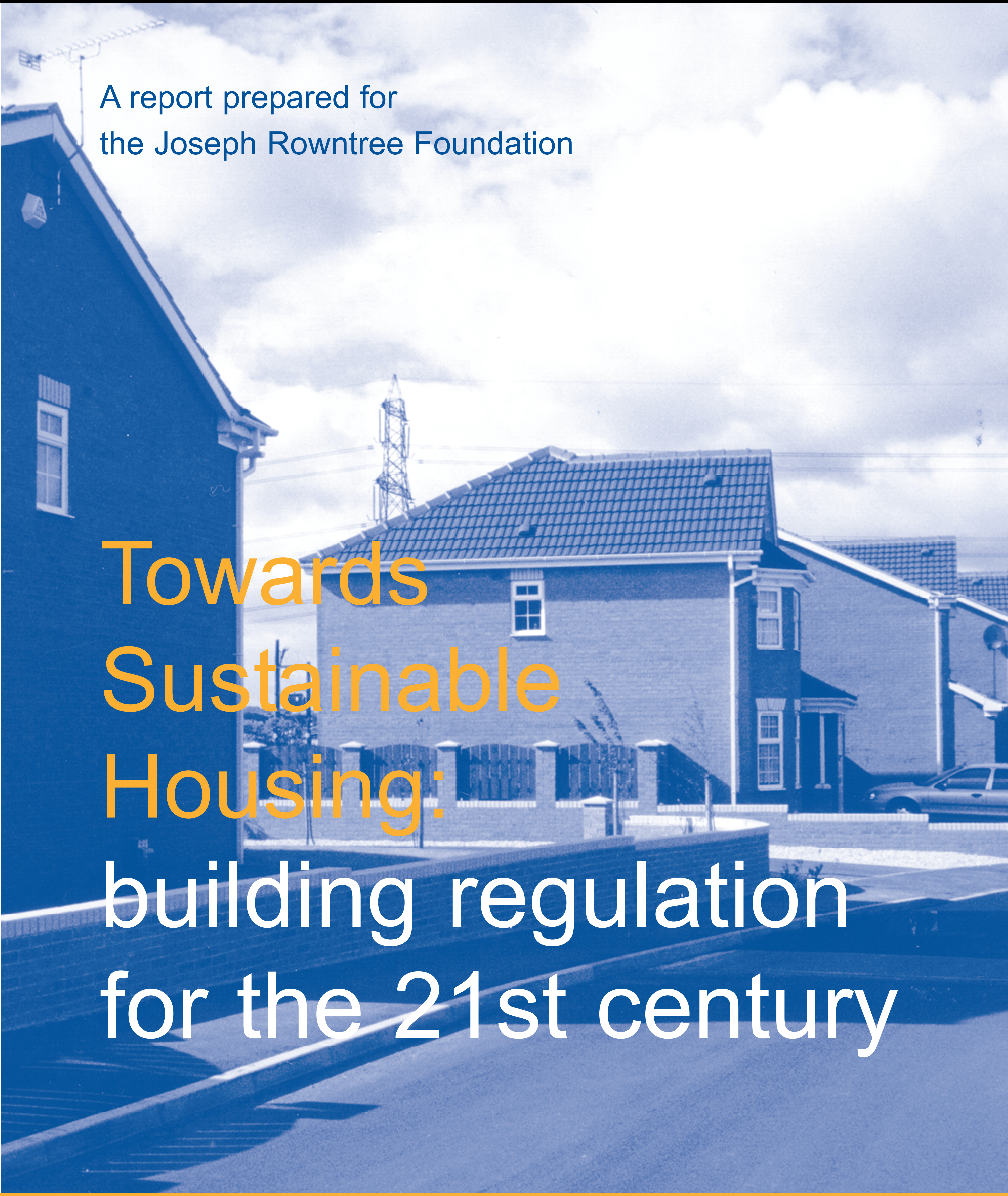


A report prepared for
the Joseph Rowntree Foundation

Towards Sustainable Housing: building regulation for the 21st century

Robert Lowe & Malcolm Bell

Towards Sustainable Housing: building regulation for the 21st century

a report prepared for
the Joseph Rowntree Foundation
by Robert Lowe & Malcolm Bell
Leeds Metropolitan University

Prepared by Centre for the Built Environment, Leeds Metropolitan University,
for Joseph Rowntree Foundation.
Published by Leeds Metropolitan University.
ISBN 1 898883 12 2

Designed and typeset by
LMU Faculty of Health & Environment Capability Learning Support Unit

contents

acknowledgements

This report has been produced with financial support of the Joseph Rowntree Foundation. We wish to acknowledge the assistance of Julie Cowans of the Foundation for her practical and moral support in this enterprise. We also wish to thank the regulatory authorities and embassy staff of Denmark, Sweden, the Netherlands and Germany for their assistance in gathering material on regulations in those countries. We are grateful to David Oliver of Energy Advisory Associates, for his invaluable assistance and comments on drafts, and to Frank Robinson for his meticulous proof-reading. Any remaining errors are ours.

July 1998

executive summary

This report has been produced at the request of the Joseph Rowntree Foundation with the prime intention of instigating debate over future developments in energy efficiency aspects of the Building Regulations in the UK. The report presents a critical review of current regulations, mainly with respect to space heating and the performance of the thermal envelope. The performance of the thermal envelope, as built, is a major determinant of overall environmental impact, with implications that extend further into the future than any other physical aspect of the dwelling. While energy use and carbon emissions for lighting and appliances will account for a progressively larger proportion of the domestic sector's total over the next twenty years, we do not consider that the Building Regulations are an appropriate tool to deal with these categories of end-use.

The report identifies a range of technical, regulatory and policy developments which should be pursued in order to ensure a significant reduction in energy consumption and greenhouse gas emissions from buildings in the 21st Century. Although we have focused on dwellings, much of the discussion is relevant to other building types. Our principal findings are as follows:

- The Building Regulations do not currently address the need to make large reductions in the emissions of CO_2 or other greenhouse gases. Estimates of reductions required by the middle of the next century to contain global climate change, vary from 60% to 90% in industrialised countries. The current regulations will need considerable revision if even the lower end of the range is to be achieved in the UK domestic sector.

- The single most important step will be to develop, and win public support for, an explicit set of energy and CO_2 objectives which the regulations will seek to achieve, covering a period of at least ten years. In the light of these objectives, performance targets and a phased programme of regulatory and other measures should be developed. This long-term approach will give the construction industry time to plan for the required changes, through an integrated programme of research, development and demonstration, focusing both on process and product development, that will minimise costs associated with change.

- If existing legislation does not enable the use of Building Regulations to address environmental objectives, then appropriate amendments should be brought before Parliament as a matter of urgency.

- The achievement of significant reductions in energy use and CO_2 emissions will require substantial reductions in conduction and ventilation heat losses from new dwellings. We propose measures to reduce average U values by 40% by the year 2000 and by 60% by the year 2005. The latter level, modelled on the current Swedish Building Regulations, will reduce the space heating requirements of a typical semi-detached house in the North of England by almost 90% compared with the same dwelling built to current UK Building Regulations.

- The methods used to calculate U values should take full account of thermal bridging and of typical construction quality. The regulatory process must also take account of empirical evidence on thermal performance, particularly where this suggests that particular constructions significantly under-perform.

- The nature and role of the Standard Assessment Procedure (SAP) in the Building Regulations are unclear. The SAP index is complex and opaque. Fundamental messages about energy use and CO_2 emissions are obscured because the index is based on energy prices. The effort expended on SAP calculations for every new dwelling is disproportionate. We propose that the Regulations include a revised SAP index, based on CO_2 emissions for space and water heating and ventilation, per square metre of accommodation. Unless the public profile of the SAP index can be raised significantly, we propose that SAP calculations be required only in support of the Energy Rating Method.

- The Regulations must address the efficiency and environmental impact of space and water heating systems in a more consistent way. We propose that upper limits on average carbon intensity for heating systems should be introduced, as part of the Elemental and Target U Value methods. These limits would replace the ad hoc provision for condensing boilers in the current Approved Document. Together with tighter upper limits on U values, this would prevent the long term performance of the dwelling, which is largely determined by the performance of the building thermal envelope, from being compromised by trade-offs against heating system efficiency. The changes that we have proposed would remove the need for a SAP threshold (currently set at 60) to trigger lower U-values.

- There is a need for a standard calculation procedure for heat losses through glazing edges and frames. This requirement should be introduced as part of a comprehensive Window Energy Rating System, which would also take account of solar gains. Such a system, funded by window manufacturers, has been in operation in North America for several years.

- The Building Regulations should include a limit on air leakage to be verified by post-construction testing 5-10% of all new dwellings. The limit should initially be set at a level that will not require changes in Part F of the Regulations (relating to ventilation) but there should be a clearly stated intention to lower the limit in subsequent amendments. We suggest a limit of 10 air changes per hour (ac/h) at 50 Pa in 2000, falling to 3 ac/h in 2005.

- The treatment of existing housing by the Regulations must be extended. In particular, the replacement of such things as roofs, windows and heating systems should be controlled to ensure that every opportunity is taken to meet standards for new housing.

- In our view, compliance cost assessment should inform, but cannot replace a broader strategic approach to the determination of standards for energy efficiency in construction. Where proposed regulations are subject to tests of economic efficiency, such tests should be based on discount rates appropriate to the long term and secure nature of investments in housing. We would suggest a test discount rate of 2% rather than the 6% used in the last Compliance Cost Assessment. Traditional approaches to analysis exaggerate transitional costs. Future compliance cost assessments should exclude transitional costs and should be based on rationalised construction details.

- Regardless of strategic arguments, it may be difficult to win and maintain widespread support for radical changes to the Building Regulations against a background of falling energy prices. While, in the short term, we support the use of shadow carbon pricing in economic analysis, the Government needs to address the question of the use of energy prices to reflect environmental impact and should act to halt and reverse the downward trend in domestic energy prices.

- While the construction industry has legitimate concerns with respect to the Building Regulations, they must be subordinate to the need to move toward sustainability in the built environment. Measures must be taken to give industry the confidence that it can manage the process of change, through training programmes, marketing and public education, support for R&D, and through a programme of practical demonstration projects.

The regulatory and technical feasibility of the technical changes that we have proposed is demonstrated by the many thousands of dwellings that have been built to these standards in Denmark, Sweden and Canada, and by a small but significant number of dwellings in the UK. There is considerable work to do to develop the details of a rolling programme of technical amendments to the Building Regulations. However, in our view, it is as important to establish overall energy and environmental targets and a long term regulatory strategy, as it is to enact particular technical improvements.

1

introduction

The purpose of this report is to critically evaluate the operation of the current Building Regulations as they relate to the energy efficiency of new housing and to explore a range of issues which should be taken into account in framing future regulation. The report pays particular attention to the developments which should be considered in order to embrace not only the need to conserve scarce fuel resources but also the need to combat global warming through significant reductions in greenhouse gas emissions, primarily CO_2.

1.1 The Regulations

Part L of the current Building Regulations (1991) was last amended in 1994 (SI 1994 No. 1850) and came into force on 1 July 1995. The objective of this part of the regulations is the conservation of fuel and power in buildings. The general requirement is expressed as follows:

> L1. Reasonable provision shall be made for the conservation of fuel and power in buildings by:
> (a) limiting the heat loss through the fabric of the building;
> (b) controlling the operation of space heating and water heating systems;
> (c) limiting the heat loss from hot water vessels and hot water service pipework;
> (d) limiting the heat loss from hot water pipes and hot air ducts used for space heating;
> (e) installing in buildings artificial lighting systems which are designed and constructed to use no more fuel and power than is reasonable in the circumstances and making reasonable provision for controlling such systems.
> (Building Regulations 1991 as amended 1994)

In the case of dwellings, regulations L1 (a), (b), (c) and (d) apply with the additional requirement that all dwellings (whether created by a change of use or constructed as new) must have an energy rating calculated in accordance with a specified standard methodology. The method currently in force is the Standard Assessment Procedure (SAP) as described in Appendix G of Approved Document L. The remainder of the discussion in this report relates primarily to Approved Document L.

1.2 Climate change

Although the process of anthropogenic climate change is still imperfectly understood, there is considerable agreement within the scientific and political communities that significant reductions in greenhouse gasses (principally CO_2) will be required during the next century if disruption to climate systems is to be minimised. Estimates of the scale of likely reductions in the developed countries vary from around 60% to 90% by the year 2050. The target depends on the view one takes about the sharing of CO_2 emission reductions between the developed and developing world. Whatever view is taken, however, it is hard to avoid the conclusion that large reductions will be required (Krause et al. 1989, Deutscher Bundestag, 1991, Bell et. al. 1996). At the World Climate Conference in Kyoto (December 1997) an overall reduction of emissions from developed nations of 5.2% based on 1990 levels over the next 15 years was agreed, with Europe contributing 8%, the USA 7% and Japan 6%. Although these reductions fall a long way short of what may be needed, the agreement represents an important step forward. Since Kyoto, the British government has maintained its commitment to a 20% reduction in UK CO_2 emissions by the year 2010, a target which we consider to be challenging, but technically achievable.

Emissions of CO_2 from buildings account for between 40% and 50% of the UK total with housing accounting for about half of building emissions (25% to 30% of total emissions). Buildings will therefore play a very important part in achieving sustainable levels of CO_2 and the role of the Building Regulations will be critical. It must be recognised of course, that new building is only one part of the total picture and that despite the large number of new homes expected to be required (over 4 million) in the next twenty years it is unlikely to be enough to concentrate on new build alone. In recognition of this, it will be necessary to seek ways in which the building regulations (working hand-in-hand with initiatives such as the Home Energy Conservation Act) can ensure that repair and improvement works to the existing stock make a contribution to achieving energy and CO_2 targets.

1.3 External benefits

Much has been written over the last ten years of the failure of housing to provide acceptable levels of warmth and health for many people at a price which they can afford. Some attempts to tackle this problem have stressed income levels and fuel prices. The "VAT on fuel" debate is an example. However, it is also recognised that the energy efficiency of the dwelling is also of great importance and that if managed well, housing improvements can benefit the fuel poor as well as contribute to reduced greenhouse gas emissions.

In housing at least, it is technologically feasible to achieve the scale of reductions in space and water heating that will be required to approach sustainable emission levels and achieve improved living conditions. There is a growing stock of exemplar dwellings from which to learn and develop new techniques (see, for example, Bell et.al. 1996, Lowe et.al. 1996 and Olivier & Willoughby 1996a & 1996b). However, the task of reshaping the Building Regulations to respond to the climate change agenda will be a difficult one. The context of declining fuel prices will make economic arguments difficult to sustain unless we seek to reflect the future economic consequences of global warming in our models; there will be important training implications for the construction industry as it attempts to grapple with levels of insulation and airtightness with which it is unfamiliar and the producers of domestic heating systems, lights and appliances will need to improve the efficiency of their products. This paper seeks to make a contribution to the debate about how far and how fast we should move on these issues. The debate will need to range across a wide front including the detailed content of regulation, regulatory structure and the energy and environmental policy, which the regulations should be designed to support.

