THE ROLE OF ENERGY PROVISION IN THE ALLEVIATION OF FUEL POVERTY

by

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Abstract

Fuel poverty occurs when a household cannot afford adequate warmth. The result is that the household is required to spend more then 10% of their income on fuel or that they keep their homes cold. There is a causal link between excess winter deaths and mean internal temperature of a dwelling. One in five households in Scotland are fuel poor.

The causes of fuel poverty were found to be income level, energy efficiency of dwelling, cost of fuel and occupancy pattern of the dwelling.

The Scottish Executive has addressed this problem by a series of actions designed to improve the energy efficiency of fuel poor households to an NHER rating of 7.0.

A model was created using esp-r building simulation software to build a link between energy efficiency and energy use. Using this model, the mean internal temperature of a test case dwelling was found increase by 1.4°C, to 16.3°C, as a result of the Scottish Executive proposals. This was found to be somewhat lower than the mean internal temperature for other countries. The model predicted that an NHER rating of 7.5 was necessary if mean internal temperatures equivalent to those seen in other countries were to be generated.

A number of alternative strategies to addressing the problem of fuel poverty were reviewed.

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Chapter 1

Fuel Poverty – Definition of the Problem

A comprehensive review of the sources and indicators of fuel poverty is outside the remit of this document. However Brenda Boardman et al[1] provide a detailed review on the subject.

Fuel poverty is a phenomenon that was first fully recognised in the 1970's but not acknowledged by the UK government until the 1990's. It differs from poverty as usually described because, while retaining an element of incomes relation, it is largely a result of living in an energy inefficient household. Two definitions are given below which cover the accepted wisdom on the subject:

'Fuel poverty occurs where a household is unable to afford adequate warmth because they live in an energy inefficient home'[1]
'Fuel poverty occurs in those households that are required to spend 10% or more of their income to achieve adequate warmth'[1]

If the household is required to spend greater than 20% of its income on warmth then they are said to be in acute fuel poverty.

Energy efficiency relates to both the fabric of the household, in terms of insulation levels, upkeep etc. and also to the type and efficiency of the heating system. The cost of installing new heating systems and insulation to households can run to four figures. One of the unique features of fuel poverty is that the householder does not have this capital to transform their home into an energy efficient one. Alternatively, they may not own the property and are therefore not able to carry out the necessary work.

Regardless of definition, it is difficult to measure fuel poverty directly. The fuel poor may spend very little (as a proportion of their income) or a great deal. The underlying issue is how much they would have to spend to provide a comfortable environment given their housing conditions. One approach to assess this is by modelling the amount of warmth that would have to be purchased to provide adequate comfort.

The most widely applied method is the BREDEM model[2]. This is a software programme that has been developed by the Building Research Establishment (BRE). A number of analytical and empirical techniques are used to assess the energy requirements needed in a dwelling to achieve a specific space-heating regime. This, together with similar energy calculation techniques for water-heating, cooking, lighting and other domestic appliance models the full energy requirements of the dwelling.

BREDEM-12 models the dwelling as a number of ‘zones’. Zone one is the main living area of the dwelling and is assumed to comprise roughly one quarter of the floor area. Zone two is assigned as the rest of the house.

In calculating the energy requirements of a dwelling, BREDEM-12 uses what has been discovered about housing in successive Scottish House Condition Surveys and allows for,

- Dwelling ‘u’ values that describe the capacity of the building fabric to allow heat loss from within to the external environment.
- Infiltration rates describing patterns of air movement within the building.
- Thermal capacity describing the intrinsic ability of different materials to hold heat.
- Internal heat transfers from zone one to zone two and from zone two to the unheated portion of the house.
- Metabolic gains essentially heat from bodies.
- Heating system control and efficiency.
- External weather conditions.

The BREDEM model calculates the fuel required to heat the dwelling to provide adequate warmth. This is ascribed as being:

- 21°C in the main living area and 18°C in the rest of the house.
- All days in the year are the same.
- Heating system is on between 7:00 and 9:00 in the morning and between 5:00 and midnight in the evening.

Annual dwelling fuel costs are calculated using a complementary programme known as 'Auto-Evaluator'. The National Energy Foundation (NEF) who developed the programme in conjunction with BRE gives a full technical description for this programme[3]. In summary, auto evaluator uses information determined from the energy analysis and, together with data on the cost of different types of fuels calculates annual dwelling running costs in terms of space heating, water heating, cooking, and lights and appliances.

Once this figure has been established, it can be compared to the income of the household and, according to the '10%' definition, the status of the dwelling relating to fuel poverty can be determined.

The Auto-evaluator also establishes a National Home Energy Rating (NHER) for a dwelling. This assesses the energy efficiency of a dwelling on a scale of 1 (= extremely poor) to 10 (= fantastically efficient).

The effect of energy inefficiency is to increase the cost of warmth. A Cost of Warmth Index (COWI) has been developed by Boardman et al[1] that used the following seven indicators to calculate the cost of warmth:

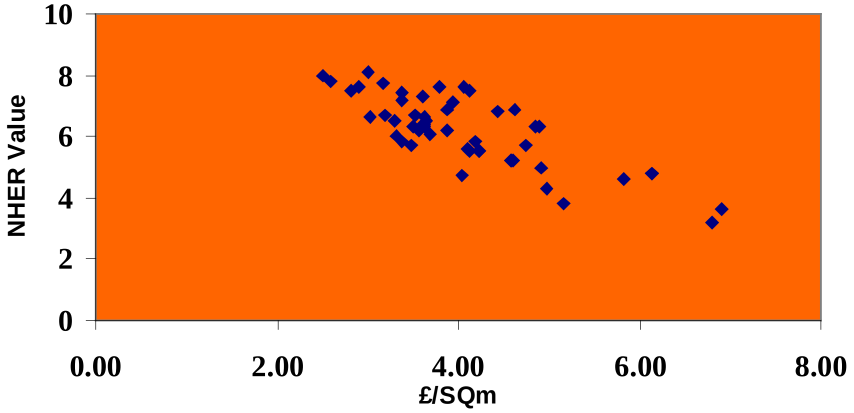
1. Rate of Heat Loss through the Building Fabric
2. Rate of ventilation Loss
3. Efficiency of the Heating system
4. Cost of Fuel
5. External temperature adjusted for incidental gains
6. Internal temperature required
7. Hours of heating required per day

Thus items 1-4 express energy efficiency of the dwelling while 5-7 quantifies the demand for warmth.

