period July – September. However read of COPs from graphs for mean temperatures in other quarters.

Table 4. Solution to Example 2

	External Temperature (°C)	COP from graph	Number of days	Difference from balance temperature	Heat Requirement (kWh)	Heat Requirement after allowing for COP (kWh)
(1)	(2)	(3)	(4)	(5)	(6)	(7)
Jan - Mar	6.5	3	90	9	3888	1296
Apr - Jun	12.5	4	91	3	1310.4	327.6
Jul - Sept	16	4.2	92			
Oct - Dec	8	3.2	92	7.5	3312	1035
Total energy requirement					8510.4	
Boiler efficiency					90%	
Energy input boiler option					9456	
Total effective input via heat pump						2658.6

Notes on figures in table 4.

Col (2) from Table 2

Col (3) from graph

Col (4) number of days in period – i.e Jan (31) Feb (28) Mar (31) = 90 days

Col (5) balance temperature is 15.5, so col(5) = 15.5 – col(2)

Col (6) heat loss rate (0.1 kW °C^{-1}) * col (5) * col (4) * 24 (hours in a day)

Col (7) col(6)/col(3)

From above table input energy for oil = 9456 kWh = 17020.8 MJ (remember 1 kWh = 3.6 MJ)

But calorific value of oil is 37 MJ/litre – so number of litres required = 17020.8/37 = 920 litres

Annual running costs with oil = 920* 45 = £414
Annual running costs of heat pump
= 2658.5 * 4.5/100 = £119.64

Annual saving in running costs = £414 - £119.64 = £294.36

From discount tables the cumulative discount factor is 8.721735

So the discounted savings over life of project

= 8.721735 * 294.36 = **£2567.36**

As this is greater than the capital cost difference of £2000 (i.e (£4000 - £2000), there will be a net saving of £567.36 over the project life and the heat pump scheme is the more attractive financially.

12. ENERGY MANAGEMENT

12.1. Introduction

Good Energy Management is the key to Energy Efficiency and Energy Conservation. Effective energy management can result in significant savings in energy, carbon emissions, and money with little need for expensive capital investment. All too frequently energy conservation strategies are directed towards technical solutions when energy management solutions can frequently be much more cost efficient.

An effective Energy Manager should:-

- **ASSESS** the energy demand by good record keeping.
- **ANALYSE** the recorded data by normalising such information to standard time periods (e.g. an exact month, week or day even if the readings were not taken at precisely the same time of the day, week or month. At the same time the manager should explore trends in energy use not only with time but also physical factors such as weather
- **ADVISE** on technical and management improvements
- **ADVERTISE** ways to save energy
- **ACCOUNT** for energy consumption by regular reporting.

12.2 ASSESSING ENERGY DEMAND

There are several parameters which must be recorded for effective analysis:

- meter readings for gas and electricity
- time the readings were taken
- the mean temperature over the preceding period of measurement
- other factors affecting demand

  e.g.

  weekday/weekend if daily records are kept

  special events e.g. over major public holidays such as Christmas – Chinese New Year in Asia countries etc.

Frequency of readings:-

The frequency that meter readings are taken is important:

- every quarter is usually too long
- every month is often too long
- every week is a useful frequency
- every day can be helpful (as long as difference between
- weekend and weekday is recognised - if relevant)

If readings are not a exactly the same time each day, week, month or quarter, then scale readings to standard interval before subsequent analysis. Thus if daily readings are taken and the meter readings are taken at 18:30 on the first day and 19:00 on the second day, the time interval is 24.5 hours. Therefore the energy consumption as denoted by the difference in the two meter readings should be scaled by the factor 24/24.5 to give a normalised value for interpretation and subsequent analysis.

The same effect will be relevant for weekly or monthly readings. In the former, for instance if readings are taken each Monday, then there will be extended periods when a particular Monday is a Public Holiday and the reading is taken on the following day

For vehicles record can be kept of the number of litres of full added and this is common practice for many fleet operators – e.g. local councils, bus companies etc.

For oil use for space heating, a problem arises in that deliveries are intermittent and usually for standard amounts – e.g. increments of say 500 litres. The problem with this is that it then becomes difficult to investigate trends with factors such as external temperature. If there is a rectangular tank then the sight glass can be measured to estimate use, but many modern oil storage tank have irregular shapes making accurate estimation difficult.

12.3 ANALYSING ENERGY RECORDS

While records are often kept objective analysis of energy consumption is frequently not done even though it is a important step in energy management..

Such analysis should not merely look at trends with time, but compare information objectively with key physical factors. Thus it is important to identify how much extra the energy consumption is in a particularly cold month. Is for instance the level of the increase energy consumption in a cold month greater or less than expected. Thus in East Anglia, January 2010 recorded 454 Degree-Days compared to an average of 349. This means that the energy consumption for space heating should 30.1% higher than normal .for this month. If the increase in consumption was greater than this amount then it might reflect a possible malfunction in equipment. Equally if was less than expected the possible reasons should be explored as this might give an insight as to how improvements in energy performance might be made in the future.

For space heating ideally the following variables should be considered:

- external temperature
- wind speed
- humidity
- solar gain

Of these by far the most dominant is the external temperature typically explaining 80 – 90% of the variation in consumption with other factors generally being of less significance. Records are kept of degree-days but those of humidity, wind speed as less well recorded and in any case are difficult to incorporate in any straight forward analysis. For a centrally heated building wind speed, humidity, and solar gain are all minor effects as far as heating goes and rarely contribute more than 10% of variation in total. External temperature variation is the dominant effect.

For lighting requires knowledge of the number of hours of darkness is a significant factor, but rarely if ever is such a factor incorporated into analysis of energy demand in buildings.

12.3.1 Analysis of space heating requirements:-

There a two convenient methods for analysing space heating:

- The Degree day Method - quicker method
- The Mean temperature method - more accurate method

The former methods requires relevant Degree-Day information to be kept which is not always the case (e.g. in China).

12.3.2 Degree Day Method – Case 1

This first example explores the analysis of energy requirements in buildings NOT heated with electricity (e.g. gas, oil, coal).

Using oil or coal makes analysis difficult as only general estimates of consumption can be made over a relatively long period of time - based on the frequency of delivery or approximate reading of dipstick in oil tank.

A plot of energy consumption against mean external temperature is shown in Figure 12.1. It is a common misunderstanding to assume that one can fit the data to the best trend line (shown dashed) as this masks two very different uses of energy. There two component parts to the consumption are:.

1) A temperature related part
2) A part which is largely independent of temperature which is the base load requirement for hot water and cooking if by gas.

Let W be amount needed for hot water, and cooking if by gas and let H be the heat loss rate for the house.

then total energy consumed over a period (E)

$$E = W + H \times DegreeDays \times 86400 \quad ....(12.1)$$

W will be approximately constant throughout the year and can be determined from the average consumption value when the nearly constant consumption level is reached.

We have two unknowns:- W and H, so if we know number of Degree-days in two successive time periods and and also the energy consumption we can estimate both the heat loss rate and the steady energy requirement.. Ideally the number of degree days in the two time periods should be very different to ensure accurate estimation of H and W. Ideally if data are available for several time periods then statistical methods may be used to determine the most likely values of H and W.

12.3.3 Example - Degree Day Method (Non-electric heating)

In two successive quarters the consumption is 31.76 GJ and 18.80 GJ while the corresponding Degree Days are 1100 and 500 respectively. What is the heat loss coefficient and the steady continuous energy requirement?

Substituting the relevant values into equation 12.1

$$1100 \times H \times 86400 + W = 31.76 \quad ....(12.2)$$

$$500 \times H \times 86400 + W = 18.80 \quad ....(12.3)$$

These two simultaneous equations may be solved in normal ways to obtain values for t H and W

In this case subtract equation 2 from equation 1

i.e. $$H = \frac{(31.76 - 18.80)}{(1100 - 500)} \times 10^9 = 250 \text{ Watts}$$

Thus if in a third quarter the degree-days parameter is 400, then we would predict consumption to be

$$400 \times 250 \times 86400 + 8 \times 10^9 = 16.64 \text{ GJ}$$

If actual consumption is 17.5 GJ we can see that organisation has been wasting energy in this last quarter (i.e. 17.5 - 16.64 GJ)

12.3.4 Mean Temperature Method - (Non-electric heating)

In this method we plot the mean consumption over a specified period against mean external temperature.

Normally we will be dealing with periods of 1 week or 1 day (i.e. much shorter than Degree Day Method) and thus give more rapid indication if things are deviating from norm. However, it is also possible to use the approach for monthly data

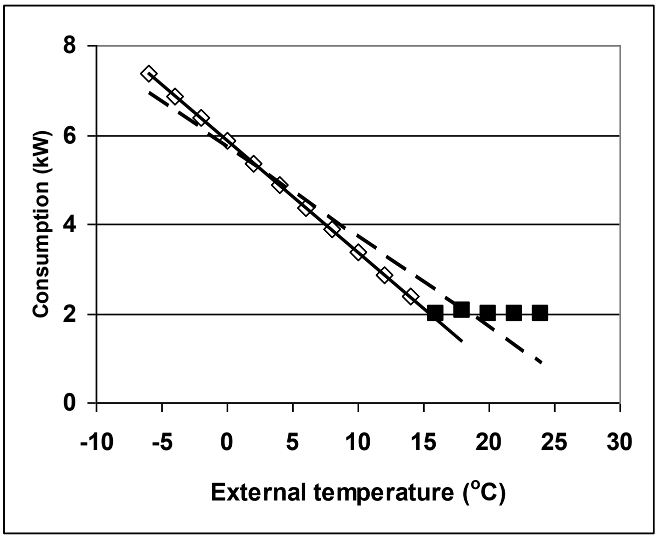


Fig. 12.1 Energy Consumption against mean external temperature

NOTE: There are two sections to graph

- DO NOT simply do a regression analysis on all data - split into two parts.
- The kink in line corresponds to the base/balance temperature.

12.3.5 Analysis of Lighting in a Non-Electrically Heated Building

Lighting varies throughout the year with hours of darkness.
To make sense of the data we need to assess a realistic time for lighting.

If for example, a family goes to bed around midnight, it is easy to assess the number of lighting hours in a particular day by subtracting lighting up time from midnight (assuming no lighting requirement in the morning).

A typical plot is shown below.