2

review of current u.k. building regulations & international comparisons

2.1 Introduction

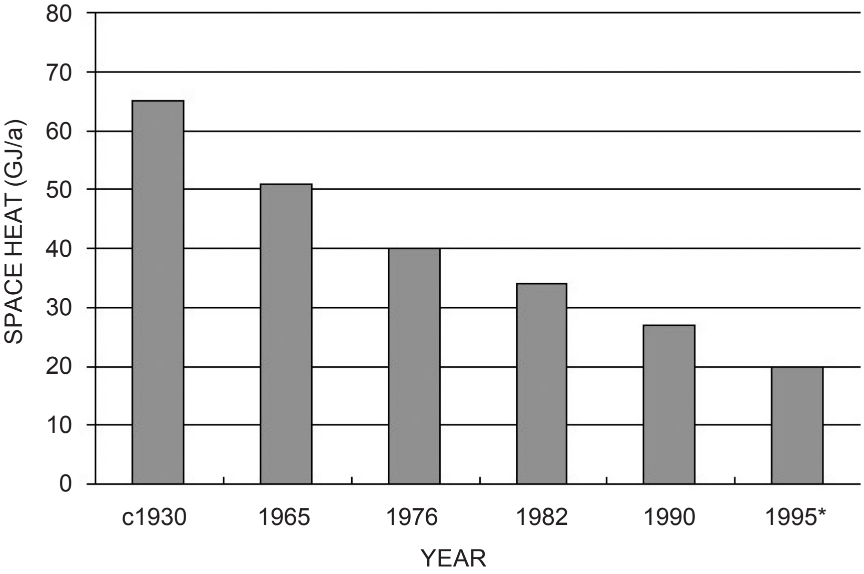
Since the unification of building regulation in the mid 60s there has been a steady improvement in energy efficiency standards. This is illustrated in Figure 2.1, which shows the impact of the Building Regulations on the space heating load for a small semi-detached house with a well controlled central heating system. Despite this improvement, significant scope exists for further reductions in the energy consumption of buildings. Figure 2.2 compares a number of dwellings in the context of the average energy consumption in GB dwellings. The York mean, which is based on existing semi-detached houses improved to a SAP rating of 84, would satisfy the 1995 Building Regulations. The remaining schemes represent a range of dwellings built over the last ten years. The Pennyland scheme represents one of the best low energy schemes of the 80s, the Longwood House (Lowe & Curwell 1996) is one of the best of the early 90s and Kranichstein (Feist et al. 1994) approaches the level of consumption likely to be required for the stabilisation of atmospheric CO_2. Profiles of other low-energy housing schemes in the UK and overseas are given by Olivier and Willoughby (1996a & 1996b)

Building Regulations improvements over the last two decades have seen a reduction in nominal envelope U values with, for example, nominal wall U values being reduced from 1.0 in 1976 to 0.45 W/m^{2}K in 1990. Between 1990 and 1995 improvements included;

- the adoption of window and door standards roughly equivalent to plain double glazing;
- improvements in the methods used to calculate U values (taking into account the thermal bridging, e.g. through timber joists or studs in an otherwise well insulated layer – see discussion of technical issues in Chapter 3);
- an initial attempt to address the problem of air leakage, in the form of guidance notes for designers and builders.

Figure 2.1
Impact of the Building Regulations on energy use for space heating (semidetatched house with well controlled central heating).

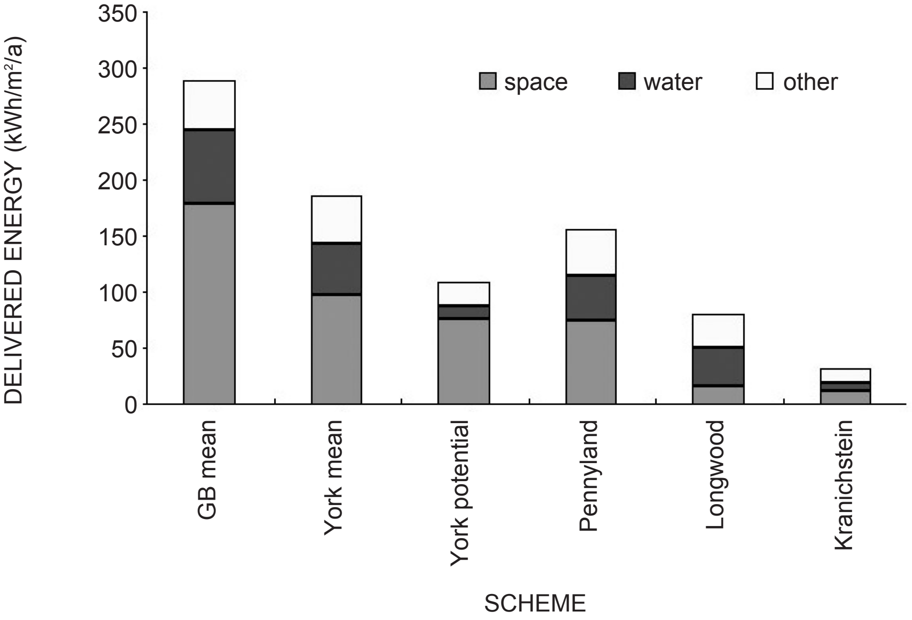
Adapted from Anderson (1988) crown copyright. Consumption for 1995 has been estimated separately (Bell & Lowe 1995).



In addition to these technical improvements, the 1995 amendment saw a number of changes in the structure of the regulations with respect to dwellings. The introduction of the Energy Rating Method based on SAP extended the notion of a whole-dwelling performance-based regulation, first introduced in 1990. From 1995, all dwellings were required to have a SAP rating. For dwellings with a SAP above 60, target U values for opaque elements of the thermal envelope remain at 1990 levels but for dwellings with a SAP of 60 or less, lower U values are now required.

Figure 2.2
Comparison of energy standards.

Source:
Bell & Lowe (1997).



Under the 1995 amendment, compliance with the regulations can be demonstrated in one of three ways. The Elemental Method aims to limit conduction losses through each separate element of the building thermal envelope, regardless of the economic or environmental cost of supplying heat to the dwelling. Regulation of elemental U values was originally introduced on health grounds, in order to reduce the incidence of damp and mould. The elemental U values required by the current building regulations are, however, not low enough to achieve the elimination of condensation, particularly in view of the differences between realised and notional U values discussed in Chapter 3.

The Target U Value Method constrains the average U value of the thermal envelope and allows trade-offs between the various elements. This method also allows higher U values to be traded-off against the installation of a condensing boiler and allows a trade-off against south facing glazing in order to account for solar gains.

Finally, the Energy Rating Method specifies a SAP rating of between 80 and 85 depending on floor area. Subject to certain constraints, the Energy Rating Method allows trade-offs between all elements of the thermal envelope, between the thermal envelope, heating system efficiency, choice of heating fuel and energy tariff, and between space and water heating.

Anecdotal evidence would suggest that most house builders rely on either the Elemental or Target U Value methods to demonstrate compliance

2.2 Comparison of compliance methods.

Since the goal of the various compliance methods is the same, it would be reasonable to expect that their effect, in energy efficiency terms, would be roughly equal. The reason for different methods, is to provide designers and contractors with some flexibility so that they can choose the methods that suit different working styles and different circumstances. Difficulties arise, however, when different methods result in significantly different efficiency standards. To be effective, regulations need to be simple and easily understood, they need to be structured so that the cost of demonstrating and checking compliance is minimised and they need to represent a consistent standard, irrespective of the compliance methods used. This section seeks to assess the current methods against these criteria.

Traditionally Building Regulations have concentrated on the performance of the building envelope through the specification of maximum elemental U values. The advantages of this approach are considerable. The thermal envelope is the most durable part of the dwelling, with an expected life between two and ten times that of the heating system. Envelope performance is a major determinant of long term energy and environmental performance of the dwelling as a whole. Maximum U value standards impinge directly on envelope performance. Elemental U value targets are conceptually easy to understand and provide a clear set of design rules. It is also a relatively straightforward matter for the building control system to check compliance.

The house building industry has maintained, however, that the Elemental U Value Method is inflexible, and that it allows the designer no freedom to depart from its stipulations. Also, without additional provisions, the Elemental Method does not constrain heating system efficiency.
The response of the Government to these observations has been the progressive introduction of performance based standards. The first of these was the Calculated Trade-off Method, which was introduced in embryo form in 1976 and consolidated in approved document L which appeared for the first time in 1985. This allowed designers to vary individual elemental U values and to vary the amount of glazing in a dwelling provided that the level of insulation was at least as good as that which would have been achieved by the application of the Elemental Method. This method was revised to appear as Calculation Procedure 1 in 1990 and revised again in 1995, with the addition

of optional allowances for solar gains and boiler efficiency, to produce the Target U Value Method. The notion of a whole-building performance assessment which takes into account incidental gains (solar and other gains) as well as losses, was first introduced for non-domestic buildings in 1985. However, it was not until the introduction of Calculation Procedure 2 in 1990 that such an approach was introduced for dwellings. This procedure specified the Energy Target Method, based on the Building Research Establishment Domestic Energy Model (BREDEM), as the prescribed method. In 1995, Calculation Procedure 2 became the Energy Rating Method based on a specified SAP target depending on floor area.

Detailed study of the Target U Value and Energy Rating Methods suggests that their main function within the system of regulation has been to allow builders to avoid the need to modify pre-1990 construction methods as the elemental U value standards have been raised. In particular, they have allowed builders to retain the option of building walls with uninsulated cavities. This is most apparent in the structure and operation of the Target U Value Method. As observed above, this method allows builders to trade-off the installation of a condensing gas boiler against envelope U values. The *ad hoc* nature of this rule can be seen from the fact that it only operates in one direction. The target envelope U value, which is based on a boiler efficiency of 72%, can be increased by 10% if a condensing gas boiler is installed. However, dwellings heated by systems with lower efficiency and higher environmental impact than a standard gas-fuelled central heating system are not required, under this method, to have lower envelope U values.

Furthermore, the overall U value target depends on the ratio of total floor area to total area of exposed elements. This formulation allows significantly higher U values where elements of the envelope of the dwelling are shared with adjacent properties, for example in terraced housing and flats. It is hard to find a convincing case for this approach, particularly in view of the evidence, presented in chapter 3, of significant heat losses associated with party walls.

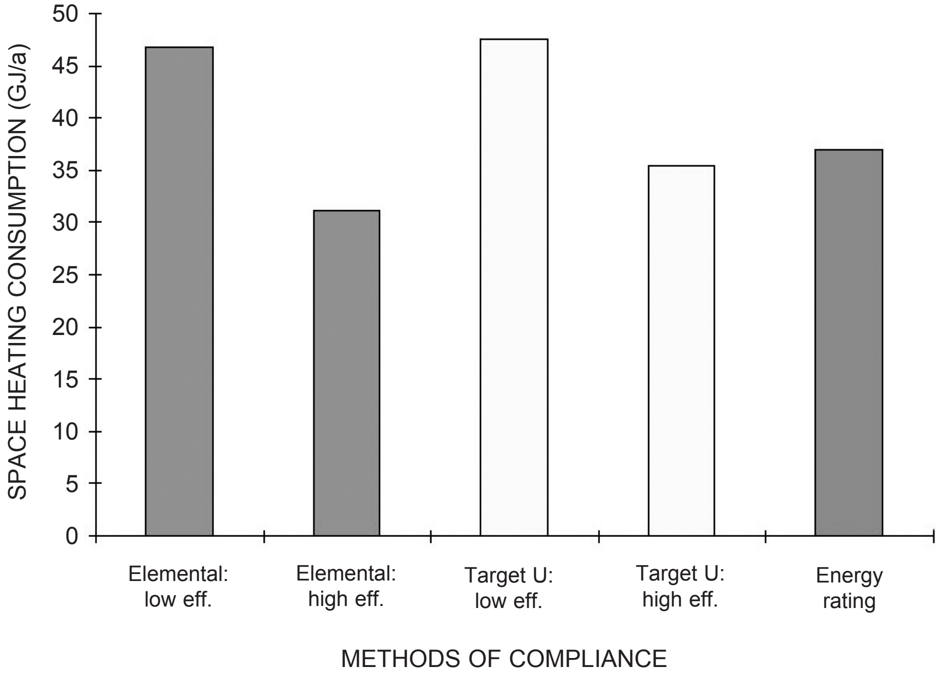
In order to explore some of the conflicts inherent in the Regulations as they stand, each of the three compliance methods was applied to a typical dwelling. This was defined as a two-storey semi-detached house, nominally of masonry construction, with a floor area of 100 m^2 and heated by gas. For the Elemental and Target U Value methods, two alternative heating systems were defined:

- Low efficiency – a gas central heating system with a traditional wall mounted boiler (efficiency 65%) together with a secondary system comprising a flame effect gas fire in a traditional chimney (efficiency 25%) supplying 15% of the lounge (zone 1) heating (overall efficiency 59%);
- High efficiency – a gas central heating system with a condensing boiler and no secondary heating system (overall efficiency 85%).

In the case of the Energy Rating Method, the approach taken was to use the high efficiency heating system defined above, and to increase the U values of the envelope as far as the regulations would allow, so that a SAP of 83 (the target for this size of house) was achieved. All modelling calculations were done using the National Energy Foundation's NHER Evaluator program version 2.86. The comparison of space heating energy requirements and CO_2 under the above scenarios is set out in Figure 2.3.

The reduction in energy consumption produced by the use of a high efficiency system is in the region of 34% in the case of the Elemental Method and around 25% in the case of the Target U value Method. The difference follows directly from the 10% increase in U values allowed by the Target U value Method as a trade-off for an efficient heating system. In fact, applying the Elemental Method with a high heating system efficiency yields a SAP of 88, giving the lowest energy consumption and satisfying, by a good margin, the requirements of the other two methods.

Figure 2.3
Comparison of methods of compliance.



The relationship between fabric performance and heating performance is an important area in defining any overall energy standard. The way the regulations are currently framed does not place an effective lower limit on overall heating system efficiency. It is possible to install very inefficient room heaters with a correspondingly high space heating energy consumption and still demonstrate compliance using the Elemental or Target U value methods. Rather than encourage high heating system efficiency in the interests of higher overall standards, the regulations actively encourage lower envelope standards in return for high heating efficiency. In deriving a SAP of 83 using the Energy Rating Method in the above example, it was possible to increase U values substantially - in the case of walls, from 0.45 to 0.7 W/m^{2}K, representing a 55% increase and the maximum allowed under the regulations. The average U value in the example dwelling increased from 0.71 to 0.81 W/m^{2}K (14%).

The significance of the above analysis, is that there is a danger that long term efficiency gains which accrue from fabric insulation (with a very long physical life) will be sacrificed for the short term gains offered by increased heating system efficiency. In an extreme case, the owner of a new home with a condensing boiler but poor U values (SAP 83) could, within days of taking possession, reduce overall efficiency by ten to twenty percent just by installing a flame effect open-flue gas fire. A more serious problem arises from the upward drift in boiler efficiencies which is to be expected as a result of general technological improvement and regulatory pressure. It is in our view likely, that all dwellings with gas-fired central heating that had achieved regulatory compliance in the 1990s, will be fitted with condensing boiler systems in the first replacement cycle. If this occurs, the energy consumption of dwellings that initially achieved compliance under the 1995 Regulations by a trade-off of condensing boilers against wall U values of up to 0.7 W/m^{2}K, will not be significantly reduced. The net effect of this situation could be that these dwellings will end up using more energy, following the first boiler replacement, than those built using the prescribed elemental U values under both 1995 and 1990 Regulations.

2.3 Detailed critique of the SAP index and its role in the Regulations

SAP was introduced in the 1995 revision of the Approved Document with three objectives.

The first, was to extend the use of a whole-dwelling performance approach by defining the Energy Rating Method based on SAP thresholds. The second, was an attempt to raise the profile of energy efficiency as a factor in the marketing of new homes. As a simple energy label, SAP was designed to provide house buyers and builders with an easy way of comparing the energy costs of alternative houses. This second objective resulted in the requirement that all new dwellings should be SAP rated. The third objective of SAP was to act as a trigger to enforce higher building envelope performance in dwellings, whose overall energy performance fell below a threshold (a SAP value of 60).

Although these goals are superficially attractive, there are a number of problems with the SAP index and the way it is used in the Regulations. They can be summarised as follows:

- the definition of the index is opaque, and not well understood either by the building industry or the public, or by key intermediaries such as estate agents; as a result SAP has not achieved the second of the objectives described above;
- the calculation procedure is complex and relatively laborious – experience suggests that many building professionals are unable to calculate a SAP index correctly without specific training and tight quality control;
- the index is based on energy cost, which is only loosely correlated with environmental impact;
- the index allows unjustifiable trade-offs between fabric performance and water and space heating performance.