There should therefore be a loose relationship between energy efficiency of a dwelling and the cost of fuel bills for space heating.

To test this hypothesis the author was permitted to view data from an unpublished study into fuel poverty conducted by a Scottish Local Authority. The study identified, among other indicators, the floor area, space heating cost and NHER level for 72 dwellings. Each had Gas Central heating.

Figure 1 Effect of Energy Efficiency on Cost of Space Heating



The data revealed, as expected, a rough relationship between cost of space heating and energy efficiency of a dwelling. Energy inefficient homes spend roughly three times as much as efficient homes on space heating. When this discrepancy is combined with low income then the effects can be catastrophic.

Chapter 2
Factors Surrounding Fuel Poverty

2.1 Introduction

Policy decisions made by governments today are far reaching in their effect. The time scales that governments are afforded to deal with fuel poverty amount to 15 years. It is therefore essential that any policy be derived given an appreciation of all the factors that are likely to impinge on fuel poverty during that period.

This chapter attempts to discuss all those factors.

2.2 Fuel Poverty – The Size of the Task

Macintyre et al [3] used the Scottish House Survey of 1996 to elucidate information concerning the fuel poor.

Among other things, the report ran the Scottish Homes Survey data through the BREDEM-12 model to establish fuel costs as described in Chapter 1. The data therefore represents a model condition of heating (21°C in the living area and 18°C in the rest of the dwelling). The fuel costs were then compared to income levels derived in the study.

A summary of the findings of the report is given below.

In Scotland, 506,000 (23.8%) households, out of a total of 2,123,000, would be required to spend more than 10% of their income to heat their homes to a standard regime.

Of these a total of 123,000 (5.8%) would be required to spend over 20% of their income.

- 52% of the fuel poor are elderly.
- 40% of the elderly are fuel poor.
- 34% of non-elderly population on benefits are fuel poor.
- 10% of the non-elderly population not on benefits are fuel poor.
- 78% of households with a weekly income of <£100 were found to be fuel poor, and 25% found to be in extreme fuel poverty (spending >20% of income on fuel).

- 55% of households that had a NHER rating of 2 or less were in fuel poverty.
- 25% of households with an NHER rating between 3 and 6 were found to be fuel poor.
- 7% of those dwellings found to have an NHER rating of greater than 7 were found to be fuel poor.

The fuel poor would therefore appear to be low-income groups, primarily elderly, who live in energy inefficient homes.

The survey then looked at different approaches to addressing fuel poverty. The approaches all concentrated on improvements to the building fabric to improve energy efficiency and so reduce the cost of warmth.

The range of improvements was first categorised. This produced 5 scenarios that could be adopted to improve energy efficiency. These are shown in the table below.

	Scenario				
Improvement	**(a)**	**(b)**	**(c)**	**(d)**	**(e)**
Installation of loft insulation to a thickness of 200mm	Yes	Yes			Yes
Insulation of hot water storage	Yes	Yes			Yes
Insulation of tanks and water pipes in loft	Yes	Yes			Yes
Installation of cavity wall insulation (houses)	Yes	Yes			
Installation of cavity wall insulation (flats)	Yes	Yes			
Internal lining of solid wall dwellings	Yes	Yes			
Installation of gas central heating in dwellings with none	Yes		Yes		
Installation of electric CH in dwellings currently using electric room heaters	Yes		Yes		
Installation of timber double glazing in dwellings with single glazing	Yes			Yes	

The impact of theses scenarios on the number of fuel poor was then calculated. All modelling work was carried out using the BREDEM-12 programme.

Scenario	**% Households Moving out of Fuel Poverty**	**Total Cost of Improvement (£M)**
Scenario (a)	53	1011
Scenario (b)	36	260
Scenario (c)	10	183
Scenario (d)	7	590
Scenario (e)	16	98

The result of Scenario (a) would be to give all housing stock in Scotland an NHER rating of 6.5 or above. The cost of this would be in the region of £1 Billion. Even with this favourable rating, there would still be 250,000 households in fuel poverty, almost 50% of the current total. The most cost-effective method of addressing the issue would be scenario (e) although this would only address 19% of those in fuel poverty.

The study by Macintyre et al confirmed findings by earlier researchers in this field. Namely that fuel poverty is caused by a combination of factors. These could be summarised as follows.

- The energy efficiency of a dwelling
- The income of a household
- The occupancy pattern of a household
- The price of fuel

The outcome of this exhaustive modelling study would appear to be that the problem of fuel poverty couldn't be alleviated by energy efficiency methods alone.

There would appear to be a need to formulate some form of co-ordinated approach to address the issue. In order for such an approach to be successful it would be first necessary to quantify the major factors that contribute to fuel poverty.

Brenda Boardman dealt with the ferocious cost associated with tackling fuel poverty through an income policy rather eloquently in her book. The cost of doing so would be equivalent of 9% of GDP or alternatively the health budget. It is clear that simply providing more income is not a feasible approach.

2.3 Fuel Poverty - Action and Sustainability

Household energy use currently accounts for 29% of primary energy use in the UK[4]. Consequently, any savings due to energy efficiency improvements will act as a significant step in meeting UK sustainability indices. Principal among these is the reduction in CO_2 emissions as a result of Kyoto protocol agreements.

The definitions of fuel poverty used in Chapter 1 make it clear that the cause of fuel poverty is the cost of warmth, a major component of which is the energy efficiency of the home.

Any policy that aims to address fuel poverty is likely to address energy use and will therefore contribute to overall sustainability.