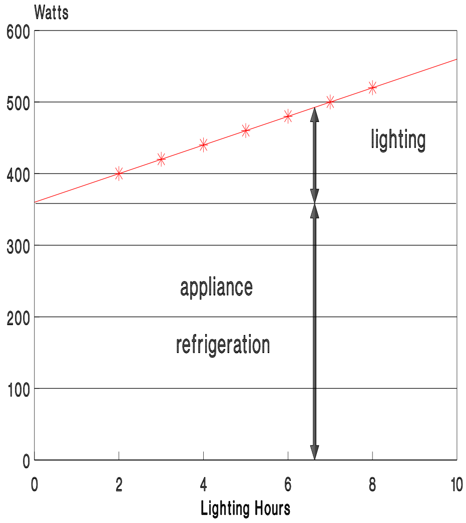


Fig. 12.2 Electricity Consumption against lighting hours

There is constant load (A) arising from appliance and refrigeration use, and an increasing amount from lighting. If we were to fit low energy lighting, then we would expect to see the gradient of the line decrease, whereas if we were to replace say refrigerators or computers with more efficient models, we would see a decrease in the intercept.

As with heating it is important to normalise the data before and after readings to take account of changes in the daylight hours.

12.4 Cumulative Deviation Method

This method combines the predictions obtained by one of the methods described in 12.3. to show the cumulative savings over time.

First evaluate the deviation from **ORIGINAL** consumption line for each time period.

1) If no energy conservation ,measures have been implemented, then graph should remain horizontal.

2) Period (2) - Winter following improved insulation

3) Period (3) - Summer - graph is horizontal as conservation measure only affected heating.

4) Period (4) – Winter energy - line is parallel to period (2)

5) Period (5) - Improved management of hot water produces savings in summer month

6) Period (6) - Expected gradient would be sum of gradient in period (4) + that in period (5). Gradient is less suggesting that energy conservation performance is slacking.

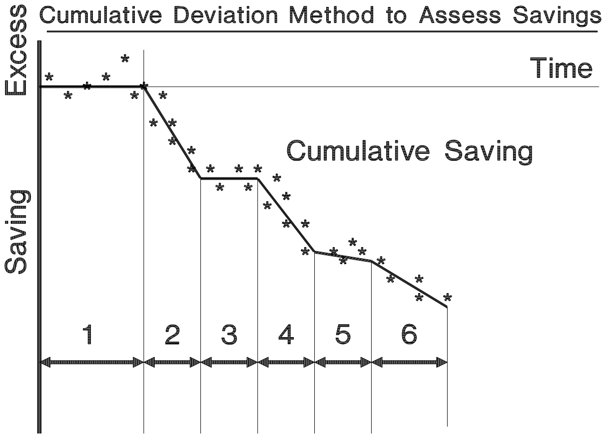


Fig. 12.3 Cumulative Deviation method to Assess Savings.

12.5 ADVISE ON ENERGY MANAGEMENT

Most firms are more interested in saving money than saving energy. Thus performance of Energy Manager will usually be judged not on how much energy saved, but how much money.

Similar graphs to above could be drawn in monetary terms, but problems arise with changes in fuel prices. With the exception of very recent trends in the last three years, changes in fuel prices have seen them reduce in real terms making strategies to justify energy conservation less attractive.

With the increasing interest in carbon emissions, this adds a further dimension and perhaps any proposed project should be considered primarily in terms of energy and carbon savings and separately in monetary terms. Remember that in future years carbon will have a price for businesses and if savings are shown as aggregated monetary savings it is difficult to explore trends in an era of fluctuating energy and carbon prices.

However, recommendations as to strategies will normally be related to cost of fuel. Thus though UEA uses much less electricity than gas, it is the electricity price which is greatest, and so the University will be more interested in measures to save electricity than gas even though latter may result in larger energy savings.

Recommendations will fall into four categories:-

1. Technical
  a) insulation, draft exclusion, (thermostatic radiator valves (TRVs), heating control etc.
  b) low energy lighting, efficient refrigeration etc.
  c) power factor correction
  d) relocation of switches, PIR/movement sensing etc

2. Energy Management
  a) checking performance
  b) record keeping
  c) analysis of energy trends

3. Financial:-

Various strategies can be employed to encourage energy savings. Thus some organisations are making sub-sections accountable for their own energy budget - with additional carrots for those who save energy above agreed targets.

4. Other Factors

Changing patterns of working/ working practices/and time of working can affect energy use and carbon emissions. (See also Figure 13.1).

12.6 ADVERTISE WAYS TO SAVE ENERGY

- Rarely are savings predicted from technical solutions to energy conservation realised.
- New technology often requires a change in attitude by the user. In other cases, user should be educated into correct use.
- Advertising Campaigns should encourage users to save energy - closing doors, switching off lights computers etc. However, such campaigns are only effective for a few months. New slogans or a change in emphasis is required.

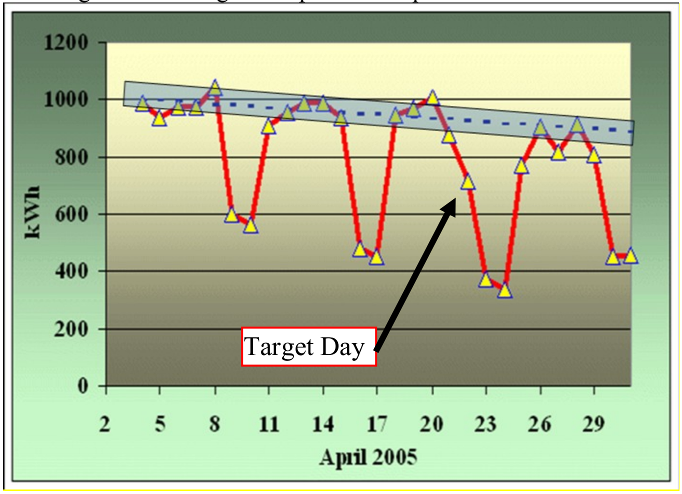


Fig. 12.4 Energy Awareness campaign at UEA.

In April 2005, UEA targeted one building for a special awareness campaign – the Registry. Dail electricity readings are shown in Fig. 12.4 with noticeable reductions at weekends and also a steadily declining consumption as less light was required as summer approached. A particular target day was selected - Friday 22nd. There is noticeable reduction approaching 25% on that day when several energy monitors challenged everyone to do their bit. However, once the intense campaign was over things slipped back towards normal consumption.

12.7 ACCOUNT FOR ENERGY USE

An Energy Manager should account for the energy use in a firm and analyse improvements using a technique as described in section 8.3.

It is essential that allowance is made for key variables and the effectiveness of awareness/advertising campaigns must be constantly appraised. This can only be done once the predicted technical performance changes have be made.

12.8 EXAMPLE of ENERGY MANAGEMENT in Large Commercial Buildings

Example 1:

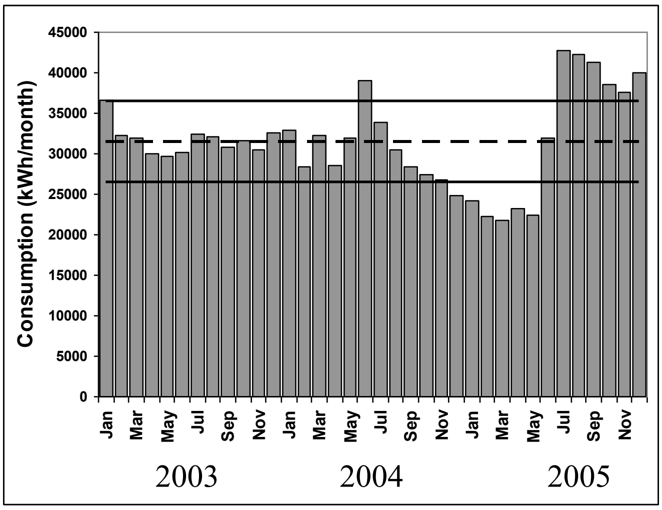


Fig 12.5 Actual electricity consumption in a large office building in the UK.

Monthly data for electricity consumption are shown in Figure 12.5. The dashed lien indicates the mean consumption between Jan 2003 and May 2004 at which time energy management strategies were adopted in incorporate low energy lighting. The solid lines represent the upper and lower limits of 1.5 standard deviations above and below the mean, selected as being indicative for good energy management – see section 12.9. Following the installation of low energy lighting progressively over 4 months the consumption fell by around one sixth by May 2005. However, following this improvement the consumption shot up and remained above the original level until an independent consultant identified the problem which was traced to a malfunction of the air-conditioning system. The cost to repair the fault was around £1000, but the extra cost in energy bills which occurred before the fault was identified amounted to nearly £12000. This demonstrates the importance of good energy management, not only to achieve the best performance, but also to give early warning of potential faults.

Example 2:

Electricity consumption data for two large multi-storey building in Shanghai are shown in Table 12.1 and Figures 12.6 and 12.7. Both buildings are heated and cooled by heat pumps.

Table 12.1 Electricity consumption data for two large buildings in Shanghai,

	Building 1 (2006)		Building 2 (2007)	
	Temperature (^oC)	MWh	Temperature (^oC)	MWh
Jan	6.5	611	5.9	811
Feb	6.1	216	9.8	416
Mar	11.6	433	12.1	633
April	17.0	228	15.9	428
May	21.3	405	22.9	605
June	25.9	543	25.0	743
July	29.8	935	30.4	1135
Aug	30.4	832	29.7	1032
Sep	24.2	614	25.4	814
Oct	22.3	302	20.6	502
Nov	15.9	292	14.2	492
Dec	8.6	592	9.8	792

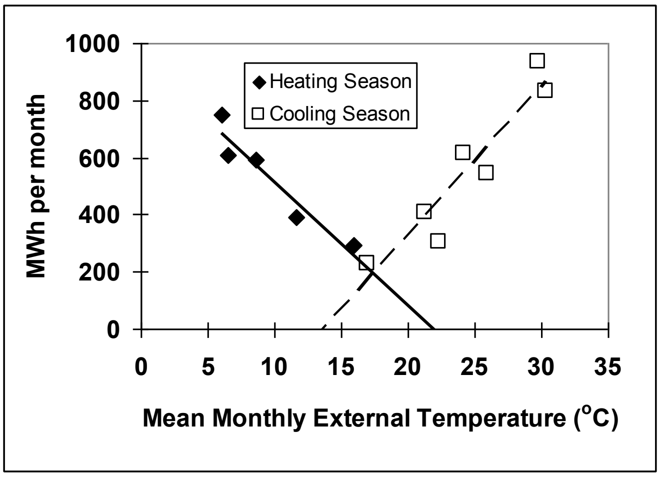


Figure 12.6 Electricity consumption data a 24 storey largely residential building in Shanghai.

