2 Energy economics

Learning objectives

Study of this chapter will enable the reader to:

1. understand the basis of energy auditing and design an energy audit;
2. be able to calculate energy costs for all applications and different types of measuring unit within SI (Système International);
3. use multiples and submultiples of SI units;
4. identify usefully employed energy;
5. evaluate energy costs in pounds per useful gigajoule;
6. understand degree days and their use;
7. compare the energy efficiency of different buildings;
8. calculate the economic thickness of thermal insulation for both hot surfaces and building structures;
9. analyse financial return on investment in energy-saving measures;
10. calculate energy use targets for buildings;
11. calculate greenhouse gas carbon emission.

Key terms and concepts

Introduction

Buildings are such major consumers of primary energy, that is, coal, oil, gas, nuclear energy and renewable sources such as hydroelectric, wind, solar and wave energy, that accounting for its use and calculating the consequent financial implications are of paramount importance to all who are involved in building design and operation.

Logical methods of dealing with the calculations are introduced to enable the new user to cope with the complex conversion equations and calculation of energy costs per standard unit, the annual energy cost and the economic thickness of thermal insulation.

Degree days are explained and their use as an accounting tool is explored. The financial implications of purchasing or leasing energy-saving hardware equipment are investigated. Energy demand targeting is outlined. Greenhouse gas emissions to the atmosphere are explained and calculated.

Energy audit

Management of the energy that is used for buildings has three major components:

1. initial design;
2. retrofitting energy-saving measures;
3. maintenance practices.

Design engineers should provide heating, ventilating and air-conditioning systems that consume the minimum amount of fossil fuel energy in satisfying the needs of the site. The initial installation is designed in conjunction with the architecture and the client's requirements, in accordance with statutory legislation and in compliance with the standards of good engineering practice. The design includes the means of controlling the use of energy. Control can mean anything from switching building services plant on and off manually, up to a fully automated computer-based system that gives audible and visual alarms when something goes wrong. The best efforts of the design engineer are limited by the initial construction cost of the new installation, which is usually minimized. The installation of energy-saving systems often increases this cost. Some buildings are designed to be low-energy users. Most building services engineering systems are designed to provide thermal comfort for the conditions that are found in the building. For example, perimeter heating to overcome the heat loss through large areas of glazing and thermostatically controlled ventilation louvres in a naturally ventilated building in a cool climate.

Energy-saving measures that are installed after the first few years of use of a new building, or during a major upgrade, can be justified for two primary reasons. Either the owner of the building has decided to refurbish it, and has found the capital funding that is needed for all the work, or the operating cost of the site is significantly greater than comparable facilities, and the owner or tenant is prepared to invest in measures that will reduce annual outgoings. The owner may be forced to provide lettable office space that has competitive energy and maintenance costs. A building that has a labour-intensive maintenance and supervision workload, from steam boilers, manual switching of mechanical plant and lighting systems, unreliable water chillers, poorly maintained closed-circuit water conditions and highly stressed belt drives on fans, is not attractive to a new user.

Many sites have maintenance practices that encourage the provision of breakdown repairs and replacements, rather than by preventing breakdowns through good-quality methods. The financial controller of the business may view the annual maintenance budget as expendable, through a lack of understanding about engineering equipment. This is understandable. The maintenance engineer has only to ask the finance director whether it is preferable for a company car to be taken for regular servicing or to wait for the car to break down on a motorway during inclement weather, because the engine has run out of oil, the engine cooling system has boiled dry and the brake pads have worn down to the metal! This is how the maintenance budget of some sites is managed, that is, breakdown maintenance only. Many building services are critical to the life safety of the users. These life-safety systems are not just the emergency exit lighting, smoke spill ventilation fans, stairway air pressurization fans and electrical earth leakage circuit-breakers, but also include the air conditioning to hospital operating theatres, lifts, outside air ventilation dampers, domestic hot-water and cooling-tower bacteria controls. Proficient maintenance practice helps to prevent breakdowns by:

1. monitoring the condition of plant;
2. optimizing the maintenance activity to replace items only when they are needed;
3. keeping the maintenance team well motivated;
4. planning expenditure;
5. comprehensive maintenance record keeping;
6. enabling a quick response to problems, such as the failure of a fan motor, before the tenants complain of experiencing poor quality air conditions. The building maintenance manager usually has about half an hour from when an air-conditioning fan ceases to function to when the tenants complain on the telephone. If the plant failure has been monitored through the building management system computer with audible and visual alarms, and an automatically sent message to the engineer's pager or mobile phone, the corrective response can be made within 5 min and the tenants provided with a briefing.

The energy audit engineer assesses the practical and financial viability of energy-saving measures for each site, as is appropriate. The purpose of the energy-saving analysis is to identify suitable investments in capital equipment that will reduce the use of energy and labour, so that the savings will provide a payback on the investment in a reasonable period. This period will vary from 1 year, for those only interested in this year's profits, to 3 years for those who rely upon their bank for capital funding, to 5 years for those who can source capital funds from an equity performance contracting partner, to the longer terms of 10–25 years when the user is a government department and is to retain ownership of the public buildings indefinitely. The retrofit energy-saving measures that are usually considered include the following:

1. thermal insulation of the building;
2. solar shading;
3. changing the fuel source for heating and cooling;
4. heat pumps;
5. heat reclaim;
6. cogeneration of electricity with heating or cooling;
7. computer-based building management system;
8. digital control refrigerant circuit of the water chiller;
9. hot-water, chilled-water or ice thermal storage;
10. load shedding large electrical loads at critical times for short periods;
11. energy tariff change;
12. reducing the lighting system power usage;
13. variable-speed drives of fan and pump motors;
14. reducing the usage of water by taps and in toilets;
15. economy air recycling ductwork and motorized damper controls;

16. air-to-air heat exchange between exhaust and incoming outside air ducts;
17. occupancy-sensing with infrared, acoustic or carbon dioxide sensing to control lighting and the supply of outside air;
18. air curtains at doorways;
19. oxygen sensing in the boiler flue gas to modulate the combustion air supplied to the burner;
20. replacement of old inefficient boilers and heating systems;
21. distribution of domestic hot water at 45°C with a mixing valve and temperature control;
22. replacement of steam-to-water heat exchangers and calorifiers with local gas-fired heating and domestic hot-water systems;
23. thermal insulation of heating, cooling and steam pipework and heat exchangers;
24. recovery of the maximum quantity of condensate in a steam distribution system;
25. replacement and overhaul of steam traps and condensate pumping.

An energy audit of an existing building or a new development is carried out in a similar manner to a financial audit but it is not only money that is accounted. All energy use is monitored and regular statements are prepared showing final uses, costs and energy quantities consumed per unit of production or per square metre of floor area as appropriate. Weather data are used to assess the performance of heating systems. Monthly intervals between audits are most practical for building use, and in addition an annual statement can be incorporated into a company's accounts.

Payne (1978) is useful for further reading. An initial energy audit has certain basic aims. To:

1. establish total costs of energy purchased;
2. locate the principal energy-consuming areas;
3. notice any obvious losses or inefficient uses of heat, fuel and electricity;
4. take overall data to gain initial results quickly, which can be refined later and broken down into greater detail;
5. find where additional metering is needed;
6. take priority action to correct wastage;
7. survey buildings and plant use at night and weekends as well as during normal working hours;
8. initiate formal records monitored by the energy manager;
9. compare all energy used on a common basis (kilowatt-hours, therms or megajoules);
10. list energy inputs and outputs to particular buildings or departments.

A vital part of auditing is enlisting the cooperation of all employee groups, and explaining the problem not just in financial terms but also in quantities of energy. A joint effort by all staff is needed. Posters, stickers and prizes for ideas can be used to stimulate interest.

An overall energy audit will list each fuel, the annual quantity used and the cost for the year, including standing charges and maintenance; then a comparison is made with other fuels by converting to a common unit of measurement.

Energy use performance factors (*EUPF*) enable comparisons to be made between similar buildings or items of equipment. These can be litres of heating oil per degree day, kilowatt-hours of electricity consumption per square metre of floor area, megajoules of energy per person per hour of building use, or other accounting ratios as appropriate. For example, car manufacturers may analyse energy used per car. As experience is gained in auditing a particular building, data can be refined to monthly energy use in conjunction with degree day figures for this period.