However, the actual impact of any policy is dependant on the relationship between the fuel poor, perceived levels of comfort and future cost of warmth.

The data in Figure 3 indicates that the fuel poor are likely to be keeping their homes cold due to a lack of affordable warmth. This data is corroborated by studies conducted on the income elasticity of the fuel poor with relation to energy purchase.

Income Elasticity

It is important to be able to distinguish the impact on consumption of reducing the cost of a product and of increasing the income of the consumer and how these interact. In the case of fuel, reducing the cost of warmth would represent reducing the cost of the product.

Economists distinguish between the effect of changes in price and changes in income through elasticities. An elasticity measures how responsive one variable is in relation to changes in another variable. The demand for a commodity can thus be assessed in relation to changes in the price (price elasticity of demand) or income (income elasticity of demand).

The values of income elasticities of demand have the following implications:

Value	Implication
0	Perfectly or Completely Inelastic. Quantity demanded does not change as income changes.
>0 <1	Inelastic. Quantity demanded changes by a smaller percentage than does income.
1	Unit Elastic. Quantity demanded changes by exactly the same amount as the income
>1	Elastic. Quantity demanded changes by a larger percentage than does income.

Income Elasticity and Fuel

A study conducted in 1987 by Hutton et al and reported by Boardman et al[1] investigated the relationship between spending on warmth and income level. The data presented here refers to those 30% of the population with the lowest income.

Social Grouping	Income Elasticity with Fuel
Single Pensioner	0.96
Two Pensioners	0.76
Single Parent	0.98
Two Adults 1 Child	0.74
Two Adults 2 Child	0.72
Two Adults 3 Child	0.76
Average	0.82

This data suggests that 82% of savings made in energy bills will be spent on more fuel. It could therefore be argued that the effect of energy efficient improvements to homes of the fuel poor would largely increase internal temperatures, rather than reduce energy usage.

The effect of this on reductions in CO_2 emissions will be to reduce and perhaps negate the benefits attributed to the Fuel Poverty Bills.

The Scottish Executive have quoted a BRE study which identified that 50% of fuel saved in energy efficiency measures would be saved (rather than 18%).

Sustainable Development

It was felt that a broader understanding of the concepts surrounding sustainable development was necessary. This required an understanding of the economic and philosophical arguments that underpin the sustainability debate in order that a suitable dialogue could be developed.

The alleviation of fuel poverty is not in itself concerned with sustainability. It is principally concerned with alleviation of poverty. It uses for its reference point a large body of work that has linked unequivocally the efficiency of a dwelling with the affordable warmth.

The desire to address fuel poverty springs from a number of sources. There is a natural requirement to address inequalities in society from a welfare perspective. There is the need to address the issue of health concerns among the elderly and the young.

To allow for a complete discussion it is necessary first to look at the origins of the current sustainable debate and to review the literature concerning its likely progress in the mid-term.

Origins of Sustainable Development

The Bruntdland commission of 1987 summarised the concept of sustainable development as

> *" … addressing the needs of the present without jeopardising the ability of future generations to meet their needs …"*

The Bruntdland[4] definition is the most widely quoted. It could therefore be assumed that this definition is guiding the policy makers when it comes to decision-making.

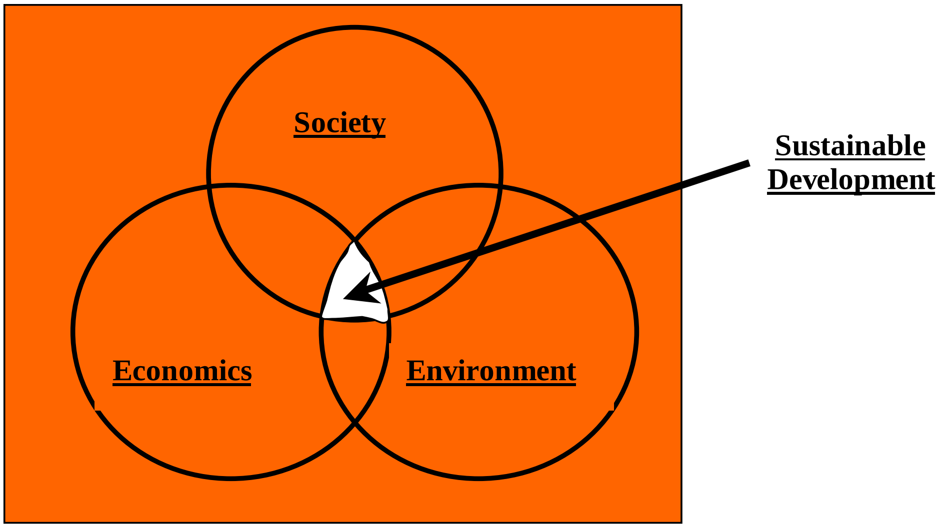
However, it is important to take a wider view of the source of the requirement for change. The general public are interested in ‘something’ being done. The groundswell of opinion is that the course on which we are on is not the correct one and modifications should be made to reduce environmental impacts and inequalities that seem to be increasing. This ‘woolly’ requirement is championed by most

sections of the media and indeed politics. Their commitment to change would appear to be transparent. How this is then distilled into action becomes more opaque.
To attempt to discover the philosophy surrounding the approach taken by policy makers it is necessary to investigate the role of economics in sustainability concepts.

The Changing Shape of Sustainable Development

The concept of development changed with the Bruntdland Commission report in 1987. Whereas previously development had been evaluated on social and economic grounds, the environment would now play a significant role[5].

Figure 2: Description of the Scope of Sustainable Development



The pace of social economic and environment change in the 14 years since the publication of the Bruntdland Report has necessitated a change in approach to the concept.

