The Kyoto Commitment: The challenge for UK building services engineers in obtaining a contribution from the domestic sector

K M Letherman BSc MSc PhD CEng FIEE FCIBSE MASHRAE*
S R Samo BE MEng MPEC StudentCIBSE *
*Department of Building Engineering, UMIST, Manchester, M60 1QD, UK

The UK government has signed the Kyoto Protocol and it has committed to reducing CO_2 emissions to 20% below 1990 levels by 2010 [1]. As buildings are responsible for approximately half of the UK CO_2 emissions, of which the domestic sector accounts for 50%, meeting this target will require a significant contribution from the domestic sector. This paper presents the results of a study into the potential for CO_2 reduction by insulation of the existing housing stock, and compares the CO_2 emission reduction and energy savings in dwellings produced by revisions of the UK thermal building regulations since 1965.

An analysis is given of energy efficiency measures to achieve the contribution of space heating in the domestic sector to the UK government's target. The older dwellings (pre-1965) in the UK produce about three-quarters of the total CO_2 emission in the domestic sector. Improvements in wall U-values to reach the standard of the 1976 building regulations can give more than 20% reduction in energy consumption and CO_2 emissions in the total domestic sector. This measure, if accompanied by the introduction of effective heating controls, would achieve an appropriate contribution towards the overall target. Cost, however, is likely to be a barrier. These findings illustrate the challenge for Building Services Engineers to identify measures for older buildings that are more cost effective than wall insulation and therefore more likely to make a real contribution to the CO_2 reduction target.

Introduction

Almost alone among the major European nations, the UK is self-sufficient in energy resources. Yet the total energy demand in the UK has fallen, by 1% a year on average [2], because of energy efficiency improvements. In the domestic sector energy use increased from 1970 to 1995, but then decreased, as was predicted by the Building Research Establishment [13]. There have been several changes in the Building Regulations, which have more than doubled, and even tripled, thermal standards over the last 30 years. Table 1 illustrates the comparison between the UK's first Building Regulations 1965 [3] and the current (1995) Regulations [4]. However, these apply only to new buildings, leaving the vast majority of the building stock (about 66%) untouched, although retrofit in existing dwellings (e.g. double-glazing and loft insulation) must have improved the thermal performance of these buildings. This study is concerned only with the effect of the UK thermal building regulations on space heating energy, and these regulations have applied only to new dwellings.

This paper presents data on the percentage of the dwelling stock, energy consumption, and carbon dioxide emission in different types of dwellings, which satisfy different revisions of the UK building regulations. A computer model; 'Housing Energy Consumption Analyser' (HECA), was produced to calculate these parameters, while considering the requirements of the UK Building Regulations from 1965 to 1995. U-value improvement could save energy and reduce CO_2 emission in dwellings [5]. The effect of decreased U-values of pre-1965 dwellings to achieve the government target was analysed and results are presented.

Methodology

The published housing data for the total number of dwellings [6] from 1985 to 1995 was used to calculate the total energy consumption and CO_2 emission of UK dwellings. Four revisions of the Building Regulations – in 1965 [3], 1976 [7], 1985 [8] and 1995 (as amended) [4] have been introduced in this country. The age and thermal performance distribution of the dwelling stock was classified according to their compliance with the Building Regulations. No reliable information is available on the thermal performance and U-values of the pre-1965 stock. For simplicity, it was assumed that the U-values of the construction elements of pre-1965 dwellings satisfied the 1965 Building Regulations. This will take advantage of the balance between those which have been improved and those which have been left in the original thermal state.

Six types of dwellings – Detached house, Semi-detached house, Bungalow, Flat, Post-1919 Terrace house and Pre-1919 Terrace house – were considered. The construction details and the U-values of the construction elements according to the different building regulations are summarised in Table 2. The percentage distributions of different types of dwellings were assumed to be as described in a BEPAC report [9] to calculate the total number of dwellings by type. Data on the dimensions and construction of flats were not included in [9]. The energy consumption of an individual flat is broadly similar to that of a terraced house, and these two types have been treated together in the calculations for the total UK domestic sector. The seasonal energy consumption for a single dwelling of each type was calculated by the method described in [10]. This method is very simple, but it is well established and founded on basic physical principles. It is useful for analyses and is supported by other researchers, e.g. Mathews et al [14]. The CO_2 emission was calculated by using the Elmhurst SAP energy rating computer program [11]. The total energy consumption of all UK dwellings was calculated by adding together the energy consumption of each part of the dwelling stock satisfying different Building Regulations from 1965 to 1995 and the energy consumption of the pre-1965 dwellings, i.e.,

$$\text{EC (total)} = \sum(EC_{95} + EC_{85} + EC_{76} + EC_{65} + EC_{pre-65})$$