This detailed analysis can be made for each building or department of a large site, each large room or factory area, each type of heating, air-conditioning or power-using system, each industrial process and each item of plant. The most serious deficiency in the acquisition of data is likely to be the lack of sufficient metering stations. Electricity, gas and other fuels are metered by the supply authority at the point of entry to the building or site; further metering is the responsibility of the site user. Frequently, no further meters are installed and capital expenditure is needed to obtain data. A careful cost benefit approach is required to assess the viability of this equipment (Moss, 1997).

Unity brackets

In order to deal with the numbers involved, a degree of familiarity with the units and conversion between the various types is needed. A handling technique known as the unity bracket helps to avoid errors being made when dealing with unfamiliar combinations of units. Suppose that we wish to convert 1260 mm into metres.

$$\text{length} = 1260 \text{ mm}$$

Now, 1000 mm $\equiv$ 1 m. Divide each side by 1 m: thus

$$\frac{1000 \text{ mm}}{1 \text{ m}} \equiv 1$$

The left-hand side is now a unity bracket exactly equal to 1 (or unity). Similar unity brackets can be formed for any suitable conversion problem. Now, multiply length by the unity bracket:

$$\begin{aligned} \text{length} &= 1260 \text{ mm} \times \frac{1 \text{ m}}{1000 \text{ mm}} \\ &= 1.26 \text{ m} \end{aligned}$$

Notice that the unity bracket is arranged so that its denominator units cancel the original units. A long chain of conversions can easily be handled and the method avoids errors of logic that can occur if an attempt is made to cope with the problem using mental arithmetic.

EXAMPLE 2.1

British Gas sold gas by the therm up to 1992. Harmonization of the units of measurement in Europe caused the change to kWh units. If 1 therm is equal to 105.5 MJ, how many kilowatt-hours are there in 1 therm?

$$\begin{aligned} 1 \text{ therm} &= 105.5 \text{ MJ} \\ 1 \text{ MJ} &= 10^6 \text{ J} \\ 1 \text{ h} &= 3600 \text{ s} \\ 1 \text{ Watt} &= 1 \text{ J/s} \end{aligned}$$

$$1\ \text{kWh} = 1\ \text{kWh} \times \frac{3600\ \text{s}}{1\ \text{h}} \times \frac{10^3\ \text{W}}{1\ \text{kW}} \times \frac{1\ \text{J}}{1\ \text{Ws}} \times \frac{1\ \text{MJ}}{10^6\ \text{J}} \times \frac{1\ \text{therm}}{105.5\ \text{MJ}}$$
$$= \frac{3600\ \text{s} \times 10^3}{10 \times 105.5}$$
$$= 0.0341\ \text{therms}$$

Therefore,

$$1\ \text{therm} = \frac{1}{0.0341}\ \text{kWh}$$
$$= 29.3056\ \text{kWh}$$

Gross calorific value of a fuel

The total heat energy content of a fuel is known as the gross calorific value (*GCV*) and is usually expressed in megajoules per kilogram (MJ/kg).

EXAMPLE 2.2

Heating oil has a specific gravity of 0.84 and a *GCV* of 44.8 MJ/kg. Find its heat content in kWh per litre.

$$GCV = 44.8\ \frac{\text{MJ}}{\text{kg}} \times \frac{0.84\ \text{kg}}{1\ \text{l}} \times \frac{10^3\ \text{kJ}}{1\ \text{MJ}} \times \frac{1\ \text{kWs}}{1\ \text{kJ}} \times \frac{1\ \text{h}}{3600\ \text{s}}$$
$$= \frac{44.8 \times 0.84 \times 10^3}{3600}\ \text{kWh/l}$$
$$= 10.453\ \text{kWh/l}$$

EXAMPLE 2.3

A site uses 48 000 l of oil of *GCV* 44.0 MJ/kg and specific gravity 0.84 costing £22 500 and 2×10^6 kWh of electricity costing 7.2 p per kWh. The fixed charge for the electrical installation is £3500 and the servicing cost for the oil-fired heating system is £8500. The period of use being considered is 1 year. Draw up an overall energy audit for the year.

$$\text{oil } GCV = 44.0\ \frac{\text{MJ}}{\text{kg}} \times \frac{0.84\ \text{kg}}{1\ \text{l}} \times \frac{10^3\ \text{kJ}}{1\ \text{MJ}} \times \frac{1\ \text{kWs}}{1\ \text{kJ}} \times \frac{1\ \text{h}}{3600\ \text{s}}$$
$$= 10.27\ \text{kWh/l}$$

$$\text{total cost of oil} = £22\,500 + £8500$$
$$= £31\,000$$

Table 2.1 Fuel cost data for Example 2.3.

Fuel	*Quantity*	*Total cost (£)*	*kWh*	*Cost per kWh*
Oil	48 000 l	31 000	492 960	6.29
Electricity	2×10^6 kWh	147 500	2 000 000	7.38
Total		178 500	2 492 960	7.16 (average)

$$\text{kWh of oil} = 48\,000\ \text{l} \times 10.27\ \frac{\text{kWh}}{\text{l}}$$

$$= 492\,960\ \text{kWh}$$

$$\text{cost per kWh for oil} = \frac{£31\,000}{492\,960} \times \frac{100\ \text{p}}{£1}$$

$$= 6.29\ \text{p/kWh}$$

$$1\ \text{kWh} = 1\ \text{unit of electricity}$$

$$\text{total cost of electricity} = 2 \times 10^6\ \text{kWh} \times \frac{7.2\ \text{p}}{\text{kWh}} \times \frac{£1}{100\ \text{p}} + £3500$$

$$= £147\,500$$

$$\text{cost per kWh of electricity} = \frac{£147\,500}{2\,000\,000\ \text{kWh}} \times \frac{100\ \text{p}}{£1}$$

$$= 7.38\ \text{p/kWh}$$

$$\text{Average cost of all energy used} = \frac{£178\,500}{2\,492\,960\ \text{kWh}} \times \frac{100\ \text{p}}{£1}$$

$$= 7.16\ \text{p/kWh}$$

The data are shown in Table 2.1.

Energy cost per useful gigajoule

The supplying authority or company quotes energy costs in the unitary system most convenient to their industry, and there is no obvious method of comparing the real cost of providing a specific amount of useful heat or power in the building. A decision can be made to reduce all costs to a common base unit and this may be the therm, the kilowatt-hour or the gigajoule, where,

$$1\ \text{GJ} = 10^9\ \text{J} = 10^6\ \text{kJ} = 10^3\ \text{MJ}$$

If the overall efficiency of the energy conversion process is included in the unit cost, then the incurred cost of using that system of heat or power can be realistically assessed. The cost per useful kWh is the cost of providing 1 kWh of useful heat, or energy, at the place of use. The overall efficiency of a central heating system will include the following.

1. Combustion efficiency of the fuel. Regular maintenance is necessary with all fuel-burning appliances to ensure that the correct fuel-to-air ratio is maintained.

2. Heat transfer efficiency of the appliance. Both flue gas and water-side surfaces must be kept clean.
3. Heat losses from distribution pipework. All hot-water pipes and surfaces must be adequately insulated unless they provide a useful heating surface in rooms. It is not good practice to allow heating system pipes to be bare metal as the uncontrolled heat transfer will lead to high fuel costs.
4. Ability of the final heat emitter to transfer warmth to the occupants. A hot-water central heating radiator placed under a window-sill should counteract down-draughts and provide a reasonably adequate air temperature at the window and at the inner surface of the outside wall; this has the effect of increasing heat flows through the window and wall. Placing the radiator on a warm internal wall will improve its useful heat output but at the loss of some warm usable space in the room as the window region will be colder.
5. Thermal storage capacity of the heating system and building. Large amounts of heat are stored in the water in heating systems and the dense fabric of buildings. An insensitive automatic control system, or the lack of such a system, will lead to wild swings above and below the desired resultant temperature and cause excessive fuel use.

The estimated overall system efficiencies are listed in Table 2.2 from Uglow (1981).

The cost in use of a fuel or source of energy, *UC*, can be calculated from the basic price *C* and the overall efficiency η. For gas,

$$UC = C\ \frac{\text{p}}{\text{kWh}} \times \frac{100}{\eta} + \frac{\text{annual standing charge}}{\text{annual kWh}}$$

Thus once the total kWh used during the year are assessed, the annual standing charge can be apportioned to each kWh. This is not necessary if the standing charge has already been incurred by another use, for example, cooking and water heating, and *UC* is being evaluated for an additional heating system.

Table 2.2 Overall efficiencies of heating systems.