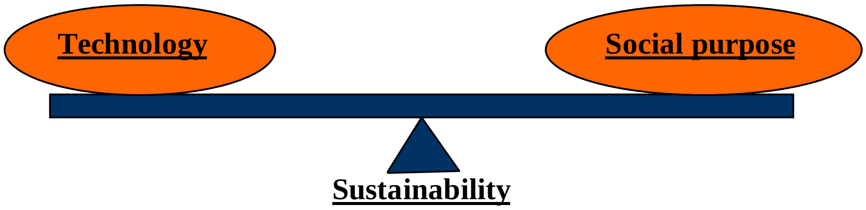
It has been argued that sustainable development as practised in the West is little more than the controlling of natures processes to the maximum benefit of mankind through technological fixes[6]. This argument has much weight when the comments of the economic literature are taken into consideration.

However, there has been a movement which is less technology led seems to have emerged in the last 5 years. Evidence of it is seen clearly the Architectural Profession.

In the year 2000 the urban population of the world exceeded the rural population for the first time[5]. The problems that such a development has on the idea of sustainable development when applied to buildings and cities are immense. Richard Rogers was moved to comment that this shifts the emphasis from the concept of buildings to urban design, and from simple choices such as low-energy to complex ones such as ecology[5].

This has meant that social purpose has been harnessed to technological improvement[5].

Figure 3: How Sustainability Harnessed Technology



The effect of these changes on the approach of the architectural profession in the Netherlands is indicated below[7].

Movement away from	Movement towards
Construction and building level	Building block, neighbourhood and district level
New housing	Refurbished housing
One point in time focus	Life cycle
Physical	Social – integration, health, quality of life
Professionals	End-users – recognising that the success of e.g. energy saving measures and refurbishment schemes are reliant upon the acceptance of the *new rules* by the occupiers

This change of focus, particularly in matters such as health, well being and spirit means that resource and sink constraints are not the only drivers for architectural change.

The real concern of sustainability is now not so much with the internationalisation of technological thought. It is more concerned with a celebration of difference and recognition that local solutions have global importance too.

The Economics of Sustainable Development

At the core of the standard economic approach to sustainability is the Hartwick model.[8] The Hartwick Rule specifies how much output can be consumed in any given time period and how much needs to be saved and added to the capital stock.

‘The amount saved (known as the rent) is the amount to which the resource contributed to the output over and above the cost of extracting the resource. [8]’

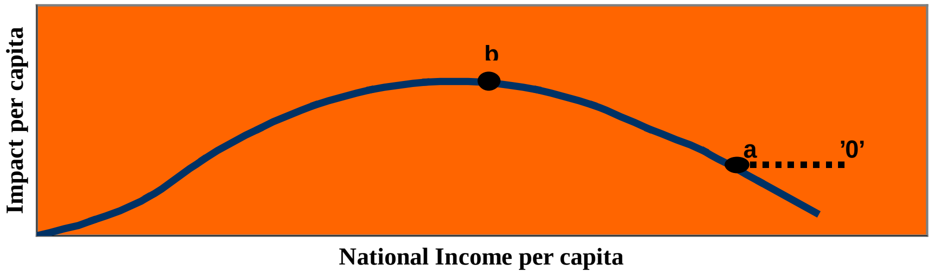
It is fair to say that it is difficult to conceptualise such addled economic speak. The rule can be understood more easily in the following terms:

‘If consumption involves depleting one asset, it is sustainable if stock of another asset is built up to replace it[8]’

The goal of the economist is constant or growing consumption allied to technological development to supplement that which is being consumed. At the heart of the current economic approach then is the idea of there being adequate substitution possibilities available.

Another economic argument is that growth will offer the solution to environmental concerns[8]. This follows the logic that the volume of resource input α volume of waste output. Therefore as resource input increases in value (as a result of scarcity) technology will develop to improve its efficiency reducing in less waste output and less environmental damage. The need for environmental legislation is therefore flawed. These arguments are based on their being a zero point of impact being reached.

Figure 17 Growth and Environmental Impact



It is argued that most environmental impacts proceed in this manner. Take electricity production from coal and NO_x and SO_x emissions for instance. If you were to take the data from **b** to **a** and extrapolate it is possible that a zero impact level can be reached fuelled by increased growth.

The likelihood, however is that a reduction in impact will not reach zero but some finite '0' level. The question then arises as to the level of sustainability to be attached to this '0' point.

Another approach taken by the economist is to address the absence of property rights attributable to the environment. If property rights could be assigned then there would be an efficient allocation of pollution dictated by the Coarse Theorem[8]. This relies on there being an amicable solution between the polluter and the victim of pollution. Traditional free market tools can be used to dictate this solution through costs and legislation derived by the courts. Again, problems persist with this approach that can be briefly described as follows:

1. The polluter can re-locate to an area where property rights have yet to be assigned.
2. The pathway from polluter to victim has to be established. Global atmospheric pollution presents a problem in this respect.
3. The pathway, even if established, can involve many polluters and many of victims, often the same people.
4. If more than one victim is identified, there relative bargaining positions can be different. This ties in with point 1.

Yet another approach taken is to assign the concept of commensurability. This assumes that the individual consumer regards the natural environment as a consumption commodity on an equal footing with ordinary commodities purchased in the market.

For instance the prospects of survival of a species are viewed by individuals on a similar footing in expenditure terms as where they can afford to go on holiday this year.

As a result of assigning a 'value' to the environment it is possible to use standard cost-benefit analysis to appraise policy alternatives.

Non-economists find this approach implausible and objectionable:

"As a citizen, I am concerned with the public interest, rather than my own interest; with the good of the community rather than the good of my family… As a consumer… I concern myself with personal or self-regarding wants and interests; I pursue the goals I have as an individual. I put aside the community regarding values I take seriously as a citizen and look out for number one instead.[9]"

All of the above approaches retain the essential principal of consumer sovereignty

This is waived by the approach taken by ecological economists. The principal argument here is that comparing private profits or social/external costs cannot set environmental limits. Rather, they are set as a result of social evaluation following scientific/political debates [10]. Once these limits have been set, conventional economics can be used to determine the lowest cost path.

Physical indicators rather than costs should be used to determine the direction of the debate. Assigning monetary values to the environment produces more argument than the core subject itself i.e. what is sustainable?

