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Energy efficiency in dwellings

This Digest identifies which factors determine the energy requirements of a dwelling and describes the methods used to assess energy efficiency.

The levels required by the Building Regulations for new dwellings are discussed. Improvements to the energy efficiency of existing buildings are also considered, taking account of the opportunities that arise when major refurbishments are carried out.

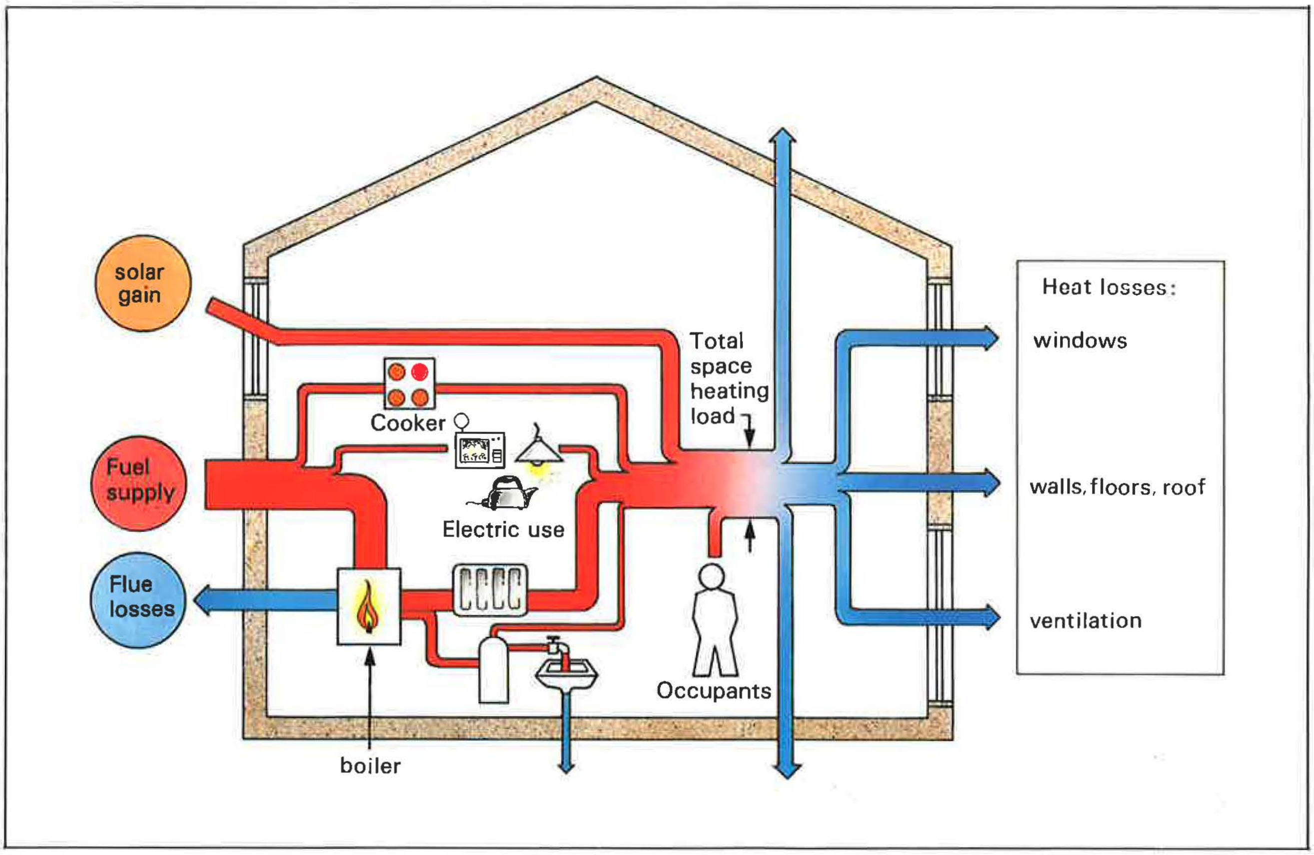

Fig 1 Energy flows into and out of a typical house

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ENERGY EFFICIENCY

Energy used in dwellings accounts for about 30% of all energy consumed in the United Kingdom and a similar proportion of energy-related emissions of carbon dioxide to the atmosphere. The average household devotes 6% of its total annual expenditure to domestic energy.