Fuel	*Appliances*	*Overall efficiency η (%)*
Electricity	Individual appliances	100
	Storage radiators	90
	Storage warm air	90
	Storage under floor	90
Gas	Individual appliances	55
	Boiler and hot-water radiators	65–70
	Ducted warm air	70–75
Solid fuel	Open grate fire	35
	Closed stove	60
	Boiler and hot-water radiators	60
Oil	Boiler and hot-water radiators	65–70
	Ducted warm air	70–75

Note: The higher figures relate to intermittent heating system operation.

EXAMPLE 2.4

A gas-fired central heating and hot-water system is to be installed in a residential property. The gas tariff is 1.8 p/kWh plus a standing charge of 10 p per day. The estimated annual heat energy that will be used by the occupants is 165 000 kWh. The annual maintenance works cost £125.Find the total energy bill and the average cost per kWh, for the year.

From Table 2.2 the overall efficiency of the heating system, η, is 70%.

$$\text{energy usefully consumed} = 165\,000 \text{ kWh/year}$$

$$\text{energy paid for at the gas meter} = 165\,000 \times \frac{100}{70} \text{ kWh/year}$$

$$= 235\,714 \text{ kWh/year}$$

The nearest whole number of kWh is the significant number. Do not waste time with too many decimal places. Fractions of a millimetre, Watt, Pascal or kWh are of little or no significance to the reality of the calculation.

$$\text{total cost of energy} = 1.8 \frac{\text{p}}{\text{kWh}} \times 235\,714 \frac{\text{kWh}}{\text{year}} \times \frac{£1}{100 \text{ p}}$$

$$= £4243$$

$$\text{annual standing charge} = 365 \frac{\text{days}}{\text{year}} \times 10 \frac{\text{p}}{\text{day}} \times \frac{£1}{100 \text{ p}}$$

$$= £37$$

$$\text{total annual energy bill} = £4243 + £36 + £125$$

$$= £4404$$

$$\text{overall average cost of energy} = \frac{£4404}{235\,714 \text{ kWh}} \times \frac{100 \text{ p}}{£1}$$

$$= 1.87 \text{ p/kWh}$$

The cost in use, *UC*, for other fuel or energy sources is calculated from the basic price. These are pence per litre for oils, £ per tonne for solid fuels and £ per kg refill for liquefied petroleum gas. The specific gravity of liquid fuel, *SG*, is used to convert volume to mass measurements. When the specific gravity of an oil is 0.83, 1 l of the oil weighs 0.83 kg. One litre of water at 4°C weighs 1 kg. Oil and paraffin is sold by the litre but its heat content, gross calorific value *GCV*, is usually listed as around 45 MJ/kg. For oil

$$UC = C \frac{\text{p}}{1} \times \frac{1 \text{ l}}{SG \text{ kg}} \times \frac{\text{kg}}{GCV \text{ MJ}} \times \frac{100}{\eta} \times \frac{1 \text{ kJ}}{1 \text{ kWs}} \times \frac{3600 \text{ s}}{1 \text{ h}}$$

$$= \frac{C \times 100 \times 3600}{SG \times GCV \times \eta \times 10^3} \text{ p/kWh}$$

For solid fuel

$$UC = C\ \frac{\text{p}}{\text{kg}} \times \frac{\text{kg}}{GCV\ \text{MJ}} \times \frac{100}{\eta} \times \frac{1\ \text{MJ}}{10^3\ \text{kJ}} \times \frac{1\ \text{kJ}}{1\ \text{kWs}} \times \frac{3600\ \text{s}}{1\ \text{h}}$$
$$= \frac{C \times 100 \times 3600}{GCV \times \eta \times 10^3}\ \text{p/kWh}$$

For electricity

$$UC = C\ \frac{\text{p}}{\text{kWh}} \times \frac{100}{\eta}$$
$$= \frac{C \times 100}{\eta}\ \text{p/kWh}$$

Liquefied petroleum gas (*LPG*) (butane or propane) can be used from refillable cylinders on sites that are remote from the mains gas distribution of methane. *LPG* is sold at a refill charge per number of kilograms, depending upon the size of the cylinder. Convert the refill cost into a price per kilogram of *LPG* by dividing by its weight. For example, a 25 kg refill might cost £18.50:

$$UC = C\ \frac{\text{p}}{\text{kg}} \times \frac{\text{kg}}{GCV\ \text{MJ}} \times \frac{100}{\eta} \times \frac{1\ \text{MJ}}{10^3\ \text{kJ}} \times \frac{1\ \text{kJ}}{1\ \text{kWs}} \times \frac{3600}{1\ \text{h}}$$
$$= \frac{C \times 100 \times 3600}{GCV \times \eta \times 10^3}\ \text{p/kWh}$$

The calculation for paraffin is the same as that for oils:

$$UC = \frac{C \times 100 \times 3600}{SG \times GCV \times \eta \times 10^3}\ \text{p/kWh}$$

EXAMPLE 2.5

Construct a table of fuel cost per useful kWh from the data given below, assuming that standing charges have already been allocated to other services and need not be included here.

Gas: 1.8 p/kWh, $\eta = 75\%$, $GCV = 38.5$ MJ/m^3
Heating oil: $SG = 0.84$, $GCV = 45.8$ MJ/kg, $\eta = 70\%$, 42.0 p/l
Anthracite: $GCV = 26.7$ MJ/kg, $\eta = 60\%$, 9.0 p/kg
Electricity: daytime 10.0 p/kWh, $\eta = 100\%$; night-time 4.5 p/kWh, $\eta = 90\%$
LPG (propane): 32.0 p/kg, $\eta = 70\%$, $GCV = 50$ MJ/kg
Paraffin: 29.0 p/l, $\eta = 80\%$, $GCV = 46.4$ MJ/kg, $SG = 0.79$

$$\text{gas cost} = 1.80\ \frac{\text{p}}{\text{kWh}} \times \frac{100}{75}$$
$$= 2.4\ \text{p/kWh}$$

$$\text{oil cost} = \frac{42.0 \times 100 \times 3600}{70 \times 0.84 \times 45.8 \times 1000}$$
$$= 5.6\ \text{p/kWh}$$

$$\text{anthracite cost} = \frac{9.0 \times 100 \times 3600}{60 \times 26.7 \times 1000}\ \text{p/kWh}$$
$$= 2.02\ \text{p/kWh}$$

$$\text{electricity (day)} = 10.0 \times \frac{100}{100}\ \text{p/kWh}$$
$$= 10.0\ \text{p/kWh}$$

$$\text{electricity (night)} = 4.50 \times \frac{100}{90}\ \text{p/kWh}$$
$$= 5.0\ \text{p/kWh}$$

$$\textit{LPG}\ \text{(propane) cost} = \frac{32.0 \times 100 \times 3600}{70 \times 50.0 \times 1000}\ \text{p/kWh}$$
$$= 3.3\ \text{p/kWh}$$

$$\text{paraffin cost} = \frac{29.0 \times 100 \times 3600}{80 \times 0.79 \times 46.4 \times 1000}\ \text{p/kWh}$$
$$= 3.6\ \text{p/kWh}$$

Notice that the cost of energy in £ per useful GJ is likely to be within the range from £2 to £25 for the foreseeable future. £3 per GJ may apply to the lowest grades of solid and liquid fuels, which are used in large power-generating stations. £25 per GJ will be the upper limit for electricity consumed during the day by household consumers.

Deregulation of the electricity in the UK and Australia has led to falling prices for peak electricity. Natural gas, where it is available, remains the most popular means of generating electrical power, heating and cooling, owing to its cleanliness, convenience and lack of site storage requirement.

EXAMPLE 2.6

Evaluate the fuel cost in pounds per useful gigajoule and add them to Table 2.3.

Table 2.3 Summary of fuel costs.