In order to explore the latter two aspects further, the typical dwelling used earlier in this section was modelled with modern electric storage heating and electric (dual immersion) water heating. Insulation levels remained at the level required for a SAP greater than 60. As would be expected, CO_2 emissions for space and water heating were more than doubled in the case of electric heating, compared with gas (from 3.0 te/a to 6.8 te/a). The SAP fell from 80 (with 72% efficient gas heating) to 66, reflecting the increased cost of electricity. The anomalous position of SAP as a means of energy rating (as opposed to a means of energy cost rating) is illustrated by changing the water heating method from dual immersion, which has a high off-peak component, to on-peak immersion. The effect on SAP was dramatic. The figure was reduced from 66 to 50. This in turn resulted in a requirement for higher elemental U values, which raised the SAP to a final figure of 53. The effect of higher U values both on SAP and on CO_2 was, however, small.

Thus, it seems that one result of changing from off-peak to on-peak water heating, with its higher running costs, is a requirement to increase the amount of wall insulation! While the resulting (small) reduction in carbon emissions is laudable, it is difficult to defend the regulatory process by which it is achieved. If the case for increased wall insulation is sufficiently persuasive to require it in the case of a dwelling with on-peak water heating, it is irrational not to require it in the case of off-peak water heating. The environmental and economic case for envelope insulation is, in the example given, almost completely independent of the details of the water heating system and should be treated accordingly.

Although the carbon coefficient for electricity has fallen steadily over the last half century, as a result of increases in the use of gas and improved conversion efficiencies at the power stations (see figure 2.5), it is likely to remain well in excess of that for natural gas for the next twenty years[1]. While the vast majority of dwellings use gas for space and water heating, it is, nevertheless, important that the problem of electric resistance heating in dwellings is addressed in a thorough and consistent way by the building regulations.

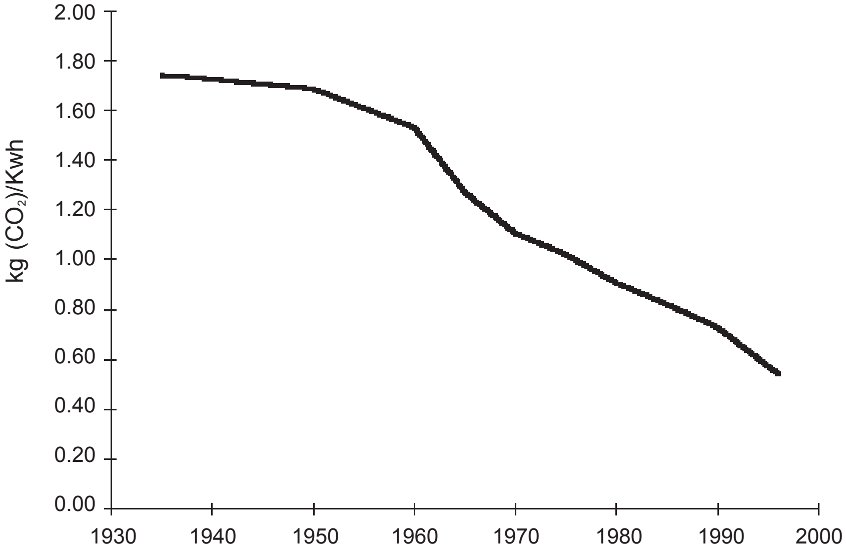


Figure 2.4
Carbon coefficient of electricity.

Some of the problems outlined above could be dealt with through modifications to SAP and the Energy Rating Method. For example, the SAP index could be made more meaningful and arguably more transparent by basing it on energy consumption or CO_2 emissions per square metre of floor area, as used in the BREEAM standard for dwellings (Prior & Bartlett 1995) and in the Danish Building Regulations (Danish Ministry of Housing 1995). Modifying the index in this way would be straightforward, but would, as a side-effect, make it much more difficult to achieve regulatory compliance for electrically heated dwellings, unless the energy rating target was made dependent on carbon intensity of delivered fuel. Although this may be necessary in the short term, the option of setting the same energy rating target for all dwellings, regardless of energy carrier used for heating, would be a powerful stimulant to the development of a range of systems for electrically heated dwellings, incorporating active solar, heat pump and heat recovery technologies. Such systems may have considerable long term potential, and constitute a rather persuasive argument in favour of retaining the Energy Rating Method in future revisions of the Building Regulations. The risk that the Energy Rating Method would continue to be used to allow builders to avoid requirements for higher envelope performance, could be dealt with by setting tighter limits on absolute maximum U values - we suggest that individual elemental U values should be allowed to rise by no more than 20% through such trade-offs.

With the modifications that we have suggested, we can see a case for retaining the Energy Rating Method. We find it harder to justify the way a SAP threshold is currently used as a backup to the Elemental and Target U Value methods. The SAP threshold of 60 actually affects very few electrically heated dwellings, and the impact of the higher envelope performance requirements that it triggers is, in any case, small. The threshold is very unlikely to affect gas heated dwellings, even with very inefficient heating systems.

In theory, a modified Energy Rating Method could be the only prescribed method of compliance in Approved Document L. However, the complexity of the method and the high cost of demonstrating and checking compliance could lead to considerable difficulties for many house builders. The retention of Elemental and Target U Value methods would, therefore be important where a standardised approach to design is required. In order to maintain equivalence with a modified Energy Rating Method an allowance would have to be made for variation in the carbon intensity of domestic fuels. Thus, in addition to U value thresholds, a carbon intensity threshold for space and water heating systems should also be established. We suggest that for the year 2000 the threshold for all systems should be set at 0.28 kg/kWh falling to 0.24 kg/kWh in 2005. These carbon intensities would, in the absence of inefficient secondary systems, be achieved by non-condensing and condensing gas systems respectively. [2]

If the above approach were adopted, compliance could be demonstrated without the need for a SAP calculation. Thus, unless the case for universal energy rating as a marketing tool were strengthened, SAP calculations should not be required for dwellings which comply by the modified Elemental and/or Target U Value methods. For those dwellings which do not meet the proposed standard U value and heating system performance criteria the Energy Rating Method would be required. [3]

What we have tried to do in this and the preceding two sections, is to debate some of the issues surrounding the structure of the Regulations. We believe that we have identified a number of problems with the Regulations as they stand, and have outlined modifications to the existing structure that would overcome some of these. We believe that our proposals for the Elemental and Target U Value methods offer more clarity and a better defined and simpler prescriptive route to compliance. If it were felt that the case for universal energy rating calculations as part of a strategy to stimulate a market in energy efficient housing were not sustainable, this proposal would make it possible for the majority of builders to avoid such calculations completely. Conversely, this proposal gives a clearer role for the Energy Rating Method. Finally, our proposals provide a consistent framework for improving the overall performance of buildings whose heating systems fail to meet minimum energy and environmental performance requirements. This is in contrast to the spirit of the present Regulations, in which trade-offs allowed under the Energy Rating and Target U Value Methods appear to be designed to allow builders to reduce envelope performance and avoid changing current construction practices.

2.4 International comparisons

For the purposes of this report, time constraints allowed detailed comparisons with only two other European countries, Denmark and Sweden. These are supplemented by a qualitative discussion of the regulations in the Netherlands.

Figure 2.4 compares space heating consumption for the example case (described in section 2.2) based on climatic conditions in the East Pennines region of the UK under the regulations for England & Wales (E&W), Denmark and Sweden. The calculations are based primarily on elemental U value methods and, in the case of Sweden, on a set of stringent airtightness and ventilation heat recovery requirements. The E&W and Danish regulations have similar ventilation requirements and neither has an airtightness standard. The Danish regulations refer to a requirement for heat recovery but this appears to be somewhat equivocal and further investigation would be required to establish how it is applied in practice. The ventilation arrangements for E&W and Denmark are therefore assumed to be the same. In order to assess the effect of heating efficiency, data are presented for high (85%), medium (72%) and low (59%) levels of efficiency. In reality, both Danish and Swedish regulations have a general requirement requiring a "satisfactory" level of efficiency for boilers.

The differences between the various standards are stark, with the Danish regulations producing a reduction of around 50% compared with the 1995 E&W regulations and the Swedish regulations producing an impressive 88% reduction. Such comparisons are often dismissed on the grounds that the climatic conditions in the different countries explain the variations in standard. While it is true that there are climatic differences (although the climate of Denmark is not significantly different from that of the North Eastern parts of the UK), these are insufficient to explain the observed differences in regulatory requirements. When the three regulatory standards were compared in their "home" climates, overall energy consumption under Danish and Swedish standards remained lower than under the standards for England & Wales – the opposite of what one would expect, other things being equal. Calculations in home climates, based on pre-1995 regulations in each country, indicated consumption levels some 33% lower in Denmark and 64% lower in Sweden (Olivier 1997). If anything, the gap between regulations in E&W and the other two countries has widened since these calculations were carried out in the early 90s.

The above comparison has been done on the basis of stated U values in each country. However, as discussed in Chapter 3, the extent to which calculated U values match reality is open to question. It should be noted that calculation methods in Denmark and Sweden are more stringent than in the UK. In general, the nominal U values of constructions calculated using methods in the E&W regulations are likely to be lower than if Danish or Swedish methods were used for the same construction. Calculations based on 1990 E&W regulation methods have suggested that U values for walls nominally calculated at 0.45 in the UK, would be calculated at between 0.6 and 0.65 in Denmark. Although the calculation method was improved in the 1995 amendment, significant differences remain. The effect of underestimation of U values in the UK may be offset by a tendency of BREDEM-based calculation methods to underestimate internal temperatures in UK dwellings that are insulated to current Danish or Swedish standards. There is, unfortunately, little firm data to go on.

In addition to the international comparison, Figure 2.4 illustrates the rather obvious truth that the better the insulation the less the absolute effect of heating efficiency on energy consumption for space heating. In addition to favouring the long-term performance of the building, an increase in insulation levels would also provide greater opportunities for heating choice, would eliminate damp and mould problems, which are still present in new UK housing, and would improve thermal comfort in summer as well as in winter[4].

The international comparisons which have been possible also illustrate some differences in approach to the process of regulation. As would be expected, there are many similarities between the approaches taken in E&W, Denmark and Sweden. All three rely to a large degree on an elemental and target heat loss approach. In Denmark this is supplemented by a limiting value on the energy consumption for heating and ventilation, which is expressed in terms of MJ/m^2 per year. Aspects of heating efficiency are included in all three countries but, as already discussed, in E&W this is used primarily as a means to allow reduced insulation levels. Of the three countries, the UK is the only one with an energy rating method (SAP) that combines space and water heating.

In contrast to the elemental approaches adopted in Sweden and Denmark the Netherlands has adopted a much stronger whole-dwelling performance approach to regulation. Since December 1995, all residential and non-residential buildings have been required to meet a particular energy performance target as defined by an Energy Performance Coefficient (EPC). This is subject to limiting standards for U values and airtightness for the building envelope. It has not been possible in the time available to obtain a detailed description of the methods used but, in outline, the approach seeks to describe the total energy performance of a building. This approach is similar to the Energy Rating Method, but with a SAP rating based directly on energy consumption, rather than energy costs. The coefficient is derived from the following ratio:

$$E_d/E_b$$

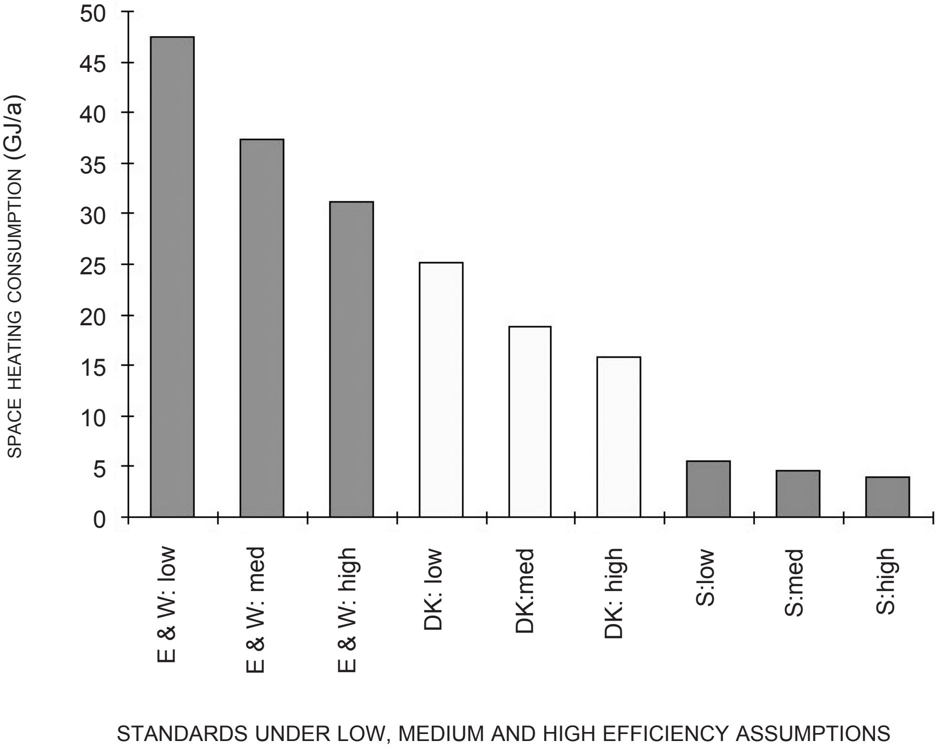
where:

E_d is the annual energy consumption of a building for space heating, domestic hot water, ventilation, pumps, lighting, cooling and humidification calculated in accordance with a standard method

and:

E_b is a standardised energy budget for the same building determined by floor area and envelope area with weighting factors depending on the need for cooling and particular ventilation requirements.

Figure 2.5 Comparison of standards in England & Wales, Denmark, and Sweden.



In the case of dwellings, the limiting EPC is currently set (Dec 1997) at 1.4. It is planned to reduce this to 1.2 in 1998 and a target of 1.0 is projected for 2000. In recognition of the complexity of this approach, a design guide (the Rainbow Book) has been produced that illustrates the main factors influencing the Energy Performance Coefficients of a range of dwelling types, so that designers can more quickly appreciate the practical implications of the system.

2.5 Existing buildings

The Building Act 1984 contains the power to apply regulations to existing buildings. The 1995 revision introduced the notion of making energy efficiency improvements whenever material alterations were made. This is an important precedent but, as they stand, the regulations are rather equivocal:

- they can apply to roof and floor insulation but only where structures are to be substantially replaced;
- they appear not to apply to normal re-roofing, despite the once-in-50-year opportunity this provides to integrate thermal insulation into otherwise difficult constructions;
- they require only a "reasonable" thickness of insulation when walls are to be rebuilt;
- there is no requirement to fill existing wall cavities, one of the most cost-effective energy conservation options available;
- there is no requirement to insulate existing dwellings when heating systems are being replaced;
- no mention at all is made of windows, despite the fact that window replacement is the most commonly undertaken improvement measure in existing housing and, particularly in solid-walled properties, represents perhaps the most important single opportunity for raising the performance of the fabric in the short to medium term;
- other than a provision for controls and insulation of pipework, no mention is made of heating system efficiency despite the fact that such improvements can have a marked effect in existing buildings where insulation levels are low.

The forthcoming revision to the regulations should address these issues and maximise the opportunities to undertake major thermal upgrades that are offered by refurbishment and repair works.The option of requiring energy efficiency improvements in the owner-occupied sector at point of sale should be explored (this option was successfully applied in Denmark in the 1980s). Finally, and though we accept that this is a complex area, the problem of energy efficiency standards in the private-rented sector should be addressed.

---

[1] In this report we have used coefficients of 0.58 kg(CO_2)/kWh for electricity and 0.2 kg(CO_2)/kWh for natural gas.

