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Energy and buildings

1.1 Introduction

Forecasting is an art in which all are likely to be wrong but some will be more wrong than others. We expect the next few years to be a time for reflection. A variety of opinions on the conservation and use of energy in buildings now exists and a limited amount of data is available. Economic recession has increased the pressure on public and private funds; and the lack of national, let alone global, strategies for resource development has hindered development of energy conservation projects and the exploitation of alternative sources of energy. The result is an atmosphere of caution which at its worst could result in inactivity and resignation and at its best could lead to significant, if somewhat restrained, progress in the use and conservation of energy in the built environment. This may have to be enough – building, after all, is another art of the possible.

Our approach in this book has been to provide designers with a systematic framework for considering the use of energy in buildings. We have tried to cover the more important of the wide variety of topics that must be considered and to provide sufficient references to allow the reader to pursue points of particular interest in depth. A great deal of information has been produced during the last few years but virtually no overviews exist. Different research groups work independently of each other and often work with different aims in view. The overall result is a jungle of papers, data, evaluations and opinions for which we have tried to offer a guide.

Because of our past work we have a strong bias towards integration – energy use in buildings is a function of the site, form, method of construction, controls available, pattern of use by the occupants and the psychological feeling of comfort, as well as the material and energy flows through the building.

The structure of the book reflects this by starting with broader considerations of site and design, then examining specific topics such as solar and wind energy and then finishing with a fairly detailed examination of a number of applications in both domestic and non-domestic buildings.

Our preoccupations have been the areas most familiar to us and so the book is centred on northern Europe, especially the United Kingdom. However, because much of the impetus for the development of ambient energy sources comes from the United States and because of the extensive work

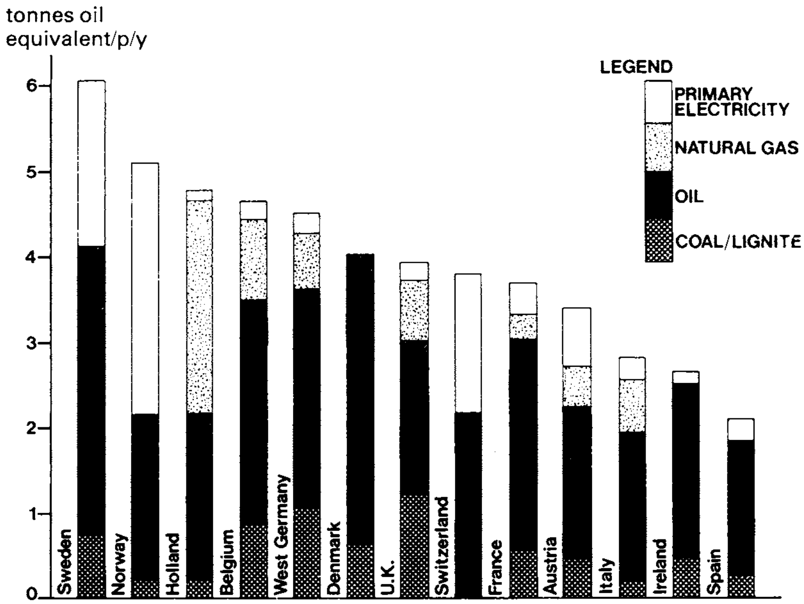

Fig. 1.1. Energy consumption in European countries (tonnes oil equivalent/p/y).[1] (Primary electricity is that derived from nuclear power and hydroelectric plants.)

done there we have tried to bridge the oceanic gap and draw extensively on developments in the US. From another point of view, characteristics of the European built environment such as higher densities and lower acceptable space heating temperatures are of relevance to energy use across the Atlantic.

We have not dealt with numerous topics ranging from alternative sources of energy such as wave power to feed the national grid to the legal aspects of alternative sources of energy, for example overshadowing of solar collectors by neighbouring buildings. In certain cases we have provided references to specialist topics not included in the text.