Fuel	*Cost per useful unit*	
	Pence/kWh	*£/GJ*
Gas	2.4	7.14
Electricity (night)	5.0	13.9
Paraffin	3.6	9.9
Oil	5.6	15.6
Anthracite	2.02	5.61
LPG (propane)	3.3	9.14
Electricity (day)	10.0	27.78

$$\text{gas cost} = 1.80\ \frac{\text{p}}{\text{kWh}} \times \frac{100}{70} \times \frac{1\ \text{kWs}}{1\ \text{kJ}} \times \frac{1\ \text{h}}{3600\ \text{s}} \times \frac{10^6\ \text{kJ}}{1\ \text{kJ}} \times \frac{£1}{100\ \text{p}}$$

$$= 1.80 \times \frac{100}{70} \times \frac{10^6}{3600 \times 100}\ £/\text{GJ}$$

$$= 2.57 \times 2.778\ £/\text{GJ}$$

$$= £7.14\ \text{per GJ}$$

The 2.778 is the constant which, when multiplied by the fuel cost in pence per useful kWh, will give the equivalent in £/GJ.

$$\text{oil cost} = \frac{42.0 \times 100 \times 10^3}{70 \times 0.84 \times 45.8 \times 100}\ £/\text{GJ}$$

$$= £15.6\ \text{per GJ}$$

$$\text{anthracite cost} = \frac{9.0 \times 100 \times 10^3}{60 \times 26.7 \times 100}\ £/\text{GJ}$$

$$= £5.61\ \text{per GJ}$$

$$\text{electricity (day)} = \frac{10.0 \times 100 \times 10^6}{100 \times 3600 \times 100}\ £/\text{GJ}$$

$$= £27.78\ \text{per GJ}$$

$$\text{electricity (night)} = \frac{4.5 \times 100 \times 10^6}{90 \times 3600 \times 100}$$

$$= £13.9\ \text{per GJ}$$

$$\text{LPG (propane) cost} = \frac{32.0 \times 100 \times 10^3}{70 \times 50.0 \times 100}$$

$$= £9.14\ \text{per GJ}$$

$$\text{paraffin cost} = \frac{29.0 \times 100 \times 10^3}{80 \times 0.79 \times 46.4 \times 100}\ £/\text{GJ}$$

$$= £9.9\ \text{per GJ}$$

Greenhouse gas

The energy used by building services systems is one of the global sources of greenhouse gas production. Greenhouse gases in the atmosphere include the carbon dioxide emitted from combustion of fuels. Fuel is consumed within the building and in the provision of electricity for the building. Electricity is generated at power stations from a variety of primary energy sources: coal, oil, natural gas, nuclear fuel and renewables such as hydroelectric systems, wind turbines, wave-driven turbines and solar-powered photo-voltaic cells. There is not an electricity generation system that is free of greenhouse gas production. Where does nuclear fuel come from? Uranium 235-rich rock is mined from the ground in Canada and Australia by diesel-driven excavators, the rock is processed to separate out the silvery-white metal that is processed into fuel and transported, all of which consumes diesel fuel and electrical energy. Disposal of the spent nuclear fuel rods takes further energy for transportation, processing, mining, hundreds of years of storage with manual supervision and maintenance. Renewable energy systems require diesel energy for construction, concrete, steel, electrical energy when the wind or sunshine is not available, manual work for supervision, maintenance and replacement parts.

Table 2.4 Energy–CO_2 conversion factors.

Energy source	*CO_2 conversion factor (kg C/kWh)*
Natural gas	0.055
Oil	0.079
Coal	0.093
Electricity	0.142

The greenhouse gas, carbon dioxide, conversion factors for energy use are shown in Table 2.4 (Action Energy publication EEB006 Offices, appendix 1, figure A1.1). These are the quantity of carbon, supplied from the energy source, combusted and converted into carbon dioxide that is discharged into the atmosphere when the energy is used. These kilograms of carbon per kilowatt-hour of energy source consumed (kg C/kWh) factors usually are for the full cycle involved in acquiring the energy source, the energy used in its processing and the losses in distribution to the final user. For example, natural gas is heated at the land terminal from undersea gas fields, pumped to overcome friction in hundreds of kilometres of pipelines and some gas leaks occur. Electricity comes from a mixture of raw energy sources in the UK such as coal, oil, natural gas, nuclear and hydro schemes; the overall CO_2 conversion factor has to accommodate the mix of sources used. Electrical distribution between the power stations and the final user requires cables having resistance and leakage losses. Oil and coal are processed and then distributed by diesel engine-driven transport by road, rail and ship.

EXAMPLE 2.7

A small commercial building has a predicted energy consumption of 250 000 kWh per year for only the space heating system. The design engineer is to recommend the energy source and system type to be used on the basis of minimizing the greenhouse gas emissions. The usage efficiency of the alternative systems are 100% for electrical individual appliances, 70% for gas-fired radiator heating system, 60% for coal-fired radiator heating system and 75% for an oil-fired ducted warm-air heating system. Use the carbon conversion factors in Table 2.4 and make a suitable recommendation to the client.

The analysis is shown in Table 2.5.

$$\text{For natural gas, carbon emission} = \frac{250\,000\ \text{kWh}}{70\%} \times 0.055\ \frac{\text{kg}\ C}{\text{kWh}}$$

$$= 19\,643\ \text{kg}\ C\ \text{p.a.}$$

$$\text{For heating oil, carbon emission} = \frac{250\,000\ \text{kWh}}{75\%} \times 0.079\ \frac{\text{kg}\ C}{\text{kWh}}$$

$$= 26\,333\ \text{kg}\ C\ \text{p.a.}$$

$$\text{For coal-fired, carbon emission} = \frac{250\,000\ \text{kWh}}{60\%} \times 0.093\ \frac{\text{kg}\ C}{\text{kWh}}$$

$$= 38\,750\ \text{kg}\ C\ \text{p.a.}$$

$$\text{For electrical heating, carbon emission} = \frac{250\,000\ \text{kWh}}{100\%} \times 0.142\ \frac{\text{kg}\ C}{\text{kWh}}$$

$$= 35\,500\ \text{kg}\ C\ \text{p.a.}$$

Table 2.5 Carbon emissions in Example 2.7.

Energy source	*Useful energy (kWh)*	*System efficiency (%)*	*CO_2 factor (kg C/kWh)*	*Carbon emission (kg p.a.)*
Natural gas	250 000	70	0.055	19 643
Oil	250 000	75	0.079	26 333
Coal	250 000	60	0.093	38 750
Electricity	250 000	100	0.142	35 500

Table 2.6 Degree day data showing 20-year averages.

Region	*Month*											
	Sep.	*Oct.*	*Nov.*	*Dec.*	*Jan.*	*Feb.*	*Mar.*	*Apr.*	*May*	*June*	*July*	*Aug.*
Thames	56	129	252	333	349	306	281	200	113	49	25	27
NE Scotland	125	196	321	382	399	362	340	274	203	112	86	86

The client will be advised that a natural gas-fired heating system provides the lowest greenhouse gas emissions and that using a condensing water heater would further reduce carbon emissions by, around, 10% as the water heater efficiency would rise from a seasonal average of around 75% to at least 85%.

Annual energy costs

Annual fuel costs can be estimated in advance of their occurrence from a knowledge of the following:

1. energy cost per useful unit;
2. length of heating season;
3. operational hours of the system;
4. mean internal building temperature;
5. design external temperature;
6. degree days for the locality.

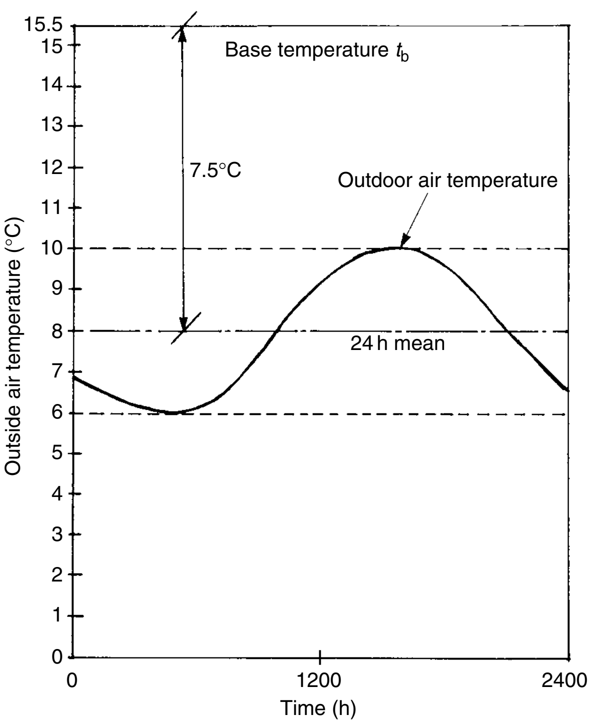
The design steady-state building heat loss is known as the design external air temperature (Chapter 3) and ranges from −1°C to −5°C. Throughout the heating season, the heat loss will fluctuate with the cyclic variations in ambient temperature. Fortuitous heat gains will reduce fuel consumption provided that the automatic controls can reduce heating system performance sufficiently and avoid overshooting the desired room temperatures. Weather variations are evaluated by using the degree day data issued monthly by the Department of Energy. Table 2.6 shows degree days for 2 of the 17 geographical regions covering the UK (Moss, 1997).