It should be noted that the fact that the data are for different years is of little consequence as the gradient of the cooling and heating lines should be the same each year.

As a first approximation we may assume that all months have 30 days or 720 hours in them. The gradients of the heating lines in the two buildings 43.0 and 54.5 MWh per month per degree Celcius. These are equivalent to 59.8 kW $^oC^{-1}$ and 75.7 kW $^oC^{-1}$ respectively.

Remember to convert from MWH per month to kW (assuming 720 hours in the month, it is merely 43.0/720*1000 in the first case.

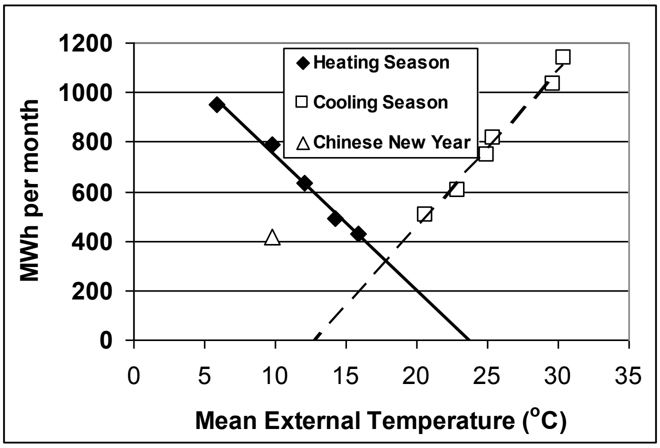


Figure 12.7. Electricity consumption data in a large commercial building in Shanghai. Noteworthy is the reduced demand in the month covering the Chinese New Year Holiday

In a similar manner the gradients of the cooling lines may be estimated as 72.2 kW ^{o}C^{-1} and 87.5 kW ^{o}C^{-1} respectively.

In building 1 the monthly baseline consumption indicated by the intersection of the heating and cooling lines is 192 MWh per month while in building 2 it is 313 MWh per month.

Any conservation strategies to improve the thermal performance of a building will not affect the baseline consumption and conversely any attempt at reducing baseline consumption will **NOT** affect the gradient of the heating and or cooling lines, but will merely see a downward shift in the baseline consumption.

Table 12.2 Component parts of electricity consumption

Nature of Electricity Consumption	Building 1 (MWh per annum)	Building 2 (MWh per annum)
Heating	1675	1832
Cooling	2515	2951
Baseline Electricity Requirement	2304	3760
Total Electricity Requirement	6494	8543
Baseline consumption as proportion of total	35.5%	44.0%

Note in this building 2, the base load electricity requirements from building services, lighting, and appliances are a dominant part of overall consumption. In such a building it is thus more important to tackle improvements in appliance and building service efficiency rather than the thermal performance of the building itself. However, this will not always be the case.

If for instance in building 2, the lighting demand is measured as 1500 MWh per annum and a decision is taken to replace all the lighting fittings with low energy bulbs which consume only 20% of the original light, what will be the predicted impact on electricity consumption in that building.? The saving in electricity consumption will be predicted as 80% of 1500 or 1200 MWh, while the total electricity consumption prior to installation was 8543 MWh, and the percentage saving in electricity consumption will be 1200/8543 or 14%. The revised plot of electricity consumption against external temperature is shown in Figure 12.8.

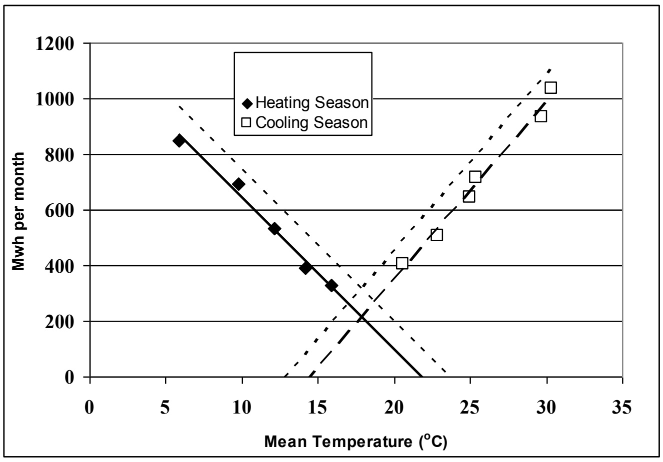


Figure 12.8 Estimated consumption performance of building 2 after installation of low energy lighting measures. Note the dotted lines are identical with the solid ones in Figure 12.7. The effects of this measure has been to move the trend lines downwards by 100 MWh per month.

General Summary Comments on Examples

The trends in energy consumption in the buildings may be summarised in the following schematic diagram (Figure 12.9):

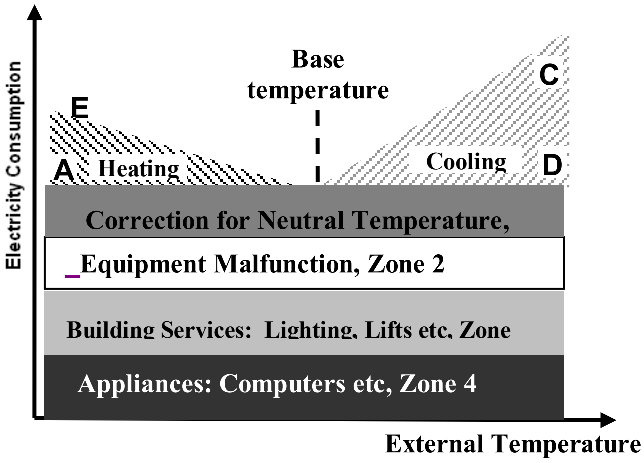


Figure 12.9 schematic representation of component parts of electricity consumption. The correction for neutral temperature will also reflect the actual thermostat setting within the building.

Frequently the base line consumption will in fact be a combination of several different aspects. Often separate monitoring will not be present to identify such difference. However, if it is then it should be possible to separate the energy consumption from what might be communal area base load – i.e. lifts lighting in communal areas from specific energy use in dedicated areas which would also include appliances such as computers etc.

There are two other areas within the base load part of the plot namely "correction for Neutral Temperature" and "Equipment Malfunction". The former will arise from additional energy consumption if the thermostat level is set above (or below) the normal average level causing the effective base temperature to be different from that taken as standard – see section 11.5.1. Equally if the incidental gains are higher than normal then this will be manifest also as a higher demand in this area. If the base temperature after allowing for the correction of incidental gains is lower than standard then this zone may have a negative thickness.

The zone representing equipment malfunction refers to the situation where there is a malfunction in equipment possibly arising from both air-conditioning and heating being on simultaneously e.g. Figure 12.5.

12.9 Effective Energy Management

Understanding the nature of graphs such as figures 12.6 – 12.9 is important in the understanding of effective energy management. Thus there will inevitably be some scatter in the data around the trend lines, but if there is effective management then this scatter will be small. It will be larger if the energy management is control is poor. This may arise from the poor positioning or the use of ineffective technical controls. Equally it may arise from widely fluctuating behaviour patterns. Measuring the degree of scatter around the trend lines provides a means to assess management performance.

In figure 12.5 lines were drawn at 1.5 standard deviations above and below the mean consumption level for electricity. In this building heating was provided by gas and thus all the electricity use was functional. The choice of 1.5 standard deviations was selected by experience in other situations. Some scatter in inevitable but a significant deviation from the expected consumption may be explainable by a specific event, but equally it could be early warning of equipment malfunction as was the case in Figure 12.5. If monthly readings are taken then experience suggests that on around two occasions a year the consumption will deviate to a region outside the zone denoted by the two lines spaced at 1.5 standard deviation. Such occurrence should be considered as reporting instances for explanations as to the reason. If there is a second successive deviation above the upper line, then this would almost certainly indicate equipment malfunction. Equally consumption falling below the lower line should also be investigated as this might be indicative of good practice and lessons learnt for future improvement in performance.

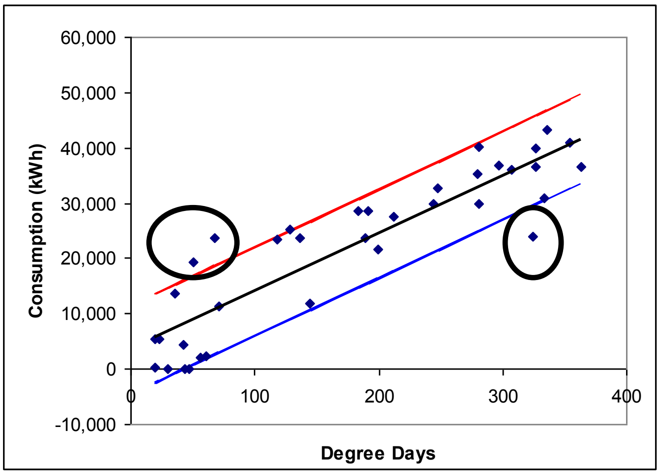


Fig. 12.10 Actual gas consumption for a moderate office building in the UK.

The same procedure may be used for gas consumption for heating. Figures 12.10 shows actual monthly consumption data for a moderately sized office block. In this .type of analysis, the consumption data should either be plotted against the relevant degree days for each month or alternatively the mean external temperature. Specific mean monthly temperatures were not available in this instance, but Degree-Day information was available. The trend line is shown together with two lines which are 1.5 standard deviations above and below this trend line.

There are three points which lie outside the trend zone and these should be points for reporting and further investigation. Figure 12.11 shows similar data from a smaller office. In this case there are once again four data points which lie outside the trend line. However in this case they show very larger deviations with one showing minimal consumption which is improbable and another showing a significant negative consumption.

