CE185

Domestic heating by electricity

energy saving trust®

Contents

Introduction

Home energy use is responsible for 27 per cent of UK carbon dioxide (CO_2) emissions that contribute to climate change. Heating and hot water are by far the largest use of energy within the home. By following the Energy Saving Trust's best practice standards, new and refurbished homes will be more energy efficient – reducing these emissions and saving energy, money and the environment. For more information on the Energy Saving Trust's standards, visit est.org.uk/housingbuildings/standards

This guide describes the options for heating homes by electricity, compares them with alternatives, and advises on specifying electric heating and hot water systems to best practice standards.

The guide focuses on electrical resistance heating systems that include direct acting heaters (convectors, panel heaters, fan heaters and radiant heaters) and storage heaters. Electric heating using additional energy sources (e.g. heat pumps, heat recovery from ventilation, solar collectors, micro-CHP) needs different technologies and special consideration, and is explained in other Energy Saving Trust publications[1,2,3]. Numbered references and further information can be found on pages 23 and 24 respectively.

In general, electricity produces more carbon emissions and is more expensive than other heating fuels, so dwellings with electric heating receive relatively poor energy ratings. On the other hand, installation and maintenance costs are usually lower than for systems using other fuels, and fuel system installation costs (e.g. connection to gas main, or oil tank installation) may be avoided. Tables in the guide compare electric heating systems and alternatives, showing relative energy demands, CO_2 emissions, and fuel costs in both new and existing homes of average size.

The best practice recommendation is that electric heating should be considered only in limited circumstances – for example small and well-insulated properties that have a low heat demand. These conditions are more likely to be found in new or recently built homes.

For new dwellings, changes to building regulations in England and Wales in April 2006 and Northern Ireland in November 2006, make whole-building design the route to compliance. Previous methods that set specified performance levels for individual components, or the average of a group of components, have now been withdrawn. The new method requires the building as a whole to meet a carbon emission target under standardised conditions of use. This flexible design approach means that, with sufficiently good thermal insulation and other energy saving measures, electric heating and hot water systems can be specified in a range of new dwelling types.

Building regulations in Scotland are under review but are likely to adopt the same general principles.

Fuel selection

The range of heating and hot water systems using different fuels (wood, gas, LPG, oil, electricity, coal) gives purchasers a wide choice. But fuel selection must be made at an early stage, as it affects the provision and distribution of building services and (if needed) storage containers.

Heating appliances using different fuels are manufactured and installed by different industries in competition with each other. It is important to be aware of the range of alternatives and to understand the principal characteristics of the main fuels – especially the economic and environmental consequences of the final choice. A range of Energy Saving Trust publications is available for all the main heating fuels[4,5,6].

Figures for heating efficiency are often quoted, but any meaningful comparison between fuels must take account of the whole energy supply chain, progressing through primary energy, delivered energy and useful energy. Simply stated:

- **Primary** energy is that required at source before conversion, distribution and delivery.
- **Delivered** energy is that supplied to the home, on which payment is based.
- **Useful** energy is that required to warm the home or heat the water.

Conversion from primary to delivered, and delivered to useful energy, involves losses and waste, which reduce the overall efficiency of the supply chain. For the national electricity supply, conversion efficiency of primary to delivered energy is between 30 and 40 per cent, varying with the mix of generating equipment used. But conversion efficiency of delivered to useful energy is very high for electric heating, and can normally be taken as 100 per cent irrespective of the type or make of appliance used.

In contrast, for gas and oil there is a far smaller difference between primary and delivered energy, but the conversion efficiency of delivered to useful energy is lower – typically around 86 per cent for new gas and oil boilers.

Heat pump systems (not the subject of this guide) use electricity more effectively to extract heat from natural resources (ground, water or air), and so have a conversion factor for delivered to useful energy in excess of 100 per cent. Please see 'Further information' for additional references.

Typical annual heat pump efficiency figures used in SAP 2005[8] are 175 per cent to 320 per cent. They are affected by system design factors such as the source of free energy, the types of collectors and emitters, controls, and the arrangements for domestic hot water.

Standard Assessment Procedure (SAP)

SAP is the UK government's procedure for the energy rating of homes[7,8]. The properties of a building, such as the insulation, determine its heat requirements, while the type of heating system and heating fuel determine the energy use, cost and CO_2 emissions under standard occupancy conditions.

In the latest version, SAP 2005, the rating scale is 1 to 100. This is based on the calculated cost of space and water heating, ventilation and lighting, less savings from any energy generated in the building. High numbers represent better energy performance, and a rating of 100 is reached when the net energy consumption (over a whole year) is zero. Ratings above 100 are possible when the dwelling is a net exporter of energy. To comply with building regulations all new homes must have a SAP assessment. SAP also calculates the environmental impact (CO_2) rating, the dwelling emission rate (DER) and the target emission rate (TER).

Environmental impact

The main environmental impact of a dwelling is the emission of CO_2 from using energy – and it makes no difference to climate change whether the emissions occur in the home itself or at a power station miles away. Environmental impact should be considered when selecting a heating system.

Emission levels from meeting any given heating need vary according to the fuel used, the efficiency of converting energy to heat, the operational characteristics of the heating system, and the system's controls. A comparison of different heating systems in an existing house of typical size and construction is given in Table 1 (page 6).

As well as differences in environmental impact and CO_2 emissions, it can be seen that the primary energy, delivered energy and running costs vary widely according to the fuel and heating system used.

In new housing, more stringent building regulations require the energy demand for heating and hot water to be very much less than in the past. A comparison of different heating systems in new houses, designed to meet carbon emission targets, is shown in Table 2 (page 7).

The target emission rate (TER) and dwelling emission rate (DER) are explained in the panel on this page and in 'Complying with building regulations:' (pages 10 and 11).