[2] This is intended to be interpreted as the weighted average efficiency of primary space heating system, secondary space heating system (where appropriate) and water heating system.

[3] A second option would be to require such houses to meet more stringent envelope targets (under either the Elemental or Target U Value methods). The proposal that we offered for consideration in a draft of this report is that U value requirements would be made dependant on the carbon intensity of useful space heat. A possible formulation of this approach would be:

$$U = U_o . \sqrt{(c_o/c)}$$

Where:

U is the U value for the same element modified to take account of the carbon intensity of space heating,
U_o is the U value for a given element in a dwelling with the base case heating system,
c_o is the carbon intensity (measured in kg(CO_2)/kWh of useful space heating) of the base case heating system,
c is the carbon intensity of the actual heating system to be used.

In this proposal, the base case carbon intensity in the year 2000 could again be taken as equivalent to a gas fired system with an annual efficiency of 72%, rising to 85% in 2005. An electric resistance heating system currently has a carbon intensity in the region of 0.58 kg/kWh, roughly twice as high. On this basis, an electrically heated dwelling would require U values which were roughly 30% lower than those of the proposed base case dwelling. This would be a tough but not impossible target for designers of electrically heated dwellings to meet. The advantages of this proposal over the position taken in the current Regulations, is that it treats gas and electric heating systems (indeed, any heating system) on a unified basis. Its strategic weakness is that it encourages designers to attempt to overcome problems that result from poor heating system performance solely by improving building envelope performance. For this reason, we are no longer of the view that this proposal offers any advantages over the Energy Rating Method, modified along the lines that we have suggested.

[4] This last point may be of considerable importance if UK summers become warmer over the next century (see DOE 1996).

3

review of technical issues

3.1 Introduction

The purpose of this Chapter is to look in more detail at the technical weaknesses in the current Building Regulations, and to discuss a range of improvements and amendments which would overcome them.

Part L of the Building Regulations is based on a physical model of heat loss from dwellings, and on simple models of heating system efficiency and performance. Analysis of the Regulations and experience with real buildings show a number of areas where the current Regulations are inconsistent or inadequate. In particular, the relationship between realised performance of the thermal envelope of dwellings and the approximations used in the Buildings Regulations is weak. The reasons for this are:

- the fact that the Regulations do not require the calculation of heat losses through a number of major thermal bridges that occur in dwellings (this is despite the fact that the 1995 amendment required, for the first time, that the effects of quasi-homogenous cold bridging be included in the estimation of U values);
- the fact that the Regulations apply at the design stage and do not take account of quality of construction;
- the fact that effective conductivities of porous, non-closed cell insulation materials can be degraded by bulk air movement within the material, caused for example, by the effects of wind;
- the lack of an explicit treatment of window performance in the 1995 edition;
- the fact that the Regulations do not control airtightness of dwellings in any meaningful way (again despite the introduction of a section dealing with infiltration in the 1995 edition of the Regulations).

The effect of these weaknesses is that there is considerable variation in the energy performance of dwellings that nominally satisfy the Regulations. The most efficient end of this band of performance is relatively well defined. Dwellings that are designed and built with care and show an understanding of technical issues (whether these are covered by the Regulations or not) will perform more or less as predicted at the design stage, and will fall in a relative narrow range of performance around the nominal target. For those dwellings that are submitted under one or other of the U value based approaches, actual U values will be close to notional U values. A small number of dwellings will be designed deliberately to improve on the target U values, and even fewer will achieve better U values by accident. On the other hand, the energy performance of buildings that are not designed and built with such care can be almost arbitrarily bad, resulting in a wide scatter of performances with a long and ill-defined tail of very poor performers.

There are two possible approaches to tightening up the Regulations (assuming for the moment that there is agreement that they need tightening up). One is to amend the energy related targets specified by the Regulations – this can be done either by reducing the nominal target U values directly, or in an energy rating approach, by improving the required energy rating. This will improve the energy performance of dwellings designed and built with care and understanding. It will also tend to shift the average energy performance of all dwellings satisfying the Regulations, but not necessarily by the same amount. However, unless the factors that currently lead to poor performance in a significant number of dwellings are addressed, it will not reduce the overall scatter in performance, or significantly affect the worst performers.

Figure 3.1
Improving the regulations by raising the notional target.

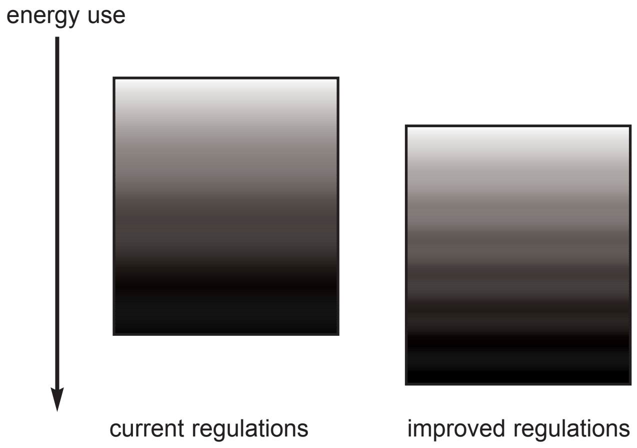
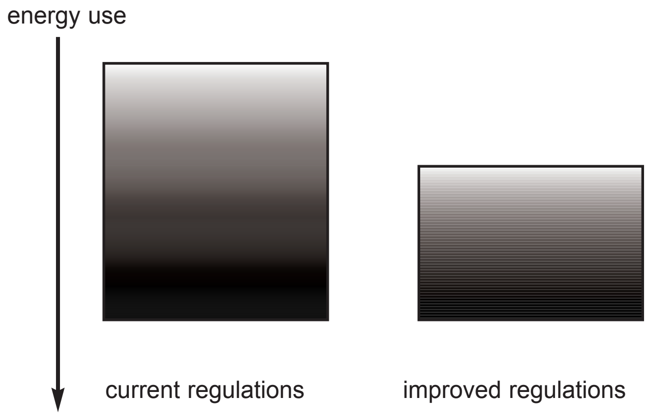


Figure 3.2
Improving the regulations by ensuring a closer correspondence between notional and real performance.



The second approach is to adopt measures to reduce the spread of performance, but leave the nominal target where it currently stands. Because of the relatively well defined upper bound to performance, the effect of reducing the scatter will also be to improve the average performance, this time by targeting the worst performers.

The judgement of the authors is that to have a reasonable chance of achieving national carbon emission targets without excessive cost, both of these approaches to improving the standards embodied in the Building Regulations will need to be adopted. Most of the issues covered in the rest of this section fall into the category of factors which affect the scatter in energy performance of dwellings.

3.2 Treatment of thermal bridging in the Building Regulations

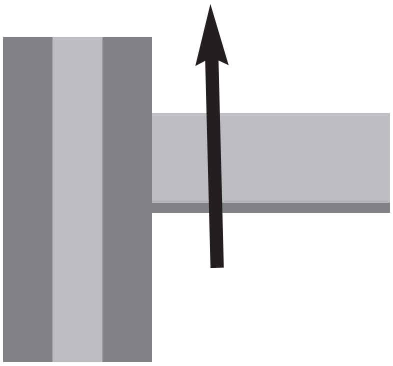
One of the most important problems with the current regulatory system is the fact that actual performance of buildings and building elements is often significantly worse than notional performance. Much of this discrepancy arises from the existence of thermal bridges which are not accounted for by the Regulations. Thermal bridges in dwellings can be classified under six main headings:

- quasi-homogenous thermal bridges (dealt with in the Regulations under the heading of structures containing repeating thermal bridges); these are defects in an element of the thermal envelope that are spread out more or less evenly over the whole area of that particular element - examples include mortar joints and wall ties in masonry walls, and the effects of timber structural elements in timber-framed constructions;
- major structural thermal bridges; these are defects in the thermal envelope that arise when two or more elements of the thermal envelope intersect or abut - examples include wall-floor junctions and wall-roof junctions where an otherwise continuous layer of thermal insulation is cut or by-passed by a major structural element (eg. the load-bearing inner leaf of a masonry wall);
- geometrical thermal bridges; these occur at edges and corners of the thermal envelope - for example at the junction between a gable wall and a non-gable wall; they are not as obvious as some of the other categories of thermal bridge, but because heat flow at geometrical thermal bridges is two- or three-dimensional, rather than one-dimensional, total heat flow will tend to exceed that based on one-dimensional calculations.
- thermal bridging associated with services and loft hatches;
- thermal bridging associated with window and door reveals; these can be a mixture of structural thermal bridges, eg. caused by the use of steel combination lintels[1] and fully returned masonry inner leaves, and geometrical thermal bridges caused by misalignment of window or door and thermal insulation in the wall[2];
- other thermal bridging associated with fenestration and doors, particularly frame and glazing edge losses - these will be dealt with in a separate part of this Chapter.

Of these six types of thermal bridge, only one, quasi-homogenous thermal bridging, is dealt with in the Regulations in a reasonably thorough way, though the calculation method specified - the proportional area method - underestimates total heat loss in many cases[3]. Thermal bridging associated with windows and doors is touched upon (paragraphs 1.22 - 1.24 and Appendix D, and implicitly in Table 2), but is not dealt with adequately, while major thermal bridging, thermal bridging associated with services, and geometrical thermal bridging are not dealt with at all in the 1995 edition of the Regulations.

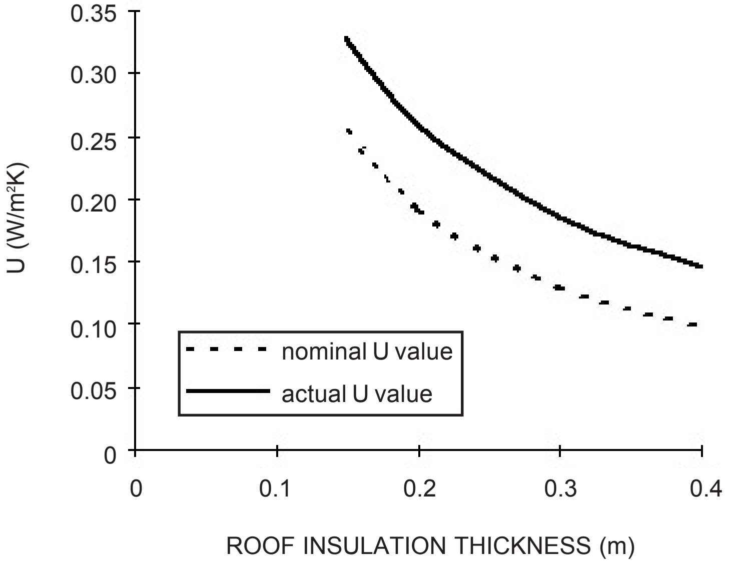
The effect of these omissions can be substantial. Potentially one of the most important of the major thermal bridges is the junction between the inner leaf of a gable wall and loft insulation at ceiling level (see figure 3.3).

Figure 3.3
Structural thermal bridge at gable wall-roof junction (vertical section).



Rough calculation suggests that for a dwelling with a dense blockwork inner leaf, the linear heat transmission coefficient of this junction is of the order of 0.2W/mK. For a two storey detached house with plan dimensions of 6m x 7m, heat loss through this thermal bridge alone is equivalent to a 30% increase in the U value of the roof, from the nominal 0.25 to a real 0.32W/m²K. The proportional impact on the average roof U value increases as the nominal U value is reduced, as shown below. The overall effect of this and other defects in roof insulation (loft hatches, service penetrations, and central heating and hot water header tanks) can be to double the notional U value of a roof that satisfies the current Building Regulations.

Figure 3.4
Effect of thermal bridging on roof U value.



3.3 Impact of construction quality on conduction heat losses

Building control and the Building Regulations apply almost exclusively to the design stage. Control over construction quality is limited to inspection of foundations and drainage systems. As a consequence there is no control over those aspects of thermal performance that are dependent on construction quality. These include:

- actual or realised U values, which are highly dependent on such factors as the care with which thermal insulation is placed, the extent of gaps between individual batts or rolls of insulation material and the rest of the construction and generally, the extent to which insulation material fills the voids intended for it;

- the extent of thermal bridging that can be inadvertently introduced, for example by the insertion of unnecessary timber into a timber framed wall or the cutting of pre-insulated concrete blocks at an external corner;
- airtightness.

Airtightness is dealt with in detail in sections 3.4 and 3.6. This section concentrates on the first and second items above.

The issue of construction quality can be addressed in a number of ways, but all require the extension of Building Control to cover work on site, as well as design drawings. On-site quality control could be undertaken by building control officers directly, but this would probably require a substantial increase in the number of such officers. Alternatively, control could be exercised by builders themselves, perhaps by establishing a requirement to photograph key stages of work.

Current Swedish regulatory practice is to add correction factors at the design stage to calculated U values to account for a number of mechanisms by which U values are degraded in practical constructions. The correction factor for workmanship and control (U_g) is taken as 0.02 W/m^{2}K under normal conditions, and as 0.01 W/m^{2}K where supervision and control are significantly improved (Swedish Board for Housing, Building and Planning, 1989 & 1995). The factor is substantial in the context of the U values required by the Swedish Regulations. The fact that the correction for workmanship can be reduced if the builder can demonstrate effective control and supervision is important in providing an incentive to improve quality.

3.4 Degradation of U values by air movement

Air movement both within and through the building thermal envelope increases effective U values. Evidence for this was first provided fifty or more years ago by work in Scandinavian and North America. Work in the UK suggests that the greatest impact of air movement is on the U values of dry-lined masonry walls. In this construction actual U values may be 1.5 times greater than nominal U values (Siviour 1994). This can only be described as an enormous discrepancy.

In the same paper, Siviour presents measurements of heat loss through party walls of semi-detached and terraced dwellings. These walls are often built as cavity masonry walls, without cavity fill. The cavity in a party wall connects freely with the cavities in the adjacent external walls and is continuous through the plane of the roof insulation on the attic floor. The Building Regulations assume that average heat loss through party walls is zero, on the grounds that dwellings on either side of a party wall will be at approximately the same temperature, and that any net heat flow will offset the space heating requirements of the cooler of a pair of adjacent dwellings. Siviour's measurements show that party wall U values can be as high as 0.85 W/m^2/K, twice as high as the nominal value for external walls, probably due to a combination of thermal bridging, convection and wind-driven air movement within the cavity, and air leakage from the inside of the house, via the first floor void, into the cavity in the party wall[4]. Technically, heat loss via party walls can be reduced to a very low level, by ensuring that construction is airtight and free from thermal bridges. Airtight construction would also help to overcome the problems of poor sound insulation that plague party walls and, perhaps, to increase the relative value of new terraced and semi-detached housing in the housing market. For construction that does not meet these standards, the Regulations need to make a realistic allowance for heat loss.

The technique of dry-lining was introduced in the late 1970s and early 1980s to simplify construction and to eliminate a skilled wet trade from much construction. The technique also appeared to offer improved thermal performance, through the creation of an additional air space in external walls[5]. There appear to have been indications in the early 1980s that dry-lined masonry walls have poor thermal performance. The main mechanism for the observed degradation of U values is likely to be air movement in the plane of the wall in the cavity between the blockwork and the dry lining. This defect is intrinsic to the construction method. Recommendations contained in the 1995 edition of the Approved Document for sealing dry-lined construction, can in principle reduce the problem, but depend on workmanship whose verification would require either extensive borescope surveys or pressurisation testing. We are of the view that these recommendations are not implemented effectively on site. Finally, there is case study evidence that suggests that airtightness deteriorates further and more quickly in dry-lined dwellings than in wet plastered dwellings, because of the ease with which the drylining can be damaged (Lowe & Johnston 1997).

The history of the introduction of this construction technique raises the general questions of:

- the degree to which novel constructions should be subject to thorough testing before they are adopted on a widespread basis by the construction industry; and
- the way in which the regulatory structure should respond when it becomes clear, particularly on the basis of empirical work, that certain constructions do not satisfy the standards laid down by the approved document.