Where

$$\begin{aligned} EC_{95} = \sum(& EC\det_{95} \times DS\det_{95} + ECsemi\det_{95} \times DSsemi\det_{95} + ECbungalow_{95}\ ) \\ & \times DSbungalow_{95} + ECflat_{95} \times DSflat_{95} + ECpost1919terrace_{95} \\ & \times DSpost1919terrace_{95} + ECpre1919terrace_{95} \times DSpre1919terrace_{95} \end{aligned}$$

and

EC_{95} = Energy consumption of dwelling stock satisfying the Building Regulations 1995
EC_{det95} = Energy consumption of detached house satisfying Building Regulations 1995
$DSdet_{95}$=The number of detached houses satisfying Building Regulations 1995, etc

Results and Discussion

In the UK, four revisions of the national building regulations have been introduced since 1965 at intervals of about 10 years. Each successive revision has improved the U-values of construction elements to reduce the energy use and its related impact on the environment. The improvement in U-values of construction elements of dwellings by each successive revision of the building regulations is shown in Fig.1. Since 1965 the roof U-values have been decreased by about 86% and the U-values of walls and floor are decreased by about 75% each, whereas the U-value of windows have been decreased only by 46% by changing single-glazed windows to double-glazed windows. As the successive revisions of the UK building regulations have reduced the U-values of the external envelope, it is well known that the typical ventilation conductance has reduced also. This paper concentrates on the fabric conductance, as the ventilation performance is far less quantified than the fabric performance. The effect of modifying the U-values of construction elements on energy consumption and CO_2 emission in the UK dwellings was analysed.

The effect of decreased U-values of construction elements of different types of dwellings to satisfy different building regulations on the energy consumption and carbon dioxide emission in each type of dwelling was also analysed. Fig.2 shows the energy consumption of a single dwelling of each type, satisfying different Building Regulations, and Fig.3 shows the carbon dioxide emission by a single dwelling of each type. It was observed that a Detached house satisfying the building regulations 1965 consumes about 80 GJ/year of energy for space heating, and produces about 8 tonnes of carbon dioxide. When the same example house was modified to give U-values which satisfy the requirement of the current building regulations (1995), these figures were both reduced by about 65%. The example Bungalow consumes the highest energy per unit of floor area and the example Detached house consumes the lowest as compared to other type of dwellings. The energy consumption in the Pre-1919 Terrace house was about 10% higher than the energy consumption in the Bungalow and about 12% less than that in a Detached house. If the pre-1919 Terrace house could be upgraded to reach the standard of the 1995 regulations then the reduction in its total carbon dioxide emission would be about 60%.

The energy consumption and carbon dioxide emission of the dwellings in Great Britain were calculated using a computer program. The total number of dwellings in Great Britain in 1995 was about 24 millions [12]. The annual energy consumption for space heating in these dwellings has been calculated as more than 1500 PJ (i.e., 1.5×10^{18}J). The total fuel consumed in UK dwellings costs about £14 billion per year and produces about 170 million tonnes of carbon dioxide annually. The calculated figures agree well, although not precisely, with published values, the difference in CO_2 emission being about 2%. This gives us some confidence in the reliability of the calculation model.

The percentage distribution of the existing dwelling stock satisfying different Building Regulations from 1965 to 1995 is shown in Figure 4. About 66% of the total (16 million) are old dwellings (pre-1965). Only 15% (3.7 million) satisfy the 1965 Regulations. More than 9% (2 million) of the dwellings satisfy the 1976 Regulations. Fewer than one million (4%) satisfy the current Building Regulations 1995 (as amended). The pre-1965 dwellings account for more than 70% of total energy consumption. The part of the dwelling stock which satisfies the 1965 Regulations consumed about 17% (about 250 PJ/year) of the total energy consumption. Ten percent (about 160 PJ/year) of the total energy consumption was accounted for by the remaining three groups of dwellings which satisfy the Building Regulations 1976, 1985 and 1995 respectively.