The benefits obtained from using energy depend upon the efficiency with which it is used. When applied to a national economy, energy efficiency is often expressed in terms of gross domestic product per unit of energy consumed. For individual dwellings it can be measured in terms of the amount of energy needed to produce a given performance. So an energy-efficient house is one which needs less energy than other houses of a similar size to meet the occupants needs. This definition allows quantitative comparisons to be made between different dwellings and changes to the performance of the dwelling stock to be measured.

In assessing energy, efficiency two issues need to be addressed:

- Firstly, it is necessary to define the levels of service to be achieved. Households vary widely in the way they occupy their homes, leading to large variations in the amounts of energy they consume. It is often convenient therefore to standardise needs, based on typical households with carefully defined living patterns. For space heating, indoor temperatures and heating patterns can be defined so that heating energy requirements can be calculated or measured. Other uses of energy can be based on average consumption derived from measurements and surveys, or by identifying the appliances used.

- The second issue is how to express energy needs once they have been calculated. *Annual energy cost* is often the most appropriate measure of energy needs since it allows energy to be assessed on the same basis as other costs and is most meaningful to the consumer. Prices can change fairly quickly, however, so energy units may be a more satisfactory basis for assessing long-term change if only one fuel is being considered.

TERMS USED TO QUANTIFY ENERGY

Useful energy
The energy required to perform a specific function at the point of application. For space heating it is measured at the output of the heating system.

Delivered energy
The energy content of fuel delivered to the consumer. *For space heating,* it is the energy input to the heating system.

Primary energy
The energy content of fuel entering the energy economy. It represents the energy content of fuel input to power stations, oil refineries, processing solid fuel, etc; energy used during extraction of the fuel itself; losses in distribution networks; and the energy delivered to users.

Energy units
The JOULE is the basic international unit of energy, abbreviated to J. Because of the joule's small size in relation to the annual energy requirements of a typical household, the GIGAJOULE (GJ) is used. Other familiar units of energy are the THERM, used for gas, and the KILOWATT HOUR which is used for electricity.

1 GJ	=	10^9 Joules
	=	278 Kilowatt hours
	=	9.48 Therms

The WATT is the basic unit of power or rate of flow of energy. It equals 1 Joule per second.

CALCULATING ENERGY REQUIREMENTS

Calculations of energy requirements in dwellings are used because accurate measurements of energy performance are rarely practicable. To be meaningful, such measurements would need to extend over a whole year and to distinguish between different uses of energy. Even then, they need interpretation to take account of the behaviour patterns of the household and the climate. This makes them very expensive. Although actual consumption varies considerably between households even when they occupy identical dwellings, it is practicable to estimate energy needs for a given pattern of usage for both new housing and existing housing.

Domestic energy calculations must take account of many factors:

- climate, including temperature, solar radiation and wind;
- the physical characteristics of the dwelling and its heating system;
- the way in which the house is used, including the extent and duration of space and water heating;
- internal temperatures and the use of domestic appliances.

Figure 1 shows the main flows of energy into and out of a typical house. It is important to note that the heating system is not the only contributor to space heating. Even in a house with average standards of insulation, solar and internal gains supply a significant proportion of space heating needs. In very well insulated dwellings, space heating may account for only a minority of energy use.

Traditionally, calculation methods have usually concentrated on the heat losses and ignored heat gains. This meant that they were suitable for estimating the maximum loads to be met by heating systems but were poor at estimating annual energy needs. The BRE Domestic Energy Model (BREDEM) has been developed to make realistic estimates of annual needs simply and conveniently. BREDEM is based on experience gained from measurements made in a large number of occupied dwellings and the results of research into many aspects of dwelling design which relate to energy use. Information Paper IP13/88 describes a worksheet version of BREDEM which can be operated using either a hand-held calculator or a personal computer. It includes standardised values for internal temperatures, solar and internal gains, hot water usage and lighting and appliance usage. Altogether, it provides a robust basis for assessing the energy efficiency of dwellings and the benefits deriving from energy efficiency measures.