1.2 Energy and the built environment – past and present

It is worthwhile recalling that, historically, oil production is negligible. On a broad timescale the oil age presently coming to its conclusion is rather insignificant, although all of us have been profoundly marked by its effects. An alternative solution to energy supply and use must be found based on renewable sources of energy.

Fig. 1.1 shows *per capita* consumption of energy in various European countries and the energy sources that contribute to the figures.

Europe on the whole is a net fuel consumer but the UK is in the unusual and fortunate position of being a net producer. For 1981, estimated total consumption of primary energy was 317 MTCE compared to a production of 350 MTCE.[2] (Primary or gross energy is the calorific value of the raw fuel, for example oil, coal, natural gas, nuclear and hydroelectricity. Delivered, or net, energy is the calorific value of the fuel actually received by the consumer.)

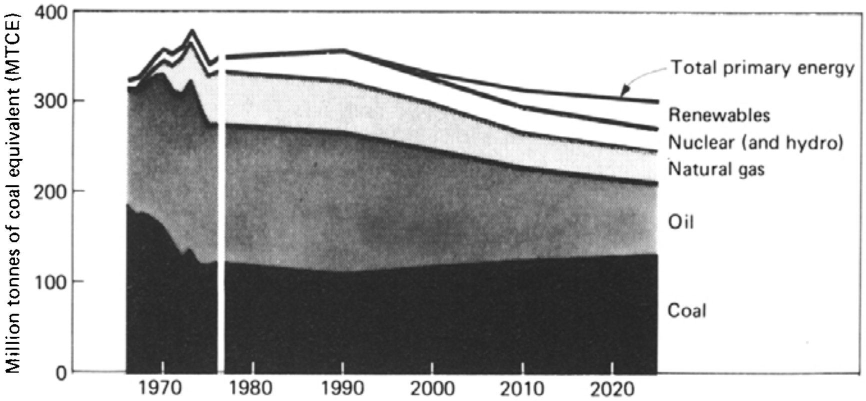

Fig. 1.2. Primary energy projections for a low-energy scenario.[4]

Coal is of major importance in the UK energy supply. Coal supplies are well distributed throughout the UK and estimates of technically recoverable reserves are in the order of 45 000 MTCE.[3] By comparison, recoverable UK North Sea oil reserves are estimated at about 6000 MTCE.[4] During the 1960s, pressure from oil led to a drastic drop in production to 110 Mt/y. In 1974 after a miners' strike a plan was developed to increase production to between 125 and 150 Mt/y by 1986. In 1981 annual output was about 128 Mt/y.[2]

In 1979 (when UK energy consumption was 356 MTCE and production only 329 MTCE), it was estimated that if a 'low-energy' strategy was adopted, in the year 2000 the UK could be entirely self-sufficient on North Sea oil and gas and indigenous coal supplies (renewable energy sources were assumed to contribute less than 2% of the total). Fig. 1.2 shows the makeup of energy sources in such a scenario, which aims for a decrease in energy consumption through a combination of conservation and increased efficiency in industry, the domestic sector, the commercial and institutional sector, transport and energy-supply industries.

Essential to any low-energy strategy is a change in the energy use in buildings. Before considering energy, though, it is worthwhile taking a quick look at population patterns and built forms. Europe is much more densely populated than the US. To the average American there was a hint of this in the absurdly small sizes of imported cars – but such cars are perfectly in scale with road widths and the pattern of buildings.