Environmental Impact (CO_2) rating, and Environmental Impact (CO_2) band
The EI rating is a number representing the annual CO_2 emissions, calculated as part of the SAP procedure. Higher numbers represent lower emissions, with 100 representing zero net emissions. Numbers above 100 are possible if the dwelling is a net exporter of energy. The number range is divided into bands labelled A to G that are intended for use on building energy certificates.

Dwelling emission rate (DER) and target emission rate (TER)
The DER and TER are calculated as part of the SAP procedure. The DER gives the CO_2 emissions per unit of floor area, expressed in kg/m^2/year. To comply with building regulations in England, Wales and Northern Ireland, the DER of a new dwelling must not exceed a target value (TER). The TER is calculated for a notional dwelling of the same size and shape, and varies with choice of fuel. The use of DER and TER are explained further in 'Complying with Building Regulations' (pages 10 and 11).

Table 1 Heating in an existing house with average insulation

	Environment			Energy			Costs	
	Impact (CO_2) rating and band		CO_2 emissions	Primary	Delivered	Useful	Fuel cost and SAP rating	
	1-100	A-G	kg/yr	kWh/yr			£/yr	1-100
Electric heating								
Panel, convector or radiant heaters with appliance thermostats	38	F	6,530	43,300	15,500	15,500	1,100	14
Storage heaters of older, larger type with automatic charge control	29	F	8,129	53,900	19,300	19,300	720	33
Storage heaters of modern, slim type with automatic charge control	31	F	7,725	51,300	18,300	18,300	690	35
Storage heaters of modern, slim type with CELECT control	33	F	7,323	48,600	17,400	17,400	650	38
Integrated storage/direct acting heaters with CELECT control	35	F	6,906	45,800	16,400	16,400	700	35
Electric ceiling heating with time and temperature zone control	35	F	6,906	45,800	16,400	16,400	1,110	13
Integrated storage/direct acting electric underfloor heating with tariff control	33	F	7,324	48,600	17,400	17,400	870	25
Ground-to-water heat pump with radiators	65	D	3,217	21,300	7,600	16,700	500	50
Ground-to-water heat pump with emitters under insulated timber floor	72	C	2,527	16,800	6,000	17,300	400	60
Other fuels								
Gas boiler, SEDBUK 86%, with radiators	58	D	3,840	22,800	19,600	16,700	360	64
Gas boiler, SEDBUK 86%, with emitters under insulated timber floor	57	D	3,975	23,600	20,300	17,300	370	63
LPG boiler, SEDBUK 86%, with radiators	51	E	4,617	21,800	19,600	16,700	790	29
Oil boiler, SEDBUK 86%, with radiators	46	E	5,229	23,700	19,600	16,700	440	57
Oil boiler, SEDBUK 86%, with emitters under insulated timber floor	45	E	5,412	24,500	20,300	17,200	450	55
Anthracite boiler, efficiency 67 per cent, with radiators	26	F	8,693	30,800	27,100	18,400	590	43
Wood pellet boiler, efficiency 67 per cent, with radiators	90	B	713	29,300	26,400	17,600	800	29

Notes to Table 1

- **a** The results are produced by SAP 2005 for a typical existing semi-detached house with floor area 88.8 m^2. The same house is used in each case, varying only the heating and hot water system.
- **b** The environmental impact (CO_2) scale is related to the annual emissions of CO_2. Higher figures are better, and a rating of 100 is achieved at zero net emissions.
- **c** Energy figures only include heating and hot water, and are rounded to the nearest 100 kWh.
- **d** The SAP rating takes into account energy for lighting (the same in each case) as well as for heating and hot water. A rating of 100 represents zero net energy cost.
- **e** Fuel costs include standing charges, except those for electricity on the standard tariff, and are rounded to the nearest £10.

Table 2 Heating in new houses, designed to meet Building Regulations 2006 England and Wales

	Regulations (England and Wales)		Environment			Energy			Costs	
	TER	DER	Impact (CO_2) rating and band		CO_2 emissions	Primary	Delivered	Useful	Fuel cost and SAP rating	
	CO_2 kg/m²/yr		1-100	A-G	kg/yr	kWh/yr			£/yr	1-100
Electric heating										
Panel, convector or radiant heaters with appliance thermostats	32.39	32.39	71	C	2,591	17,200	6,100	6,100	440	57
Storage heaters of modern, slim type with automatic charge control	32.39	32.39	71	C	2,590	17,200	6,100	6,100	250	75
Storage heaters with convector fan and automatic charge control	32.39	32.39	71	C	2,591	17,200	6,100	6,100	240	76
Storage heaters of modern, slim type with CELECT control	32.39	32.39	71	C	2,590	17,200	6,100	6,100	250	75
Integrated storage/direct acting heaters with CELECT control	32.39	32.39	71	C	2,591	17,200	6,100	6,100	270	73
Electric ceiling heating with time and temperature zone control	32.39	32.39	71	C	2,591	17,200	6,100	6,100	440	57
Integrated storage/direct acting electric underfloor heating with tariff control	32.39	32.39	71	C	2,591	17,200	6,100	6,100	310	69
Ground-to-water heat pump with radiators	32.39	20.04	83	B	1,399	9,300	3,300	7,000	230	76
Ground-to-water heat pump with emitters under insulated timber floor	32.39	17.56	86	B	1,154	7,700	2,700	7,100	190	80
Other fuels										
Gas boiler, SEDBUK 86 per cent, with radiators	22.85	22.85	80	C	1,664	9,900	8,400	7,000	180	81
Gas boiler, SEDBUK 86 per cent, with emitters under insulated timber floor	22.85	22.85	80	C	1,664	9,900	8,400	7,000	180	81
LPG boiler, SEDBUK 86 per cent, with radiators	24.88	24.88	78	C	1,870	8,900	7,800	6,600	360	64
Oil boiler, SEDBUK 86 per cent, with radiators	26.30	26.30	77	C	2,013	9,200	7,500	6,200	170	82
Oil boiler, SEDBUK 86 per cent, with emitters under insulated timber floor	26.30	26.30	77	C	2,013	9,200	7,500	6,200	170	82
Anthracite boiler, efficiency 67 per cent, with radiators	28.53	28.53	74	C	2,264	8,500	6,900	4,600	170	82
Wood pellet boiler, efficiency 67 per cent, with radiators	22.85	12.76	90	B	675	13,500	10,600	7,300	360	64