Figure 2 shows the results of some BREDEM calculations on a semi-detached house, illustrating how energy costs vary with insulation levels. It shows that space heating costs are dominant where the house is poorly insulated but are greatly reduced with better insulation.

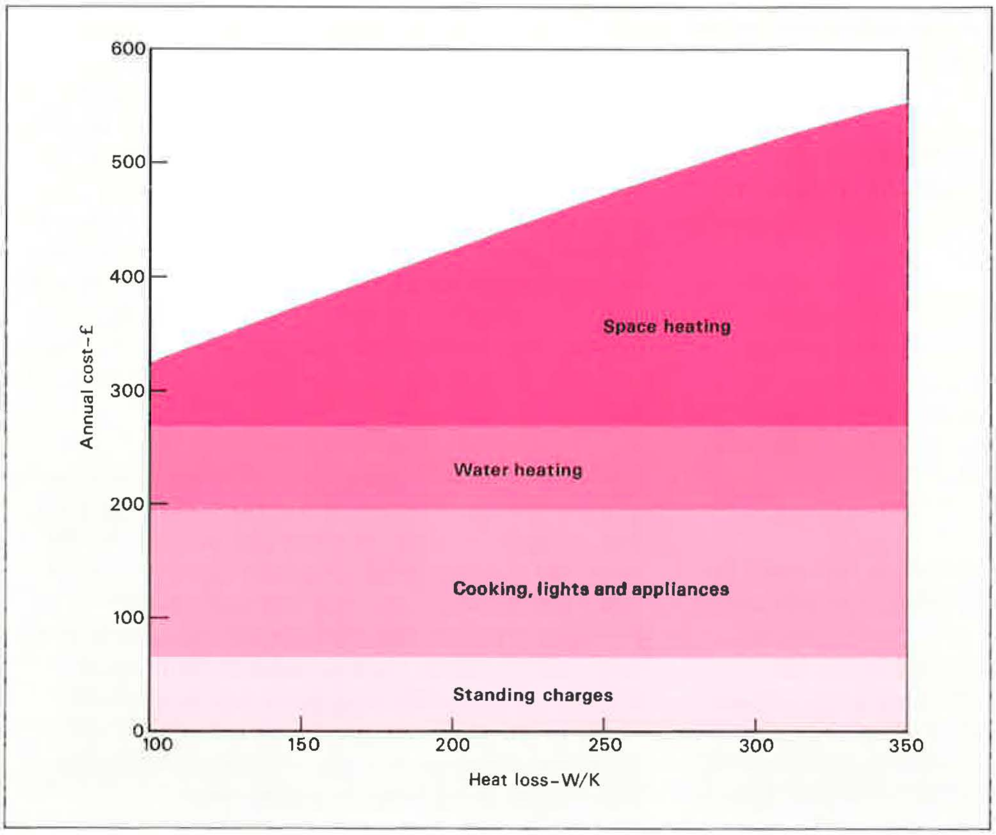

Fig 2 Energy costs against heat loss - typical figures for a UK dwelling
Based on a semi-detached house of floor area 80m² with space and water heating by gas. 1988 fuel prices

FACTORS AFFECTING ENERGY EFFICIENCY

Heat losses

When a building is heated, indoor temperature is higher than outdoor temperature and heat is lost by conduction through the fabric of the building. The *fabric heat loss rate* is quantified in terms of heat flow in watts per degree of temperature difference between indoors and outdoors (W/K).

Heat is also lost through the replacement of heated air by fresh air drawn from outdoors. The amount of air involved is the product of the internal volume of the building and the rate at which air is replaced. This rate must include both adventitious ventilation, or infiltration, as well as deliberate ventilation by the use of windows, extract fans etc. The *ventilation heat loss rate,* like fabric heat loss rate, is quantified in W/K.

Together, fabric and ventilation heat loss rates make up the *specific heat loss rate;* this is a good measure of the thermal performance of the building and gives one basis for comparing its performance with other buildings of similar size.