The UK has a population of about 60 million and an area of 245 000 km^2 – a density of about ten times that of the US. As one observer, commenting on the dangers of nuclear power plants and reflecting on the accident at Harrisburg, said: 'Ours is a small, densely populated island. It is not possible to run very far or very fast.'[5]

Housing densities reflect this with average residential developments in the UK having about 125–175 p/ha.[6] A recent scheme for energy-conscious housing uses passive solar gain and a density of about 40 houses/ha. Looking back a bit, one of the present authors has a home in an area of nineteenth-century, urban two-storey terraced houses which has a present density of about 300 p/ha. The approximate breakdown of the UK housing

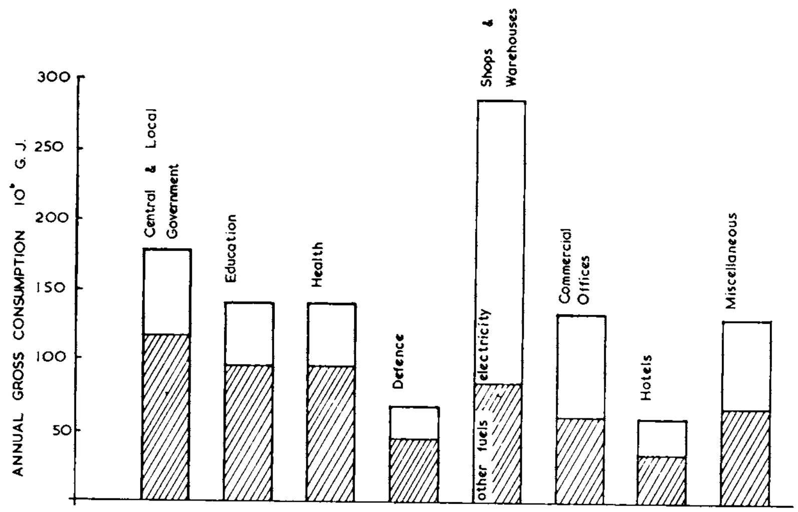

Fig. 1.3. Estimated gross energy consumption of buildings in the public-service and miscellaneous categories.[11] (BRE, Crown Copyright, HMSO.)

stock is semidetached houses, 31%; terraced houses, 30%; detached houses, 16%; purpose-built flats, 14%; converted flats, 8%, and miscellaneous, 1%.[7]

It has been estimated that building services account for 40–50% of the national consumption of primary energy. By sector, industry uses 41% of the energy input; households use 29%; transport, 16%; and other users, 14%.[8] Of the mean net energy consumption per household of 81 GJ/y the breakdown has been estimated as space heating, 64%; water heating, 22%; cooking, 10%; and TV, lighting, etc., 4%. The comparable mean gross energy-consumption figure is 138 GJ/y and the respective percentages 54, 22, 11 and 13.[8] In the domestic sector in the UK and in much of the rest of northern Europe there is no requirement for air conditioning. This is, of course, in contrast to a large part of the US.

During the space heating season it has been estimated that 41–61% of households are intermittently occupied.[9] It is now common for occupied living rooms to be kept at about 20 °C.[10] This represents a rise of about 1 °C per decade from a post-World-War II level of about 17 °C. The most likely reason for this trend was reported to be that, given the choice, people now prefer to wear less clothing in a warmer room than more clothing in a cooler one, although their thermal comfort would be the same in both. (See Chapter 3.) In the interest of energy conservation for society as a whole, a number of countries have taken steps to limit temperatures in spaces. In Britain, for example, temperatures in non-domestic buildings should not exceed 19 °C.

In non-domestic buildings the pattern of energy use varies greatly. Fig. 1.3 shows energy-consumption estimates.

In the non-domestic sector lighting, and hence electricity, plays a much greater role. Cooling loads, often linked to lighting as an unwanted heat source, are also often important.

Table 1.1. *Approximate delivered energy demands (for all energy requirements)*

Building type	Delivered energy demand (MJ/m^2 floor area/y)
(1) Commercial glass houses[a]	2500
(2) Large office buildings and large shops[b]	1700
(3) 1975 schools[c]	1280
(4) 2000 low-energy school target[c]	600
(5) 1982 house[d]	610
(6) Extremely well-insulated house of the future[e]	300

[a] Ref. [12]
[b] Ref. [4]
[c] Ref. [13]
[d] Authors' calculation updating[14] for 1982 Building Regulations.
[e] Based on the Wates House at the National Centre for Alternative Technology.[15]

An approximate idea of the energy consumption in a range of building types is given in Table 1.1.