Notes to Table 2

- **a** The results are produced by SAP 2005 for a new semi-detached house with floor area 88.8m². Each case is adapted to meet the building regulations in England & Wales (Part L1A, April 2006). Consequently the insulation and other factors affecting energy demand are not the same, and the construction costs are not comparable.
- **b** The TER and DER are the Target Emission Rate and Dwelling Emission Rate. See box text on page 5 and 'Complying with Building Regulations – England and Wales', page 10, for further details.
- **c** The environmental impact (CO_2) scale is related to the annual emissions of CO_2. Higher figures are better, and a rating of 100 is achieved at zero net emissions.
- **d** Energy figures only include heating and hot water, and are rounded to the nearest 100kWh.
- **e** In the examples with a heat pump and a pellet boiler, the general specification is the same as for a gas boiler. No additional 'trade-offs' have been made. In the example with an anthracite boiler, a solar thermal water heating system was included to help meet the target.
- **g** The SAP rating takes into account energy for lighting (the same in each case) as well as for heating and hot water. A rating of 100 represents zero net energy cost.
- **h** Fuel costs include standing charges, except those for electricity on the standard tariff, and are rounded to the nearest £10.

Comparing costs

Heating and hot water systems are the largest users of energy in the home. The Domestic Energy Fact File[9] estimates that, in the UK housing stock as a whole, about 62 per cent of energy is consumed for space heating and 23 per cent for hot water. In new housing, energy use for space heating is far less, though a substantial energy requirement for hot water remains.

Purchase, installation, maintenance and running costs affect the choice of a heating system. They can be combined in a whole life cost analysis, using a discounted cash flow technique, to produce a net present value (NPV). The NPV provides a realistic basis for comparing different types of heating systems and fuels over a long period.

Running costs include fuel and standing charges. Under some tariffs, standing charges have been replaced by higher unit charges for a specified number of units used first in each charging period. The purchase, installation and maintenance costs for an electric heating system with storage radiators and direct acting heaters will generally be lower than for a heating system with a boiler and radiators, and the statutory requirement for an annual safety check of gas appliances in rented properties is avoided. However, fuel costs will be significantly higher, and with most supply tariffs they depend critically on the proportion of off-peak electricity used. For more information see 'Using whole life costing as a basis for investments in energy efficiency – guidance' (CE119).

Some means of heat storage is needed to make effective use of the off-peak tariff. This is taken into account when energy demand and heating costs are calculated using SAP (see page 4).

Green electricity

'Green' electricity, i.e. electricity generated from renewable sources such as the wind or sunshine, is a small but growing proportion of the national supply and has near-zero carbon emissions. Consumers may elect to purchase green electricity, but supply agreements do not alter the carbon emissions for buildings calculated under SAP, nor do they change restrictions under the building regulations.

The availability of green electricity delivered through the national grid should not be used to justify selection of electric heating, although when electric heating is chosen for other reasons the arguments for purchasing green electricity still apply.

Design considerations

Space heating and hot water services for homes are normally designed together because many systems use shared equipment and appliances. In older housing, which is usually poorly insulated, space heating needs far more energy than water heating.

In new housing, built to meet the latest regulations, the energy used for heating and hot water may be roughly equal – and as insulation is improved further, hot water becomes the larger energy user. But there is a very wide variation in the demand for heating and hot water, even in apparently identical households.

For satisfactory performance and economic operation, electric heating systems depend on careful and responsible design. For heating systems with storage heaters, detailed design guidance is given in the TEHVA 'Guide to the Design of Electric Space Heating Systems'[10]. A European standard for the design of electrical room heating systems was first published in 2005[11], although it is not limited to housing.

In the UK, specifiers of heating for new housing will be concerned initially with the relevant parts of the building regulations that deal with conserving fuel and power as summarised in the following section.

Complying with building regulations

The building regulations containing provisions for the conservation of fuel and power are:

- In England and Wales, Parts L1A and L1B of the Building Regulations[12].
- In Scotland, Section 6 of the Domestic Technical Handbook of the Building (Scotland) Regulations[13].
- In Northern Ireland, Technical Booklet F1 of the Building Regulations (Northern Ireland)[14].

In each case the regulations differentiate between types of heating system and fuel used, with more demanding levels of building design required for electric heating because of the higher rate of CO_2 emission.

England and Wales

In England and Wales the method of demonstrating compliance with the regulations is described in Approved Documents ADL1A and ADL1B[12] for new and existing homes respectively.

For a new home, the main requirement is to meet a carbon emissions target for the building as a whole. A dwelling emission rate (DER) is calculated in units of $kgCO_2/m^2$/year, which must not exceed a target emission rate (TER) for a notional dwelling of the same shape and size. Both the DER and TER calculations are carried out using SAP 2005[8]. As it would be difficult to achieve the same CO_2 target for all heating fuels, the TER includes a fuel factor to relax the target for fuels of higher carbon intensity.

A second requirement is the compliance with minimum design limits for the building fabric and services. For heating systems the efficiency and controls should be at least as good as those specified in the 'Domestic Heating Compliance Guide'[15].