The carbon dioxide emissions were also analysed and the results are shown in Figure 4. The dwellings which satisfy the 1995 Regulations, cause less than 3 million tonnes of carbon dioxide emission per year (1.5% of the total). Older dwellings (pre-1965) were responsible for about 130 million tonnes of carbon dioxide per year (about 75%). The dwelling stock which satisfies the 1965 Regulations produced about 15% (25 million tonnes/year) of the total carbon dioxide emission. The energy consumption and carbon dioxide emission of the dwelling stock satisfying the 1976 Regulations were both about 7%. Currently, about 6% of the total dwelling stock (about 1.4 million dwellings) satisfy the 1985 Regulations, and about 4% satisfy the 1995 Regulations (as amended). This latest portion of the dwelling stock (10%) consumes only about 4% (60 PJ/year) of the total energy used and is responsible fcr about 4% (7 million tonnes/year) of the total carbon dioxide emission.

The effect of improved thermal insulation of walls, floor and roof (windows were considered either single or double-glazed) on the energy consumption in the pre-1965 dwelling stock was analysed by decreasing each of the U-values by between 20 and 80%. Figure 5 shows the effect of individually decreased U-values on the energy consumption of the pre-1965 dwelling stock.

By decreasing the U-values of the walls by 20%, the energy consumption of this older dwelling stock can be decreased by 12%. A 40% decrease in U-values of this construction element will reduce the energy consumption by up to 20%. Significant savings of energy for space heating (about 40%) in this dwelling stock could be made if the U-values of walls can be decreased by 80%. If the U-values of roof and floor are decreased by 80%, then a 13% saving of energy consumption in the pre-1965 dwelling stock can be made (Fig.5). By considering double glazed windows instead of single glazed in the pre-1965 dwelling stock the energy consumption decreased by only about 9%.

The effect of U-values of various construction elements of pre-1965 dwelling stock on the reduction of CO_2 emission in this particular stock was also analysed. The decrease in U-values of walls has the highest impact on reduction of energy consumption as compared to the other construction elements, which is to be expected, because of the larger area of this element. If the U-values of walls could be decreased by 40% then the energy consumption in this dwelling stock can be reduced by 20%. As a result a reduction in total CO_2 emission in pre-1965 dwelling stock of about 30% and in the overall domestic sector of about 23% can be made, as shown in

Fig.6. This energy efficiency measure is of the same order as that required to achieve the contribution of the domestic sector to the government's target.

Clearly, in practice it is out of the question that this enormous task of insulation upgrading will actually be achieved by 2010, even if only because of the size of the financial investment that would be required. Also, it is well known that in practice, when homes are upgraded by adding insulation, not all of the expected energy savings for space heating are achieved because the occupants prefer to enjoy higher room temperatures than before the upgrading. However, this work has shown that the greatest reduction in energy consumption and carbon dioxide emission could be achieved by concentrating on the older, pre-1965, dwellings, rather than relying on new buildings.

Conclusions

- Building Regulations apply only to new buildings, leaving the vast majority of the building stock (about 66%) untouched.
- Dwellings which were constructed before 1965 consume about 73% of the total heating energy in housing and are responsible for about 75% of carbon dioxide emissions.
- About 4% of the dwelling stock satisfies the current Building Regulations 1995, consumes 2% of total energy, and produces about a similar percentage of carbon dioxide emission in housing.
- A typical standard detached house satisfying the building regulations 1965 produces about 8 tonnes of carbon dioxide annually. The same example house satisfying the requirement of the current building regulations produces only about 3 tonnes of carbon dioxide annually.
- If the U-values of walls could be decreased by 40% then the space heating energy consumption in the pre-1965 dwelling stock would be reduced by 20%. As a result a reduction in total CO_2 emission in pre-1965 dwelling stock of about 30% and in overall domestic sector of about 23% can be made This reduction is of the same order as would be required to achieve the contribution of the domestic sector to the government's target.

Acknowledgement
One of the authors (S. R. Samo) wishes to acknowledge the support of the Commonwealth Scholarship Commission for this work.