1.3 Energy and the built environment – the future

The built environment changes slowly – a commonly cited figure for the lifetime of buildings is 60 years although, of course, this varies greatly. Office buildings are likely to last 30–70 years and houses 60 years or more. Servicing systems change more rapidly, with innovation and replacement occurring, say, every 10–30 years. In the last 40 years in the home of one of the authors the heating system has changed from open coal-burning fires to a mixture of gas room heaters and electric resistance heaters to gas central heating with an open fireplace for amenity. Each change has represented an increase in comfort and, because of this, probably in primary energy consumption, although the efficiency of use, particularly from open coal-burning fires to central heating, has been improved.

Will the next change be to solar energy? Probably not or at least not in the immediate future. Solar energy influenced both Greek and Roman urban planning and house design and in the latter civilization by the end of the first century the use of the sun for heating had become so important that laws were enacted to protect a structure's exposure to the sun.[16] For the next 2000 years solar energy applications were limited but diverse and included lenses for heating copper (Leonardo da Vinci) and coupled copper tanks partly filled with water and air to produce pressurized air to play organ pipes (de Caus).[17]

In the nineteenth century the foundations of widespread use of solar energy were laid with experiments in steam generation to drive an engine and pump (1876), generating electricity by focussing sunlight on selenium–platinum junctions (1876), and theoretical studies on solar radiation intensity and transmission through glass.[17] In the early twentieth century, flat-plate collectors were being used for domestic hot-water heating in California. Since then, numerous attempts have been made to use solar energy actively and passively in building design and services, but until the 1970s the ready availability (for part of the world's population) of oil delayed research and development for alternative sources of energy and meant that those applications available, as well as a number of energy conservation measures, were not cost-effective.

In the last decade, increasing prices and a realization that fossil-fuel resources are limited encouraged solar energy work. One UK project on which the present authors participated was that of the Cambridge University Autarkic House,[18, 19, 20] a plan for a house that would be completely independent of mains services, that would rely solely on solar and wind energy for heating and power and that would recycle water and wastes to make the best use of scarce resources. If ever a project was a child of its time, this was it, but unfortunately it was a child of the world and an orphan in the UK with this country's North Sea oil and gas and its 300-year supply of coal. The project was not continued but it did stimulate enormous interest. Unfortunately, many of the problems it had hoped in part to alleviate remain.

For example, the use of solar energy for space heating is environmentally sounder than the use of coal. Coal is a source of pollution and perhaps, on a large scale, a major danger to our climate. One immediate problem with coal (and oil and natural gas) is the so-called 'acid rain' produced when sulphur dioxide and other contaminants from power stations combine with vapour in the atmosphere to form sulphuric acid. Upon falling to earth as rain it seeps into the soil, releasing aluminium and manganese, and poisoning trees. It has been estimated that half of Germany's trees are suffering from this pollution.[21] In Norway, the effect of Britain's power stations has been to destroy fish life in more than half of the country's rivers.[21]

In the long term, fossil-fuel burning affects the carbon dioxide content of the atmosphere and this is presently a subject of great concern. The danger is that the increasing CO_2 content could lead, via the 'greenhouse effect', to a retention of heat that would otherwise escape from the lower atmosphere and so warm the earth's surface and perhaps drastically affect climate. More knowledge of the carbon cycle is required but, in the meantime, solar energy should not be dismissed as uneconomical or unnecessary because of abundant coal. In both the short and long terms we should be striving for environmentally safe solutions to energy supply and, indeed, ultimately we must find them.