There are additional requirements for passive control measures to limit solar gains in summer, for the performance of the building to be consistent with the predicted DER, and for commissioning to ensure energy efficient operation.

Requirements for heating systems in existing homes can be met by following the 'Domestic Heating Compliance Guide'[15] in respect of efficiency and controls, and by commissioning and installing the systems correctly.

For electric heating, the Compliance Guide specifies local time and temperature control for direct acting heating, charge control and temperature control for storage heating, and zone control for warm air systems. For electric boiler systems, the Compliance Guide specifies zone control and boiler interlock.

Scotland

In Scotland there are three alternative methods of demonstrating compliance with the requirements for building insulation[13]:

- **The Elemental Method** sets maximum allowable U-values (see panel, below) of the elements of the building fabric. These are lower (i.e. harder to achieve) for electric heating than for gas and oil central heating systems where the boiler efficiency is of a particular level.
- **The Target U-value Method**, in which an average U-value is calculated for the various elements of the building envelope. This should not exceed a target value that depends on the ratios of total floor, ground floor and roof areas to the total area of all exposed building elements. The target value is reduced (i.e. made more demanding) by dividing by a factor of 1.15 when electric heating is used, which makes it difficult to meet the lower target except in flats with a low ratio of window to floor area.
- **The Carbon Index Method**, by which a result of 8.0 or higher should be obtained when the overall energy performance of the building is assessed under SAP 2001[7]. The guidance to the building standards also recommends that storage heaters have automatic charge control (see 'Storage heaters', page 15).

The regulations are under review and are expected to be changed in May 2007. A revised version of Section 6: Energy, was issued for consultation early in 2006.

If implemented it will follow a similar whole-building approach to that adopted in England and Wales, by setting dwelling carbon emission targets that vary with fuel type. These targets will be backed up by minimum standards for building fabric, heating efficiency and controls, lighting and measures to limit solar gains.

Northern Ireland

In Northern Ireland (since 30th November 2006) the method of demonstrating compliance with the regulations is described in Technical Booklet F1 for new and existing homes.

The regulations for new homes follow the same general methodology as England and Wales. The primary difference for electric heating is that an additional factor is included when heating with fuels other than mains gas, renewable energy and solid multi-fuels. This partially reduces the 'carbon penalty' for electric heating (and other fuels).

U-value

The U-value is a scientific measure of thermal transmittance that expresses how much heat passes through the walls or other external elements of a building. The heat flow per unit of surface area, per degree of temperature difference between the air on either side, is measured in Watts per square metre per degree Kelvin. Lower figures are better, as they represent better insulation and lower heat loss.

What is best practice?

Best practice requires good insulation, glazing, and consideration of other options before finally deciding on electric heating. Visit www.est.org.uk/housingbuildings/standards for full details of the Energy Saving Trust's standards for new and existing dwellings.

Electric heating can be considered best practice when all of the following conditions have been met:

- New housing should meet the Energy Saving Trust's best practice standard. This is based on a whole house approach and requires a 25 per cent reduction in carbon emissions compared to the building regulations in the relevant part of the UK. Existing housing should meet the refurbishment standard, which is summarised in 'Refurbishing dwellings – a summary of best practice'[16].
- The total heating and hot water requirement is small, such that the estimated net present value of the heating and hot water service (from whole-life cost analysis) is lower for electricity than for other fuels and systems over the same period.
- A suitable design method (such as in the 'Guide to the Design of Electric Space Heating Systems'[10]) has been used to ensure that a reasonable proportion of electricity for heating and hot water is provided at off-peak rates, using appliances or installations with adequate heat storage capacity.
- Storage heating systems have automatic charge control.
- Storage heaters in rooms not occupied throughout the day are fan-assisted, to deliver more heat at the times required.
- Good controls, preferably managed from one central unit, are provided for time and temperature programming, with separate zones for living and sleeping areas.
- Large properties are divided into multiple heating zones, none exceeding 150m^2.
- The hot water cylinder is large enough to supply most of the hot water demand between off-peak periods, is well insulated to a high specification, and has dual immersion heater elements.
- Where feasible and cost effective, electric water heating is augmented by a thermal solar system.

Where these conditions cannot easily be met other options are indicated, such as 'wet' central heating with condensing boilers, or a ground source heat pump (GSHP). In flats and high-density residential areas community heating should be considered, sharing one or more large boilers or a combined heat and power (CHP) unit, see 'Community Heating – a guide'[17] and 'CHP opportunities for local authorities'[18].

Electricity tariffs

There is a wide range of tariffs from competing energy suppliers, and it is worth searching for the most favourable. This can be done on the Energywatch website[19]. Off-peak tariffs offer lower electricity unit prices during restricted hours, the most common arrangement being for 7 hours between midnight and early morning.

Others allow a short top-up period at other times, and off-peak tariffs for 10, 15 or 18 hours a day are available from some suppliers. For very low heating and hot water requirements, the additional standing charges for an off-peak tariff may exceed the benefit of lower costs for the amount of electricity used.

When an off-peak tariff is chosen, the price of electricity outside the off-peak period is described as the on-peak price, and is usually not the same as the single price under the standard tariff. Prices vary over time and in different parts of the UK. However, for whole house calculations standard energy prices are used – see Table 3 for prices used in SAP. These are calculated averages for the 3 years preceding that edition (in this case 2005).

Electricity suppliers have various special tariffs designed for electrically heated homes, some of which provide 24-hour remote control of separate circuits for space and water heating as part of a load management (i.e. overload avoidance) scheme.