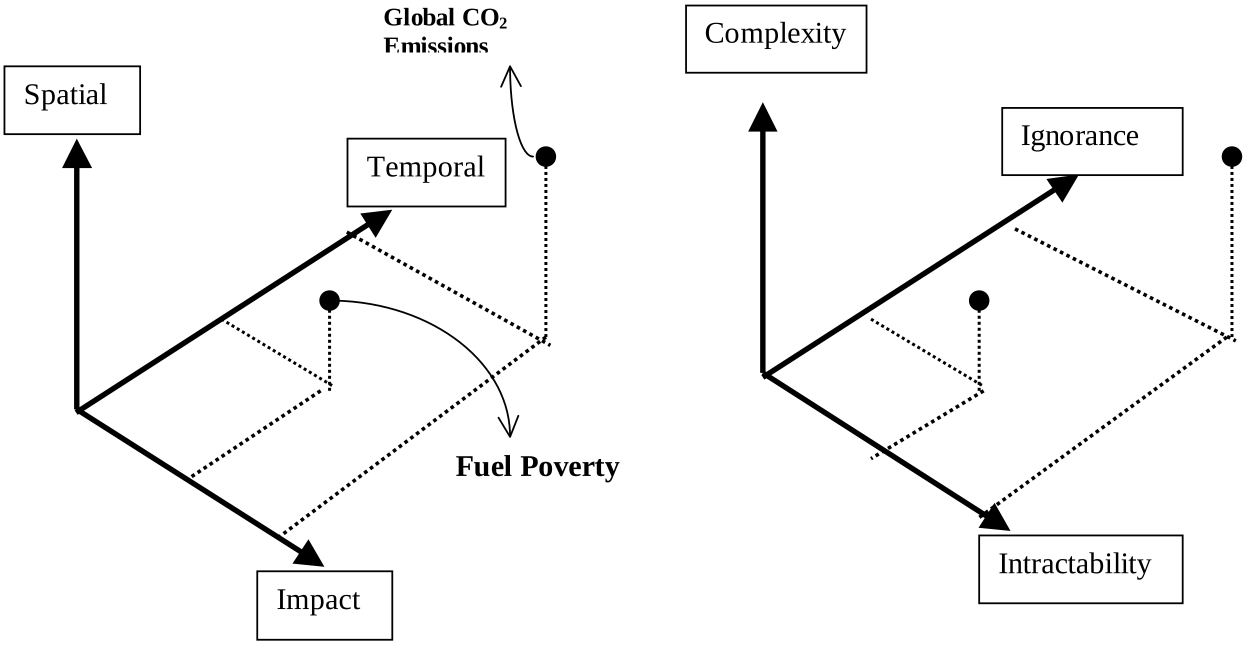
This approach is largely borne from ecological thinking with respect to the environment. The principals established by the ecologists can briefly be summarised as:

1. The interactions between all facets of the environment are not understood scientifically. Use of historical data to extrapolate conditions in the future cannot therefore be relied upon.
2. Eco-systems are subject to catastrophic failure rather than linear decay. The 'cliff' over which this occurs is again not known and therefore the

precautionary principal approach must be taken as a first instance to project appraisal.

One method of applying this principal is by measuring problems according to Environmental Problem Attributes:

Figure 4 Environmental Problem Attributes



The attributes considered here are summarised in the table below:

Attribute	**Definition**
Spatial Extent	Geographical range of the problem
Temporal Extent	Duration for which the problem will persist
Impact Size	Effect on, and the number of, individuals
Complexity	Number and nature of cause and effect relationships
Ignorance	Human awareness and understanding of the problem
Intractability	Difficulty of devising and implementing an approach to the problem

The example given looks at the different responses of this approach fuel poverty and CO_2 emissions from the global economy. Fuel poverty presents the smaller problem as its scope can be comprehensively defined and solutions to the problem are known. It is apposite that there is no measure of political will in this model. However, the choice of fuel poverty and CO2 emissions shows the difficulties that can occur when trying to specify the extent of a problem. If fuel poverty is seen in the context of an energy problem then it could quite easily be seen as an emissions problem and the approach to solving it then takes on a different meaning.

Summary

There are four basic approaches taken by economists to make flesh of the problem of sustainability. These can be grouped as follows:

Free Market Economists

No change in approach is necessary and certainly no limit to growth. Expansion and technological progress will solve problems associated with economic growth as a result of normal market forces.

Resource Economists

Apply analytical constraints to economic growth. Sustainability can be assured by calculating optimum yields for renewable resources and ensuring exhaustion is not reached by setting these as limits. Non-renewable resources can be harvested at such a rate as assimilation of output can tolerate

Environmental Economists

They are the champions of ameliorating external costs into internal costs through the assignment of property rights. Therefore, those emitting CO2 would pay for CO2 abatement policy. Use of taxation and such like measures will force the market to switch to benign forms of production thereby delivering sustainability.

Ecological Economists

Believe in assigning limits based on scientific knowledge. Neo-classicists, thus constrained, can take over at this point. Strict precautionary principal approach is favoured when evaluating all development.

The idea of sustainability is confusing as many different definitions persist. The simple truth of the Brundtland statement has been adopted and manipulated by various groups for their own ends.

This spread of opinion displays the possible definitions of sustainable development. It also indicates that on occasion development that purports to be sustainable is anything but dependant on the definition chosen.

However, recent developments in architecture have suggested that an approach more aligned with ecological economic thought is being developed. The emphasis on life-cycle analysis and community surrounding construction is pulling development concepts closer to the original definition as supplied by Bruntdland.

2.4 EU Security of Supply Issues

Many of the accoutrements of modern living are provided by ready and easy access to energy. The ready supply of energy is therefore of considerable political and economic importance to the country. The ability to maintain a supply of energy is determined by the security of supply. Maintaining security of supply means that the lights never have to go out.