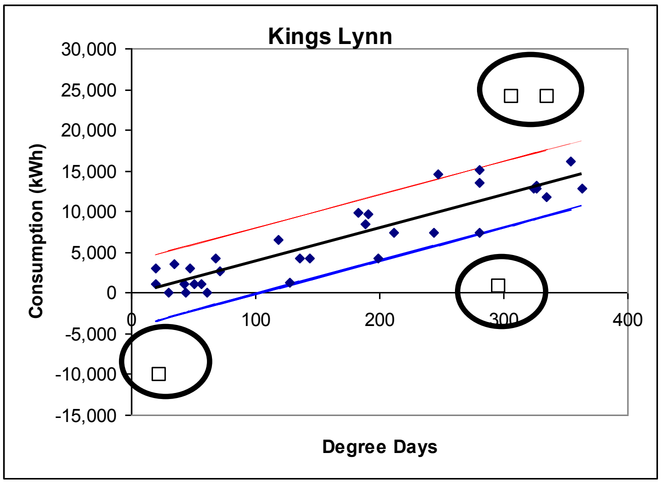


Fig. 12.11 Actual gas consumption for a small office building in the UK.

Such wide discrepancies almost certainly arise from a misread of the meter. It is not infrequent that inadvertent interchange of digits occur when meters are manually read and such incidences always occur in pairs with one reading being particularly low and the next reading particularly high (or vice versa). Once again these should count as reporting incidents and if the matter cannot then be resolved then it is appropriate to remove such data points when determining the trend lines as has been done in the case in Figure 12.11.

13. CARBON EMISSIONS

13.1 Background

A major source of green house gases arises from direct energy use and unlike several other areas associated with green house gas emissions, fairly precise estimates of emissions may be made provided that the energy consumption is carefully monitored and there is an accurate estimate of the carbon emission factors for the fuels used.

The carbon emission factor for most fuels will be fairly constant provided that it is quoted in terms of mass or volume e.g. kgs, tonnes litres or cum. There will be variations relating to the grade of coal etc and should be selected related to the country or region of interest.

Declared emission factors are published for most fuels, however some such as biofuels and electricity must be treated differently.

13.2 Emission Factors for Fossil Fuels in UK

Emission factor for Fossil fuels as used in the UK are shown in Table 13,1. These were obtained from the following Website produced by the Department of Energy and Climate Change.

http://www.decc.gov.uk/en/content/cms/statistics/climate_change/gg_emissions/intro/intro.aspx

In many instances emission factors per unit of energy e.g. kWh, MWh, GJ, therms etc are required and for such parameters the emission factor depends on whether the net or gross calorific value is used. There is debate as to which should be used and as indicated in section 3.12 of the lecture handout for NBSLM01E. The difference arises from the way in which the products of combustion are treated. If any water that is produced is condensed then the fuel has a higher energy content. However in some applications it is not possible to avoid having the water being exhausted as steam in which case less energy is extracted from the fuel. Intrinsically the higher CV is the more defensible approach even though it practically may not be achieved.

If the lower CV is used then the emission factor is higher and vice versa if the higher CV is used.

Table 13.1 Carbon Emission Factors for Fossil Fuels in UK

		CO_2	CH4	NOx	Total
Fuel Type	Units	kg CO_2 per unit	kg CO_2eq per unit	kg CO_2eq per unit	kg CO_2eq per unit
Aviation Spirit	tonnes	3127.7	30.4	31	3189.1
	kWh net	0.25023	0.00243	0.00248	0.25514
	kWh gross	0.23771	0.00231	0.00236	0.24238
	litres	2.2261	0.0216	0.0221	2.2698
Aviation Turbine Fuel 1	tonnes	3149.7	1.6	31	3182.3
	kWh net	0.25837	0.00013	0.00254	0.26104
	kWh gross	0.24545	0.00013	0.00242	0.24799
	litres	2.5278	0.0013	0.0249	2.554
Biofuels	See Annex 8 of DECC Report http://www.decc.gov.uk/en/content/cms/statistics/climate_change/gg_emissions/intro/intro.aspx				
Burning Oil1	tonnes	3149.7	6.7	8.6	3164.9
	kWh net	0.25847	0.00055	0.00071	0.25972
	kWh gross	0.24555	0.00052	0.00067	0.24674
	litres	2.5319	0.0054	0.0069	2.5442
Coal (industrial)2	tonnes	2301	0.1	36.9	2338.1
	kWh net	0.32415	0.00002	0.0052	0.32937
	kWh gross	0.30794	0.00002	0.00494	0.3129
Coal (electricity generation)	tonnes	2256.5	0.4	19.5	2276.4
	kWh net	0.32637	0.00006	0.00282	0.32925
	kWh gross	0.31005	0.00318	0.00833	2354.0
Coal (domestic)	tonnes	2506.3	329.7	37.8	2873.8
	kWh net	0.31139	0.04096	0.0047	0.35705
	kWh gross	0.29582	0.03892	0.00447	2873.8
Coking Coal	tonnes	2931.5	26.9	70.6	3029.1
	kWh net	0.36423	0.00335	0.00877	0.37635
	kWh gross	0.34601	0.00318	0.00833	3029.1

Table 13.1 Carbon Emission Factors for Fossil Fuels in UK (continued)

		CO2	CH4	NOx	Total
Fuel Type	Units	kg CO2 per unit	kg CO2eq per unit	kg CO2eq per unit	kg CO2eq per unit
Diesel	tonnes	3164.3	2.3	34	3200.6
	kWh net	0.26328	0.00019	0.00283	0.2663
	kWh gross	0.25012	0.00018	0.00268	3200.6
	litres	2.6391	0.0019	0.0283	2.6694
Electricity	See Annex 3 of DECC Report and section 13.3				
Fuel Oil	tonnes	3215.9	2.4	11.2	3229.5
	kWh net	0.27927	0.00021	0.00097	0.28045
	kWh gross	0.2653	0.0002	0.00092	3229.5
Gas Oil	tonnes	3190	3.3	305.1	3498.4
	kWh net	0.26542	0.00027	0.02539	0.29108
	kWh gross	0.25215	0.00026	0.02412	3498.4
	litres	2.7619	0.0028	0.2642	3.0289
LPG	kWh net	0.22546	0.00009	0.00017	0.22572
	kWh gross	0.21419	0.00009	0.00016	3.0289
	therms net	6.6077	0.0026	0.0049	6.6153
	therms gross	6.2773	0.0025	0.0047	0.21444
	litres	1.4951	0.0006	0.0011	1.4968
Lubricants	tonnes	3171.1	1.9	8.5	3181.5
	kWh net	0.27537	0.00017	0.00074	0.27628
	kWh gross	0.26161	0.00016	0.0007	3181.5
Naphtha	tonnes	3131.3	2.9	8	3142.2
	kWh net	0.24989	0.00023	0.00064	0.25076
	kWh gross	0.2374	0.00022	0.00061	3142.2
Natural Gas	kWh net	0.20374	0.00031	0.00012	0.20417
	kWh gross	0.18358	0.00028	0.00011	0.23822
	cum	2.0091	0.003	0.0012	2.0133
	therms net	5.9712	0.009	0.0036	5.9837
	therms gross	5.3801	0.0081	0.0033	2.0133
Other Petroleum Gas	tonnes	2894	3.6	66.5	2964.2
	kWh net	0.21651	0.00027	0.00497	0.22175
	kWh gross	0.20568	0.00026	0.00472	2964.2
Petrol	tonnes	3135	6.4	30.7	3172.1
	kWh net	0.25238	0.00052	0.00247	0.25537
	kWh gross	0.23976	0.00049	0.00235	3172.1
	litres	2.3035	0.0047	0.0226	2.3307
Petroleum Coke	tonnes	3422.7	2.2	74.7	3499.7
	kWh net	0.36301	0.00024	0.00792	0.37117
	kWh gross	0.34486	0.00023	0.00753	3499.7
Refinery Miscellaneous	kWh net	0.25693	0.00025	0.0007	0.25789
	kWh gross	0.24444	0.00024	0.00067	0.35261
	therms net	7.53	0.0074	0.0206	7.558
	therms gross	7.164	0.007	0.0196	0.24535
Wood	See Annex 8 of DECC Reporthttp://www.decc.gov.uk/en/content/cms/statistics/climate_change/gg_emissions/intro/intro.aspx				

While the emission factors for different fuels vary slightly from year to year and from region of the world to another they are essentially very similar. The composition of natural gas may vary slight and the calorific values and emission factors will thus vary similarly. Indeed as the nature of gas imported into the UK is different depending on the source, the calorific value and emission factor will vary slightly from day to day and from month to month. The calorific value as declared on gas bills will be the weighted average for the period covered, but detailed daily information may be obtained from:

http://www.nationalgrid.com/uk/Gas/Data/Operational_Summary/

The calorific value is monitored automatically at over 100 points on the gas transmission network and information exists as to the value in each region of the UK as shown in the example in Table 13.2. The data fro Stornoway is different as gas on the Hebridies is provided separately by LNG.

Table 13.2 Calorific Values across the UK on 29/05/2010

Charging Zone	Calorific Value MJ/cum
Eastern	38.9
East Midlands	39.4
Northern	40.2
North East	39.5
North Thames	39.0
North West	39.0
Scotland	39.7
South East	39.1
Southern	39.1
South West	39.1
West Midlands	39.1
Wales North	39.0
Wales South	39.3
Scottish Independents	38.3
Stornoway	93.0
Stranraer	39.6