Table 3 Electricity prices (SAP 2005)

		UK average £
Standard tariff	p/kWh	7.12
On-peak	p/kWh	7.65
Off-peak (7-hour)	p/kWh	2.94
– additional off-peak standing charge	£/yr	20.00
Electricity – 24-hr heating tariff	p/kWh	4.09
– additional standing charge	£/yr	51.00

Direct acting heaters

Direct acting heaters are radiant or convector heaters with heating elements that are in direct contact with the air. They have low thermal inertia (i.e. they are light weight, and rapidly warm up or cool down), and are highly responsive to immediate heating needs. If correctly controlled, they react to solar, body and other heat gains in the room to avoid overheating.

All types of direct acting electric heating will have similar costs and environmental impacts, but economy can be achieved with good controls to avoid heating at unwanted times or excessive temperatures. Operation and control may also change the distribution of heat and affect the air temperature at which occupants feel comfortable. The principal performance characteristic is rated output in kW, and claims for 'high power' or 'economy of operation' should be judged against that.

Direct acting heaters are unable to take full advantage of the off-peak tariffs, and will be supplied mostly at the standard or on-peak rates. They are often connected to the general purpose household power circuits that have socket outlets or connection points rated at 13 amps (the ring main), in which case the total circuit rating of 30 amps (about 6.9kW) must be observed. To comply with the 13-amp limit on individual appliances connected to a ring main, most direct acting heaters are designed with a maximum rating no greater than 3kW.

Photographs courtesy of Glen Dimplex

Convector heater (top), Radiant heater (bottom)

There is a wide variety of appliances for direct acting electric heating. They can be categorised as convectors, panel heaters, fan heaters and radiant heaters, and all are equally efficient in converting delivered to useful energy.

- Convectors are designed to give out most of their heat as warm air that rises naturally (or with fan assistance) and circulates slowly in convection currents.
- Panel heaters are slimmer and also give out a large proportion of heat by convection, but with some radiation from the hot front surface as well.
- Convector and panel heaters are either portable or made for wall mounting and, as they are intended to meet heating requirements over longer periods, usually include a thermostat and sometimes a time switch.
- Fan heaters circulate air in the room very rapidly, responding well to short-term demands. Wall-mounted models are suitable for high level, fixed installation in bathrooms.
- Radiant heaters are better suited to short-term comfort heating in small areas – they are either portable or intended as room features, often designed for attractive appearance.

Controls for direct acting heaters

Time and temperature: controls should include a programmable room thermostat, or separate programmer and thermostat. Programmable thermostats allow a combination of heating times and temperatures to be set up for a daily or weekly cycle, and may include low settings for frost protection. Temporary manual override is normally provided. Timers are useful for the pre-heating of intermittently occupied rooms. Programmers and thermostats may be integrated with the appliance.

Thermostat types: traditional mechanical thermostats use either a bi-metallic or vapour pressure mechanism, and achieve relatively poor room temperature control. Although cheaper than other alternatives, they may lead to higher running costs through larger temperature variations. Electronic thermostats have much improved temperature control, typically to ±0.1°.

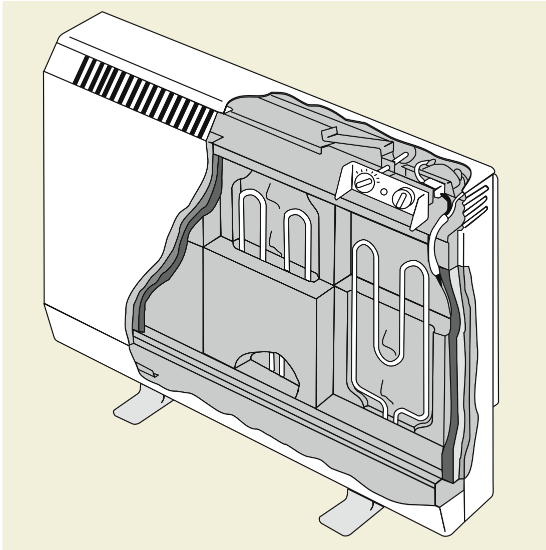
System-wide heating controls for the whole building, and controls reacting to signals from electricity suppliers for remote load management, are described in 'Whole-house controls', page 22).

Storage heaters

Electric storage heaters are designed to take advantage of the off-peak electricity tariffs under which electricity is supplied at a lower price for a few hours a day. The principal performance characteristics are storage capacity and rate of heat emission. Storage heaters are unable to respond rapidly to changes in demand, so effective controls to set the amount of heat they are charged with, and alter their emission rates, are particularly important. The amount of storage needed to meet daily heating requirements should be considered carefully at the design stage, and may be calculated following the principles in the TEHVA 'Guide to the Design of Electric Space Heating Systems'[10].

Storage heaters are larger, heavier and more expensive than direct acting heaters and require more complex controls for satisfactory performance, but offer a substantial reduction in fuel costs. Each heater is independently wired to a consumer unit connected to the off-peak supply, and as for all electrical installation work, the IEE Wiring Regulations[20] must be observed.

Storage heaters are charged with heat during the off-peak periods, and release it slowly over far longer periods. They perform better in well-insulated draught-proofed homes, where heat loss from the building is lower and is not strongly affected by sudden changes in the weather (e.g. changes in wind speed). Storage heaters are manufactured in a range of sizes with storage capacity quoted in kWh.



Storage heaters

Photograph courtesy of Glen Dimplex

A typical heater is capable of being charged at a rate of 3.4kW, and able to accept a maximum charge of 24kWh in a 7-hour charging period. It is important to set overnight charging correctly. Failure to do so leads either to insufficient storage for the next day's requirements – in which case more heat will be wanted from direct acting heaters at the more expensive on-peak rate – or to an excessive amount that will be wasted if milder weather reduces heating needs. Automatic charging systems are preferable, and there are several types as described below.