Air movement within thermal insulation can also degrade U values in ventilated roofs. The magnitude of this phenomenon in roofs in the UK is not known.

3.5 Thermal performance of windows

Windows and outer doors probably account for 25% of the total heat loss of buildings built, with reasonable care and understanding, to the current Regulations. Windows and doors are the most complex elements of the building thermal envelope. Heat is lost through these elements by:

- conduction through glazing;
- conduction through the edges of glazing systems, particularly through the edge seals of multiple glazing units;
- conduction through window frames;
- infiltration of air through windows and doors.

These heat losses are offset to a greater or lesser degree by solar gains, for which there is a variety of calculation methods in the Building Regulations. Window performance is particularly important in that state-of-the-art glazing represents one of the few envelope technologies which can have a major impact on the energy consumption of existing, particularly solid walled, properties.

The main problem with the current Regulations in this respect is that they do not provide the building designer with a method for calculating U values which gives a clear picture of the relative importance of the different heat loss mechanisms outlined earlier. This is likely to result in excessive conservatism amongst designers and manufacturers of windows and doors, and to discourage manufacturers from addressing the technical areas where application of current state-of-the-art technology could result in large improvements in performance. This last point is illustrated by Figure 3.5, which shows a comparison of U values for four categories of windows taken from Table 2 in the 1995 edition of the Approved Document, and a state-of-the-art window. The latter incorporates three glazings, two low emissivity coatings, inert gas fill in both glazing spaces and makes use of insulating glazing spacers and modified frame design to minimise edge-of-glass and frame conduction losses.

This state-of-the-art triple glazed window gives a whole window U value in the region of 0.8 W/m^2K. The benefit, simply in terms of improved U value, is similar to that gained by switching from single -glazing to a low performance double glazed window[6]. Moreover the cost differential of such a window in mass production, compared with a low emissivity argon-filled double glazed window (low e.Ar d.g.) would be similar to that involved in exchanging single glazing for low performance double. Additional benefits from the state-of-the-art triple would include:

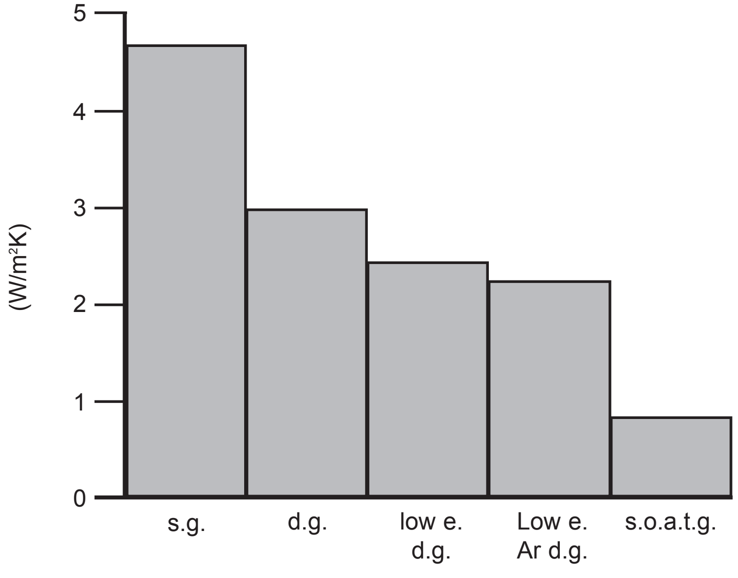
- elimination of the need for perimeter heating
- elimination of condensation
- increased longevity of window frames (particularly wooden frames).

There are two models for improving the current regulatory structure with respect to windows. The European Union is developing a range of Standards (currently at prEn stage) for the measurement and prediction of heat losses through windows. In August 1997, Denmark adopted an amendment to DS 418 (Dansk Ingeniørforening 1986) which is based on the emerging European Standards. This recognises heat losses through frames and glazing edges, and goes some of the way to providing designers and manufacturers with a framework for calculating whole window heat loss.

A more complete approach is provided by the current North American standards for window performance, exemplified by Canadian Standard CSA A440.2 (CSA 1993). This is based on two key pieces of software, VISION for the calculation of solar heat gain fraction and FRAME for the calculation of frame and edge losses by explicit, two dimensional simulation. The standard allows the prediction of whole window U values, solar performance, and overall energy performance for windows of arbitrary design. It also provides an agreed structure which fosters the continual development of window performance across the whole range. A project to develop a UK Window Energy Rating System based on the North American model has recently been funded by the DETR under the PIT Programme (Anon 1997).

Figure 3.5
Comparison of whole window U values

Data for single glazing, double glazing, low emissivity double glazing, low emissivity double gazing with argon fill and state-of-the-art triple glazing



3.6 Airtightness in new and existing buildings

Airtightness is of crucial importance to the thermal performance of buildings, and contributes to a number of other areas of performance including resistance to driving rain and sound transmission. Airtightness affects thermal performance in the following ways:

- through the need to heat infiltrating air to the internal temperature of the dwelling; this is taken into account through the ventilation heat loss coefficient;
- by increasing conduction losses of elements through which and within which air movement takes place (see Section 3.4 above);
- by increasing temperature stratification and air movement within the dwelling, both of which will tend to be offset by occupants through increased thermostat set-points.

Airtightness cannot be considered in isolation from ventilation. Ventilation is essential for a healthy indoor environment and Part F of the Building Regulations contains a requirement for adequate ventilation. However ventilation is also a source of heat loss. The prerequisite for minimising the energy and environmental impact of ventilation is control of the air flow through the dwelling. Air flow must be sufficient to remove indoor air contaminants and maintain internal concentrations at an acceptable level, but to the extent that air flow exceeds this level, space heating will be increased with no significant benefit to the occupants of the dwelling.

Ventilation in most new UK dwellings can be described as natural with intermittent mechanical assistance. This strategy is simple and cheap, and relies on a combination of relatively high levels of air leakage and occupants' window opening behaviour to provide adequate ventilation. Naturally ventilated dwellings probably require an envelope air leakage in the region of 10-15 ac/h at 50 Pa, provided occupants are prepared to make use of window opening to correct occasional under-ventilation. The relatively high air leakage of naturally ventilated dwellings means that they will be over-ventilated in windy and cold weather, but under-ventilation may also occur in calm, mild weather.

Three alternative ventilation strategies are available. Passive stack ventilation attempts to reduce the variability in ventilation rates in naturally ventilated dwellings by making ventilation more dependent on stack effect and less dependent on wind. Features such as humidity-controlled inlet vents can, in principle, provide an element of demand-controlled ventilation and further reduce heat losses.

Continuous mechanical extract ventilation superimposes a continuous flow of air on the background naturally induced ventilation flow. This strategy requires quiet, reliable and very energy efficient extract fans, which are now available. This ventilation option has been widely used in Sweden and is increasingly common in energy efficient dwellings in Germany. It was shown in field trials in the early 1980s to be as energy efficient as the third ventilation strategy, whole house balanced mechanical ventilation with heat recovery (MVHR), particularly in houses of intermediate air tightness.

Mechanical ventilation of either type works better in air tight dwellings, in the sense that air flow patterns are more constant and total air flow is less variable. Total energy use declines monotonically with envelope air leakage in dwellings with balanced mechanical ventilation, but reaches a minimum at a leakage somewhere between 2 and 3 ac/h at 50 Pa in dwellings fitted with continuous mechanical extract.

There is a very wide range of airtightness in the UK housing stock, as illustrated by Figure 3.6. Little improvement appears to be taking place in the airtightness of the UK stock. Perera & Parkins (1992) present data that suggest that recent new build is, on average, as leaky as dwellings built at the turn of the century.

Figure 3.6 shows that air leakage exceeds the requirements of natural ventilation in approximately 50% of the housing stock. The most leaky dwellings in the BRE dataset would be almost impossible to live in, in windy weather. There is also a possibility that ventilation rates are too low in a significant number of dwellings - unaided natural ventilation is probably inadequate at an air leakage of less than 10 ac/h at 50 Pa. The installation of trickle vents, the operation of

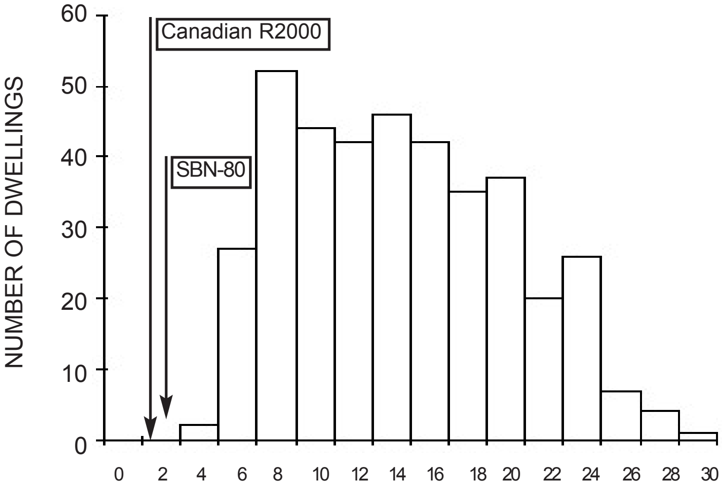


Figure 3.6
Distribution of air leakage rates in UK dwellings. The requirements of the 1980 Swedish Building Regulations (SBN-80), and of the Canadian R2000 Standard and Advanced House Programme (CANMET 1992) are also shown. In practice, R2000 houses consistently achieve below 1 ac/h at 50 Pa.

Source:
Perera & Parkins, 1992

extract fans and the opening of windows would however tend to offset the low envelope leakage in many of these dwellings. Trickle vents alone, when open, add something like 3 ac/h at 50 Pa to envelope air leakage.

Airtightness is effectively unregulated in new and existing dwellings. The 1995 Approved Document presents practical guidance (of the "tips" variety) on reducing air leakage (draught sealing around windows and doors etc.). Although this would be of some benefit if it were widely understood and applied, there is little evidence of either. More fundamentally, there are currently no means by which designers and builders can be given feedback on the actual results of airtightness measures which are applied.

Currently, the only practical way of measuring air leakage is by fan pressurisation. This technique can form the basis for regulation of air tightness based on post-construction testing. The alternative of a prescriptive approach, if pursued rigorously, is likely to be viewed by the construction industry as unnecessarily restrictive, and is likely to act as a brake on the development and introduction of new construction techniques. Airtightness is so dependent on construction quality that the prescriptive approach is in any case unlikely to be effective.

The authors can understand the reluctance of those who argue that envelope air tightness is the lid of a rather complicated can of worms, and that we run a number of risks by attempting to regulate it. This is, however, to argue for ignorance in the face of complexity, a position that we are uncomfortable with. The case for regulating airtightness can be made in a number of ways. The most obvious is the need to reduce the incidence of very high leakage rates in new dwellings, and to give early warning of the introduction of new construction techniques that significantly increased air leakage. The case for such regulation would be based to a large extent on the direct benefit to those people who would otherwise suffer the discomfort and cost of leaky dwellings; the argument would start in the domain of consumer protection rather than climate change. If regulation were introduced for this purpose, the result would be to shift the distribution of air leakage downward, as builders sought to minimise the additional costs associated with failing to meet the standard. This would, in turn, shift a larger number of dwellings into the region in which natural ventilation rates may be too low to provide adequate air quality. Because the construction industry already unwittingly builds such dwellings, we would argue that this would not be a qualitative change. Indeed, one could argue that testing would, for the first time, identify dwellings that fall into this latter category and allow remedial work to be undertaken. At the very least, testing would identify builders who consistently built very air tight dwellings, and would allow them to modify their construction practices or to adopt ventilation strategies better suited to the leakage rates that they regularly achieved.

Reductions in envelope air leakage would make the argument for continuous mechanical ventilation stronger. This option can be introduced at negligible cost in most new dwellings, because of the widespread use of intermittently operated extract fans to meet the requirements of Part F of the regulations. Continuous mechanical ventilation appears to offer a number of advantages to the dwelling occupant over intermittent mechanical ventilation:

- it significantly improves air quality, even in comparatively leaky dwellings;
- it is likely to be perceived as acoustically less intrusive;
- it may be less likely to be switched off or disabled by occupants.

Widespread introduction of continuous mechanical extract ventilation would in turn reinforce the case for reducing envelope air leakage to between 2 and 3 ac/h at 50 Pa. The direct energy saving with respect to current practice as represented by Figure 3.6 would be equivalent to reducing the average air change rate in the UK stock by of the order of 0.25 ac/h. This would in turn be equivalent to almost 1000 kWh of delivered gas or 200 kg CO_2 /per annum in a typical dwelling. Air leakage at this level would strengthen the case for heat recovery ventilation, which could lead to even larger savings in the long term.

In the view of the authors, there is a strategic case for introducing an airtightness target backed by post-construction testing of a significant fraction of all new dwellings (we would suggest 5-10%). Averaged over all new housing, the direct costs of pressure testing at this level would be of the order of £20-40 per dwelling. This would be justified economically if it resulted in a reduction in the mean ventilation rate of new housing of just 0.05 ac/h. We consider that such a figure is eminently achievable. The educational value of fan pressurisation testing to an industry for which airtightness is currently a purely metaphysical concept, would be large and, almost regardless of the level at which the airtightness standard were set, would initiate a process of improvement. We would suggest tentatively that the standard might initially be set at 10 ac/h. This would be consistent with the continued use of the strategy of natural ventilation assisted by intermittent mechanical extraction. On the assumption that Figure 3.6 is a good guide to leakage rates in new housing, it would require additional sealing work to approximately two thirds of houses. In practice, the fraction of new houses that would fail an initial pressurisation test would be much smaller than this, as builders adapted to the new standard.

3.7 Technical scope for improvement and barriers to change

The scope for improving the thermal performance of new dwellings is large. A significant number of dwellings has been built in the UK with fabric U values significantly less than those required by current Regulations. Many of the changes in practice that would be required to achieve large reductions in space heating in new dwellings, have already been implemented in the UK, in some cases in hundreds of dwellings, over a period of more than twenty years. The following examples illustrate this point. The first fully-filled, wide cavity masonry walls were built in Salford in the late 1970s (the Wates House at Macchynlleth was built slightly earlier, but with a wall cavity of 450mm that even the present authors would consider to be excessive). Salford is on the rainy side of the country. The Salford houses (173 mm cavities) were quickly followed by the Linford and Pennyland demonstrations in Milton Keynes (100 mm fully-filled cavities, see Everett et al. 1985), and by dozens of subsequent developments (see Olivier & Willoughby 1996a & 1996b), culminating in the Southwell House with its 250 mm fully-filled wall cavities (Bunn 1994). The first superinsulated timber framed houses in the UK were built at Two Mile Ash in Milton Keynes in 1985, and achieved an air leakage of less than 3 ac/h at 50 Pa. The technical basis for radical improvements in the UK Building Regulations has also been exhaustively established by the construction of millions of dwellings in other parts of the Northern hemisphere, in particular in Denmark, Sweden, Norway, Austria, Switzerland, Canada and parts of the United States.

The notion of barriers to change is frequently invoked to explain the apparent reluctance to adopt higher standards of construction in the UK. Barriers to change can be considered under three headings – technical/economic, perceptual and procedural. As we have observed above, genuine technical barriers to change are rare, in the sense that few, if any, of the measures that one would need to implement to reduce space heating requirements in new housing to very low levels, have not been tried out successfully, either in the UK or elsewhere. Nevertheless, proposals for higher standards of thermal insulation are often countered with reference to the additional technical risks that they impose on the industry – from condensation, driving rain, poor workmanship and so on. These risks rarely bear close scrutiny – it is in fact very hard to conceive of a situation in which reducing the U value of a construction does not simultaneously reduce most of them – for example, better insulated load bearing masonry walls appear to be easier to build[7], more resistant to driving rain[8], harder to build wrong[9], less likely to suffer from internal condensation and mould growth, and structurally at least as strong[10]. If the wider cavity is used as a case for changing from partial-fill to full-fill, one finds that walls with a U value 0.3 W/m^{2}K are also cheaper than walls built to current Building Regulations (Warm & Willoughby 1998).