Some results of the research into the potential of solar energy have been encouraging. For example, one recent study[6] of passive solar heating of houses showed that a number of measures, including lean-to conservatories and glazing the south-facing aspect of a roof so that it may be used as a warm-air plenum, are likely to be cost-effective in the not too distant future. Reports on active solar heating systems for domestic hot water vary. The Building Research Establishment (BRE) finds them uneconomic at present but estimates that costs might be reduced to about 50% of the current figure for a 4.5 m^2 system by attention to collector design (with significant potential for high-performance collectors) and to satisfactory installation on buildings.[22] However, at least one report has indicated that domestic solar hot-water heating systems will soon become economically viable.[23] One difficulty facing all ambient energy sources is that they are judged by different economic criteria than are conventional and nuclear sources. Similarly, they are not given the generous tax allowances that these latter often receive. Thus, for example, a comparison between solar energy and energy from coal, where the UK Central Electricity Generating Board is heavily subsidized, is necessarily biassed.

A general consensus seems to be that, given present trends, which is another way of saying if we bumble along and continue to spend phenomenally more on nuclear power than alternative sources of energy, the 'alternatives' may be contributing something under 5% to the UK primary energy requirement in the year 2000.[4, 11, 24]

The most likely development in the field of energy and buildings and one which is to be welcomed is greater emphasis on energy conservation. Ever since cow dung was applied to the walls of dwellings by our ancestors, the benefits of increased insulation and greater thermal comfort have been appreciated. Perhaps because it is one of the crudest and easiest ways to conserve energy, as well as one of the most cost-effective, greater insulation has been widely adopted. The dramatic trend in insulation of domestic buildings is shown in Table 3.11.

There are, of course, numerous other ways to conserve energy. Good management can be exceptionally effective – particularly in existing buildings that have undergone numerous transformations; over the years the scope for conservation is enormous. Techniques now available such as heat recovery on extract air and activated carbon filters, which permit a greater proportion of recirculated to fresh air in controlled ventilation systems, can be expected to reduce energy consumption in the near future. Other means are only in their infancy – controls are likely to be one of the greatest areas for development. On the domestic scale, for example, one of the present authors is currently developing a home-energy management system linked to a microcomputer which will sense temperatures throughout the home and outdoors, sense solar radiation and wind speed, allow for the thermal response time of the house and provide desired comfort conditions according to as complex a schedule as the occupants desire – all they will have to do is vary the program at the computer console which may well be linked to their own television for display. Additional features include control of the electrical loads, an energy-accounting system for recording consumption and paying bills and a home-security system.

The BRE has estimated that a combination of energy-conservation measures and the use of ambient energy sources could save 15% of the primary national energy consumption.[11] The programme would include combined generation of heat and electricity in which the waste heat of electrical generation would be used in district heating schemes, widespread employment of heat pumps, increased thermal insulation, controlled mechanical ventilation, solar collectors to supplement the hot-water supply of existing dwellings and a limited use of aero generators for space and water heating.

In the following chapters, we have tried to present a systematic approach to energy conservation and the use of ambient energy in buildings and to provide information on a variety of techniques, not all of which are presently cost-effective, but which we expect to be in the short- to medium-range future.

The question of costs is a vexed one, in part because of its relation to the assumed future real cost of energy. The uncertainty of energy costs affects everyone and large organizations such as the Central Electricity Generating Board are attempting to develop flexible, step-by-step strategies which try to ensure that, whatever the future vagaries of energy supply and demand, the requirements of customers for economical and reliable supplies of electricity are met. Predictably enough, one of the central strategies is the continued development of nuclear power. Another is to explore better ways of burning coal and a third is to identify and develop renewable sources of energy which may be useful for electricity generation.[25]

An approach to cost-calculations, which is gaining in favour, is lifecycle costing in which assumptions about the future, such as those for fuel costs, are made explicit. When energy-conservation measures are assessed on this basis they are often much more attractive than on the simple payback method commonly used. Nevertheless, there is no clear consensus as to what is to be done and in what order. As a preface to the work which follows we present the results of a number of studies of the comparative value of energy-saving measures. One of the present authors made one of the first detailed studies and the results are given in Table 1.2. (Because of the context of the study, passive solar measures were not included.)