The rate of heat release from modern storage heaters is governed by a mechanical damper that is thermostatically controlled and can be altered by the householder. Greatly improved control can be provided by a fan connected to a separate electrical circuit, which can be switched on at any time (manually or by thermostat) to increase the rate of heat output. These features help to make storage heating more responsive to need, and are especially valuable in rooms not occupied continuously throughout the day.

In general, heating with storage heaters consumes more energy than with direct acting heaters, though the margin will be small in houses that are well insulated or occupied all through the day. Designing a satisfactory heating system using storage heaters requires some care in managing the different time periods for charging and heat release, and a design method is given in the TEHVA Guide[10]. It is not normally practicable or cost effective to aim for heating by storage appliances alone, and provision should be made for some supplementary direct acting heating. A reasonable proportion of the annual heating to be provided at off-peak rates should be decided as part of the design method, and a target of 90 per cent is recommended in the Guide[10].

Controls for charging storage heaters

- **Manual control:** installed in each appliance, to be adjusted by the householder every night in anticipation of the next day's heating requirements.
- **Automatic control:** detects the rate of temperature fall during the night and brings on the charge accordingly. This has been found to be the most accurate form of control.
- **Weather sensing control:** reacts to measured indicators of the next day's requirements, such as the present indoor or outdoor temperature. May either be part of each heater, or installed independently for a group of heaters.
- **Weather prediction control:** offered by the electricity supplier in conjunction with a special tariff, allowing the supplier to alter the charging period for all the storage heaters to suit the weather forecast.

Controls for heat emission from individual storage heaters

- **Mechanical damper**: set by the householder, in conjunction with an integral thermostat.
- **Fan with manual switch and/or thermostat and timer control**: greatly improves the range of controllable heat output (although the fan is a construction feature rather than a control).
- **Fan with central control**: the fan is controlled separately from a central thermostat and timer or programmer.

System-wide heating controls for the whole building, and controls reacting to signals from electricity suppliers for remote load management, are described in 'Whole-house controls', page 22.

Integrated storage/direct systems

Integrated storage/direct systems are a combination of storage and direct acting heaters in a single appliance. The two separate heat sources are independent, automatically controlled and able to provide more consistent room temperatures than storage systems alone. For economy they take advantage of off-peak electricity for the majority of the energy used, but to improve temperature control throughout the day they consume some on-peak electricity too.

Heat from off-peak electricity (mainly at night) is stored in an insulated core of reduced capacity. The storage core has automatic charge control that monitors room temperature during the charge period and adjusts the charge accordingly. Heat is emitted from the casing throughout the day and, whenever necessary, is automatically supplemented by a direct acting, low power radiant element fitted at the front of the appliance.

The direct acting element is controlled by a room thermostat that can be linked to a central zone controller. The output from the direct acting element is related to the output from the core, and will only operate if the stored heat is insufficient to meet the desired room temperature. In milder conditions a higher proportion of heating is provided from the direct acting element, so as not to waste energy through over heating.

Controls for charging integrated storage/direct systems

- **Electronic automatic control:** detects the rate of temperature fall in the room during the night and brings on the charge accordingly. Electronic thermistor sensors measure the accuracy of room temperature to within ±0.5°.

Controls for heat emission from integrated storage/direct systems

- **Thermostat**: allows user adjustment of the required room temperature. Continually monitors the room temperature and turns on the radiant element if the temperature cannot be sustained by heat emission from the storage core alone.
- **Thermostat with central control**: the desired room temperature can be programmed for different times of day and days of the week for a particular occupancy pattern. This can be done at a central programmer designed to control multiple heaters.

Warm air units

A single storage unit, charged from the off-peak electrical supply, can be installed in a central position and provide warm air to nearby rooms. This works best in small compact properties where heat can be discharged through grilles at the sides of the unit rather than via long ducts.

A fan within the unit controls air movement and rate of heat output, and the warm air supply to different rooms is balanced by making adjustments to the outlet grilles. The central unit will need sufficient heat storage capacity for all the rooms to be heated, so will be larger than an individual room storage heater and require a higher rated electrical circuit.

Controls for warm air systems

- **Time and temperature**: controls should include a programmable room thermostat, or separate programmer and room thermostat.
- **Zone control**: dwellings with a floor area of less than 150m^2 should be divided into two or more heating zones, with independent temperature control in each, unless they are single storey open-plan with a living area at least 70 per cent of the total area. Dwellings with a floor area of 150m^2 or more should be divided into zones, none of which exceeds 150m^2, with independent time and temperature controls in each zone.

Boilers

Electric boilers are designed for connection to a hot water distribution system with radiators or underfloor pipes. There are two types – flow and storage boilers.

In a flow boiler, water is heated as it flows through the boiler and is circulated immediately to the heat emitters.

In a storage boiler, heat is accumulated so that the system can make greater use of cheaper off-peak electricity, and water from the heated store is circulated to the heat emitters separately. The heat store may be 'wet' or 'dry' – wet stores are tanks of hot water, and dry stores are usually ceramics of high thermal mass in which water pipes are implanted to extract the heat.

The size of the heat store is a critical factor governing the proportion of heat that can be obtained from off-peak electricity. The balance between heat demand and store size should be considered as part of the system design method, and the off-peak contribution estimated. The store should be very well insulated to reduce standing losses, and located within the heated envelope of the building. Wet stores should have insulation properties that exceed, by at least 15 per cent, those given in the WMA 'Performance Specification for Thermal Stores'[21]. The space allowance for the store should be considered at an early stage of planning.

As for all wet heating systems, circulation should be fully pumped (i.e. to both space and water heating circuits) and pipes outside the heated living space must be insulated.