An EU Green Paper[11] evaluated the effect of current legislation and policy on the need for and make up of energy use to 2030. The effect this had on security of supply was then assessed. Assuming either no significant technological breakthrough or no significant shifts in policy the findings and recommendations contained in the paper can be summarised as follows:

- There will be a 90% growth in GDP in the 28 years to 2020 and a resultant 11% increase in energy consumption.
- 300GW of new and 300GW of replacement electricity production is required in the next 20 years in the EU. This is the equivalent of a new power 1.2GW power station being built somewhere in Europe every 12 days.
- Despite the success of largely decoupling energy use from economic growth, CO_2 levels in 2030 will be 18% higher than in 1990 meaning Kyoto targets will not be met.

- Renewable energy sector will contribute only 8% of total energy required in 2030 given current legislation.
- Currently 40% of the energy used in the EU is imported. Given current legislation and the most favourable projections concerning North Sea Oil and Gas reserves, this would rise to 70% in 2030.

The energy make up of the EU would change as shown below.

Fuel Type	**% in 2000**	**% in 2030**
Oil	35	38
Gas	15	29
Coal	19	19
Renewable	6	8
Nuclear	25	6

This increased reliance on imports has prompted a number of economic studies that have gauged the likely effect. The conclusions are that prices are likely to increase significantly and that the frequency of price shocks is likely to increase. Falls in gas prices since privatisation in the UK have been of the order of 20%. However, gas prices increased by 5% in 2000 due to crude oil price variation. It could be assumed that the effect of competition on driving prices down would diminish as margins are reduced and prices mature. Domestic consumers are likely to be subject to fluctuations in downward as well as upward directions dependant on geo-political instability in the Middle East, Africa and the former USSR.

The events of the last three weeks have naturally heightened the potential problems associated with energy security.

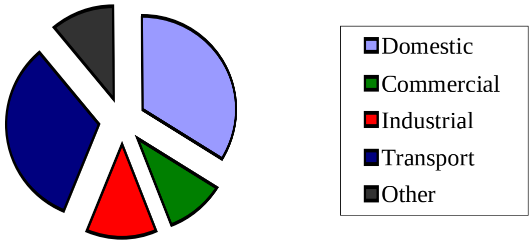
The effect of increasing price shocks will naturally be felt by all sectors. However, the group, which is least likely to be able to withstand such price fluctuations, will be the fuel poor. This fact was borne out by the effects of the fuel crisis in 1973/74.

It is likely that significant numbers of the population will oscillate in and out of fuel poverty in the near future as a result of increasingly unstable energy markets.

2.5 Domestic Energy Use

Currently in the UK the heating, lighting and ventilation of buildings consumes roughly 50% of total energy consumption of the nation. The pattern of development and the trend towards urban dispersal also has significant impact through fossil fuel use in transportation[4].

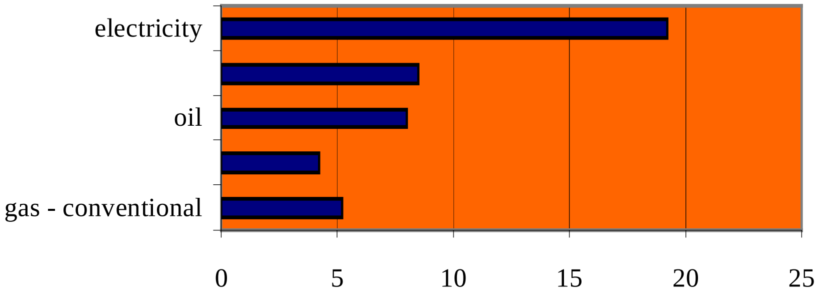
Figure 5 Total Energy Consumption of UK



There is a massive opportunity in the domestic sector to reduce energy levels and contribute to the UK target of reducing greenhouse gas emissions. Improving NHER levels but also by altering the strategy for energy deployment can do this.

The carbon dioxide emissions from domestic central heating systems in the UK are given in the Figure 5[4].

Figure 6 CO2 Emissions per year (Mt)



The implication of these findings is that ~8% of CO2 emissions in the UK are derived from central heating systems. There is clearly considerable scope for reductions if more benign sources of heat can be developed to deliver this load.

2.6 Effect of Fuel Poverty on the Health of Households

A chief indicator that is used to describe the effects of fuel poverty on the community is the number of excessive winter deaths. Crudely speaking, this describes the number of deaths that occur in winter above those which occur in summer. It is assumed by many that a causal factor of excessive winter deaths is fuel poverty.

Excessive winter deaths are calculated using a co-efficient of variation in seasonal mortality[1]. The number of deaths per month is recorded as a proportion of the number that would have been expected, if they were equally distributed throughout the year. The twelve resultant percentages are then used to compute a coefficient of variation. A figure of zero would represent an equal number of deaths in each month of the year. The larger the figure, the larger the number of deaths in that month compared to the figure of equal distribution.

The table below shows the coefficient of variation for January in a range of countries together with the mean external temperatures for January[1]

The British Isles has the largest coefficient of variation of those countries studied. This was despite the highest mean temperatures recorded in January.

		Coefficient of Variation in Seasonal Mortality (Jan)	
	Mean External Temp (Jan)	**1978**	**1984**
Northern Ireland	4.5	0.12	0.14
Eng + Wales	4.1	0.13	0.10
Scotland	3.7	0.12	0.11
France	3.3	0.07	0.06
Denmark	0	0.07	0.06
Norway	-1.1	0.05	0.04
Austria	-2.7	0.11	0.05
Sweden	-2.7	0.07	0.05
Finland	-3	0.05	0.04
Canada	-7.8	0.07	0.06

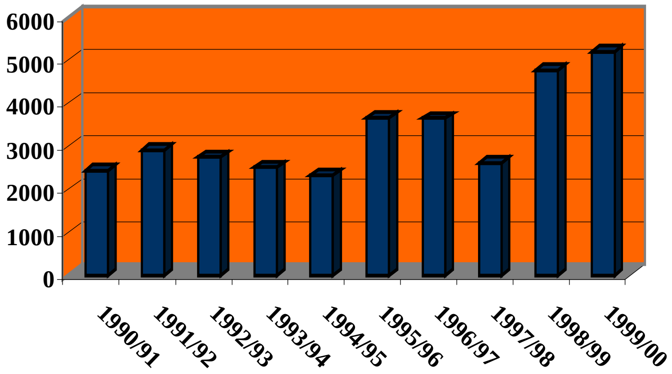
The effect of the external temperature on the cost of warmth is well established and felt by us all. The fact that our bills are higher in winter means that the effects of fuel poverty are likely to be more acute in cold periods.
The assumption is that the UK should have little or no seasonal variation in mortality given its climate compared to the other countries surveyed.