Heating system efficiency

The efficiency of a heating system is the ratio of the energy it produces to that it consumes; it is usually expressed as a percentage. It can vary over a wide range and can therefore have a strong effect on the amount of fuel consumed (see Table 1). The benefits of good insulation can be offset by an inefficient heating system while, conversely, a hard-to-heat building can benefit greatly from the installation of a highly efficient system. A calculation of running cost allows investment in an improved system to be compared with investment in better insulation and the most cost-effective combination of measures to be selected.

The controls fitted to a heating system are also important because they affect both the efficiency of the system itself and the extent to which it matches the requirements of the occupants.

Table 1 shows the annual efficiencies that can be expected from a range of commonly used heating systems. The figures given are generally below the rated efficiencies of appliances under test conditions at full load, reflecting the fact that for much of the time they are operating at low loads.

Internal heat gains

Many of the heat gains in dwellings are inevitable by-products of activities such as cooking, water heating and the use of electrical appliances. In these cases, energy efficiency considerations dictate that the appliances themselves should be made more efficient. This will, of course, reduce the heat gains and thereby give a marginal increase in the need for space heating. It will, though, have a beneficial effect overall since by no means all of the gains will contribute usefully to heating, many of them occurring at times when no heat is needed. Moreover, electrical appliances predominantly use full tariff electricity which is likely to be much more expensive than the fuel used for space heating.

Heat gains from sunshine are not the result of other energy use and should, therefore, be made as large as possible when space heating is required. The benefit that can be derived from solar heat gains is determined by the design of the dwelling as well as the climate of its location. Passive solar design sets out to make the best use of sunshine through controlling the form and fabric of the building.

Although heat gains need to be taken into account when calculating annual energy needs, they should not be considered when sizing a heating system for maximum demand as there will be times when heating is required and gains are a low level.

Fuel cost

The cost of the energy required to heat and light the dwelling and to supply it with hot water and power for the appliances is what matters to the householder. Clearly the unit cost of the fuel affects this directly and is as important as the physical factors that affect the need for energy. This issue is partly obscured from the layman by the different units employed by the fuel industries as their basis for charging. Table 2 shows the familiar units converted to a common basis to allow comparison of costs.

Electric storage heaters are designed to take advantage of off-peak tariffs. It is usual to design systems based on storage heaters so that they are able to meet 90% of heating needs by using electricity at the off-peak rate. In practice, the proportion of electricity actually consumed at off-peak rate can vary quite widely according to the way the heating is used, but experience has shown the 90% figure to be a good guide for systems designed and used for whole house heating. Systems used for heating only part of a house generally require a greater proportion at the on-peak rate.

Sometimes the most effective improvement that can be made to energy efficiency is a change of fuel or tariff. For example, a change of electricity tariff to the off-peak rate can often make a large reduction to space and water heating costs. The benefit from fuel changing must also be considered in the context of the price stability of the fuels in question. In the past decade, oil has varied from being one of the most costly to one of the cheapest fuels available. Coal prices have been more stable but vary considerably with region, being lower in mining areas.

CALCULATION OF BUILDING HEAT LOSSES

U-value
The rate at which heat is lost through an element of a building expressed in $W/(m^2K)$.

Fabric heat loss rate
The rate at which heat is lost through all the enclosing elements of a building, such as the walls, roof and windows. It can be calculated by adding up the products of the areas and U-values of each individual element:

$$\text{Fabric heat loss (FHL)} = \sum_{i=1}^{N} A_i U_i \ \text{W/K}$$

Ventilation heat loss rate
The rate at which heat is lost through the replacement of air in the building by fresh air drawn from outdoors. It may be calculated from the volume of air replaced and its specific heat and density:

$$\text{Ventilation heat loss (VHL)} = n V \sigma \rho \ \text{W/K}$$

where n is the number of air changes per hour
V is the enclosed volume of the building (m)
σ is the specific heat of air in J/kg C
ρ is the density of air in kg/m

Using typical values for σ and ρ,

$$\text{VHL} = 0.33\, n\, V \ \text{W/K}$$

Specific heat loss (SHL) rate for the building
The sum of the fabric and ventilation loss rates:

$$\text{SHL} = \text{FHL} + \text{VHL} \ \text{W/K}$$

$$= \sum_{i=1}^{N} A_i U_i + 0.33\, n\, V$$

These are expressed in terms of a temperature difference of 1 degree K between indoors and outdoors. *Design heat loss* is an alternative expression based on the difference between indoor and outdoor temperature under design load conditions. It is normally expressed in kilowatts:

$$\text{DHL} = \text{SHL} \times (T_i - T_e) \ \text{kW}$$

where T_i and T_e are indoor and outdoor design temperatures respectively.