Controls for electric boilers

Electric boiler heating systems should be fitted with controls similar to other wet central heating systems; i.e. a programmable room thermostat (or separate programmer and room thermostat), and thermostatic radiator valves (TRVs) on radiators. The controls for space and water heating should be independent, and should be wired to ensure that the boiler is switched off when there is no demand for either – this is known as boiler interlock. An automatic bypass valve may be necessary to maintain a minimum flow rate through the boiler. Motorised valves can be installed to divide the system into separate zones. If a storage boiler and heat store are fitted to make use of off-peak electricity, charge controls should be included as for storage heaters.

Floor heating

Floor heating exploits a large surface area to provide unobtrusive heating at a relatively low emission rate, replacing hot sources such as radiators and convector panels. It is best suited to rooms with well insulated walls, high specification windows and low heat losses. It is relatively expensive to install, although costs are minimised if installation is carried out during construction. As the maximum heat emission from the floor is limited to approximately 70 to 100 W/m^2, depending on the type of floor covering, it is essential to check at the design stage that the heat provided will be sufficient to meet the heat losses from the room.

Underfloor heating can be provided either by warm water circulated in pipes or electrical heating elements. The 'wet' option requires a separate heat generator, such as a heat pump or boiler, and has the potential for lower carbon emissions depending on system type and fuel chosen. The boiler fuel may be any of wood, gas, LPG, oil, coal or electricity.

Electric underfloor heating, i.e. floors with embedded electrical heating elements, is described by manufacturers as direct acting or dual storage. With the direct acting type, electric heating elements are incorporated in the floor as part of its construction. Suitable floor types are those with thin screeds, and suspended timber. The mass of the heated floor is insufficient to provide much thermal storage, and response times are relatively short.

Timber floors are more responsive and better suited to buildings where intermittent heating is required. In both cases the economic performance of the system relies on the choice of effective controls to minimise energy use for a satisfactory level of comfort.

In dual storage floor heating systems, the floor screed is at least 65mm thick and two separate networks of heating elements are embedded. The lower responsiveness of the system makes it better suited to buildings that are heated continuously for occupation throughout the day. The design method aims to produce around 80 per cent of the heat from overnight charging on an off-peak tariff, and the rest from standard rate electricity when required to boost heat output during the day. Best performance is obtained from weather compensating controls to set the off-peak input charge, and intelligent programmable room thermostats.

With all types of floor heating it is essential that downward heat loss is reduced to a low level by installing sufficient insulation. All systems should be professionally designed using a recognised design method and code of practice. Floor insulation standards are discussed further in 'Refurbishing dwellings – a summary of best practice'[16].

Controls for direct acting floor heating

Programmable room thermostats are recommended to give control of individual room temperatures. Users set a programme to match their occupancy patterns, and intelligent predictive pre-heating minimises energy use during unoccupied periods. Automatic temperature setback during unoccupied periods limits temperature drop.

Controls for dual storage floor heating

The storage component is slow to respond and automatic charge control is essential. Weather sensing is one way to achieve this. Intelligent programmable room thermostats can be used to analyse the heating demand pattern, set the overnight charge and augment heat output from the on-peak supply during the day. Division into zones gives a better opportunity to achieve overall system economy.

Ceiling heating

Ceiling heating is usually designed as a direct acting rather than storage system. Heat is radiated downwards and warms the floor and furniture to produce some degree of re-radiation. A heat output up to $150W/m^2$ can be achieved, possibly with multiple or high/low settings.

The system should be professionally designed in accordance with an established method, taking account of heat losses from the room. Unless there is a habitable room above in the same dwelling, it is essential that upward heat losses are limited by providing a high level of insulation.

Controls for ceiling heating

Controls should include a timer or programmer, and a room thermostat shielded from radiation from the ceiling.

Water heaters

Domestic hot water in the UK is traditionally heated and stored in upright copper cylinders, although other types of storage vessels are also available. Cylinders are available both for vented systems, where the pressure is limited by a supply cistern usually installed in the loft, and for unvented systems connected directly to the incoming water supply. The latter have the advantage of supplying hot water at mains pressure, which is better for showers. In each case electrical immersion heaters are installed and, to minimise temperature stratification of the hot water, horizontally mounted heater elements are preferable to vertical ones.

It is economically desirable to make use of the off-peak electricity tariff – but it is then important to ensure the storage vessel is large enough to supply the hot water demand between off-peak periods, and is especially well insulated to maintain temperature throughout the day. Cylinders are made to a higher specification to meet this requirement, and the heat loss should not exceed $1.28 \times (0.2 + 0.051V^{2/3})$ kWh per day, where V is the volume of the cylinder in litres. For a cylinder of 144 litres that is equivalent to about 2kWh per day, or 0.6 watts per litre. The cylinder should be installed within the heated envelope of the building. Further advice is given in the 'Guide to the Design of Electric Water Heating Systems'[22].

A volume of 144 litres is recommended for small households (one or two persons), and 210 litres for larger households. Twin immersion heaters, or dual element single immersion heaters, can be installed and connected so that a small quantity of hot water at the top of the vessel is always available, as it is heated from the permanent electrical supply (mainly on-peak), but a larger volume (e.g. for baths) is heated during the off-peak periods to save costs.

Solar thermal systems

In suitable buildings, electric water heating can be augmented by a thermal solar system. Water is circulated through a solar collector on the roof and a heat exchanger inside the hot water storage vessel. A design procedure must be followed to choose a suitable type, size and position of the collector panel on the roof. The size of hot water storage vessel, and the solar zone inside it, must be chosen to match. The electric immersion heater should not intrude into the solar zone, and positioning of the temperature sensors controlling the immersion heater and the solar system pump is critical.