References

1 HMSO (1998), UK Climate Change Programme, Consultation Paper, Department of the Environment, Transport and the Regions, St Clements House, Colegate, Norwich, UK

2 J O Lewis and J Goulding (1993), European Directory of Energy Efficient Building 1993, James & James, London, UK.

3 C Kennard and J Dufton (1966), The Building Regulations, Butterworths, London.

4 HMSO (1995), The Building Regulations 1991, Conservation of Fuel & Power, Approved Document Part L1, 1995 Edition, UK.

5 K M Letherman and S R Samo (1998), The Effect of the UK Building Regulations on Environmental Change, paper presented at the workshop of CIB W67, Czech Technical University, Prague, Czech Republic.

6 HMSO (1997), Housing and Construction Statistics 1985-1995 Great Britain, Department of the Environment, St. Clements House, Colegate, Norwich, UK.

7 A J Elder (1979), Guide to the Building Regulations 1976, The Architectural Press: London.

8 HMSO (1991), The Building Regulations 1985, Conservation of Fuel & Power, Approved Document Part L1.

9 E A Allen and A A Pinney (1991), Standard Dwellings for Modelling: Details of Dimensions, Construction and Occupancy Schedules. Building Research Establishment, Garston, Watford, UK.

10 BRE (1976), Heat Losses From Dwellings, Building Research Establishment (BRE) Digest 190, Department of the Environment, Building Research Establishment, HMSO

11 Elmhurst Energy Systems Limited (1996), SAP Energy Rating Software, version 1.08 (Design), 1996, Elmhurst Energy Systems Limited, Elmhurst Farm, Bow Lane, Withybrook, Nr. Coventry, UK

12 HMSO (1996), English House Condition Survey 1991, Energy Report, Department of the Environment, St. Clements House, Colegate, Norwich, UK.

13 L D Shorrock, (1994) Future Energy use and Carbon Dioxide Emissions for UK Housing-a scenario, BRE Information Paper IP 9/94, Building Research Establishment, Garston, Watford, UK.

14 E H Mathews (1994), A First Order Thermal Model for Building Design, Energy and Buildings, Vol. 21, p 133-145.

Year of Building Regulation	U-values (W/m²K)				
	Wall	Window	Floor	Roof	Door
1965	1.7	5.6	1.42	1.42	3.0
1995	0.45	3.0	0.35	0.2	3.0

Table 1 U-values of construction elements according to different Building Regulations

Dwelling Type	Total Floor Area (m^2)	Volume (m^3)	Wall to Floor ratio	Fabric Thermal Conductance (W/K)
Detached	99	240	1.4	433
Semi-Detached	85	199	1.6	378
Bungalow	63	149	1.2	345
Post 1919 Terrace	75	173	1.5	337
Pre 1919 Terrace	86	212	1.9	414

Table 2 Areas, volumes and thermal conductance of different types of standard dwellings

Note : Data on the dimension and construction of flats was not included in the BEPAC report [9].