Degree days are recorded temperature data that facilitate the production of a climatic correction or load factor for calculation of heating system operational costs and efficiency over months or yearly time intervals. They are applied to normally occupied buildings where the heat loss from the warm interior is balanced by gains of heat from the sun, occupants, lighting, cooking and hot-water usage at an external air temperature of 15.5°C; this is known as the base temperature t_b. The value taken for the base temperature is an estimate of the conditions under which there will be no net heat loss from a traditionally constructed residence; thus no fuel will be consumed at this and higher outside temperatures.

Calculation of the actual base temperature for a particular building may reveal another value; consequently, care is needed in the application of degree day data, and correction factors may be included for other than traditionally constructed dwellings: for example, highly insulated or commercial structures and where internal heat gains from electrical equipment are high (CIBSE, 1986).

The standard method of use is to assess the daily difference between the base temperature and the mean value of the external air temperature during each 24-h period. A modified calculation is made when the base temperature is below the external mean temperature, as this would indicate a net heat gain to the building. Degree day data are not used for air-conditioning cooling-load calculations as they are not appropriate. Figure 2.1 shows a typical fluctuation in external air temperature relative to base temperature. As the maximum and minimum air temperatures are 10°C and 6°C respectively, the 24-h mean is 8°C. Therefore, as there is a difference of 7.5°C per day, 7.5 degree days are added to the accumulated total for that month.

The maximum possible number of degree days for a particular location and period of heating system operation can be found as shown in the following example.



2.1 Method of calculating degree days during a 24-h period.

EXAMPLE 2.8

A house is continuously occupied during a 30-week heating season. The design external air temperature is $-1.0°C$. Find the maximum possible number of degree days.

$$\begin{aligned}\text{days} &= 30\ \text{weeks} \times \frac{7\ \text{days}}{1\ \text{week}} \\ &= 210\ \text{days} \\ \text{maximum temperature difference} &= [15.5 - (-1.0)]°C \\ &= 16.5°C \\ \text{maximum degree days} &= 210\ \text{days} \times 16.5°C \\ &= 3465\ \text{degree days}\end{aligned}$$

The load factor L is the ratio of actual to maximum degree days and is used to find the average rate of heat loss from a building over the heating season:

$$L = \frac{\text{degree days for locality}}{\text{maximum possible degree days}}$$

EXAMPLE 2.9

Find the average rate of boiler power used during the heating season when there were 2460 degree days, and steady-state heat losses were calculated to be 24.5 kW at an outside air temperature of $-1°C$.

$$\begin{aligned}L &= \frac{2460}{3465} \\ &= 0.71\end{aligned}$$

$$\begin{aligned}\text{seasonal average rate of heat loss} &= \text{design heat loss} \times \text{load factor} \\ &= 24.5\ \text{kW} \times 0.71 \\ &= 17.4\ \text{kW}\end{aligned}$$

The boiler will have an average heat output of 17.4 kW over the heating season, that is, in addition to the hot-water service requirement and heat losses from pipework.

Degree days can be used to monitor fuel consumption and check that it is not being used wastefully. Incorrectly serviced fuel-burning appliances would show an increasing use of energy per degree day rather than a constant rate. Deterioration of the performance of an automatic control system or lack of proper manual regulation of ventilation openings would also result in a departure from expected ratios. A graph of energy consumption against degree days should be linear for a building, and any major divergence will show that corrective action is needed. Figure 2.2 shows an example.

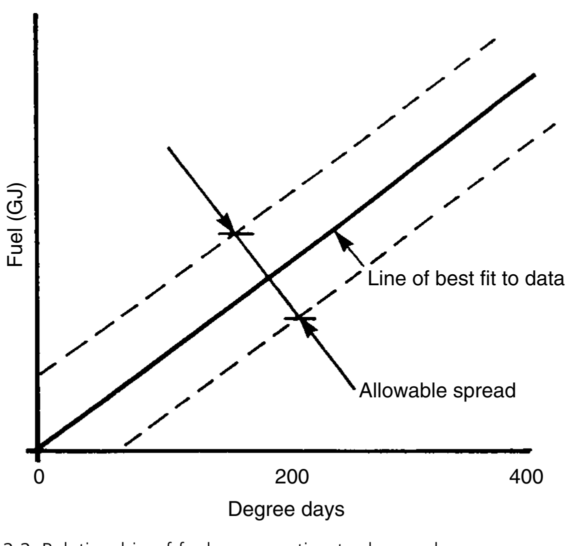
The calculation of expected annual fuel costs is now a matter of finding the number of gigajoules or therms consumed in the building and then the cost of providing this useful amount of heat.

EXAMPLE 2.10

A hospital is heated for 24 h per day, 7 days per week for 30 weeks a year. Its steady-state heat loss at −1°C outside is 2850 kW, and a gas-fired boiler with hot-water radiator central heating system is used. Estimate the annual fuel cost for heating the building if there are likely to be 2240 degree days in that locality. Maximum degree days are 3465. Gas costs £7.20 per useful gigajoule.

$$\text{load factor} = \frac{2240}{3465} = 0.65$$

$$\begin{aligned}
\text{annual energy} &= \text{heat loss} \times \text{load factor} \times \text{operating time} \\
&= 2850\ \text{kW} \times 0.65 \times \frac{24\ \text{h}}{\text{day}} \times \frac{210\ \text{days}}{\text{year}} \times \frac{3600\ \text{s}}{1\ \text{h}} \\
&\quad \times \frac{1\ \text{kJ}}{1\ \text{kWs}} \times \frac{1\ \text{GJ}}{10^6\ \text{kJ}} \\
&= 2850 \times 0.65 \times 24 \times 210 \times 3600 \times 10^{-6}\ \text{GJ} \\
&= 33\,612\ \text{GJ/year}
\end{aligned}$$



2.2 Relationship of fuel consumption to degree days.

$$\text{annual cost} = \text{useful energy required } \frac{\text{GJ}}{\text{year}} \times \frac{\text{cost £}}{\text{useful GJ}}$$

$$= 33\,612 \ \frac{\text{GJ}}{\text{year}} \times \frac{£7.20}{\text{GJ}}$$

$$= £242\,006 \text{ p.a.}$$

EXAMPLE 2.11

An initial energy audit of a hospital revealed the data shown in Table 2.7. The data were for a month that had 260 degree days, and the energy manager required energy use performance factors of total cost per square metre of floor area, heating system energy used per degree day and electrical energy used per person per hour. All gas consumed was for the heating system and cost 1.85 p/kWh plus £750 per month standing charge and £550 per month for maintenance.

Electricity cost was 10 p/kWh and maintenance costs amounted to £550 per month.

Table 2.7 Energy audit data for Example 2.11.

Location	*Electricity (kWh)*	*Gas (kWh)*	*Floor (m^2)*	*Usage (h)*	*Occupants*
Medical	12 000 000	13 000 000	45 000	670	2300
Administration	1 500 000	1 000 000	3500	350	220
Engineering	150 000	250 000	1000	400	23
Totals	13 650 000	14 250 000	49 500	1420	2543

Energy use performance factor of total cost per square metre of floor area for the month, $EUPF_1$:

$$\text{electricity cost} = 13\,650\,000 \text{ kWh} \times 10 \ \frac{\text{p}}{\text{kWh}} \times \frac{£1}{100 \text{ p}} + £550$$

$$= £1\,365\,550$$

$$\text{gas cost} = 14\,250\,000 \times 1.85 \ \frac{\text{p}}{\text{kWh}} \times \frac{£1}{100 \text{ p}} + £750 + £550$$

$$= £264\,925$$

$$EUPF_1 = \frac{£1\,365\,550 + £264\,925}{49\,500 \text{ m}^2}$$

$$= £32.94 \text{ per m}^2 \text{ floor area}$$

$EUPF_2$ gas heating system energy used per degree day:

$$EUPF_2 = \frac{14\,250\,000 \text{ kWh}}{260 \text{ degree days}}$$

$$= 54\,808 \text{ kWh/degree day}$$

$EUPF_3$, electrical energy used per person per hour:

$$\begin{aligned}\text{total occupation} &= \text{sum of (occupants} \times \text{usage hours)}\\ &= (2300 \times 670) + (220 \times 350) + (23 \times 400)\\ &= 1\,627\,200 \text{ person-hours}\\ EUPF_3 &= \frac{14\,250\,000 \text{ kWh}}{1\,627\,200 \text{ person-hours}}\\ &= 8.76 \text{ kWh/person/h}\end{aligned}$$

You may wish to evaluate the energy use performance factors for various locations for comparison.