A single large storage vessel is desirable to maximise the benefits from solar gains during the day, and off-peak electricity at night. As an approximate guide, an extra 50 litres of storage vessel volume should be provided for each square metre of the area of the solar collector. The storage vessel must be well insulated, and the system designed and controlled to ensure that none of the water heated by electricity can be circulated through the roof panel. Well designed systems can produce about 50 per cent of the hot water demand, taken over a full year.

For further details of thermal solar systems see 'Solar hot water systems – guidance for professionals'[2] and the 'Guide to the Design of Electric Water Heating Systems'[23].

Controls for electric water heaters

- **Integral thermostat**: all immersion heaters must have one to limit water temperature.
- **Time switch**: minimises heat losses by allowing occupants to choose heating times to meet personal hot water requirements. Also used to exploit off-peak rates where an off-peak supply is available but the heater is not permanently wired to it.
- **Switching of dual elements**: enables a second heater element to be switched on or off at any time, where the first element is permanently wired to an off-peak supply.

Hot water control

Whole-house controls

Controls for electric heating help to match heating performance to individual occupancy patterns and preferences, and are essential to reduce waste and unnecessary expense. For storage systems, charge controls are needed as well as time and temperature controls. Local controls for individual electric appliances and systems have been described in previous sections. This section describes whole-house controls, covering a number of zones and heaters.

Zone control is recommended best practice for all dwellings, unless they are single storey, open-plan with a living area at least 70 per cent of the total area. Dwellings with a floor area of less than 150m^2 should be divided into two or more heating zones, with independent temperature control in each. Dwellings with a floor area of 150m^2 or more should be divided into multiple zones, none exceeding 150m^2, with independent time and temperature controls in each zone.

Central programmer

This provides independent time and temperature control in two or more space heating zones in accordance with a programme set by the user. It may also control the hot water cylinder. There are communication and control paths (wired or wireless) to a number of room sensors and separate heaters.

CELECT

This is the generic name for the central control of electric space heating, treating it as a complete system. It controls a variety of heaters in different rooms, like a central programmer, but also manages the charging of storage heaters. A typical CELECT system would comprise a mixture of storage fan heaters, storage heaters and panel convector heaters, with one central controller. The controller manages three individual areas or zones in the building, each of which can be programmed individually for multiple daily heating periods and temperature settings. By programming specific heating periods and temperature profiles for each zone, energy use can be minimised for the desired level of comfort.

CELECT uses two-way mains signalling technology, over the existing electrical wiring, as the communications link between heaters and the controller. There is no need for additional signal wiring, and a continuous electricity supply is all that is needed for the controller. Heaters include integral transceivers to communicate with the controller. Additional control circuitry and sensors react to the characteristics of the room and the pattern of the restricted hours supply. This allows the individual heaters to adjust the ratio of on and off-peak consumption in response to the time/temperature profile programmed into the controller. The level of charge taken is determined from a rolling historic analysis of the system behaviour. CELECT meets the controls requirements of Part L of the building regulations.

24-hour (or other) special tariff

24-hour remote control can be provided by the electricity supplier to separate circuits for one or more of:

- Storage heating with weather-dependent control.
- Stored hot water.
- Unrestricted top-up of both space heating (using direct acting heaters) and water heating.

The time periods are set by the supplier.

Load-management special tariff

The electricity supplier switches heating loads on and off within agreed time limits. Load management allows the supplier to balance electricity generation and demand at a more uniform level, switching on controlled loads at times of light loading in exchange for a lower price to consumers.

References

1 Heat pumps in the UK – a monitoring report (CE186/GIR72)

2 Solar hot water systems – guidance for professionals (CE131)

3 Domestic ground source heat pumps: design and installation of closed-loop systems (CE82/GPG339)

4 Domestic heating by gas: boiler systems (CE30)

5 Domestic heating by oil: boiler systems (CE29)

6 Domestic heating by solid fuel: boiler systems (CE47)

7 The government's standard assessment procedure for energy rating of dwellings, 2001 edition (see www.bre.co.uk/sap2001)

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10 DOM 8: Guide to the design of electric space heating systems, TEHVA, February 2006

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13 Section 6: Energy, of the domestic technical handbook on possible ways of complying with the Building (Scotland) Regulations 2004 (see www.sbsa.gov.uk)

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16 Refurbishing dwellings – a summary of best practice (CE189)

17 Community heating – a guide (CE55)

18 CHP opportunities for local authorities (GPG322), Carbon Trust

19 Energywatch – the independent gas and electricity consumer watchdog for consumers (see www.energywatch.org.uk)

20 BS 7671:2001, Requirements for electrical installations, IEE wiring regulations, Sixteenth edition

21 Waterheater Manufacturers' Association – Performance specification for thermal stores, 1999

22 DOM 9: Guide to the design of electric water heating systems, TEHVA February 2006

Further information

The Energy Saving Trust sets energy efficiency standards that go beyond building regulations for use in the design, construction and refurbishment of homes. These standards provide an integrated package of measures covering fabric, ventilation, heating, lighting and hot water systems for all aspects of new build and renovation. Free resources including best practice guides, training seminars, technical advice and online tools, are available to help meet these standards.

The following publications may also be of interest:

- Domestic heating by oil: boiler systems (CE29)
- Domestic heating by gas: boiler systems (CE30)
- Domestic heating by solid fuel: boiler systems (CE47)
- Community Heating – a guide (CE55)
- Domestic Ground Source Heat Pumps: Design and installation of closed-loop systems (CE82/GPG339)
- Energy efficient refurbishment of existing housing (CE83 / GPG155)
- New and renewable energy technologies for existing housing (CE102)
- Solar hot water systems – guidance for professionals (CE131)
- Heat pumps in the UK – a monitoring report (CE186/GIR72)

To obtain these publications or for more information, call 0845 120 7799, email bestpractice@est.org.uk or visit www.est.org.uk/housingbuildings

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