Table 1 Heating systems seasonal efficiency

	Efficiency %
CENTRAL HEATING RADIATOR SYSTEMS	
Gas boilers	
Older boilers	55 — 65
Modern boilers	60 — 70
Condensing boilers	80 — 85
Oil boiler	60 — 70
Solid fuel auto-feed boiler	60 — 70
Solid fuel manual feed boiler	55 — 65
Electric (off-peak boiler)	100
Control options for any radiator system	
Programme and room thermostat	
Programmer, roomstat and TRVs	
TRVs, programmer and boiler manager	
Zone control (2 thermostats and programmers)	
CENTRAL HEATING WARM AIR SYSTEMS	
Gas	65 — 75
Oil	65 — 75
Electric	100
INDIVIDUAL ROOM HEATERS	
Gas fires	
Older gas fires	45 — 55
Modern gas fire	55 — 65
Wall heater with balanced flue	65 — 75
Electric fires	100
Solid fuel	
Room heater	55 — 65
Open fire	30 — 35
Open fire with throat restrictor	40 — 45
Open fire with back boiler	50 — 60
ELECTRIC STORAGE HEATERS	
(In all cases topped up with on-peak heaters)	
Old heaters, manual control	100
Old heaters, automatic	100
New heaters, manual control	100
New heaters, automatic	100
Fan assisted heaters	100

Table 2 Factors to convert fuel prices to £/GJ

Fuel	Unit of price	Conversion factor
Electricity	p/kWh	2.78
Gas	p/therm	0.096
Solid fuel	£/tonne	0.033
Oil, paraffin	p/litre	0.27
LPG (butane)	p/kg	0.20
LPG (propane)	p/litre	0.39

THE BUILDING REGULATIONS

Building Regulations have had provisions for thermal insulation since they were first established. Provisions were also included in the model bye laws which predated the Regulations and have influenced insulation of most dwellings built since 1945.

The 1965 Regulations for thermal insulation were pitched at a level which could be met by a standard brick-brick or brick-block cavity wall and 20 mm of glass-fibre quilt in the roof. Those levels remained in force until concern about energy conservation grew in the early 1970s in response to the international 'oil crisis'. Regulations were formally revised in 1976 including the specification of better U-values and a provision for limiting the total area of windows. Further improvements were introduced in 1982 and 1990 with significant increases in insulation on each occasion. The 1990 revision is notable because it introduces ground floor insulation for the first time in the UK. It also allows much more flexibility than in previous Regulations, making it possible for builders to compensate for reduced insulation in one element by increasing it in another. Table 3 shows the U-values required by the successive revisions of the Regulations. Figure 3 shows how the changes in the Regulations have affected specific heat loss rate and energy costs in a typical house.

Construction methods have evolved to take account of the changing Regulations. The 1976 revision could be met by the adoption of lightweight concrete blocks for the inner leaves of cavity walls. The 1982 revision increased the use of insulation within the cavity itself but also led to the development of high performance insulating blocks which allowed the cavity to be kept clear. The 1990 revision may result in the development of a range of new techniques although satisfactory methods already exist. For example, ground floor insulation has not been widely used to date and the most economic solutions will evolve to meet the growing market for such insulation. The Approved Document for Part L of the Building Regulations gives a range of solutions which meet the requirements.