Economic thickness of thermal insulation

A balance needs to be made between the capital cost of thermal insulation of buildings or hot surfaces and the potential reduction in fuel costs in order to obtain the lowest total cost combination of these two cash flows. Capital cost is normally expected to be recovered from fuel cost savings during the first 2–3 years of use; however, longer periods than this are needed for major structural items, such as cavity fill and double glazing, and there will be additional benefits, such as improved thermal storage capacity, reduced external noise transmission, fewer draughts and added value to the property, that do not fit easily into a financial treatment of their worth.

For a flat surface, the cost of heat loss per square metre through the structure can be represented as follows:

$$\begin{aligned}\text{Fuel cost} &= U\,\frac{\text{W}}{\text{m}^2\text{K}} \times (t_{ai} - t_{ao})\text{ K} \times L \times S\,\frac{\text{h}}{\text{year}} \times \frac{3600\text{ s}}{1\text{ h}} \times \frac{1\text{ J}}{1\text{ W s}} \times \frac{1\text{ GJ}}{10^9\text{ J}} \times \frac{\pounds C}{\text{GJ}}\\ &= \pounds[U(t_{ai} - t_{ao})LS \times 3.6C \times 10^{-6}] \text{ per m}^2\text{year}\end{aligned}$$

The cost of fuel usage for a range of thermal transmittances U can be calculated for a particular structure. This is usually a decreasing curve for increasing insulation thickness as each additional layer reduces the thermal transmittance by progressively smaller amounts.

If the cost £/m^3 of the thermal insulation as installed is known, then the cost for each thickness per square metre of surface area can be found from

$$\text{insulation cost} = \frac{\pounds}{\text{m}^3} \times \frac{\text{thickness m}}{\text{repayment time years}}$$

Data from these equations can be drawn on a graph. Addition of the two curves produces a total cost curve. The lowest point on this curve gives the optimum insulation thickness; if its lower part is fairly flat, then any one of a number of commercially available thicknesses will be economic.

EXAMPLE 2.12

Expanded polystyrene board is to be added to the internal face of a wall having an initial thermal transmittance of 3.30 W/m^{2}K in thicknesses of 25, 50, 75, 100, 125 and 150 mm. Insulated wall thermal transmittances will be 0.96, 0.56, 0.40, 0.31, 0.25 and 0.21 W/m^{2}K. The insulation costs £48 per cubic metre fitted and the capital recovery period is to be 3 years. Fuel costs £8.93 per useful gigajoule. Internal and external design temperatures are 21°C and −1°C respectively, the load factor is 0.608 and the building is to be heated for 3000 h per year. Use the information provided to find the economic thickness of insulation.

$$\text{fuel cost} = U[21 - (-1)] \times 0.608 \times 3000 \times 3.6 \times 8.93 \times 10^{-6}\ \text{£/m}^2\ \text{year}$$

$$= 1.29U \text{ per m}^2 \text{ year}$$

$$\text{insulation cost} = \frac{\text{£}48}{\text{m}^3} \times \frac{\text{thickness } l \text{ m}}{3 \text{ years}}$$

$$= 16\, l \text{ per m}^2\text{year}$$

The results are shown in Table 2.8. Figure 2.3 shows that the total cost curve can be drawn by adding the fuel and insulation cost curves for each insulation thickness. The economic thickness is 50 mm.

The economic thermal transmittance of a structure with a flat surface can be evaluated from the following equation (Diamant, 1977):

$$U_e = \left[\frac{\lambda \alpha l}{8.64C(Y + S\Delta t)}\right]^{1/2}$$

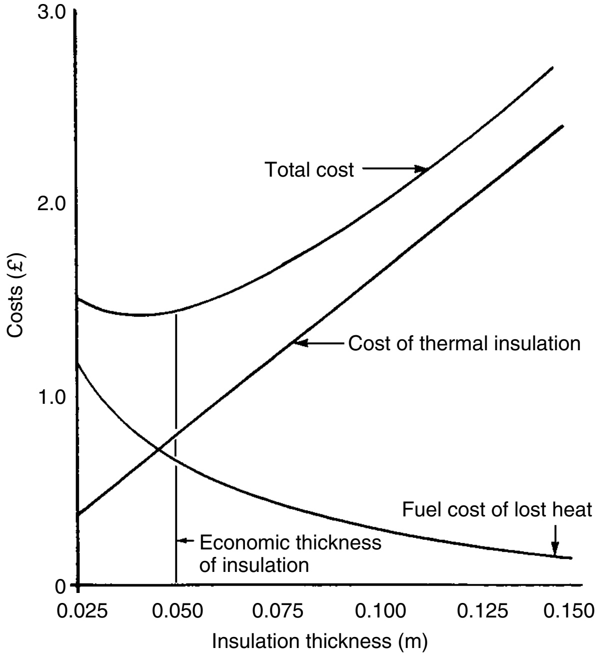
where U_e is the economic U value (W/m^{2}K), λ is the thermal conductivity (W/mK), α is the depreciation and interest charges (%), l is the total cost of thermal insulation fitted into the building (£/m^3), C is the cost of useful heat (£/MJ), Y is the annual degree days for a base temperature of 18°C, S is the length of the heating season (days) and Δt is the difference between the average internal air temperature and 18°C. Once U_e has been found, the thermal insulation thickness can be found from

$$l = \lambda\left(\frac{1}{U_e} - \frac{1}{U}\right) \text{m}$$

where U is the uninsulated thermal transmittance (W/m^{2}K).

Table 2.8 Cost data for Example 2.12.

Thickness l (m)	*0.025*	*0.050*	*0.075*	*0.100*	*0.125*	*0.150*
U (W/m^{2}K)	0.96	0.56	0.40	0.31	0.25	0.21
Insulation cost (£)	0.40	0.80	1.20	1.60	2.00	2.40
Fuel cost (£)	1.24	0.72	0.52	0.40	0.32	0.27
Total cost (£)	1.64	1.52	1.72	2.00	2.32	2.67



2.3 Economic thickness of the wall insulation in Example 2.12.

EXAMPLE 2.13

The roof of a factory in Lancashire is insulated with expanded polystyrene (EPS) slab. The locality has 3070 degree days for a base temperature of 18°C and a heating season of 235 days. The average internal air temperature is 20°C. The EPS costs £65 per cubic metre fitted, interest is charged at 7% and the life expectancy of the insulation is 45 years. Heat costs £8.50 per gigajoule. The thermal conductivity of EPS is 0.035 W/mK. Find the economic insulation thickness.

The original thermal transmittance of the single sheet roofing is 6.0 W/m^{2}K.

$$\alpha = 7\% \text{ interest per annum} + 2\% \text{ depreciation per annum}$$
$$= 9\%$$
$$C = \frac{£8.50}{\text{GJ}} \times \frac{1\ \text{GJ}}{10^3\ \text{MJ}}$$
$$= £8.50 \times 10^{-3} \text{ per MJ}$$
$$U_e = \left[\frac{0.035 \times 9 \times 65}{8.64 \times 8.5 \times 10^{-3} \times (3070 + 235 \times (20 - 18))}\right]^{1/2} \text{ W/m}^2\text{K}$$
$$= 0.28 \text{ W/m}^2\text{K}$$

$$l = 0.035\left(\frac{1}{0.28} - \frac{1}{U}\right)$$

$U = 6.5$ W/m^{2}K for the uninsulated roof.

Therefore

$$l = 0.035\left(\frac{1}{0.28} - \frac{1}{6.5}\right)$$

$$= 0.120 \text{ m}$$

Thus the economic thickness of insulation for this roof is 120 mm. As EPS slab is manufactured in 50 mm thickness, the insulated U value for 150 mm thickness will be 0.225 W/m^{2}K.

Accounting for energy-economizing systems

Once the capital cost and fuel cost savings have been assessed for thermal insulation, fuel-saving equipment or automatic controls, the capital repayment period or return on capital investment can be calculated in simple terms:

$$\text{capital repayment period} = \frac{\text{capital cost}}{\text{energy savings per year}}$$

$$\text{percentage return on investment} = \frac{\text{energy savings per year}}{\text{capital cost}} \times 100$$

Further refinements such as discounted cash flow, loan interest charges, tax allowances and grants can be included to improve accuracy.