The fact that it is the highest in Europe is often attributed to the condition of the housing stock. In Scotland an average NHER of 4.3 was returned in the 1996 Scottish Homes Survey[11].

Alternatively, it could be argued that external temperature is not a predictor of coefficient of variation in seasonal mortality. Other factors maybe more important in causing the excessive deaths seen in winter. For instance, the number of time that the temperature oscillates above and below freezing in the UK is one of the highest in the world[1]. The moisture levels are also very high during winter in the UK.

The number of excessive winter deaths recorded in Scotland during the last decade[12] is shown in Figure 2.

Figure 7 Excess Winter Deaths in Scotland 1990-2000

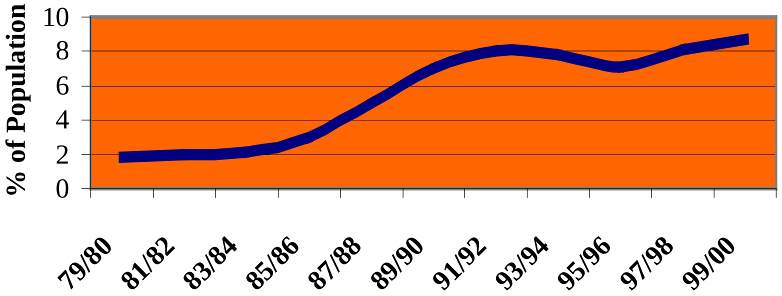


There has been an upsurge in excessive winter deaths in the last two years. This cannot be due to excessively cold winters. Data from the meteorological office[13] shows that the coldest winter in the last decade occurred in 1995 when a temperature of –17°C was recorded in Glasgow, yet excessive winter deaths were relatively low that year.

It maybe due in part to worsening housing stock although no evidence could be found to suggest a significant reduction in conditions between 1990 and 2001.

According to figures from the New Policy Institute[14], instance of general poverty has increased over the last two decades despite growing GDP in the country as a whole.

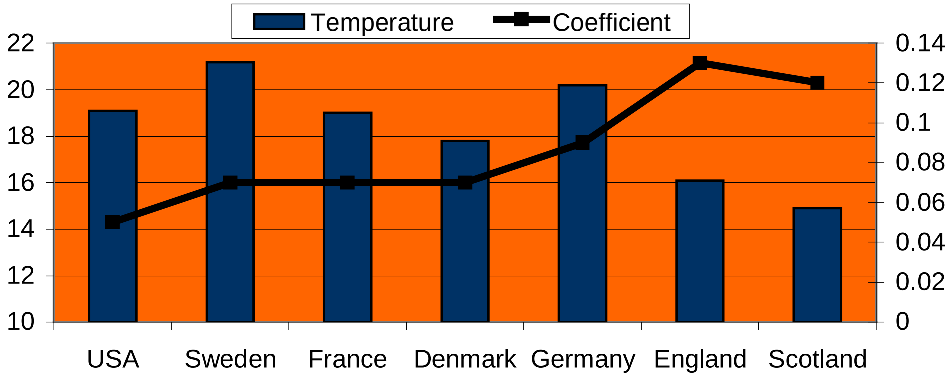
Figure 8: Numbers in Poverty as Described by Those Earning below 40% of Average Income



There would appear to be a significant anomaly in the approach being taken to alleviating fuel poverty. Poverty levels were rising making it more likely that the influence of income level and fuel price were becoming as important as the energy efficiency of the home. Despite this, the policy still concentrated solely on improving energy efficiency.

The effect of internal house temperature on coefficient of variation in seasonal mortality is described in the Figure 4 below[1].

Figure 9: Relationship between Average Daily Internal Temperature and Seasonal Mortality



Of the countries surveyed, the mean internal house temperatures were found to be lowest in the UK. However, the highest coefficient of variation in seasonal mortality rate in the study was found to be in the UK.

It could, therefore, be assumed that the internal house temperature achieved is related to the occupier's chance of making it through the winter.

Another point to take from the study is that the average house temperature ascribed to Scotland in the study is 14.9°C.

The figure used by BREDEM-12 to indicate adequate warmth was 18.75°C. This is comfortably higher than the average condition found in a Scottish home in 1984.

There would appear to be a large discrepancy in the temperatures of dwellings and the temperatures that are deemed to reflect adequate warmth.

The table below shows results of a government survey published in 1991[15]. This would suggest that less than a third of homes in England comply with the BREDEM-12 model temperature calculations.

Temperature range (°C)	**Home Mean Temperatures At external temperature of**		**Living Room Temperatures At external temperature of**	
	2°C (% of Homes)	**0°C (% of Homes)**	**2°C (% of Homes)**	**0°C (% of Homes)**
Over 21	4.5	3.9	13.1	12.8
18 – 21	23.8	21.3	35.6	33.4
16 – 18	22.7	21.7	27.2	21.2
12 – 16	32.1	30.9	21.9	29
9 – 12	10.5	12.3	2.2	3.6
Below 9	6.4	9.9	none	none

The biggest causes of winter deaths are cardiovascular and respiratory conditions. Hypothermia itself is relatively uncommon and accounts for an estimated 1% of excess deaths in the UK. However, a study of admissions to hospitals in the West of Scotland in 1993/94[16] suggested that there could be considerable under-reporting. Results from that study were extrapolated to show that there could be as many as 4,000 cases in the UK and 1,000 deaths annually. An analysis of deaths mentioning hypothermia showed that mortality rates among the elderly were three times higher in Scotland than in England and Wales[17].