Detailed practical guidance on insulation for new dwellings is given in the BRE report: *Thermal insulation: avoiding risks.*

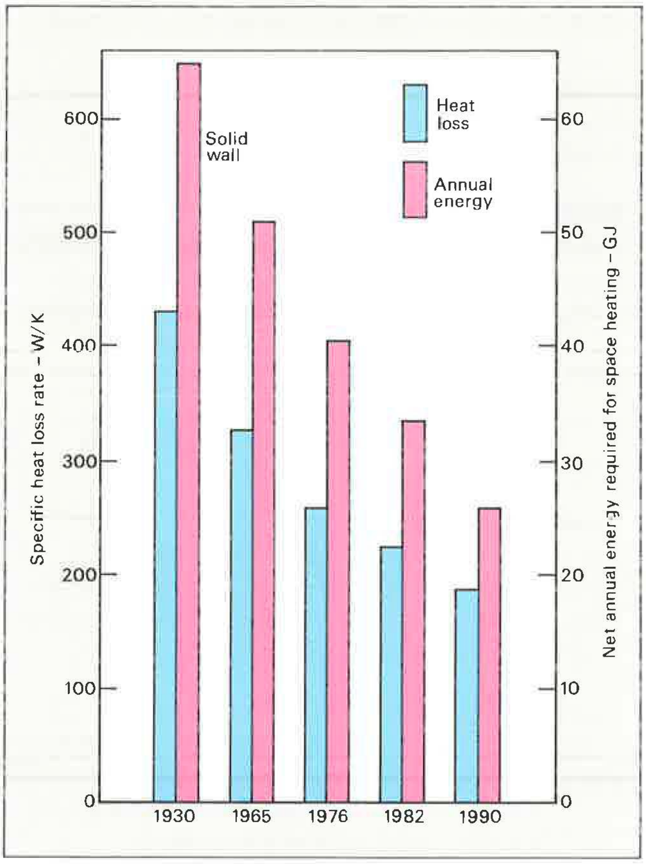

Fig 3 Impact of Building Regulations on heat loss and annual space heating energy requirements
Based on a semi-detached house of floor area 80m² and presuming the same standard of heating over the period

Table 3 U-values required by the Building Regulations

	Roofs	Walls	Floors
1965	1.42	1.70	1.42*
1976	0.60	1.00	1.00*
1982	0.35	0.60	0.60*
1990	0.25	0.45	0.45**

* applies to exposed floors only
** applies to all floors including those in contact with the ground

PASSIVE SOLAR ENERGY

Solar radiation can be a significant source of heat even in an existing house in the UK climate. In a new building, the designer can deliberately set out to minimise heating requirements by controlling the area and orientation of windows and by the use of special architectural features such as conservatories and roof-space collectors. This is often referred to as passive solar design.
At the simplest level, this means ensuring that glazing is predominantly on south-facing aspects and limiting overshading from adjacent buildings. This can often be done without incurring significant extra cost. It is beneficial when applied to the layout of a new estate development where there are often opportunities for influencing orientation and positioning of dwellings.

Passive solar designs which have very large areas of glazing need to be carefully analysed to ensure that overheating does not occur in summer. Overheating may be avoided by limiting the amount of glazing and by the appropriate use of shading, ventilation and thermal mass.

IMPROVING INSULATION IN EXISTING BUILDINGS

Many existing dwellings were built before even basic thermal insulation provisions were introduced and many more before the standards of 1976 and 1982 were established. Consequently there are considerable opportunities for improving energy efficiency in existing dwellings. Those opportunities depend upon how individual buildings are constructed both for the practical difficulty of carrying out the improvements and their cost-effectiveness.

Pitched roofs with accessible lofts are usually easy to improve and highly cost-effective. Many such improvements have already been carried out, often supported by the Government's Home Insulation Scheme. Flat roofs are more difficult to insulate as the space between ceiling and roof deck is often inaccessible. However, it is possible to install insulation above the roof deck using 'warm deck' or 'inverted' construction. This is likely to be most cost-effective when renewal of the roofing felt is needed.

The practicality of insulating external walls depends particularly on whether they have cavities which can be filled with insulating material. Cavity insulation can yield a large and cost-effective improvement to energy efficiency. However, it should be undertaken only by a competent installer working to the relevant British Standards or covered by a British Board of Agrément certificate. The solid brick walls of older homes (built before about 1935) may also be insulated but usually at higher cost than for cavity walls. Insulation applied externally is particularly appropriate when the existing wall is in poor repair or an external render needs renewing. In such cases the marginal cost of insulating at the same time as re-rendering may be low enough to make the insulation cost-effective, at the same time greatly reducing the risk of the condensation which is often found in solid-walled dwellings. Insulation may also be applied internally either using composite insulation boards or by placing insulation behind a plasterboard dry lining. A vapour barrier is needed on the warm side of the insulation to prevent moisture reaching the cold surface behind the insulation.