Cash flow statements for limited companies are handled differently from those for home-owners, as allowances for capital expenditure and taxation on increased profitability due to energy economies can markedly improve estimates of payback times. A purchase costing £500 000, which would save £200 000 in the first year's energy bill, would appear to take 2.5 years for capital recovery, but the cash flow projection may be as shown in Table 2.9. Figures in parentheses are outward cash flows from the business. Energy costs are indicated to increase by 5% per year, so savings increase by the same amount.

This investment commences cash generation during the second year of equipment use and would start to provide funds for further investment. Certain items of equipment can be leased

Table 2.9 Cash flow forecast for the purchase of an energy-economizing system.

		Year 1	*Year 2*	*Year 3*
A	Cash balance brought forward	0	(315 000)	(53 000)
B	Capital purchase	(500 000)	0	0
C	Energy saving	200 000	210 000	220 500
D	Capital allowance, 1 year in arrears 25% × B	0	125 000	0
E	Cash balance (A − B + C + D)	(300 000)	20 000	167 500
F	Interest, say 10% × E × 0.5	(15 000)	1000	8375
G	Tax, 1 year in arrears, 40% × (C + F)	0	(74 000)	0
H	Net cash flow (C + D + F − B − C)	(315 000)	262 000	228 875
I	Cash balance (A + H)	(315 000)	(53 000)	175 875

Table 2.10 Cash flow forecast for the leasing of an energy-economizing equipment.

		Year 1	*Year 2*	*Year 3*
A	Cash balance brought forward	0	157 500	270 375
B	Leasing payment, 10% × cost	(50 000)	(50 000)	(50 000)
C	Energy saving	200 000	210 000	220 500
D	Capital allowance	0	0	0
F	Cash balance (A − B + C + D)	150 000	317 500	440 875
F	Interest, say 10% × E × 0.5	7500	15 875	22 044
G	Tax, 40% × (C + F − B), 1 year in arrears	0	(63 000)	(70 350)
H	Net cash flow (C + D + F − B − G)	157 500	112 875	122 194
I	Cash balance (A + H)	157 500	270 375	392 569

rather than purchased, and this releases cash earlier but calls for continuous payments to the leasing company. Table 2.10 shows a sample cash flow forecast. Cash flow is always positive to the company, but leasing payments are made for 10 years and then at a reduced rate after that period. Self-contained items of plant such as heat pumps or electricity generators may be leased.

Low-energy buildings

Low-energy buildings are those that utilize energy efficiently to maintain a comfortable thermal environment suitable for the purpose of the building. Design software for steady-state and dynamic use of the building are available from many sources such as the Building Regulations, Building Research Establishment Environmental Assessment Method, BREEAM, Leadership in Energy and Environmental Design, LEED, Green Star and Greenhouse Rating schemes, and are applied variously to the design stage and also during the service period of the building to meet agreed standards. Energy design targets may be proposed that include uses for heating, ventilation, hot-water services, lighting and electrical power. The total demand target T for a building is assessed by adding the thermal demand target T_T to the electrical demand target T_E in the CIBSE *Building Energy Code* (CIBSE, 1981).

In heated and naturally ventilated buildings, the rate of heat loss is related to the floor area by the dimensionless building envelope number B:

$$B = \frac{A_W}{A_f} + \frac{K_1}{n_f} + K_2 H$$

where A_W is the gross external walling surface area (m^2), A_f is the total floor area (m^2), n_f is the number of storeys and H is the floor-to-ceiling height (m). When hot-water services are included:

$$T_T = C_1 B + C_2 \text{ W/m}^2$$

where K_1, K_2, C_1 and C_2 are constants given in Table 2.11, C_3 is the mean electrical power requirement for the lighting system (W/m^2) and,

$$T_E = C_3 + 0.10 T_T \text{ W/m}^2$$

which shows that the electrical power consumption associated with the heating services is expected to be 10% of the thermal target.

Table 2.11 Values of constants for demand target.

Building type	K_1	K_2	C_1	C_2	C_3
Office, 5 days/week	0.5	0.1	13	−5	24
Shop, 6 days/week	0.5	0.1	16	−6	27
Factory, 5 days/week, single shift	1.1	0.2	6	3	8
Hotel	1.0	0.1	15	−3	15
Warehouse	1.1	0.2	6	−2	6
Hospital	1.0	0.1	17	+12	15
Institutional residence	1.0	0.1	15	±4	15
Educational	0.5	0.2	16	−4	13

EXAMPLE 2.14

Find the total demand target for a proposed 10-storey hospital medical building 50 m long, 30 m wide and 3 m floor-to-ceiling height, and compare it with an alternative design having the same floor area but of single-storey design, 172 m long and 87 m wide. Comment on the relative energy use of these alternative configurations.

For the 10-storey block

$$A_f = 50 \times 30 \times 10 \text{ m}^2$$
$$= 15\,000 \text{ m}^2$$
$$A_W = 10 \times 3 \times 2 \times (50 + 30) \text{ m}^2$$
$$= 4800 \text{ m}^2$$
$$n_f = 10$$
$$H = 3 \text{ m}$$

From Table 2.11, $K_1 = 1$ and $K_2 = 0.1$. Then:

$$B = \frac{4800}{15\,000} + \frac{1}{10} + (0.1 \times 3)$$
$$= 0.72$$

Also from Table 2.11, $C_1 = 17$, $C_2 = +12$ and $C_3 = 15$ W/m^2. Then:

$$T_T = (17 \times 0.72 + 12) \text{ W/m}^2$$
$$= 24.24 \text{ W/m}^2$$
$$T_E = (15 + 0.1 \times 24.24) \text{ W/m}^2$$
$$= 17.4 \text{ W/m}^2$$

Thus:

$$T = T_T + T_E$$
$$= (24.24 + 17.4) \text{ W/m}^2$$
$$= 41.6 \text{ W/m}^2$$

Similarly, for the single-storey building:

$$B = 1.4$$

$$T_T = 35.8 \text{ W/m}^2$$

$$T_E = 18.6 \text{ W/m}^2$$

$$T = 54.4 \text{ W/m}^2$$

The single-storey building has a better chance of being ventilated by assisted natural systems, rather than the mechanical plant needed in multi-storey designs. The walls and perimeter glazing are more easily shaded from solar heat gains; floor usage is more efficient as vertical service shafts, lifts and stairways are unnecessary; wind exposure is reduced; and maintenance of the external surfaces of the building is less costly.

Both buildings have the same floor area; the lower fatter configuration has less external wall surface area and consequently a higher total demand target.

Compliance with the demand target is achieved when the total demand of the proposed building does not exceed its target figure; the thermal demand may be up to 10% greater than its target value, but the total demand target must not be surpassed.

The effect on gas consumption of thermal insulation in houses

When the design steady-state heat loss from a dwelling is reduced by the addition of thermal insulation and draught-proofing, increased standards of thermal comfort are provided. However, the full potential saving due to the extra insulation may not be reflected in the fuel bills as expected. Field measurements (British Gas, 1980) have shown a correlation between domestic gas consumption, design heat loss, occupancy and degree days for the locality:

$$\text{annual therms} = 61 + \frac{70YQ}{2222} + 59N$$

where Y denotes annual degree days, N is the number of persons in the household and Q is the design heat loss in kilowatts. This relationship permits an assessment of anticipated gas consumption for heating and hot-water services in housing and quantification of thermal insulation savings.

Therms are no longer used, so they are converted into kWh by multiplying by 29.3056:

$$\text{annual gas consumption} = 29.3056 \times \left(61 + \frac{70 \times 2120 \times 36}{2222} + 59N\right) \text{ kWh}$$

EXAMPLE 2.15

A house in the Thames region has a design heat loss of 28 kW and up to six occupants. Added thermal insulation reduces the design heat loss to 23 kW. Estimate the probable energy, greenhouse gas and cost savings for the gas-fired central heating and hot-water system.

Natural gas costs 2.8 p/kWh.