Faced with such stark contradictions, it is hard to resist the conclusion that most technical barriers are in fact perceptual. Perceptual barriers are not only to be found within the construction industry. The perception, held until recently within the DETR, that a requirement for lower wall U values would lead to the decline or disappearance of masonry house construction, has probably been a significant barrier to change. Perceptual barriers of the sort described here, can probably best be overcome by a combination of careful argument, backed by experiment and high profile, well-documented and disseminated demonstration. Where necessary, such demonstration should include large scale field trials of the sort that were undertaken in the late 1970s and early 1980s.

We would define a procedural barrier as arising where a designer wishes to adopt a construction technique which offers improved thermal performance, but is deterred from adopting it, either because readily available codes of practice do not cover it, or because to demonstrate compliance would be more expensive than for a construction of inferior performance. Once again, procedural barriers are particularly obvious in the case of wall construction. We would suggest that the DETR should institute a programme to systematically identify and remove such barriers.

---

1 Attempts by manufacturers of combination lintels to reduce thermal bridging, by inserting thermal insulation into hollow steel sections, have displayed a swashbuckling but ultimately futile disregard for the laws of physics.

2 It is also possible for geometrical bridges to arise because the wall insulation is thicker than the window frame that abuts it. For buildings built to current building regulation this is practically impossible, but in walls incorporating 150 mm or more of thermal insulation, it can become significant.

3 Furthermore the practical application of the proportional area method is flawed in some significant cases, by systematic under-estimation of the area of thermal bridge. The most important is probably the case of timber-framed walls, where the current Regulations assume a proportion of timber bridging of 6.3%, while field studies regularly show 30% or more. The effect of this is to raise the U value of a typical timber framed wall from a notional 0.45 to around 0.6 W/m^{2}K, a fact which is clearly acknowledged in the 1993 edition of the ASHRAE Handbook of Fundamentals (ASHRAE 1993).

4 Part F of the 1976 Edition of the Building Regulations (see Elder 1981) assigned a U value of 0.5 W/m^{2}K to party walls, apparently to allow for the situation in which one of a pair of adjoining dwellings was unoccupied. The restoration of this provision would go some way towards reflecting the true thermal performance of party walls. There is obviously a risk that this would increase the current tendency to construct detached houses at very high densities on sites where use of semi-detached or terraced forms would make much better use of land.

5 This would have been significant in the late 1970s when the elemental U value requirement for walls was 1.0 W/m^{2}K.

6 This is one example of the way in which rapid technological development gives the impression of defying the law of diminishing returns.

7 This assertion is based on a series of informal conversations between the first author and various builders going back to the late 1970s. Observations include the fact that it is easier to keep a wide cavity clean, and that plastic wall ties are much easier to handle and less dangerous than stainless steel fish-ties.

8 The 1st edition of "Thermal Insulation Avoiding the Risks" (BRE 1989) suggests that increasing the width of a fully filled cavity wall by 50 mm raises its exposure rating by up to 2 categories. On this basis a 100 mm fully filled cavity masonry wall would be rated at least very severe. The 2nd edition of this document (BRE 1994) suggests that 100 mm fully filled cavity walls perform as well with respect to exposure as 100 mm cavities with a 50 mm clear gap. There is no published information on the performance of masonry walls with cavities wider than 100 mm, an omission which is frankly astonishing.

9 See footnote 1. The performance of partial cavity fill depends on getting a snug fit between rigid insulation boards and the inner leaf of the wall. The authors' own observations on site suggest that this is frequently not achieved.

10 This last point may be confusing to those brought up on the notion that that a wider cavity means that the two leaves of the wall are less able to act together structurally. Our assertion is based on unpublished BRE test results (Warm & Willoughby 1998).

4

the economic justification for the regulations

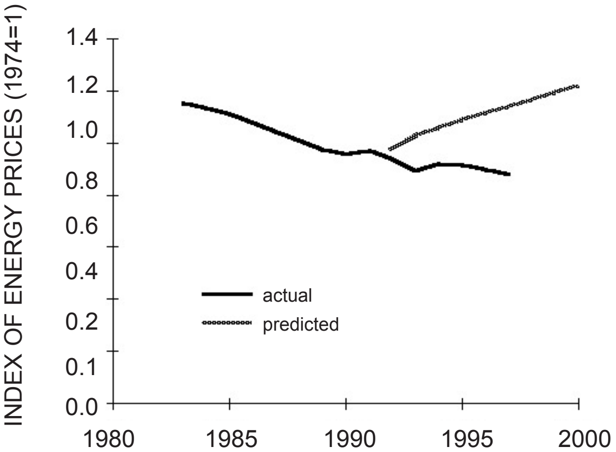
4.1 Introduction

To the extent that the Building Regulations are justified by calculations of the marginal economic value of improvements in performance, the Government currently faces a major problem. This is, how to justify, to the construction industry and to a lesser extent to the public, its requirements for increased insulation thicknesses, improved glazing, fan pressurisation testing etc. against a background of steadily declining energy prices.

The problem is illustrated in Figure 4.1, which shows the price assumptions underlying the 1995 edition of the Building Regulations and the actual trajectory of average domestic energy prices. This figure is an example of a general tendency in energy policy analysis in the UK, which is to base future scenarios on the assumption that energy prices will rise steadily over the period covered by the scenario, despite the obvious long term tendency for energy prices to fall.

Figure 4.1
Comparison of actual and projected energy price.

Projected price assumptions (with weighting 90% gas, 10% electricity) taken from Compliance Cost Assessment (17th May 1994) for revisions to Building Regulations (King, 1997)



This Chapter reviews the current economic justification for the Building Regulations, the sensitivity of this justification to variations in economic assumptions and the possible impact and justification for including a shadow cost for carbon emissions into the economic analysis. The Chapter also looks at a variety of external benefits from improved energy efficiency in new-build.

4.2 Theoretical analysis of impact of price on energy use

In this section we attempt to address the question, when does adding insulation to a building become self-defeating, either by costing more or by consuming more energy or emitting more carbon in the production of the insulation than it saves? We begin by addressing the question analytically. Let:

E	lifetime energy use (J/m² of envelope)
ΔT	mean inside-outside temperature difference (K)
t	insulation thickness (m)
e	embodied energy cost of insulation (J/m³)
λ	conductivity (W/m/K)
L	life of building (s)
C	lifetime financial cost (assuming zero real interest rate) (£)
c_i	cost of insulation (£/m³)
c_h	cost of space heat (£/J)

then if we:

- ignore many of the complexities introduced by thermal mass, internal heat gains and seasonality;
- assume that the marginal cost of adding thermal insulation to a property is given by the cost of the thermal insulation alone and excludes associated costs such as additional masonry, roof tiles etc.; and
- neglect the associated benefits of improved thermal insulation, such as improved comfort, reduced condensation and mould, reduction in cost and complexity of heating system etc.:

$$C = c_i.t + \Delta T.L.\lambda.c_h/t \qquad 1.$$

The first term in the above equation represents the capital cost of the additional thermal insulation, while the second represents the lifetime cost of space heating. The whole life cost of space heating is minimised when $dC/dt = 0$:

$$dC/dt = c_i - \Delta T.L.\lambda.c_h/t^2 \qquad 2.$$

hence

$$t_{min} = \sqrt{(\Delta T.L.\lambda.c_h/c_i)} \qquad 3.$$

and

$$C_{min} = 2\sqrt{(\Delta T.L.\lambda.c_h.c_i)} \qquad 4.$$

with equal contributions from capital and running cost.

One of the uses to which the above analysis can be put is to test the sensitivity of optimal insulation thicknesses to uncertainties in some of the key assumptions. The present price of mineral fibre cavity wall batt (including discount and excluding VAT) is in the region of 26 £/m³. The price of loft insulation is in the region of 12 £/m³. The marginal cost of space heating using natural gas at 1.24 p/kWh (including discount of 15% and excluding VAT) in a condensing boiler with an annual efficiency of 85%, is equivalent to about 4.1 £/GJ.

Our default assumptions about discount rate, changes in fuel price and an assumed physical lifetime for insulation measures have been taken from Compliance Cost Assessment that was prepared for the 1994 Revision to the Building Regulations. These assumptions are listed below:

Table 4.1

Default economic assumptions	
annual discount rate	6%
effective lifetime (years)	3
annual rate of fuel price rise	2%
physical life (years)	60

It is obvious that the treatment of the problem presented here is highly simplified. Perhaps the most important issue not dealt with is the additional construction costs incurred by building in additional thermal insulation. Our justification for treating the problem in this way is the view that much of the cost incurred by builders in coping with additional thicknesses of thermal insulation is transitional and is often related to an unwillingness to revise construction practices, which even in their own terms frequently make little sense. Obvious examples are the returned inner leaf at window and door reveals, the practice of closing wall cavities at eaves with a masonry return and the use of partial-fill cavity wall insulation. The cost of thermal insulation defines an approximate lower bound for estimates of the direct cost of reduced U values.

As well as the technical uncertainties alluded to above, there are significant uncertainties attached to the key economic parameters – energy price, discount rate and effective life of the typical dwelling. The question of what discount rate is appropriate for analysis of long term, relatively secure investments has dogged energy analysis for decades. The test discount rate (TDR) applied to nuclear power fell, over the period from the mid 1970s to the mid 1980s, from 10% to 5%. By the time of the Sizewell public enquiry, we note that the CEGB had begun to use a 2% TDR, as being representative of the long term, real rates of return available in the economy as a whole. An empirical measure, which might be more directly relevant to the optimisation of the Building Regulations, is the real rate of interest charged to home owners for mortgage repayments. This is currently (at December 1997) between 4% and 5%, depending on whether one uses the headline or the underlying rate of inflation. However, for the preceding three decades, this real rate of interest was less than 2% and for substantial periods, negative. The discount rate of 6% used in the 1994 Compliance Cost Assessment therefore appears to be at the top end of the range of real interest rates seen by house buyers over much of the last thirty years. The range of optimal insulation thicknesses generated by plausible variations in economic parameters is shown in Table 4.2 over.

A number of conclusions can be drawn, even at this level of detail.

- The functional form of the relationship between thickness of thermal insulation and other variables suggests that optimal insulation thickness should be relatively insensitive to assumptions. In particular, a doubling of energy price or physical lifetime should increase the optimal insulation thickness by about 40%. Conversely, a doubling of the marginal cost of insulation reduces the optimal insulation thickness by about 30%.
- The analysis suggests that the thickness of insulation currently required in roofs (approximately 200 mm) is below optimal, except at high discount rates and with falling prices.

- The thickness of insulation required in walls appears to be substantially sub-optimal under all assumptions. This conclusion is valid even if one accounts for the full cost of increasing the width of the cavity[1]. We suspect that this is related to perceived difficulties and avoidable costs alluded to earlier in this Chapter and at the end of Chapter 3.
- Use of a 2% discount rate significantly increases optimal insulation thicknesses.
- Analysis of the economic cost of non-optimal insulation thicknesses, shows that it rises rapidly for actual thicknesses less than optimal, but slowly for thicknesses greater than optimal. The implication of this is that, under conditions of uncertainty, it is rational to install more insulation than one calculates to be optimal on central assumptions[2].
- Against a background of falling prices, high levels of insulation can still be justified on the basis of a low discount rate. Nevertheless, it may be difficult politically to sustain the case for the current level of insulation if the cost of domestic gas were to continue to fall.

Table 4.2
Optimal thermal insulation thicknesses (mm)

default assumptions (see Table 4.1)	
wall	220
roof	310

default discount rate, falling prices (-2% per annum)	
wall	150
roof	220

low discount rate (2%), constant prices	
wall	260
roof	390

The analysis presented here has been phrased in economic terms. Similar analyses can be undertaken on the basis of energy use or carbon emissions. Such work tends to yield optimal insulation thicknesses which are greater than the economically optimal thicknesses presented above. Lowe et al. (1997) report carbon-optimised cavity wall insulation thicknesses in the range of 250-340 mm. Their conclusion was that there is no immediate risk, at least on environmental grounds, of installing too much thermal insulation in dwellings[3].

While the simplified economic analysis presented here suggests that significantly higher standards of thermal insulation are justified, we believe that there are limits to the weight that can be placed on purely economic, as opposed to strategic arguments in the area of energy use in buildings. These limits arise because of the long timescales involved, because of significant external costs and benefits that are not captured by the above analysis and because of the need, not just to maximise the direct economic benefit of energy efficiency against a business-as-usual view of the future, but to minimise the risk arising from possible extreme events. There is no question that improved standards of energy efficiency in dwellings will reduce a variety of risks, both to individuals and to society, over the next 50 to 100 years and that there should, therefore, be a strategic bias in this direction in the setting of such standards.

4.3 Impact of carbon pricing

One of the effects of the Kyoto summit has been to lay the political foundations for an international market in carbon emissions. This has not generally been portrayed as a positive step, at least in Europe, but this may be misleading. If an international market for carbon emissions does develop, it will establish a global price for carbon emissions for the first time.

The effect of this will be that countries such as the UK, which emit significantly more carbon per capita than the global average and significantly more than can currently be absorbed by global carbon sinks, will initially find themselves paying other nations for the right to continue to emit carbon. Once this happens, energy efficiency will begin to have a direct and positive impact both on the UK balance of payments and on the UK domestic budget deficit, since any reductions in carbon emissions will allow HM Treasury to reduce its disbursements to countries with surplus carbon emission rights. Conversely, domestic energy profligacy will harm the balance of payments and increase the pressure on the Treasury. To offset these effects, the Treasury will need to increase domestic taxation or cut expenditure. If the former route is adopted and the taxation is not specific to energy, the result would be to deflate the domestic economy generally, without fostering energy efficiency. Despite the general opposition of the current and the previous Governments to domestic energy taxation, we consider that future UK governments will find it hard not to pass on the whole of the external cost of carbon emissions to internal energy markets as a carbon tax. The magnitude of such a tax will depend on a combination of factors. These include the availability and cost of options for reducing carbon emissions worldwide (technically, the shape of the supply curve for carbon emission reductions), and the level of reductions in global carbon emissions that are sought.

On the latter point, it is clear that in a world that has accepted the need to limit the increase in atmospheric carbon dioxide concentration to a particular level and in which the trading of a reducing stock of carbon emission rights becomes the main tool by which this is achieved, the price for carbon emissions is whatever is necessary to drive global carbon emissions down to the required level. Under these circumstances, it is possible that the price for domestic energy will be determined, in the future, more by the price of carbon emissions than by the cost of extracting and supplying fossil fuels. It is also clear that despite the short term possibilities offered by the establishment of a system of international carbon trading for countries such as the US, and to a lesser extent the UK, to offset any internationally imposed national carbon targets by buying carbon emission rights from other countries, the price of carbon must eventually rise high enough to drive down carbon emissions in industrialised countries. Prices that appear in the literature range from 10 to 250 £/tonne of carbon. The analysis presented above suggests that increases in energy price by a factor of two or more are likely to be needed to achieve substantial reductions in energy use and that this would be equivalent to a carbon tax at the top end of this range based on the current price of natural gas. Such levels of taxation can comfortably be envisaged within the overall burden of UK domestic taxation – for example, a halving of the overall VAT burden would allow energy prices in all sectors to be doubled. There are precedents for taxation at this level, for example in Denmark, though there it appears to have been used to reduce dependence on imported oil rather than to limit carbon emissions.