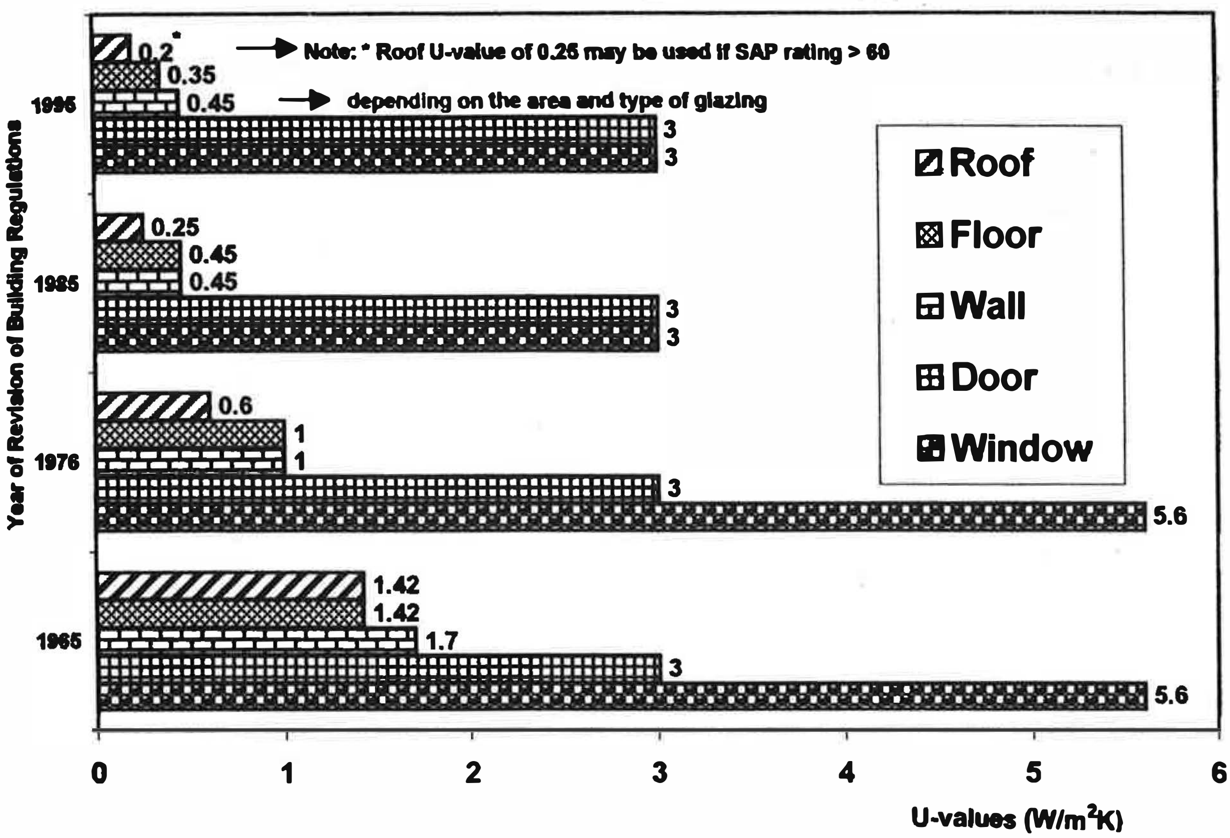

Fig.1 Improvement of U-values of construction elements of dwellings by different revisions of Building Regulations