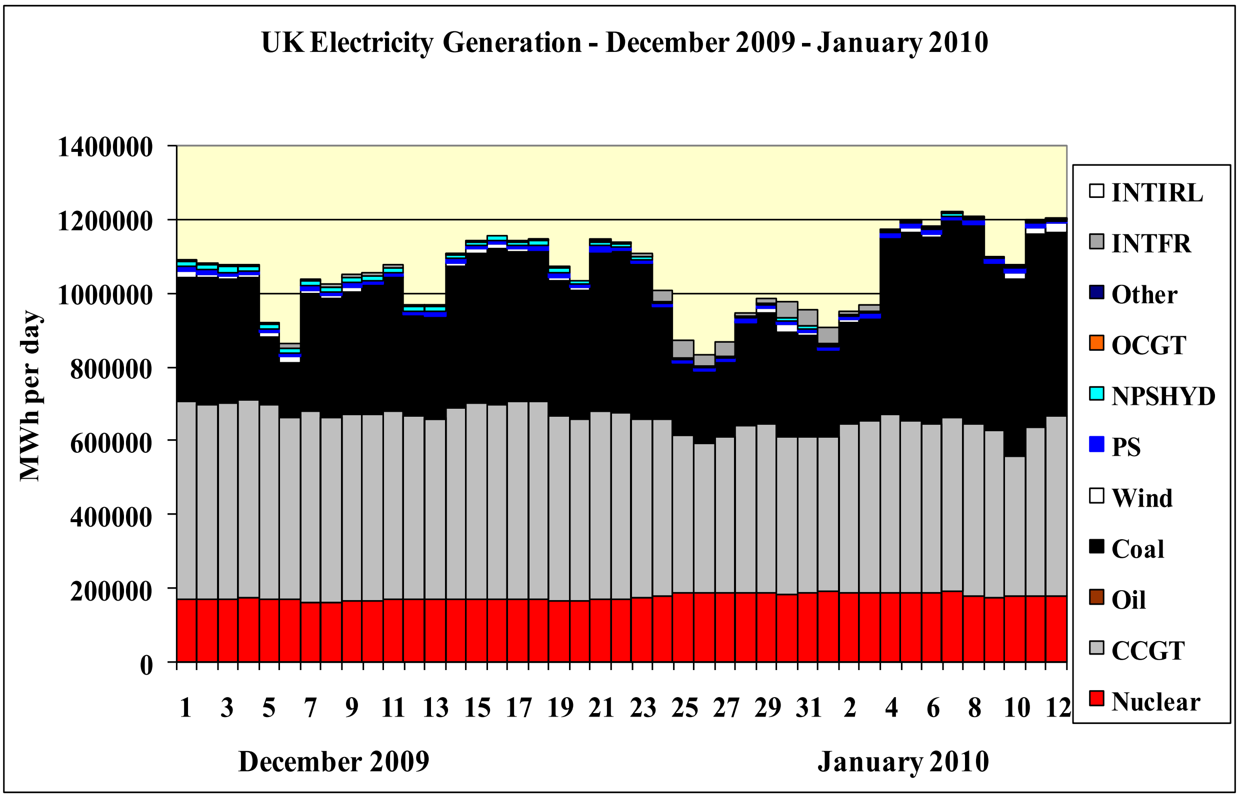


Fig. 13.1 Daily Variations in Fuel Mix for Electricity Generation.

13.3 Emission factors for electricity

The emission factors for electricity will vary significantly depending on the actual mix of fuels used for generation (Fig. 13.1).

Thus exploring just the fossil fuels of gas, fuel oil and coal, the gross emission factors for the three fuels from Table 13.1 are 0.18358 kg/kWh, 0.2653 kg/kWh, and 0.31005 kg/kWh, respectively.

However, these emission factors are for direct combustion of the fuel and the emission factor for electricity generated will depend on the fuel mix but also the efficiency of generation for each fuel type and also other issues such as the overheads associated with the delivery of fuel to the power station (i.e. the Primary Energy Ratio) and also transmission losses. The upstream emission associated with electricity generation are often not covered, and care must be taken as to whether the electricity is generated on site – in which case transmission losses can be ignored or whether grid electricity is imported in which case such transmission losses must be included.

Data for the average efficiency of power plants is given in DUKES which may be accessed at:
http://www.decc.gov.uk/en/content/cms/statistics/source/source.aspx

The efficiency of gas fired CCGT and coal fired power stations is shown in Table 13.3

Table 13.3 Efficiency of Electricity Generation (DUKES 2009)

	2004	2005	2006	2007	2008
CCGT	47.0	49.0	48.9r	48.9	51.9
Coal fired	36.2	35.6	35.7r	35.7r	36.0

The figures with "r" have been revised since original declaration.

Using the carbon emission factors for the two fuels allows the overall emission factor for generation (excluding the upstream activities) to be calculated as shown in Table 13.4

Table 13.4 Emission factors for electricity generation for coal and gas in the UK (excluding upstream and transmission losses)

	2004	2005	2006	2007	2008
CCGT	0.391	0.375	0.375	0.375	0.354
Coal fired	0.856	0.871	0.868	0.868	0.861

In section 10.5.4 of the handout associated with the module NBSLM01E, the Primary Energy Ratios were evaluated as shown in Table 13.5.

Table 13.5 Primary Energy Ratios for Fuels in UK

Fuel	Primary Energy Ratio
Coal	1.0227
Oil	1.1292
Gas	1.062
Electricity	2.911

As a first approximation we could assume that to provide the gas used in a power station, there is an overhead of 6.2% and in the case of coal 2.27%. In reality, the energy expended in delivering the fuel to the power station will not entirely be just of that fuel itself, but will certainly include electricity as well. In reality for a detailed analysis it would be necessary to study the Energy Balance Tables in detail to find out exactly which energy sources were used in the extraction, processing and delivery of the fuel to the power station. Such a Second order analysis would give more definitive figures, but the simple first order analysis is sufficient here.

The figures in Table 13.4 can thus be modified to account for upstream activities as:

Table 13.6 Emission factors for electricity generation for coal and gas in the UK excluding transmission losses, but including first order estimates of upstream fuel activities

	2004	2005	2006	2007	2008
CCGT	0.415	0.398	0.399	0.399	0.376
Coal fired	0.876	0.891	0.888	0.888	0.881

The transmission losses in the UK are shown in Table 13.7 together with the computed overall emission factors for delivered Grid Electricity in the UK

Table 13.7 Emission factors for electricity as delivered at point of end use.

	2004	2005	2006	2007	2008
Transmission Losses	8.30%	7.40%	7.40%	7.20%	7.20%
CCGT	0.452	0.430	0.431	0.430	0.405
Coal fired	0.955	0.962	0.959	0.957	0.949

Table 13.8 shows the overall emission factors for electricity generation in the UK taking account of the relevant fuel mix each year. Table 13.9 shows the corresponding table when transmission losses are taken into account.

The corresponding tables for EU and Non-EU countries are shown in Tables 13.10-13.13.

Table 13.8 Emission factor for Electricity Generation in the UK (excluding transmission losses). Table reproduced from http://www.decc.gov.uk/en/content/cms/statistics/climate_change/gg_emissions/intro/intro.aspx

					Rolling 5 year averages				
	CO2	CH4	Nox	All GHG	CO2	CH4	Nox	All GHG	
Uk Electricity Year	kg CO2 per kWh	kg CO2 eq per kWh	kg CO2 eq per kWh	kg CO2 eq per kWh	kg CO2 per kWh	kg CO2 eq per kWh	kg CO2 eq per kWh	kg CO2 eq per kWh	Tranmission Losses
1990	0.71225	0.00019	0.00582	0.71827	0.71225	0.00019	0.00582	0.71827	7.50%
1991	0.69375	0.00018	0.00565	0.69959	0.703	0.00019	0.00574	0.70893	7.50%
1992	0.6475	0.00018	0.00527	0.65295	0.6845	0.00018	0.00558	0.69027	7.50%
1993	0.5735	0.00017	0.00437	0.57804	0.65675	0.00018	0.00528	0.66221	7.50%
1994	0.56425	0.00018	0.00421	0.56864	0.63825	0.00018	0.00507	0.6435	7.50%
1995	0.5365	0.00018	0.00392	0.5406	0.6031	0.00018	0.00468	0.60796	7.50%
1996	0.5222	0.00018	0.00354	0.52593	0.56879	0.00018	0.00426	0.57323	8.10%
1997	0.48181	0.00017	0.00304	0.48503	0.53565	0.00018	0.00382	0.53965	8.10%
1998	0.48313	0.00018	0.00305	0.48637	0.51758	0.00018	0.00355	0.52131	8.10%
1999	0.45367	0.00019	0.00262	0.45648	0.49546	0.00018	0.00323	0.49888	8.10%
2000	0.48044	0.00019	0.00289	0.48352	0.48425	0.00018	0.00303	0.48747	8.30%
2001	0.49512	0.0002	0.00308	0.4984	0.47884	0.00019	0.00294	0.48196	8.50%
2002	0.4799	0.0002	0.00289	0.48299	0.47845	0.00019	0.0029	0.48155	8.30%
2003	0.49466	0.0002	0.00309	0.49795	0.48076	0.0002	0.00291	0.48387	8.20%
2004	0.49461	0.0002	0.00299	0.4978	0.48895	0.0002	0.00299	0.49213	8.30%
2005	0.4877	0.00022	0.00308	0.491	0.4904	0.00021	0.00302	0.49363	7.40%
2006	0.51405	0.00023	0.00339	0.51767	0.49418	0.00021	0.00309	0.49748	7.40%
2007	0.50411	0.00023	0.00315	0.50748	0.49902	0.00022	0.00314	0.50238	7.20%

Table 13.9 Emission factor for Grid Electricity Supply in the UK (including transmission losses). Table reproduced from http://www.decc.gov.uk/en/content/cms/statistics/climate_change/gg_emissions/intro/intro.aspx

					Rolling 5 year averages				
	CO2	CH4	Nox	All GHG	CO2	CH4	Nox	All GHG	
Uk Grid Electricity Year	kg CO2 per kWh	kg CO2 eq per kWh	kg CO2 eq per kWh	kg CO2 eq per kWh	kg CO2 per kWh	kg CO2 eq per kWh	kg CO2 eq per kWh	kg CO2 eq per kWh	Tranmission Losses
1990	0.77	0.00021	0.0063	0.77651	0.77	0.00021	0.0063	0.77651	7.50%
1991	0.75	0.0002	0.00611	0.75631	0.76	0.0002	0.0062	0.76641	7.50%
1992	0.7	0.00019	0.0057	0.70589	0.74	0.0002	0.00604	0.74624	7.50%
1993	0.62	0.00019	0.00472	0.62491	0.71	0.0002	0.00571	0.7159	7.50%
1994	0.61	0.0002	0.00455	0.61475	0.69	0.0002	0.00548	0.69567	7.50%
1995	0.58	0.0002	0.00423	0.58443	0.652	0.00019	0.00506	0.65726	7.50%
1996	0.56845	0.0002	0.00386	0.5725	0.61569	0.00019	0.00461	0.6205	8.10%
1997	0.52448	0.00019	0.00331	0.52798	0.58059	0.00019	0.00413	0.58491	8.10%
1998	0.52592	0.0002	0.00332	0.52944	0.56177	0.0002	0.00385	0.56582	8.10%
1999	0.49345	0.0002	0.00285	0.4965	0.53846	0.0002	0.00351	0.54217	8.10%
2000	0.52368	0.00021	0.00315	0.52704	0.5272	0.0002	0.0033	0.53069	8.30%
2001	0.5411	0.00022	0.00336	0.54469	0.52173	0.0002	0.0032	0.52513	8.50%
2002	0.52306	0.00022	0.00315	0.52642	0.52144	0.00021	0.00317	0.52482	8.30%
2003	0.53859	0.00022	0.00336	0.54218	0.52398	0.00021	0.00317	0.52737	8.20%
2004	0.53945	0.00022	0.00326	0.54293	0.53318	0.00022	0.00326	0.53665	8.30%
2005	0.52665	0.00024	0.00333	0.53022	0.53377	0.00022	0.00329	0.53729	7.40%
2006	0.55502	0.00024	0.00366	0.55892	0.53655	0.00023	0.00335	0.54013	7.40%
2007	0.54303	0.00025	0.00339	0.54667	0.54055	0.00023	0.0034	0.54418	7.20%