Windows account for a substantial proportion of total heat loss in a typical dwelling. Double glazing will usually reduce the loss through windows by about half; low-emissivity glass and inert gas fillings give further reductions. Although replacement windows are not usually cost-effective purely on the basis of energy savings, it makes sense to specify double glazing if windows are being replaced for other reasons.

In flats, windows can form a large proportion of external surface area and, consequently, be the dominant factor determining space heating needs. In such cases, double glazing may result in much lower demands being placed on the heating system and overall savings being achieved when the heating system has to be replaced at the same time.

Other energy efficiency improvements to existing dwellings include draughtproofing and the insulation of hot water storage cylinders. There is also considerable potential for improving the efficiency of existing heating systems. This has already occurred on a large scale through the replacement of open fires by central heating systems. Many existing gas central heating boilers are now in need of replacement and improvements in efficiency can be obtained simply by replacing them with their modern counterparts. Condensing boilers offer greater opportunities for savings although they are more expensive. Typically they operate at an annual average efficiency of 85%, compared with about 70% for a standard type. Since many of the boilers to be replaced will have been installed in the early 1970s or before, they have even lower efficiencies and it is possible to reduce fuel consumption by up to one third. This improvement is greatest where demand for heat is highest, ie in large, badly-insulated properties, and is often the most cost-effective measure available. Clearly, the best opportunity for installing a condensing boiler is when the existing boiler needs replacement: at that time only the marginal cost of the condensing boiler over the standard type needs to be considered. Replacement of a boiler with many years of useful service ahead of it is less likely to be economic.

Practical guidance on improving the energy efficiency of existing dwellings can be found in *A designer's manual for the energy efficient refurbishment of housing*. The cost-effectiveness of some common measures is shown in Table 4.

Table 4 Energy efficiency in existing dwellings

Measure	Typical payback period	Applications and comments
Hot water cylinder jacket	6 to 12 months	All dwellings with hot water storage
Loft insulation	1 to 3 years	All dwellings with accessible lofts
Condensing boilers	2 to 4 years	At replacement of worn-out boilers
Draughtproofing windows and doors	2 to 10 years	All dwellings — subject to need to maintain adequate ventilation
Cavity wall insulation	4 to 7 years	Dwellings with cavity walls not subjected to severe driving rain
Double glazing	10 to 12 years	Cost effective when windows need replacing

ENERGY EFFICIENCY GOOD PRACTICE IN HOUSING

New buildings
The Building Regulations set minimum standards for new buildings based upon cost-effectiveness calculated using typical fuel and building costs. Individual circumstances may justify higher standards of energy efficiency, for example, when:

- fuel costs are higher in a particular location
- higher than usual temperatures are needed
- unusual methods of construction are used.

In some cases, it is possible to achieve significant improvements at little or no extra cost, either through simple passive solar design or because extra insulation costs are offset by lower heating system costs.

Existing buildings
There are many opportunities for improving the energy efficiency of existing buildings. Some may be applied without disruption to the occupants of the dwelling and are cost-effective whenever they are applied. These include:

- pitched roof insulation
- hot water cylinder insulation
- cavity wall insulation
- draughtproofing

Further opportunities arise when buildings are refurbished or components are replaced:

- double glazing when windows are replaced
- solid wall insulation when re-rendering or rain screening
- ground floor insulation when floors are renewed
- high efficiency boilers and controls when boilers are replaced or central heating is installed.

Good practice will require consideration of all these opportunities but may result in some of them being rejected in particular circumstances.

FURTHER READING

ANDERSON, B R. Energy assessment for dwellings using BREDEM worksheets. BRE Information Paper IP13/88.

The Building Regulations 1985. 1990 edition. Approved Document L1. HMSO, 1989.

Thermal insulation: avoiding risks. BRE Report BR143, BRE, 1989.

A designer's manual for the energy efficient refurbishment of housing. BSI, 1989.

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