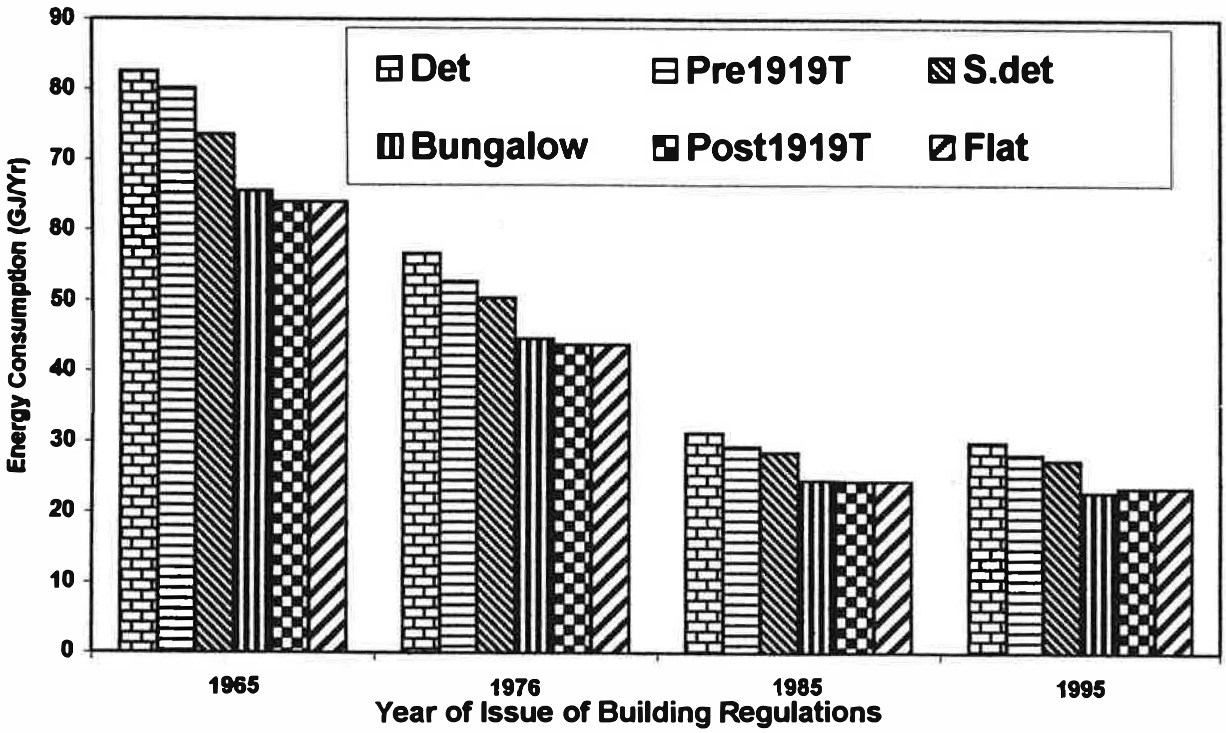

Fig.2 Effect of Building Regulations on energy use in dwellings (by type) of Great Britain
(Notations: T = Terrace, Det. = Detached, S.det = Semi detached)

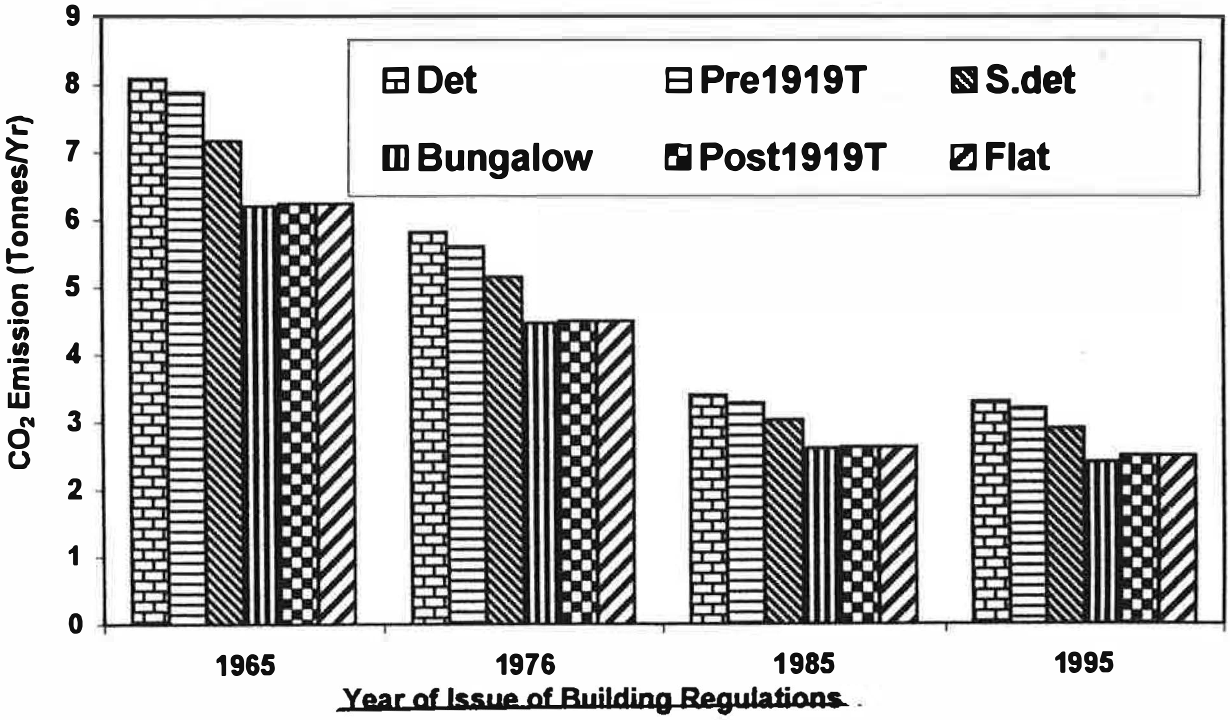

Fig.3 Effect of Building Regulations on CO_2 emission in dwellings of Great Britain
(Notations: T = Terrace, Det. = Detached, S.det = Semi detached)