Table 13.10 Emission factors for Centralised Heat and Electricity Generation (excluding transmission losses) in EU countries. Table reproduced from http://www.decc.gov.uk/en/content/cms/statistics/climate_change/gg_emissions/intro/intro.aspx

	EU Electricity/Heat Conversion Factors from 1990 to 2006: kgCO2 per kWh electricity and heat GENERATED																	% GWh		Transmission Losses (%)	
Country	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	Elec-tricity	Heat	Elec-tricity	Heat
Austria	0.2447	0.2519	0.2088	0.1937	0.207	0.214	0.2296	0.2278	0.2078	0.195	0.1833	0.194	0.1944	0.236	0.23	0.2249	0.214	80.4%	19.6%	5.7%	8.0%
Belgium	0.3485	0.3423	0.3317	0.346	0.3656	0.3582	0.3399	0.311	0.3154	0.2784	0.2849	0.2719	0.2664	0.2736	0.2685	0.268	0.26	93.4%	6.6%	4.9%	7.8%
Bulgaria			0.476	0.4825	0.4566	0.4296	0.4184	0.4749	0.4806	0.4456	0.4307	0.4634	0.4329	0.4703	0.4706	0.448	0.448	74.9%	25.1%	16.0%	13.0%
Cyprus			0.8315	0.8321	0.8359	0.8264	0.8368	0.8455	0.8475	0.8608	0.8419	0.7812	0.7597	0.8372	0.7764	0.7923	0.758	100.0%	0.0%	3.9%	0.0%
Czech Republic	0.5993	0.5902	0.5867	0.5822	0.5857	0.5848	0.5814	0.5616	0.5693	0.5593	0.5675	0.56	0.5461	0.5019	0.5035	0.5156	0.527	68.1%	31.9%	8.3%	16.8%
Denmark	0.4762	0.5061	0.4697	0.4566	0.4699	0.43	0.4669	0.4215	0.3897	0.3633	0.3393	0.3359	0.332	0.3572	0.3082	0.2836	0.341	50.6%	49.4%	4.4%	20.1%
Estonia			0.6487	0.6199	0.6188	0.689	0.6791	0.6797	0.7196	0.7065	0.6972	0.6854	0.6722	0.7233	0.7009	0.6649	0.64	57.8%	42.2%	15.5%	13.3%
Finland	0.2304	0.235	0.2074	0.2324	0.2687	0.2498	0.2897	0.2678	0.2123	0.2116	0.211	0.2395	0.2529	0.2929	0.2546	0.1936	0.242	60.9%	39.1%	3.5%	6.7%
France	0.1099	0.1245	0.0995	0.0691	0.0698	0.077	0.078	0.0719	0.0974	0.0864	0.0827	0.0708	0.0763	0.0804	0.0781	0.0909	0.085	91.7%	8.3%	7.0%	0.0%
Germany	0.5714	0.5837	0.5527	0.5499	0.5477	0.5325	0.5249	0.5175	0.5083	0.4946	0.4959	0.5062	0.5184	0.4379	0.4357	0.3492	0.404	63.6%	36.4%	5.4%	7.8%
Greece	0.9912	0.9408	0.9585	0.9336	0.8841	0.8723	0.8282	0.869	0.8602	0.8216	0.8136	0.8323	0.8152	0.7739	0.7772	0.7765	0.725	99.1%	0.9%	9.9%	0.0%
Hungary	0.4693	0.4603	0.4853	0.4587	0.4419	0.4457	0.4331	0.4313	0.4273	0.4144	0.4118	0.3948	0.3916	0.4209	0.3895	0.3387	0.344	66.9%	33.1%	10.9%	0.0%
Ireland	0.75	0.7533	0.7595	0.7366	0.7292	0.7287	0.7279	0.7196	0.7152	0.6978	0.6392	0.6751	0.6371	0.5974	0.5715	0.5842	0.535	100.0%	0.0%	7.9%	0.0%
Italy	0.5739	0.549	0.5356	0.5252	0.5165	0.5467	0.5253	0.5151	0.5161	0.498	0.5038	0.4852	0.509	0.5248	0.4106	0.4054	0.404	85.0%	15.0%	6.4%	0.0%
Latvia			0.2763	0.2688	0.2504	0.2381	0.2625	0.2182	0.1973	0.2168	0.2002	0.1897	0.1881	0.1829	0.1665	0.162	0.167	36.2%	63.8%	12.7%	16.7%
Lithuania			0.1858	0.1859	0.2151	0.1727	0.1731	0.1654	0.1722	0.1765	0.1578	0.1437	0.1198	0.1123	0.1102	0.1296	0.139	51.6%	48.4%	13.3%	16.4%
Luxembourg	2.5884	2.4703	2.4837	2.4643	2.1074	1.34	1.1929	0.81	0.2489	0.2577	0.2551	0.2399	0.3288	0.3302	0.3338	0.3278	0.326	85.4%	14.6%	1.7%	0.0%
Malta			1.0235	1.3916	1.164	0.9617	0.9789	0.9416	0.9365	0.9086	0.8678	1.0282	0.8195	0.8138	0.9016	0.8919	0.834	100.0%	0.0%	11.6%	0.0%
Netherlands	0.6022	0.5838	0.5709	0.5745	0.5382	0.5294	0.5007	0.4992	0.4694	0.4675	0.4468	0.4624	0.4586	0.4671	0.4399	0.3867	0.394	67.9%	32.1%	4.1%	17.0%
Poland	0.6563	0.6507	0.6526	0.6403	0.6432	0.6752	0.6646	0.6669	0.6643	0.6651	0.6716	0.6604	0.6624	0.6623	0.665	0.6589	0.659	62.4%	37.6%	12.8%	0.0%
Portugal	0.5173	0.5224	0.6219	0.5459	0.497	0.5696	0.4291	0.4667	0.4642	0.5393	0.4801	0.4425	0.5127	0.4139	0.4523	0.4982	0.416	92.4%	7.6%	8.3%	0.0%
Romania			0.4096	0.3844	0.4561	0.4405	0.4443	0.3853	0.3513	0.3599	0.3954	0.4122	0.4124	0.4512	0.4183	0.3941	0.429	62.6%	37.4%	13.0%	22.0%
Slovak Republic	0.3785	0.3887	0.3603	0.4125	0.3607	0.3698	0.3627	0.3789	0.3512	0.3487	0.2668	0.2488	0.2239	0.2555	0.2473	0.2321	0.223	68.3%	31.7%	6.9%	12.9%
Slovenia			0.3662	0.3732	0.3345	0.3371	0.3175	0.387	0.3937	0.367	0.3313	0.341	0.3719	0.3673	0.3366	0.3283	0.332	84.4%	15.6%	7.0%	16.9%
Spain	0.4279	0.4237	0.4817	0.4192	0.4166	0.4566	0.3587	0.3919	0.3806	0.4448	0.4296	0.3833	0.4371	0.381	0.3826	0.3943	0.35	100.0%	0.0%	9.7%	0.0%
Sweden	0.048	0.0581	0.0508	0.052	0.0558	0.05	0.0733	0.0503	0.0544	0.0481	0.0421	0.0432	0.052	0.0595	0.0512	0.0445	0.044	75.9%	24.1%	8.2%	3.5%
European Union - 27			**0.4431**	**0.4217**	**0.4205**	**0.419**	**0.4092**	**0.3986**	**0.3932**	**0.3837**	**0.3808**	**0.378**	**0.3838**	**0.3767**	**0.3623**	**0.3409**	**0.354**	**78.1%**	**21.9%**	**7.4%**	**7.7%**

Table 13.11 Emission factors for Grid Supplied Heat and Electricity (including transmission losses) in EU countries. Table reproduced from http://www.decc.gov.uk/en/content/cms/statistics/climate_change/gg_emissions/intro/intro.aspx