To maintain current levels of thermal insulation in the Building Regulations, would be to expose owners of the millions of dwellings yet to be built, to the eventual effects of significantly raised energy prices in poorly insulated homes. We have argued above (see Table 4.2) that substantially higher insulation requirements can be justified even at current energy prices, provided one is prepared to take a long economic view. Nevertheless, the use of a shadow carbon price in compliance cost assessments reinforces the argument, and may make it politically easier to justify significantly more stringent regulations and thereby to minimise the risks associated with possible future energy price rises. However, the perception of a disparity between the requirements of the Building Regulations and the level of insulation that is micro-economically justified on the basis of actual energy prices, runs the risk of bringing the regulations into disrepute. This in turn suggests that shadow carbon pricing should be an interim measure only, pending the early introduction of real carbon pricing in the UK energy markets.

The symbolic effect of price may be larger than would be expected on the basis of a narrow economic analysis. Thus, the certainty that prices will rise in the future, may be more significant than the rate at which they rise, in sending a message to builders and the general public that change is necessary. The question of the role of price in controlling carbon emissions has unfortunately been largely ignored in recent years. The key to progress in this area would appear to be a political consensus that energy is too important to be used solely as a vehicle for income redistribution.

4.4 Minimising transitional costs and managing the process of change

Despite the established pattern of quinquennial review and amendment of the Regulations, there has been little sense over the last twenty years of a strategy designed to achieve a clearly stated goal, or of a political process aimed at recruiting opinion behind such a strategy. Against this background, intensive lobbying by the industry has successfully ensured minimal change in the regulations, despite persuasive arguments in favour of change. Against the resulting leisurely pace of improvement, planning and technical change within the industry have been directed largely at minimisation of construction cost rather than at optimising energy or environmental performance.

The transition to a low carbon economy will require CO_2 reductions of at least 60% in the medium to long term across the housing sector as a whole (including existing housing), with larger reductions in new housing to offset the difficulties of improving the existing stock. This transition will require a significantly accelerated pace of improvement in regulation and building performance. Minimisation of the associated transitional costs will require the industry to be able to predict regulatory requirements at least five years in advance. In our view, this will require the DETR to move toward a rolling process of amendment, with a time horizon long enough to encompass at least two quinquennial reviews at any one time. Industry must know where the regulations are going, and the intended intermediate steps, far enough in advance to anticipate and plan, rather than merely to react to change.

Such anticipation and planning will involve:

- Exploration and adoption of improved construction techniques by designers and builders;
- Development and/or licensing of products necessary for the construction of energy efficient dwellings and the adaption or establishment of production facilities; such products will include improved lintels, wall ties, windows, external doors and structural systems for roofs; in many if not all cases, construction techniques and products are already in use and in production in other countries;
- Improvements in the management of the construction process so that the necessary improvements in site practices and construction quality can be achieved;
- Campaigns to market improved energy efficiency and to clarify and address consumer concerns; for example, there are cost savings to be made from reduced heating systems in very well insulated dwellings, but consumers are frequently unwilling to accept houses with, apparently, inadequately sized central heating systems;
- Development of educational and continuing professional development programmes by professional bodies, education establishments and training agencies at all levels, to ensure a steady supply of people with the skills to design and construct low energy dwellings;
- Research, development and most importantly, demonstration programmes to support the change process.

Government has a key role to play in co-ordinating and maintaining the momentum of such a programme and in funding exercises such as demonstration programmes that will be required to transfer and, where necessary, to develop technology. The costs of change will be significantly reduced if maximum use is made of the experience of countries that have for many decades been building to higher standards than those of the UK. These include Sweden, Denmark, Canada and, to a lesser extent, Germany, Austria and Switzerland. This will require in-depth exploration of construction practice, building performance and regulation in these countries by competent and knowledgeable professionals (see for example Olivier 1992 & 1996c), but it will enable the UK to avoid multiple re-invention of the wheel.

---

[1] Costing exercises suggest that the bulk cost of thermal insulation represents about one third of the total cost of increasing the thickness of wall insulation. Because of the mathematical form of the relationship between optimal insulation thickness and insulation cost (see equation 3 above), accounting for the full cost of wall construction therefore reduces optimal insulation thickness by a factor of about $\sqrt{3}$. On default economic assumptions, optimal wall insulation thickness is in the region of 130 mm, less than the 220 mm suggested in Table 4.2, but comfortably in excess of current regulatory requirements.

[2] These arguments are reinforced by the fact that walls with wider cavities are easier to build and more resistant to a range of problems including driving rain (see Chapter 3).

[3] These estimates were based on a dwelling with a 100 year physical life.

5

conclusions & recommendations

The purpose of this report is to review the structure, function and justification of the Building Regulations relating to energy efficiency and to compare them with the task of moving the UK housing sector towards sustainability in energy use over the first half of the next century. Despite the attractions of the free market, we see no alternative to a regulatory approach to achieving realistic emission reduction targets in the domestic sector. Times scales are too long, the salience of energy among the many factors affecting dwelling design is too low and the technical understanding of the general public is insufficient to enable a purely market based solution[1]. Nevertheless, a regulatory approach that is in flat contradiction to market signals is unlikely to be successful or politically sustainable. In our view it will be essential to address the need to reinforce regulation with appropriate price signals.

The overall conclusion from this review is that the Building Regulations must be recast to add environmental objectives (specifically with respect to global warming) to the traditional objectives of health, safety and welfare, and that the standards of energy and environmental performance required by the Regulations must be significantly upgraded to achieve these objectives.

5.1 Technical targets for sustainability

Realistic carbon emission targets, by which we mean targets that are likely to lead to stabilisation of atmospheric CO_2 by the end of the next century, will require reductions in carbon emissions of 60% or more by 2050 in countries like the UK. The UK is already committed (and remains committed since Kyoto) to a 20% cut in emissions by 2010. Cuts of this order will require substantial cuts in energy use in the domestic sector. In this paper, we have focused on cuts in energy use that can be achieved in space heating within in housing. However, the Building Regulations should seek to intervene to improve the standard of existing housing, particularly where works of repair and/or alteration take place. We consider that a number of issues, most particularly efficiency of lights and appliances, should not be dealt with by the Building Regulations. Measures such as minimum appliance efficiency standards combined with pricing signals, are likely to be more appropriate and effective.

Table 5.1

UK Building Regulations 1995, elemental U values	
exposed walls	0.45
roofs	0.25
floors	0.45
semi-exposed walls & floors	0.6
windows, outer doors & rooflights	3.3
average U value (100m^2 two storey dwelling)	≈0.7

Table 5.2

Proposed UK Building Regulations 2000, elemental U values	
exposed walls	0.3
roofs	0.15
floors	0.3
windows, glazed outer doors & rooflights	2.0
opaque outer doors & hatches	1.0
air change rate at 50 Pa	10
average U value (100m^2 two storey dwellings)	≈0.4

Table 5.3

Proposed UK Building Regulations 2005, elemental U values	
walls	0.25
roofs	0.15
floors	0.2
windows, glazed outer doors & rooflights	1.3
opaque outer doors & hatches	0.6
air change rate at 50 Pa	3
average U value (100m^2 two storey dwellings)	≈0.3

In the short term, new housing is relatively unimportant. The UK adds less than 1% to its housing stock each year. However, in the perspective of attempts to stabilise the atmosphere over a period of half a century, new housing is crucial. Post-2000 housing will account for 16% of the total stock by 2020 and perhaps 25% by the middle of the century. Moreover, earlier work by the authors has shown that although it is possible to significantly improve the efficiency of the existing stock, the potential is less than in the case of new housing and a major effort will be required if the technical and social difficulties involved are to be overcome. (Bell et al. 1996, City of York 1996). If allowance is to be made for these difficulties, it is clear that a proportionately larger reduction will be required in new housing. Less directly, but perhaps even more importantly, the performance of new housing, in terms of running costs, comfort levels in winter and in summer, freedom from moisture problems, air quality, noise reduction and so on, can exert a powerful upward force on standards in the existing stock. We therefore see development of standards for new housing as key to the development of an energy and carbon emissions strategy for the domestic sector as a whole.

Figure 5.1
CO_2 emissions for a typical dwelling.

(Base case = business as usual, assuming steady improvement of 15% every 5 years. Improved regulation is broadly equivalent to application of current Danish standards in 2000 and of current Swedish standards in 2005)

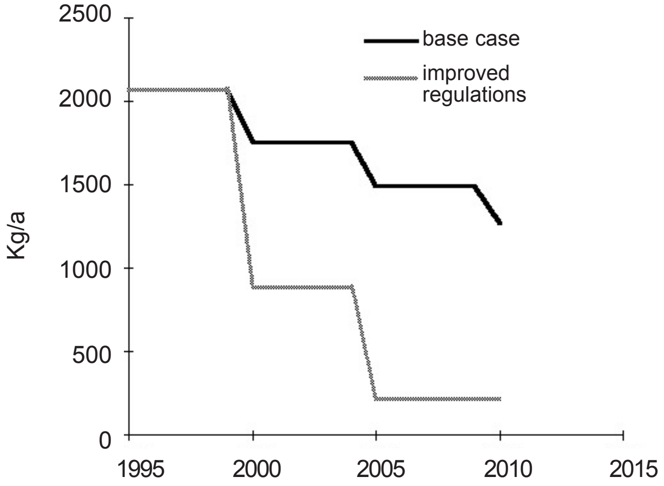
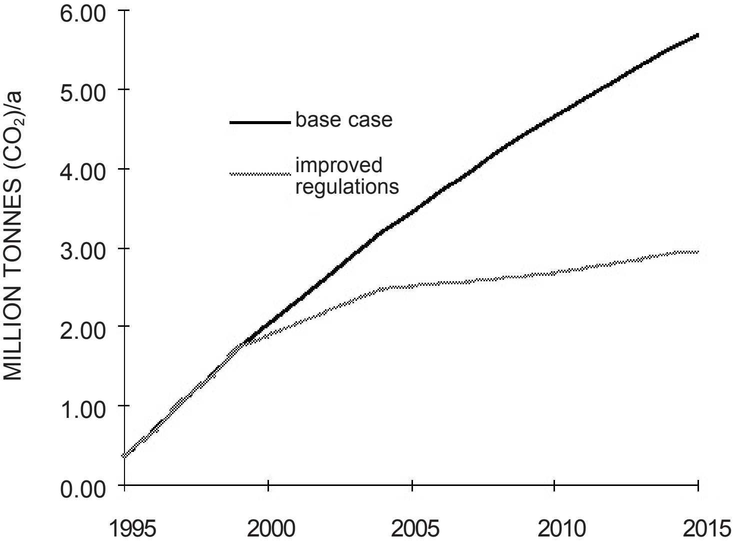


Figure 5.2
Cumulative impact of improved regulations on CO_2 emission from post 1995 housing

(Scenarios as in Figure 5.1)



The scope for reducing carbon emissions from post-2000 housing is illustrated in Figures 5.1 and 5.2. These compare a business-as-usual trajectory for regulatory development (assumed to result in a 15% reduction in carbon emissions every 5 years), with a policy based on the implementation of the current Danish building standards in 2000 followed by the current Swedish standards in 2005. A summary of the changes that this would require in elemental U values is presented in Tables 5.1, 5.2 and 5.3. Figures 5.1 and 5.2 show that on the basis of business as usual, emissions from space heating in post-2000 houses grow steadily to and beyond 2010. A more vigorous regulatory approach can effectively halt the growth of emissions due to space heating in new housing by 2005.

An indication of the practical implications of the standards shown in Tables 5.1 to 5.3 is presented below:

(i) Walls
The proposed U values can be achieved in masonry construction by the use of wider cavities between the inner and outer leaf. The average cavity is currently between 65 and 75 mm. The proposed U value for 2000 can be achieved with a fully filled cavity of between 100 and 120 mm (dependent on materials: for example, with an inner leaf of lightweight block and minimal thermal bridging, 100 mm might suffice). With conventional timber framed walls, a stud depth of approximately 140 mm would be required to meet the U value requirement for 2000. This is significantly greater than that currently used.[2]

(ii) Windows
The U value proposed for 2000 could be achieved by using gas-filled low-emissivity double glazing. The value for 2005 could be achieved with gas-filled low-emissivity triple glazing, though other solutions may become available in the interim. It must be emphasised that these U values include edge of glass and frame losses. Our proposals for opaque outer doors and hatches would require insulated panel construction with a minimum thickness of the order of 50 mm, a construction that is commonplace or obligatory in Canada and Scandinavia.

(iii) Roofs
It is suggested that the improved U value could be achieved relatively easily by increasing the loft insulation from the current 200 to 300 mm (again, depending on materials used).

(iv) Floors
The suggested U value for 2000 could be achieved by increasing the thickness of floor insulation from the current 25-50 mm, to between 80 and 100 mm, depending on soil conductivity and edge detailing. The U value for 2005 would require approximately 150 mm of thermal insulation.

We have summarised the rest of our conclusions under three broad headings; those concerned with the economic, environmental and legislative basis for the Regulations; those concerned with the structure and content of the Regulations; and those concerned with the development of policy designed to minimise the transitional costs and time lags associated with a move toward sustainability in the UK domestic sector.

5.2 Economic, environmental and legislative basis for the Regulations

1. The present Regulations are based on objectives of health and safety and the conservation of fuel and power. We consider that this forms an inadequate basis for the pursuit of sustainability and, specifically, for the reduction in carbon emissions from the built environment. The legislative basis for the Regulations should in our view be extended to explicitly include these goals.

2. The present Approved Document required a Compliance Cost Assessment, the terms of which are too restrictive to enable the pursuit of environmental goals, particularly against a background of falling energy prices. There are various ways in which the much more stringent requirements of climate stabilisation might be justified politically. These include taking a much longer-term view within the confines of a traditional cost-benefit analysis (eg. the use of a 2% instead of a 6% discount rate), the exclusion of transitional costs from the analysis and ensuring that costs are based on rationalised construction details, and further development of the shadow carbon price technique used in the last Compliance Cost Assessment. We are however of the view that while compliance cost assessment can inform, it cannot replace a broader strategic approach to the determination of standards for energy efficiency in construction.

5.3 Content and structure of the Regulations

1. The last fifteen years have seen the development of an increasingly complex regulatory structure, with multiple and sometimes conflicting routes to compliance, that has nevertheless tended to ignore realised performance in favour of nominal performance. In the future this emphasis must be reversed, with simpler regulatory structures based firmly on the results of research and performance achieved in the field.

2. The building thermal envelope is the most important determinant of the energy and environmental performance of the dwelling as a whole, and its influence extends for many decades into the future. It should, therefore, be the most important focus for changes in the Regulations.

3. Elemental U values can and should be significantly reduced, particularly with respect to wall heat loss. Detailed proposals for 2000 and 2005 are presented in Tables 5.2 & 5.3 above. We propose a maximum wall U value of 0.3 W/m^{2}K for a gas heated dwelling for the year 2000 revision and of 0.25 W/m^{2}K for 2005, in the context of a clear plan for the development of energy and carbon targets for dwellings to the year 2010.

4. The calculation methods for elemental U values in the current Regulations are flawed in a number of respects. Calculation methods must be revised to include the impacts of major structural thermal bridging and air movement within the structure. A process for reviewing the actual thermal performance of innovative constructions should be implemented, to ensure a close relationship between calculated and realised U values.

5. The Regulations should include an airtightness target, which should be verified by post-construction testing of air-tightness of 5-10% of new dwellings. The initial air-tightness target need not be stringent (we tentatively suggest 10 ac/h at 50 Pa), but a clear intention to move to tighter construction in the future should be signalled (we would suggest 3 ac/h by 2005). These measures need to mesh with provisions for ensuring adequate ventilation, either mechanically or passively. Our initial target of 10 ac/h at 50 Pa would not require significant alteration of current provisions for ventilation, but our proposed target for 2005 probably would.