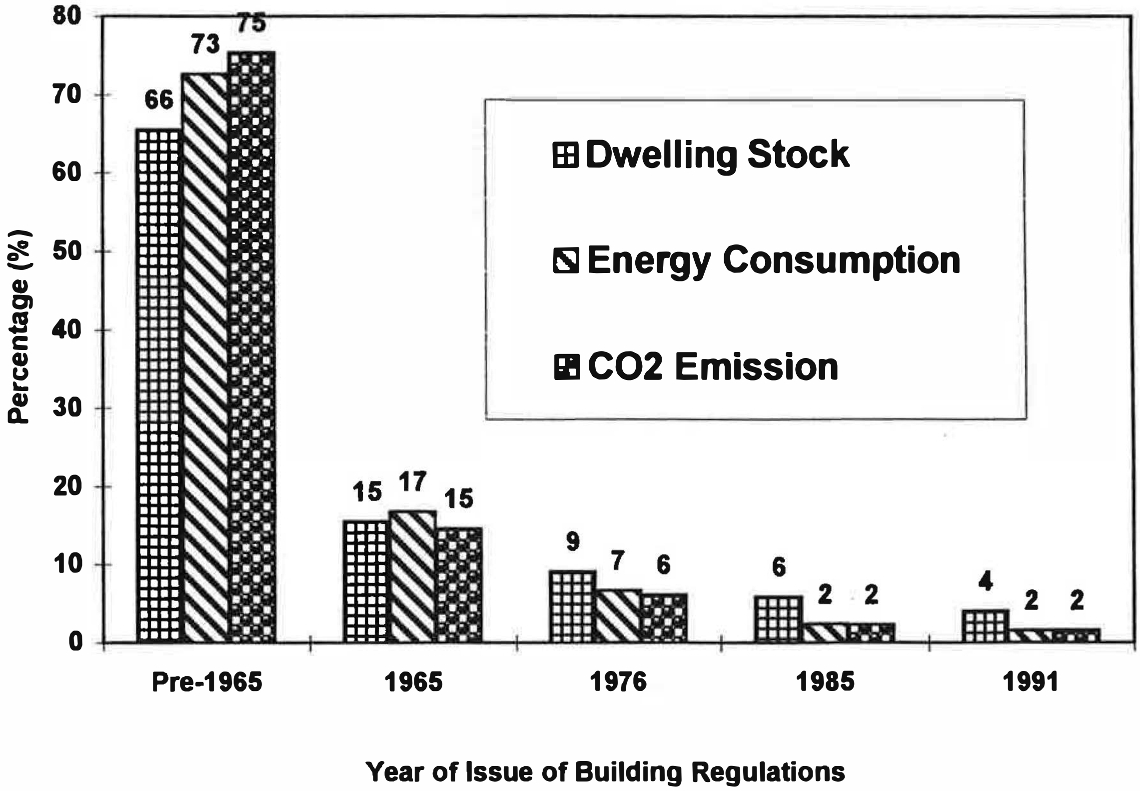

Fig.4 The energy consumption and CO_2 emission of dwellings of Great Britain satisfying different building regulations.