From Table 2.4 the total degree days for the year are 2230.

$$\text{Energy before insulation} = 29.3056 \times \left(61 + \frac{70 \times 2230 \times 28}{2222} + 59 \times 6\right) \text{ kWh}$$

$$= 69\,808 \text{ kWh}$$

$$\text{Energy after insulation} = 29.3056 \times \left(61 + \frac{70 \times 2230 \times 23}{2222} + 59 \times 6\right) \text{ kWh}$$

$$= 59\,514 \text{ kWh}$$

$$\text{Energy saving} = (69\,808 - 59\,514) \text{ kWh}$$

$$= 10\,294 \text{ kWh}$$

$$\text{Carbon emission saving} = 10\,294 \text{ kWh} \times \frac{0.055 \text{ kg } C}{\text{kWh}}$$

$$= 566 \text{ kg}$$

$$\text{gas cost saving} = 10\,294 \text{ kWh} \times \frac{2.8}{\text{kWh}} \times \frac{£1}{100 \text{ p}}$$

$$= £288.00 \text{ during the first year}$$

Questions

1. State the function of an energy audit. What data are collected? How are the data presented? What is likely to be the most serious barrier to data collection?
2. Explain the uses of energy use performance factors.
3. How can the costs of different fuels be compared with each other?
4. Ascertain current energy prices and update Table 2.3.
5. Explain the term ‘degree day’ and state its use.
6. How is the load factor calculated and how is it used?
7. A factory uses 20 000 l of oil for its heating and hot-water systems, 160 000 kWh of electrical power and 300 000 kWh of gas for furnaces in a year. Fixed charges are £800 for the oil, £700 for the electrical equipment and £1200 for gas equipment. Use the data provided in this chapter and current energy prices to produce an overall energy audit based on the gigajoule unit and find the average cost of all the energy used.
8. Calculate the annual cost of a gas-fired heating system in a house with a design heat loss of 30 kW at −2°C for 16 h per day, 7 days per week for 30 weeks in the year. Use the data provided in this chapter and the current fuel price.
9. Find the total annual cost of running a gas-fired heating and hot-water system in a house with four occupants if its design heat loss is 32 kW. Maintenance charges amount to £160 per year.
10. Determine the following energy use performance factors for offices A and B:

    (a) total energy cost per square metre of floor area;
    (b) heating system energy used per degree day;
    (c) total energy used per person per occupation hour.

    The data required are given in Table 2.12. They refer to a year having 2150 degree days for office A and 2310 degree days for office B. Maintenance costs are £800 for the gas system and £750 for the electrical installation in each building. All the gas is used for heating systems. Compare the performance of the two office buildings.

Table 2.12 Buildings A and B for Question 10.

Building	*Electricity (kWh)*	*Gas (kWh)*	*Floor (m^2)*	*Usage (h)*	*Occupants*
Office A	115 000	720 000	2400	2600	160
Office B	100 000	850 000	2600	2300	210

11. Calculate the economic thickness of rock wool thermal insulation which is to be applied to a wall with an uninsulated thermal transmittance of 1.6 W/m^{2}K. The thermal conductivity of rock wool is 0.04 W/mK. The locality has 2900 degree days for a base temperature of 18°C and a heating season of 240 days. The average internal temperature is 20°C. Rock wool costs £50 per cubic metre fitted. Interest is charged at 9% and depreciation at 10%. Fuel oil for heating costs £5.00 per useful gigajoule.
12. Find the total demand target for an eight-storey office 22 m long, 15 m wide, 3 m floor-to-ceiling height. How will compliance with this target be achieved?
13. A building has a predicted energy consumption of 1 500 000 kWh/year for only the space heating system. The design engineer is to recommend the energy source and system type to be used on the basis of minimizing the greenhouse gas emissions. The average seasonal usage efficiency of the alternative systems are 95% for electrical heating systems of various types, 75% for gas-fired radiator heating system, 65% for coal-fired radiator heating system and 75% for an oil-fired ducted warm-air heating system. Use the carbon conversion factors in Table 2.4 to calculate the carbon emission in tonnes per year and make a suitable recommendation to the client.
14. Which of these adequately describe an energy audit of a building?

    1. Points out what building operators could do to save energy.
    2. Are only for cosmetic appearance of doing something to reduce greenhouse emissions.
    3. Identify and quantify viable energy-saving investments.
    4. Concentrate on finding almost zero cost short-term payback energy-saving opportunities.
    5. Only analyses technical projects and not financial investment criteria.

15. Which of these is not a correct multiple?

    1. kJ = 10^3 J.
    2. MWh = 1000 W × 1 h.
    3. 1 GJ = 10^6 kJ.
    4. 1 mm = 10^{-3} m.
    5. 1 GW = 1000 MW.

16. Which is not correct for CO_2 greenhouse gas?

    1. Produced by ruminating animals.
    2. Continuously converted back into O_2 by photosynthesis.
    3. It is burnt carbon from fuel combined with atmospheric oxygen.
    4. Easily reversed to solid carbon plus oxygen gas into the atmosphere.
    5. Combusted hydrocarbons are not the sole source of greenhouse gases.

17. Which is degree day load factor not relevant to?

    1. Calculation of heating system kW load for design.
    2. Ratio of degree days from meteorological data.

3. Minimum outside air temperature for design.
4. Seasonal weather variability.
5. Maximum possible degree days for the locality.

18. Which is correct about energy use in buildings?

    1. Design energy use accurately predicts actual consumption.
    2. Design energy use predictions rely on input data from the owner.
    3. Usage of a new building always complies with design prediction patterns.
    4. New building users never find design inadequacies.
    5. Predicted energy use for new buildings is often exceeded in reality.

19. Which of these is not included in the annual financial accounts for energy-saving projects?

    1. Energy cost savings due to the investment.
    2. Cash balance of the proposed investment prior to the commencement of the energy-saving project.
    3. Cash balance of the proposed investment at the end of each year of the project.
    4. Financial capability of the contractor who is to undertake the energy-saving installation.
    5. Capital allowance from taxation system against costs of the energy-saving installation.

20. Which of these describes low-energy buildings?

    1. Design predictions of energy use mean nothing to the user of the building.
    2. Always uncomfortable for occupants.
    3. Cannot maintain low-energy use after three years of use.
    4. Must comply with an energy rating mandatory standard upon construction.
    5. Cannot have large areas of glazing.

21. What does sustainability mean for low-energy buildings?

    1. Brick, steel and concrete walls save more energy consumption while in use than they cost to produce and construct.
    2. All windows have low emissivity glass.
    3. Aluminium window frames are not used in this building.
    4. Double-glazed windows always used in cold climates.
    5. All thermal insulation, glass, aluminium, steel, timber and concrete in this building were harvested from renewable resources.

22. What does sustainability mean for low-energy buildings?

    1. The concrete for this building came from a very large quarry that can supply the national need beyond the lifetime of the present occupants.
    2. Heat loss through the windows in winter are exceeded by the heat gains in summer.
    3. All the timber used in concrete formwork were recycled from previous projects and are to be passed on to our next construction site.
    4. All timber in this building came from managed forestry.
    5. Electricity used to crush and melt primary ground resources into glass and aluminium used in this building all came from renewable energy sources.

23. Which of these has the correct units?

    1. 1 Newton $= 1$ kg $\times$ 1 m^2.
    2. 1 Joule $= 1$ kg $\times$ 1 m.
    3. 1 Watt $= 1$ kg $\times$ g m/s^2.

4. 10^3 Joules = 3600 kN/m^2.
5. 1 Joule = 1 N/m^2.

24. Which of these has the correct units?
    1. 1 atmosphere = 10^3 b.
    2. 1 Pascal = 1 N/m^2.
    3. Pascal is a unit of radiation measurement.
    4. 1 kN/m^2 = 1 b.
    5. 1 mb = 10^3 N/m^2.

25. Which of these does not apply to low-energy buildings?
    1. Should be audited and re-accredited as complying with nationally mandated standard at regular intervals.
    2. Never need re-accreditation.
    3. Energy rating accreditation maintains credibility of design.
    4. Must be accredited by licensed raters complying with a professional code of conduct.
    5. Highly insulated.

26. What does BREEAM stand for?
    1. Building Rehabilitation Electrical Energy Alternative Methodology.
    2. Building Research Establishment Energy Audit Methodology.
    3. Building Recycling Energy Effectiveness Association Member.
    4. Brick Recycling Energy and Environment Assessment Method.
    5. Building Research Establishment Environmental Assessment Method.

27. What does LEED stand for?
    1. Low Energy Environmental Design.
    2. Leadership in Energy and Environmental Design.
    3. Low Electrical Energy Demand.
    4. Leading Electrical Energy Demonstration.
    5. Leader in Energy Environment and Design.

28. What does Green Star stand for?
    1. This building only uses renewable energy sources.
    2. No such thing as a green star.
    3. A low mould-growth building.
    4. Zero condensation risk.
    5. Standard for environmental performance of the building.

29. What does sustainability mean for low-energy buildings?
    1. All the glass in this building comes from self-sustaining resources.
    2. All the aluminium in this building comes from self-sustaining resources.
    3. All the primary energy used by this building comes from self-sustaining resources.
    4. All the concrete and reinforcing steel in this building comes from self-sustaining resources and recycled materials.
    5. None of these answers.