6. We propose that the Elemental and Target U Value Methods should be supplemented by a requirement for heating systems to have a minimum energy and environmental performance. This minimum performance level would be specified in terms of average carbon intensity of both space and water heating, and should be capable of being met in 2000 by a reasonably efficient non-condensing gas fired system, and in 2005 by a condensing system. We propose that energy rating calculations would not be required for dwellings that met such a standard. Most of the information needed to calculate carbon intensity of heating is already present in Appendix G of the current Approved Document.

7. We find that there are strong arguments for limiting or eliminating the scope for raising allowable elemental U values through trade-offs. We propose that individual element U values be allowed to rise by a maximum of 20% either by trade-offs with other elements, or by trade-offs against heating system performance. Together with the minimum performance standards proposed above for heating systems, this would largely prevent the use of trade-offs to circumvent requirements to improve envelope performance.

8. We have grappled with the problem of what to do with SAP. In its present form, SAP does not appear to achieve the purpose of underpinning a market in domestic energy efficiency, it muddles economic cost and environmental impact, and provides a poor basis for the handling of trade-offs. Much of the effort that has gone into calculating SAP indices for all new dwellings would probably have been better spent ensuring that design U values were achieved in practice and that they were not compromised by avoidable air leakage and thermal bridging. If the marketing role of SAP is to be retained, the public profile of the index must be raised significantly, both among the public and among intermediaries such as estate agents (our own informal inquiries suggest that the latter are almost wholly ignorant of the index). If this cannot be done, we can see no reason for continuing to insist on a SAP rating for all dwellings.

9. Despite the above, we can see a strong case for retaining an Energy Rating Method using a revised SAP index. The SAP index should no longer be cost based, but should be based on CO_2 emissions for space heating, water heating and ventilation per square metre of accommodation. Regulatory compliance could be demonstrated by the Elemental Method, the Target U Value Method or by the Energy Rating Method. We would expect that most designers would continue to use the first two methods, with the Energy Rating Method providing a flexible alternative.

10. The above proposal would provide a unified approach to dealing both with inefficient gas-fired heating systems and with electric heating systems. Initially, separate energy rating targets might need to be established for gas and electrically heated houses, but in the longer term it may be desirable to bring them together. This would exert a powerful pressure to reduce the carbon emissions from electric systems through the use of technologies such as ventilation heat recovery, heat pumps, active solar and measures to reduce hot water use.

11. We suggest for the year 2000, energy rating targets for dwellings with electric resistance heating should be set so as to require the equivalent of reduced U values and measures to reduce water heating consumption (the use of low flow-rate showers and spray-head taps). We suggest that targets for the year 2005 should be set so as to require the equivalent either of an active solar system, sized to supply 50% of annual demand, or the use of a heat pump in electric hot water systems, together with ventilation heat recovery. Taken together with our proposals for envelope performance, these measures would sharply reduce the environmental impact of electric heating in new houses.

12. The treatment of windows and doors in the present Regulations provides little incentive for the development of improved products or performance. Procedures for calculating whole window U values and solar heat gain fractions should be adopted or developed, as part of a window energy rating system (perhaps based on the North American model). Performance, based on a window energy rating system, should be the basis for determining the upper limit to the glazed area of the dwelling.

13. Consideration should be given to place an upper limit on unshaded window areas to prevent overheating, particularly against a background of climate change and significantly increased summer temperatures in the 21st Century. This limit could also be based on a window energy rating system of the type discussed above and in Chapter 3.

14. The application of the Regulations to existing buildings should be strengthened so that whenever major works of refurbishment or repair are to take place to an existing building, the energy and CO_2 consequences are assessed and opportunities are taken to improve the energy efficiency of the whole building. The standards to be achieved should bring the altered building as near to the standard for new buildings as is reasonable. Such regulations should apply to all envelope alterations (particularly window replacements) and the replacement of heating and hot water systems.

5.4 Developing policies for change

As discussed earlier, it is unrealistic to expect change to occur over a short time scale. However, it will be necessary to set goals for our buildings which make a significant contribution to national and global strategies for sustainable development. It will, therefore, be necessary to manage the change process. We reach the following conclusions in this area:

1. The background to the Building Regulations must be the establishment of an explicit set of energy and carbon emission targets that the regulatory process is designed to achieve, over a period of at least ten years. These targets must be chosen to support declared national targets for carbon emissions from each sector of the economy. Development of these targets, and of a political consensus around them, is an absolute priority. We note that the UK has so far attempted nothing on the scale of the German Enquete Kommission Report (Deutscher Bundestag 1991), nor of the work of the Danish Energy Agency (Danish Energy Agency, 1990).

2. The next revision of the Building Regulations should be part of a clear development plan encompassing both new and existing buildings, designed to achieve these energy and carbon emission targets. The likely requirements of the 2005 revision, and an outline of the provisions for 2010 should be made clear at the time of publication of the 2000 revision. The development plan must provide the construction industry with the incentives and support needed to implement the proposed changes. Dialogue will be needed to achieve the right balance between the short term goals of the industry and the goals of the plan.

3. Linked to the notion of building a political consensus, a marketing strategy is required, designed to convince the public that sustainable housing is desirable. If the public wants low energy use and low environmental impact in new dwellings, then the only problem for the construction industry is how to meet the demand, at a price which provides the right profit margin.

4. As part of the development plan, a demonstration and evaluation programme is needed to provide built examples of a wide range of approaches to low energy construction. This would give the construction industry and the public, confidence that low energy housing is practical, free from technical risk and desirable. Such a programme will begin to overcome many of the perceptual barriers which exist to the construction of low energy housing.

5. There is a need to identify and remove procedural barriers to the introduction of energy efficient housing. This will entail a thorough review of regulation, codes of practice and design guidance, which currently make it difficult for designers to go beyond current practice.

6. A training plan is required to ensure an adequate supply of people who understand the requirements of energy efficient housing. Training will be required at all levels in the industry, from design to site management and construction practice.

7. Guidance and support will be needed to ensure that materials and component manufacturers are able to licence or develop products to support the construction of low energy housing.

Examples of such products include long plastic wall-ties, improved doors, high performance glazing, and thermally broken lintels.

8. While we can see no technical obstacles to the implementation of standards that we have proposed for the year 2000, there is a need for a long term research and development programme to identify and develop innovative solutions at both conceptual and detailed design levels, to develop management techniques that ensure that very high levels of energy efficiency can be realised cost effectively on site, and to begin to address wider sustainability issues.

9. A research programme is needed to establish the reality and magnitude of external benefits of very high levels of energy efficiency in new housing. An obvious example is the connection between energy efficiency and health.

10. It is essential that all work that is done to explore or support the case for improved standards of energy efficiency should be made public in a timely fashion, and should not be withheld for reasons of commercial confidentiality. There is a strong case for requiring that all work that has been paid for with public funds should be placed, without delay, in the public domain.

---

[1] This is not intended as a criticism. There is no compelling reason to expect the public to share the detailed concerns of building professionals.

[2] It has been suggested that our proposals for walls would favour timber framed construction. The relatively poor performance of most timber-framed walls and the modest incremental costs of better insulated cavity masonry walls means that, in our view, they do not. The arguments are presented somewhat more fully in Chapter 3.

6
references

ANDERSON, B.R. (1988) *British Standard Code of Practice for Energy Efficient Refurbishment of Housing. Energy Efficiency in Buildings, Information Leaflet No 7, 1988 (updated 1991)*. Watford, UK: Building Research Establishment.

ANON (1983) *Svensk Byggnorm 1980 (SBN 80), 2nd edn*. Stockholm: Statens Planverks Författningssamling.

ANON (1997) *The Development of a UK Domestic Window Energy Rating System*. Partners in Technology proposal, prepared by the British Woodworking Federation, Leeds Metropolitan University, University College London, Energy Advisory Associates, Fenestration Associates & the Centre for Window & Cladding Technology.

BELL, M. & LOWE, R.J. (1997) *The York Energy Demonstration Project: Final Report. CeBE report no. 3*. Centre for the Built Environment, Leeds Metropolitan University, Leeds, UK.

BELL, M., LOWE, R.J. & ROBERTS, P. (1996) *Energy Efficiency in Housing*. Aldershot, UK: Avebury.

BUNN, R. (1994) Living on Auto. *Building Services*, vol 16 (7).

BRE (1989) *Thermal Insulation: Avoiding the Risks*. Report 143. Watford: BRE.

BRE (1994) *Thermal Insulation: Avoiding Risks. 2nd edn*. Report 262. Watford: BRE.

CITY OF YORK COUNCIL (1996) *Home Energy Conservation Act: Report to the Department of the Environment*.

CSA (1993) *A440.2-93/A440.3 Energy Performance Evaluation of Windows and Sliding Glass Doors.* Toronto: Canadian Standards Association.

DANISH MINISTRY OF ENERGY (1990) *Energy 2000.* Copenhagen: Danish Energy Agency.

DANISH MINISTRY OF HOUSING (1995) *Building Regulations.* Copenhagen: Danish Ministry of Housing.

DANSK INGENIØRFORENING (1986) *Regler for Beregning af Bygningers Varmetab. DS 418. 5. udgave.* (Rules for calculating heat losses from buildings. 5th edn.). Copenhagen: Norm Styrelsen.

DANSK STANDARD (1997) *Beregning af Bygningers Varmetab: Tillaeg omhandlende vinduer og yderdøre. Tillaeg 1 til DS418.* (Supplement to DS418 dealing with windows and outer doors). Copenhagen.

DEUTSCHER BUNDESTAG (1991) *Protecting the Earth: A Status Report with Recommendations for a New Energy Policy. Third Report of the Enquete Commission on Preventative Measures to Protect the Earth's Atmosphere.* Bonn: Bundestag.

DOE & WELSH OFFICE (1990) *Building Regulations 1991*: Conservation of Fuel and Power. London: HMSO.

DOE & WELSH OFFICE (1994) *Building Regulations Approved Document, Part L: Conservation of Fuel and Power.* London: HMSO.

DOE (1991). *Housing and Construction Statistics 1981 to 1990.*, London: Central Statistical Office.

DOE (1993) *English House Condition Survey: 1991.* London: Department of the Environment.

DOE (1996) *Review of the Potential Effects of Climate Change in the United Kingdom.* London: HMSO.

ELDER, A.J. (1981) *Guide to the Building Regulations. 7th edn.* Architectural Press.

EVERETT, R., HORTON, A., DOGGART, J. with WILLOUGHBY, J. (1985) *Linford Low Energy Houses. ERG 050/ETSU-S-1025.* Milton Keynes: Open University Energy Research Group.

FEIST, W. (1994) *95% Heizenergieeinsparung im Passivhaus.* das Bauzentrum, 4/94.

KING, E. (1997) Personal communication.

KRAUSE, F. et al. (1989) *Energy Policy in the Greenhouse. Final Report of the International Project for Sustainable Energy Paths (IPSEP).* El Cerrito, California: IPSEP.

LOWE, R.J. & CURWELL, S.R. (1996) Case study 2: The Longwood Low Energy House. In *Energy Efficiency in Housing.* M.BELL, R.J. LOWE & P. ROBERTS. Aldershot, UK: Avebury.

LOWE, R.J. & JOHNSTON, D. (1997) *Mechanical Ventilation with Heat Recovery in Local Authority, Low-Rise Housing: Final Report on the Derwentside Field Trial.* CeBE Report No. 6. Leeds Metropolitan University.

LOWE, R.J., CURWELL, S.R., BELL, M. & AHMAD, A. (1994) Airtightness in Masonry Dwellings: Laboratory and Field Experience. *Building Services, Engineering, Research & Technology vol 15 (3).*

LOWE, R.J., BELL, M. & JOHNSTON, DK. (1996) *Directory of Energy Efficient Housing.* Chartered Institute of Housing for the Joseph Rowntree Foundation, York, UK.

LOWE, R.J., STURGES, J.S. & HODGSON, N.J. (1997) Energy Analysis and Optimal Insulation Thickness. In *Proc. 2nd International Conference on Buildings and the Environment.* Paris: CSTB.

OLIVIER, D. (1992) *Energy Efficiency and Renewables: Recent Experience in Mainland Europe.* Milton Keynes: Energy Advisory Associates.

OLIVIER, D. & WILLOUGHBY, J. (1996a) *Review of Ultra-low-energy Homes: A Series of UK and Overseas Profiles.* BRECSU, General Information Report 38. Watford, UK: Building Research Establishment.

OLIVIER, D. & WILLOUGHBY, J. (1996b) *Review of Ultra-low-energy Homes: Ten UK Profiles in Detail.* BRECSU, General Information Report 39. Watford, UK: Building Research Establishment.

OLIVIER, D. (1996) *Energy Efficiency and Renewables: Recent North American Experience.* Leominster: Energy Advisory Associates.

OLIVIER, D. (1997) personal communication

PERERA, E. & PARKINS, L. (1992) Airtightness of UK Buildings: Status and Future Possibilities. *Environmental Policy and Practice vol 2 (2).*

PRIOR, J.J. & BARTLETT, P.B. (1995) *Environmental Standard: Homes for a Greener World. BR278.* Watford, UK: Building Research Establishment.

ROSSETTI, S. & TARANTINO, C. (1997) *Legislation and standards concerning energy in buildings.* A survey presented at a joint meeting of AICARR and REHVA (Federation of European Heating and Air Conditioning Associations). 10 April 1997. Rome.

SHORROCK, L.D., HENDERSON, G. & BROWN, J.H.F. (1992) *Domestic Energy Fact File, 2nd edn. BR 220.* Watford, UK: Building Research Establishment.

SHORROCK, L D. & BROWN, J H F. (1993) *Domestic Energy Fact File 1993 Update. BR251.* Watford, UK: Building Research Establishment.

SIVIOUR, J.B. (1994) Experimental U-Values of Some House Walls. *Building Services Engineering Research & Technology vol 15 (1).*

SWEDISH BOARD FOR HOUSING, BUILDING AND PLANNING (1989) *Värmeisolering: Värmegenomgångskoefficienter för Byggnadsdelar och Köldbryggor, Tjälfri Nivå.* (Thermal insulation: Heat transfer coefficients for building elements and cold bridges). Stockholm.

SWEDISH BOARD FOR HOUSING, BUILDING AND PLANNING (1995) *Building Regulations BBR 94. BFS 1993:57 with amendments BFS 1995:17 & BFS 1995:65.* Stockholm.

VALE, R. (1995) *The Autonomous House in Theory and Practice.* PhD Thesis, Nottingham University.

WARM, P. & WILLOUGHBY, J. (1998) personal communication.

Towards
Sustainable
Housing:
building regulation
for the 21st century

Since the Earth Summit in Kyoto in December 1997, governments throughout the world have accepted the need to meet stringent targets for reductions in the emission of greenhouse gases, principally carbon dioxide. The UK has set its own target of a twenty percent reduction in carbon dioxide emissions by the year 2010. Housing. This report focuses on the contribution that can be made by the housing sector, which currently accounts for almost thirty percent of UK carbon emissions, to this overall target.

The report reviews the structure, content and context of the Building Regulations, the performance of the construction industry and the technical and economic scope for improvement. The situation in the UK is compared with regulatory and technical developments in the Netherlands, Denmark and Sweden. The report s major finding is that while it is technically possible to achieve large reductions in carbon emissions from housing, such reductions will not be realised by the action of market mechanisms alone. The authors present a phased programme of action, to be set firmly in the context of a long-term national strategy for reducing carbon emissions from all sectors. This programme includes regulatory changes that would raise the performance of new UK housing to the level of the best in Europe within ten years. The current review of Part L of the Building Regulations provides a major opportunity to put such a framework in place.

The authors are staff members at the Centre for the Built Environment, Leeds Metropolitan University and have been involved in a wide range of housing energy efficiency projects over a period of twenty years. They are co-authors of two books and numerous papers on the subject.

£9.95
ISBN 1 898883 12 2

LEEDS
METROPOLITAN
UNIVERSITY

JR
JOSEPH
ROWNTREE
FOUNDATION