	EU Electricity/Heat Conversion Factors from 1990 to 2006: kgCO2 per kWh electricity and heat including LOSSES in transmission and distribution																
Country	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006
Austria	0.2608	0.2685	0.2225	0.2063	0.2206	0.228	0.2447	0.2427	0.2214	0.2077	0.1953	0.2067	0.2071	0.2514	0.245	0.2396	0.228
Belgium	0.3672	0.3606	0.3495	0.3647	0.3853	0.3774	0.3582	0.3277	0.3324	0.2934	0.3002	0.2866	0.2808	0.2883	0.283	0.2824	0.274
Bulgaria			0.5605	0.569	0.5384	0.5066	0.4935	0.5601	0.5668	0.5255	0.508	0.5465	0.5106	0.5546	0.555	0.5284	0.5284
Cyprus			0.8657	0.8663	0.8702	0.8603	0.8712	0.8802	0.8823	0.8961	0.8765	0.8133	0.7909	0.8715	0.8083	0.8249	0.7891
Czech Republic	0.6751	0.665	0.6609	0.6544	0.6584	0.6574	0.6535	0.6313	0.6399	0.6287	0.6379	0.6295	0.6138	0.5641	0.566	0.5795	0.5924
Denmark	0.5384	0.5722	0.531	0.5198	0.5349	0.4896	0.5315	0.4799	0.4437	0.4136	0.3862	0.3824	0.3779	0.4066	0.3508	0.3228	0.3882
Estonia			0.7577	0.7257	0.7244	0.8065	0.7949	0.7957	0.8424	0.8271	0.8161	0.8024	0.7869	0.8467	0.8205	0.7784	0.7492
Finland	0.2416	0.2464	0.2175	0.2441	0.2822	0.2623	0.3043	0.2812	0.223	0.2223	0.2216	0.2516	0.2656	0.3077	0.2674	0.2033	0.2542
France	0.1173	0.1328	0.1061	0.0739	0.0746	0.0823	0.0834	0.0768	0.1041	0.0923	0.0884	0.0756	0.0815	0.0859	0.0835	0.0971	0.0908
Germany	0.6099	0.623	0.5899	0.5866	0.5843	0.568	0.5599	0.552	0.5422	0.5276	0.529	0.54	0.553	0.4671	0.4647	0.3725	0.4309
Greece	1.0988	1.0429	1.0626	1.0351	0.9802	0.9671	0.9183	0.9634	0.9537	0.9109	0.902	0.9228	0.9038	0.858	0.8617	0.8609	0.8038
Hungary	0.5067	0.497	0.524	0.4946	0.4765	0.4807	0.4671	0.4651	0.4608	0.4469	0.4441	0.4258	0.4223	0.4539	0.4201	0.3653	0.371
Ireland	0.8144	0.8181	0.8248	0.7999	0.7919	0.7914	0.7905	0.7815	0.7767	0.7578	0.6942	0.7331	0.6919	0.6487	0.6207	0.6344	0.581
Italy	0.607	0.5806	0.5664	0.5555	0.5463	0.5783	0.5556	0.5448	0.5458	0.5267	0.5328	0.5132	0.5384	0.5551	0.4343	0.4288	0.4273
Latvia			0.3248	0.3173	0.2956	0.2811	0.3099	0.2575	0.233	0.256	0.2364	0.2239	0.2221	0.2159	0.1966	0.1913	0.1971
Lithuania			0.2188	0.2182	0.2525	0.2027	0.2032	0.1941	0.2022	0.2071	0.1852	0.1687	0.1406	0.1318	0.1294	0.1521	0.1632
Luxembourg	2.6277	2.5078	2.5215	2.5	2.1379	1.3594	1.2102	0.8218	0.2525	0.2614	0.2588	0.2434	0.3335	0.335	0.3386	0.3325	0.3307
Malta			1.1575	1.5739	1.3164	1.0877	1.1071	1.0649	1.0592	1.0276	0.9815	1.1629	0.9268	0.9203	1.0196	1.0087	0.9432
Netherlands	0.6498	0.63	0.6161	0.6262	0.5866	0.5771	0.5458	0.5442	0.5117	0.5096	0.487	0.5041	0.4999	0.5092	0.4795	0.4215	0.4295
Poland	0.7058	0.6997	0.7017	0.6958	0.6989	0.7338	0.7222	0.7247	0.7219	0.7228	0.7298	0.7176	0.7198	0.7197	0.7226	0.716	0.7161
Portugal	0.5604	0.5659	0.6738	0.5915	0.5385	0.6172	0.4649	0.5056	0.5029	0.5843	0.5201	0.4794	0.5554	0.4484	0.49	0.5398	0.4507
Romania			0.4905	0.4596	0.5454	0.5266	0.5312	0.4607	0.42	0.4303	0.4728	0.4928	0.4931	0.5395	0.5001	0.4712	0.5129
Slovak Republic	0.4152	0.4264	0.3952	0.4522	0.3954	0.4055	0.3977	0.4154	0.385	0.3823	0.2925	0.2727	0.2454	0.2801	0.2711	0.2544	0.2445
Slovenia			0.4001	0.4079	0.3657	0.3685	0.3471	0.4231	0.4304	0.4012	0.3622	0.3728	0.4066	0.4015	0.368	0.3589	0.3629
Spain	0.4738	0.4692	0.5333	0.4642	0.4612	0.5056	0.3972	0.4339	0.4214	0.4924	0.4756	0.4243	0.484	0.4218	0.4236	0.4366	0.3875
Sweden	0.0516	0.0625	0.0546	0.056	0.0601	0.0538	0.0789	0.0541	0.0585	0.0517	0.0453	0.0465	0.056	0.0641	0.0551	0.0479	0.0474
European Union - 27			**0.479**	**0.4559**	**0.4546**	**0.453**	**0.4423**	**0.4309**	**0.425**	**0.4148**	**0.4117**	**0.4086**	**0.4148**	**0.4072**	**0.3916**	**0.3685**	**0.3827**

Table 13.12 Emission factors for Centralised Heat and Electricity Generation (excluding transmission losses) in Non-EU countries. Table reproduced from http://www.decc.gov.uk/en/content/cms/statistics/climate_change/gg_emissions/intro/intro.aspx

	Non-EU Electricity/Heat Conversion Factors from 1990 to 2006: kgCO2 per kWh electricity and heat GENERATED																	% GWh		Transmission Losses (%)	
Country	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	Elec-tricity	Heat	Elec-tricity	Heat
Australia	0.8111	0.8143	0.8211	0.8058	0.7821	0.7758	0.8233	0.8655	0.8799	0.872	0.8647	0.8449	0.8922	0.8717	0.8438	0.8733	0.921	100.0%	0.0%	7.6%	0.0%
Brazil			0.0608	0.0553	0.051	0.0552	0.057	0.062	0.0622	0.0825	0.0879	0.1039	0.0856	0.0792	0.0852	0.0842	0.081	99.7%	0.3%	15.6%	0.0%
Canada	0.195	0.1873	0.1961	0.1751	0.1718	0.1766	0.1706	0.1897	0.216	0.207	0.2166	0.226	0.2134	0.2248	0.2066	0.1987	0.184	98.5%	1.5%	8.2%	0.0%
China			0.7943	0.7939	0.7679	0.8029	0.8206	0.8042	0.8232	0.7978	0.7649	0.7399	0.7485	0.7761	0.8056	0.7879	0.788	79.7%	20.3%	7.8%	1.4%
Chinese Taipei			0.4899	0.5056	0.5035	0.5144	0.5211	0.5505	0.5596	0.5797	0.6038	0.6158	0.6057	0.6327	0.6277	0.6317	0.659	100.0%	0.0%	3.7%	0.0%
Croatia			0.3251	0.3279	0.2499	0.2726	0.2536	0.2983	0.3233	0.3032	0.2993	0.3097	0.3538	0.3768	0.2978	0.3113	0.318	77.1%	22.9%	12.9%	13.5%
Egypt			0.5296	0.5032	0.4665	0.4433	0.4327	0.4422	0.4675	0.4545	0.4118	0.381	0.4367	0.4325	0.4731	0.4714	0.47	100.0%	0.0%	16.4%	0.0%
Gibraltar			0.7774	0.7771	0.7551	0.7696	0.7556	0.7766	0.7696	0.7696	0.7635	0.7574	0.7637	0.7581	0.7696	0.7431	0.73	100.0%	0.0%	0.0%	0.0%
Hong Kong			0.8191	0.8604	0.871	0.8524	0.8296	0.7239	0.7401	0.715	0.7108	0.7189	0.724	0.7937	0.8294	0.8098	0.855	100.0%	0.0%	10.9%	0.0%
Iceland	0.0005	0.0005	0.0005	0.0008	0.0008	0.0016	0.0012	0.0011	0.0029	0.0038	0.0006	0.0006	0.0006	0.0006	0.0006	0.0006	0.001	77.1%	22.9%	4.7%	10.4%
India			0.889	0.9112	0.8757	0.9258	0.9706	0.9426	0.9214	0.9191	0.9385	0.9341	0.919	0.9031	0.942	0.9434	0.944	100.0%	0.0%	26.8%	0.0%
Indonesia			0.6393	0.7561	0.6416	0.5819	0.6382	0.6755	0.6506	0.6765	0.6428	0.7393	0.7135	0.7752	0.7504	0.7707	0.677	100.0%	0.0%	12.3%	0.0%
Israel			0.8204	0.8224	0.8209	0.8213	0.8271	0.8218	0.7657	0.7673	0.7609	0.7728	0.8228	0.8176	0.8075	0.7675	0.774	100.0%	0.0%	2.9%	0.0%
Japan	0.4305	0.421	0.4269	0.4086	0.4261	0.4082	0.4056	0.3912	0.3791	0.3949	0.3986	0.3997	0.4197	0.4415	0.4248	0.4285	0.418	99.3%	0.7%	4.9%	0.0%
Korea	0.5123	0.5504	0.5779	0.5593	0.5431	0.5315	0.5281	0.5497	0.4944	0.4792	0.5011	0.5019	0.4251	0.4453	0.444	0.4182	0.533	87.9%	12.1%	3.7%	1.9%
Malaysia			0.6233	0.6044	0.5563	0.5564	0.5591	0.4661	0.5394	0.5277	0.5167	0.5407	0.5911	0.5255	0.5312	0.557	0.655	100.0%	0.0%	4.3%	0.0%
Mexico	0.5355	0.5348	0.5095	0.5099	0.5611	0.5068	0.5062	0.5219	0.5716	0.5612	0.5662	0.5685	0.5581	0.5599	0.5223	0.5155	0.541	100.0%	0.0%	17.6%	0.0%
New Zealand	0.128	0.1303	0.1741	0.1387	0.1155	0.1117	0.1393	0.213	0.214	0.2376	0.2303	0.2758	0.2468	0.29	0.2407	0.2754	0.309	99.7%	0.3%	7.6%	0.0%
Norway	0.0034	0.0045	0.0039	0.0042	0.0052	0.0045	0.0063	0.0055	0.0055	0.006	0.0041	0.0058	0.0053	0.0083	0.007	0.0055	0.007	97.5%	2.5%	8.1%	16.1%
Pakistan			0.3932	0.3842	0.3911	0.4049	0.4426	0.4537	0.4114	0.4678	0.4794	0.4628	0.4425	0.37	0.3967	0.3796	0.413	100.0%	0.0%	25.2%	0.0%
Philippines			0.4834	0.479	0.5188	0.5086	0.514	0.5699	0.5914	0.5009	0.4981	0.5299	0.4822	0.4602	0.457	0.4951	0.435	100.0%	0.0%	13.1%	0.0%
Russia			0.3084	0.2913	0.2962	0.2919	0.342	0.3284	0.3265	0.3271	0.3209	0.3216	0.3268	0.3294	0.3249	0.338	0.329	36.9%	63.1%	14.8%	2.6%
Saudi Arabia			0.8329	0.8377	0.8157	0.8151	0.802	0.8087	0.8149	0.8116	0.8098	0.7782	0.7513	0.7395	0.7595	0.7476	0.755	100.0%	0.0%	7.8%	0.0%
Singapore			0.8412	1.004	0.9765	0.9384	0.8798	0.7692	0.7742	0.656	0.6637	0.6346	0.595	0.5737	0.5562	0.5439	0.536	100.0%	0.0%	5.5%	0.0%
South Africa			0.8553	0.8805	0.8636	0.8781	0.8607	0.8695	0.9275	0.8897	0.893	0.8289	0.8194	0.8452	0.8655	0.8484	0.869	100.0%	0.0%	7.2%	0.0%
Switzerland	0.0218	0.0244	0.0278	0.0207	0.0198	0.0219	0.0255	0.0227	0.0277	0.022	0.0221	0.0214	0.0218	0.0226	0.0237	0.0262	0.026	92.5%	7.5%	6.8%	7.5%
Thailand			0.6463	0.6301	0.6234	0.6061	0.6254	0.6337	0.6082	0.5961	0.5641	0.5624	0.5385	0.5279	0.5379	0.5313	0.511	100.0%	0.0%	8.0%	0.0%
Turkey	0.584	0.5933	0.5938	0.5242	0.5727	0.5325	0.5385	0.5506	0.5584	0.5772	0.5259	0.5505	0.4785	0.4483	0.427	0.4328	0.438	94.2%	5.8%	15.7%	0.0%
Ukraine			0.3667	0.3836	0.3548	0.3643	0.331	0.321	0.3294	0.3365	0.3443	0.3273	0.3227	0.3786	0.3127	0.3143	0.344	52.5%	47.5%	15.6%	25.2%
United States			0.5882	0.5903	0.5872	0.571	0.5801	0.6039	0.6045	0.5961	0.5861	0.6023	0.5748	0.5748	0.5754	0.5729	0.559	98.4%	1.6%	6.6%	18.0%
Africa			0.6786	0.6899	0.6822	0.6871	0.6711	0.6788	0.71	0.6799	0.667	0.6221	0.6228	0.6366	0.6508	0.6427	0.645	99.9%	0.1%	12.0%	0.0%
Latin America			0.1921	0.1832	0.178	0.182	0.1868	0.1929	0.2008	0.2039	0.1958	0.2057	0.1975	0.1932	0.2029	0.197	0.194	99.9%	0.1%	16.7%	0.0%
Middle-East			0.7163	0.7222	0.7256	0.7279	0.7205	0.7189	0.7051	0.7089	0.7056	0.7056	0.6918	0.6873	0.6966	0.6901	0.67	100.0%	0.0%	14.0%	0.0%
Non-OECD Europe			0.4792	0.468	0.4798	0.4834	0.4705	0.4805	0.477	0.4494	0.4737	0.4871	0.4853	0.5126	0.4893	0.4786	0.499	74.70%	25.3%	15.70%	15.4%