Fig. 1.4 shows the Electricity Council Research Centre's results for a number of conservation measures based on dividing the potential annual energy savings by the additional capital cost (above that of an electric warm-air heating system).

Fig. 1.5 shows the results of a study of energy conservation in the Felmore Housing Scheme at Basildon, a group of 430 houses supplied by a district heating scheme.

Of course, there are many considerations other than cost involved in energy conservation – these vary from providing resources for future generations and achieving self-sufficiency in energy in order to escape political dependence on countries controlling the energy supply, to individual decisions about comfort and a desire to have the most modern technology available in one's home.

We believe that we are moving towards a community which uses energy and resources both more efficiently and in closer harmony with nature – but progress is, and will continue to be, slow. There is a great need for research into materials, equipment, techniques and attitudes. The vicious self-fulfilling argument that 'since the renewable sources of energy have

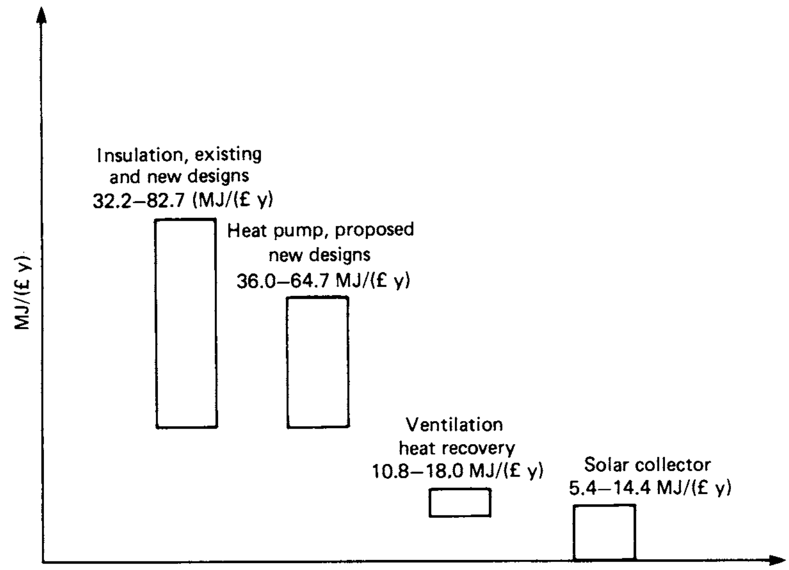

Fig. 1.4. Ranking of energy-saving measures.[27] (Internal temperatures are 20 °C/16 °C.)