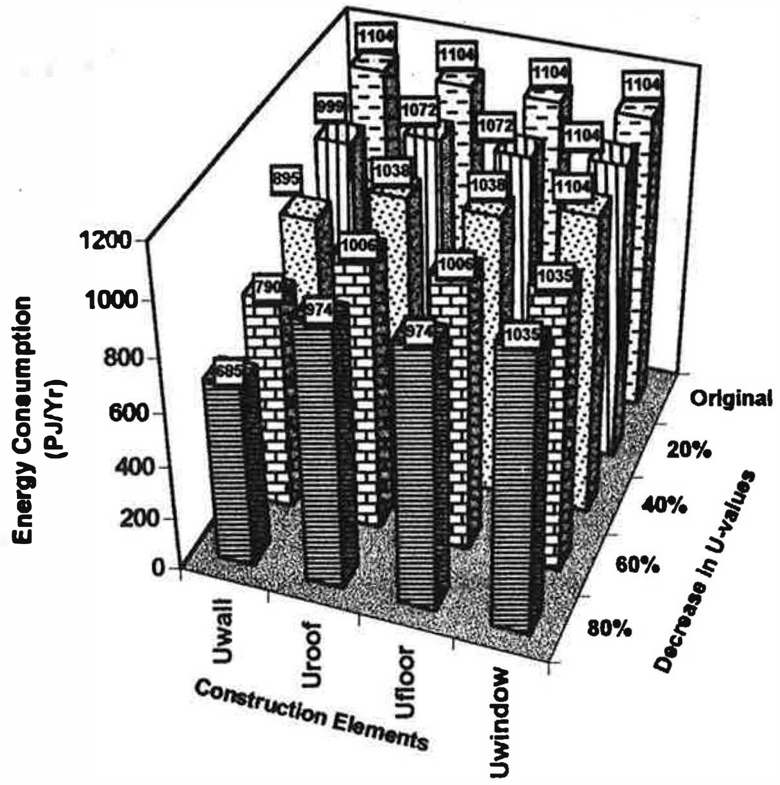

Fig. 5 Effect of Decreased U-values on Energy Consumption in dwellings built before 1965

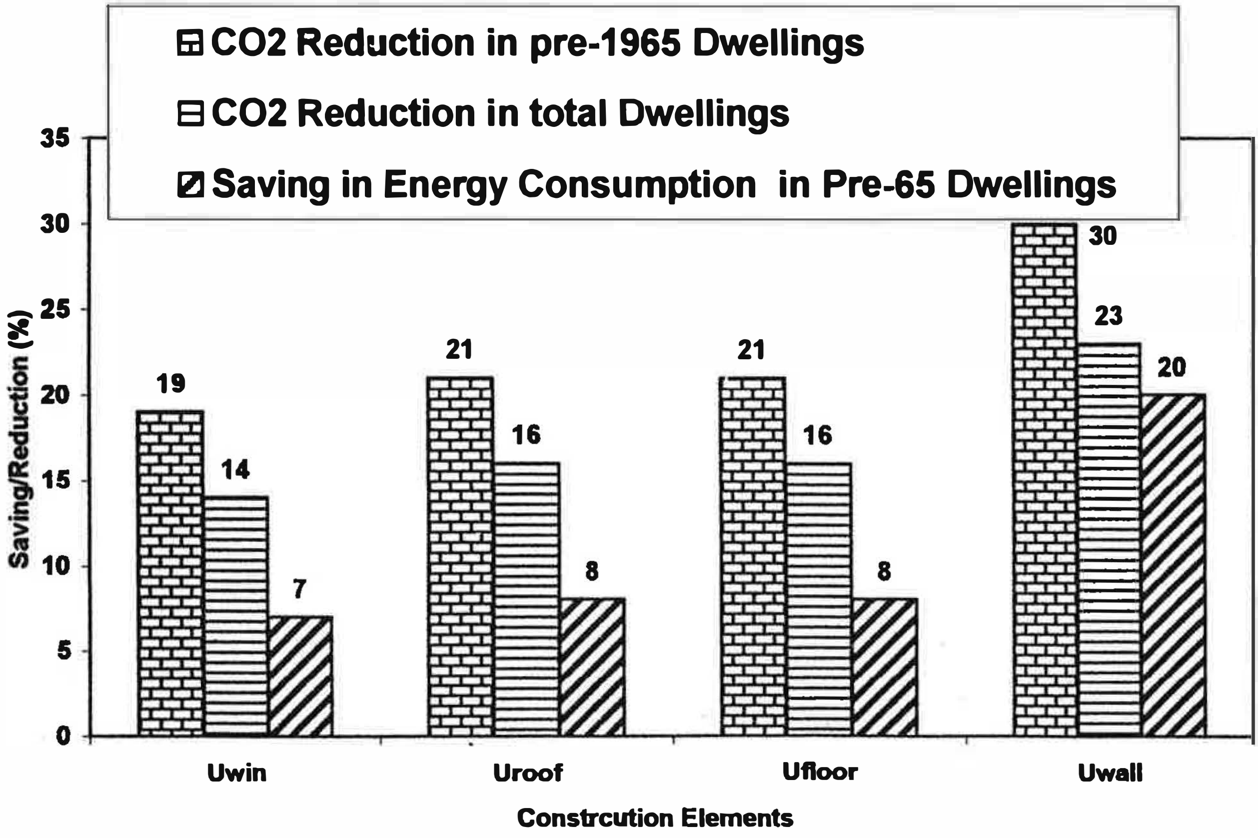

Fig.6 Effect of 40% decrease in U-values of construction elements of pre-1965 dwellings on CO2 emission and energy consumption of Great Britain