Table 13.13 Emission factors Grid Supplied Heat and Electricity Generation (including transmission losses) in Non-EU countries. Table reproduced from http://www.decc.gov.uk/en/content/cms/statistics/climate_change/gg_emissions/intro/intro.aspx

	Non- EU Electricity/Heat Conversion Factors from 1990 to 2006: kgCO2 per kWh electricity and heat including LOSSES in transmission and distribution																
Country	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006
Australia	0.8776	0.881	0.8883	0.8719	0.8461	0.8394	0.8908	0.9364	0.952	0.9435	0.9356	0.9141	0.9653	0.9431	0.9129	0.9449	0.9965
Brazil			0.0721	0.0655	0.0605	0.0653	0.0675	0.0734	0.0737	0.0977	0.1042	0.123	0.1014	0.0938	0.101	0.0997	0.0959
Canada	0.2121	0.2037	0.2133	0.1905	0.1869	0.1922	0.1857	0.2064	0.2351	0.2253	0.2358	0.246	0.2322	0.2447	0.2248	0.2162	0.2002
China			0.8496	0.8491	0.8213	0.8587	0.8777	0.8602	0.8804	0.8534	0.8181	0.7914	0.8006	0.8301	0.8617	0.8427	0.8428
Chinese Taipei			0.5086	0.525	0.5228	0.5341	0.541	0.5716	0.5811	0.602	0.6269	0.6394	0.6289	0.657	0.6518	0.6559	0.6842
Croatia			0.3737	0.3769	0.2873	0.3135	0.2915	0.343	0.3717	0.3486	0.3441	0.356	0.4068	0.4332	0.3423	0.3579	0.3656
Egypt			0.6337	0.602	0.5581	0.5303	0.5177	0.5291	0.5593	0.5438	0.4927	0.4558	0.5225	0.5174	0.5661	0.564	0.5623
Gibraltar			0.7774	0.7771	0.7551	0.7696	0.7556	0.7766	0.7696	0.7696	0.7635	0.7574	0.7637	0.7581	0.7696	0.7431	0.73
Hong Kong (China)			0.9194	0.9658	0.9778	0.9568	0.9312	0.8126	0.8307	0.8026	0.7979	0.807	0.8128	0.8909	0.9311	0.909	0.9598
Iceland	0.0006	0.0005	0.0005	0.0009	0.0009	0.0017	0.0013	0.0012	0.0031	0.004	0.0007	0.0006	0.0007	0.0007	0.0007	0.0007	0.0011
India			1.2141	1.2445	1.1959	1.2644	1.3256	1.2873	1.2583	1.2553	1.2817	1.2757	1.2551	1.2334	1.2865	1.2884	1.2893
Indonesia			0.729	0.8623	0.7317	0.6636	0.7278	0.7703	0.7419	0.7715	0.733	0.8431	0.8137	0.8841	0.8557	0.8789	0.772
Israel			0.8451	0.8472	0.8456	0.846	0.852	0.8465	0.7887	0.7903	0.7838	0.7961	0.8475	0.8422	0.8317	0.7906	0.7973
Japan	0.4524	0.4424	0.4486	0.4294	0.4478	0.429	0.4262	0.4111	0.3984	0.415	0.4188	0.4201	0.441	0.464	0.4464	0.4504	0.4393
Korea Republic of	0.5307	0.5703	0.5987	0.5795	0.5627	0.5507	0.5472	0.5695	0.5122	0.4965	0.5192	0.52	0.4405	0.4614	0.46	0.4333	0.5523
Malaysia			0.6514	0.6316	0.5814	0.5815	0.5843	0.4871	0.5637	0.5515	0.54	0.5651	0.6178	0.5492	0.5552	0.5821	0.6845
Mexico	0.6501	0.6493	0.6186	0.6191	0.6813	0.6154	0.6145	0.6336	0.694	0.6813	0.6874	0.6902	0.6776	0.6798	0.6342	0.6258	0.6568
New Zealand	0.1385	0.141	0.1883	0.1501	0.1249	0.1208	0.1506	0.2303	0.2315	0.257	0.2491	0.2983	0.2669	0.3136	0.2603	0.2979	0.3342
Norway	0.0037	0.005	0.0042	0.0046	0.0056	0.0049	0.0069	0.006	0.006	0.0066	0.0044	0.0064	0.0058	0.0091	0.0076	0.006	0.0076
Pakistan			0.5256	0.5136	0.5229	0.5412	0.5916	0.6065	0.5499	0.6253	0.6409	0.6187	0.5916	0.4946	0.5303	0.5074	0.5521
Philippines			0.5562	0.5512	0.5969	0.5852	0.5914	0.6558	0.6804	0.5764	0.5731	0.6097	0.5548	0.5295	0.5258	0.5697	0.5005
Russian Federation			0.3298	0.3137	0.3189	0.3143	0.3682	0.3536	0.3515	0.3522	0.3455	0.3462	0.3518	0.3546	0.3498	0.3638	0.3542
Saudi Arabia			0.9035	0.9086	0.8848	0.8841	0.8699	0.8772	0.8839	0.8803	0.8784	0.8442	0.8149	0.8021	0.8238	0.8109	0.8189
Singapore			0.8897	1.062	1.0329	0.9926	0.9306	0.8136	0.8189	0.6939	0.702	0.6712	0.6293	0.6069	0.5883	0.5753	0.567
South Africa			0.9212	0.9483	0.9301	0.9458	0.927	0.9365	0.9989	0.9583	0.9618	0.8928	0.8826	0.9103	0.9322	0.9137	0.936
Switzerland	0.0234	0.0262	0.0298	0.0222	0.0212	0.0235	0.0274	0.0243	0.0298	0.0236	0.0237	0.023	0.0234	0.0243	0.0254	0.0282	0.0279
Thailand			0.7028	0.6852	0.6779	0.6591	0.6801	0.6891	0.6613	0.6482	0.6134	0.6116	0.5855	0.574	0.585	0.5778	0.5557
Turkey	0.684	0.6949	0.6956	0.6156	0.6725	0.6253	0.6323	0.6465	0.6557	0.6778	0.6175	0.6465	0.5619	0.5265	0.5015	0.5083	0.5143
Ukraine			0.4606	0.4802	0.4441	0.4561	0.4143	0.4018	0.4124	0.4213	0.4311	0.4097	0.404	0.474	0.3915	0.3935	0.4307
United States			0.6308	0.6334	0.6302	0.6127	0.6225	0.6481	0.6488	0.6397	0.629	0.6463	0.6169	0.6168	0.6176	0.6149	0.5999
Africa			0.7716	0.7844	0.7756	0.7811	0.7629	0.7716	0.8071	0.7729	0.7583	0.7072	0.708	0.7238	0.7399	0.7307	0.7333
Latin America			0.2306	0.2198	0.2136	0.2183	0.2241	0.2314	0.2409	0.2446	0.2349	0.2468	0.2369	0.2318	0.2435	0.2363	0.2327
Middle-East			0.8332	0.8401	0.844	0.8466	0.838	0.8362	0.8201	0.8246	0.8207	0.8207	0.8047	0.7994	0.8103	0.8027	0.7793
Non-OECD Europe			0.5678	0.5546	0.5685	0.5729	0.5575	0.5693	0.5652	0.5325	0.5614	0.5772	0.575	0.6074	0.5799	0.5671	0.5913