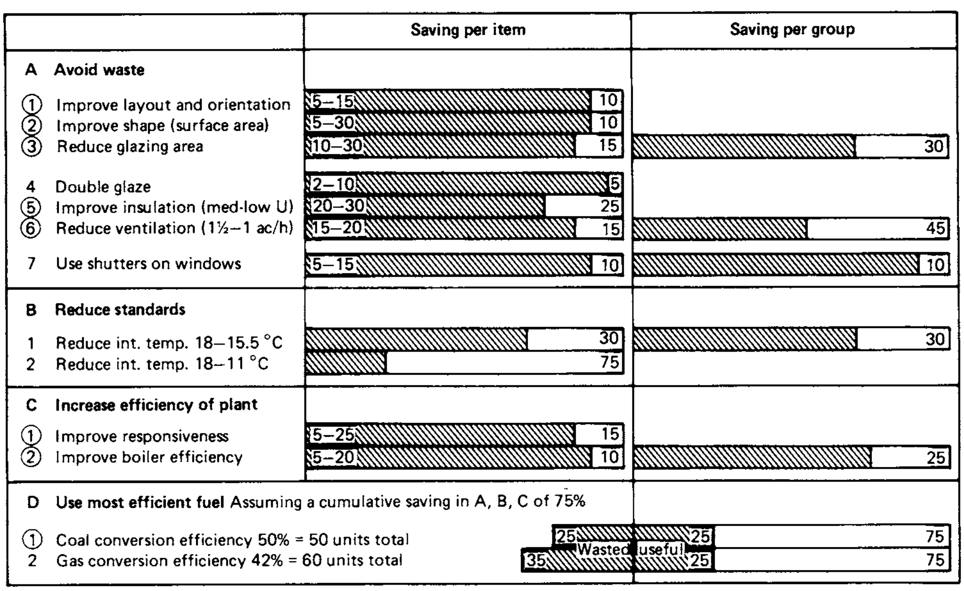

Fig. 1.5. Aspects of energy conservation at the Felmore Housing Estate in Basildon.[28] (The main design effort was placed on items marked by a circle.)

not been proven to be reliable and capable of contributing significantly to our energy supplies, the capital allocated to their research and development must be severely limited' will have to be attacked.

It seems reasonable to expect the following for the near future in the field of energy and buildings:

(1) The building stock will not have changed greatly; design professionals will be working largely on existing buildings; both new and existing buildings will be vital to improving the national use of energy.

Table 1.2. *Ranking of energy cost-effectiveness for measures of conservation and alternative energy supplies*[26]

Measure			Annual GJ/£[a, b, c]	
			Break-even	9% dividend
Roof insulation	50 mm	DIY	3.8	1.2
Roof insulation	100 mm	DIY	2.4	0.7
Roof insulation	150 mm	DIY	1.8	0.5
Roof insulation	50 mm	Installed	1.4	0.4
Double glazing	–	DIY	1.5	0.5
Roof insulation	200 mm	DIY	1.4	0.4
Roof insulation	100 mm	Installed	1.2	0.4
Roof insulation	250 mm	DIY	1.2	0.3
Roof insulation	150 mm	Installed	1.0	0.3
Wall insulation (cavity)	100 mm	Installed	0.9	0.3
Roof insulation	200 mm	Installed	0.8	0.3
Double glazing	–	Installed	0.8	0.2
Double glazing with heat-reflecting coatings	–	Installed	0.8	0.3
Heat recovery from hot water	–	Installed	0.7	0.2
Wall insulation (cavity)	150 mm	Installed	0.7	0.2
Roof insulation	250 mm	Installed	0.7	0.2
Double glazing with heat-reflecting coatings and krypton	–	Installed	0.7	0.2
Single glazing with foam blinds	–	Installed	0.6	0.1
Wall insulation (cavity)	200 mm	Installed	0.6	0.2
Electric heat pump in new house	–	Installed	0.5	0.1
Wall insulation (solid)	50 mm	Installed	0.4	0.1
Wall insulation (solid)	100 mm	Installed	0.4	0.1
Wall insulation (solid)	150 mm	Installed	0.4	0.1
Conversion from oil to electric heat pump	–	Installed	0.4	0.1
Conversion from electric resistance heating to electric heat pump	–	Installed	0.3	0.1
Wall insulation (solid)	200 mm	Installed	0.3	0.1
Heat recovery from warm air	–	Installed	0.3	0.1
Solar collectors for water heating on wall of:				
New house			0.3	0.1
Existing house			0.3	0.1
Solar collectors for water heating on roof of:				
New house			0.3	0.1
Existing house			0.3	0.1
Solar collectors for space and water heating without long-term storage on wall of:				
New house			0.2	0.1
Existing house			0.2	0.1
Solar collectors for space and water heating without long-term storage on roof of:				
New house			0.3	0.1
Existing house			0.2	0.1
Solar collectors for space and water heating with long-term storage on a house of floor area 100 m^2			0.1	0.0
Aerogenerator			0.1	0.0