The incidence of domestic accidents also increases in winter, probably due to the effect of cold temperature on cerebral function.

Two analyses of hospital admissions for cold related illnesses in Edinburgh and Glasgow between 1970 and 1980 and between 1980 and 1985 showed that cold weather explained at least 10% of admissions, with highest correlation with bronchitis/emphysema. Although the causal link with cold housing is not proved, other surveys have demonstrated the extent of cold houses, for example Primrose and Smith 1981[17] found that 64% of the elderly surveyed had living rooms below 16 °C. Although excess winter mortality may arise in part from exposure out of doors, it is argued that as the elderly spend so little time out of doors in winter, the indoor environment may be more influential. An analysis of "excess" winter mortality in Scotland between 1958 and 1987 showed a consistent drop over that period from 42.1% 1958-62 to 24.5% 1983-7 and it is suggested that this may, in part, be attributable to increased central heating and other home improvements.

However Keating[18] refuted this theory in a study that found that elderly residents in sheltered accommodation, with continuous high daytime temperatures maintained, mortality rose by a percentage similar to the general population.

It would not be churlish to suggest that the significant change in social conditions over the period mentioned including access to better health care and improvements in diet could have had a significant influence on the data trend observed. The cause of the trend to increase in the last two years suggests that the causes of excess winter deaths are still not fully understood.

2.7 Analysis of Scottish Local Authority Survey

In order to understand the causes of fuel poverty more thoroughly, data was made available form a survey into fuel poverty carried out by a Scottish Local Authority.

72 households in the central belt were evaluated. All had gas central heating. Of the 72 households, 18 were found to be fuel poor (25% of the sample).

Each dwelling was evaluated using the BREDEM-12 model to establish an NHER rating. The energy required to heat the house according to the 21°C/18°C regime was also calculated.

The survey also established the actual income of the household together with the heating type and occupancy level.

Analysis of variance techniques were used to identify the properties of the fuel poor group which most differed from those in the non-fuel poor group.

Five factors were used to investigate the differences between the two populations. These were income level, NHER rating, occupancy level, predicted energy usage and predicted cost of bill.

The analysis of the data is shown in the table below.

The mean value for each variable is presented for those in and those not in fuel poverty.

The F-factor gives an indication as to whether the groups of data are statistically distinct. A value of >2.0 suggest that the two groups of data are statistically different.

The p-value reflects the likelihood that the statistical variation in the data population has been caused by the difference specified. A value of <0.1 is indicative of this.

Variable	**MeanValue Fuel Poor**	**MeanValue Not Fuel Poor**	**F-Factor**	**p-value**
Income	102.8	136.6	5.28	0.02
NHER	6.01	6.45	2.65	0.11
Predicted cost of bill (£)	387	358	1.39	0.24
Predicted energy usage (GJ/m2)	1.01	1.05	0.3	0.6
Occupancy	2.71	2.61	0.09	0.983

The variable that is most significant then in determining fuel poverty is the income in the home. Those not in fuel poverty earn an extra £30 per week.
The NHER rating of the house is lower by 0.44. This is reflected in the higher predicted cost of space heating per annum in the fuel poor population.
There was no difference in amount of energy used between the two populations or the occupancy level.

2.8 Conclusions on Factors Surrounding Fuel Poverty

A number of factors can be considered concerning the general situation regarding fuel poverty in Scotland:

- 506,000 households in Scotland are fuel poor.
- The fuel poor would therefore appear to be low-income groups, primarily elderly, who live in energy inefficient homes.
- Broadly speaking, there is evidence to suggest that energy inefficient homes, income disparity and price of fuel cause fuel poverty.
- The cost of warmth in energy inefficient homes is roughly three times as much as in an energy efficient home.
- Analysis of a Scottish Local Authority Survey found that the most significant determinant of fuel poverty was income level followed by NHER rating. The fuel poor were found to have £30 less per week and live in a home with an NHER rating 0.45 lower than those not experiencing fuel poverty.
- It is thought that, energy security will be compromised in the next 30 years as the proportion of primary fuel imported rises to ~70%. The effect of this will be to increase price fluctuations. As was found in 1973/74 during the energy crisis the sector least likely to withstand price shocks are the low-income sector.
- Space heating in the domestic sector is responsible for ≈8% of all CO_2 emissions in the UK.
- Sustainable development is becoming characterised by approaches that consider the community over the single and the life cycle over the point in time.
- Macintyre et al found that improving the NHER rating of all fuel poor households to 6.5 would cost ≈ £1.1 Billion. Such a programme would result in only 50% of households being removed from fuel poverty.
- There are currently ≈ 4000 excess winter deaths per annum in Scotland.
- There is some evidence to suggest a causal link between mean internal temperature and excess winter deaths.
- Mean internal temperatures were recorded as being 14.9°C in Scotland
- This is considerably lower than in other countries where the instance of excess winter deaths is much lower.

Chapter 3
Key Policies Used to Address Fuel Poverty

The Scottish Executive has chosen to address the problem of fuel poverty by attacking the issue of energy inefficient housing.
Current policy initiatives are summarised below.[19]

3.1 Fuel Poverty Bill

This is the Scottish Executive’s key policy for tackling fuel poverty in the most vulnerable groups. Over 5 years from April 2001, a central heating and insulation package will be installed in (a) 100,000 local authority and housing association properties and (b) 40,000 pensioner homes in the private sector that, in both cases, currently lack any form of central heating.

The package is worth up to £2,500 per household for loft, tank and pipe insulation & cavity fill and a central heating system. The Scottish Executive will work with local authority and housing association landlords, the power companies and Transco to deliver the programme. It is expected that a managing agent will deliver the programme for the private sector. The programme will begin on 1 April 2001 and will be completed by March 2006.

The table sets out the categories of beneficiary, the numbers currently in fuel poverty and the effect on those numbers of the insulation and heating package.

Effect of new central heating and insulation programme (figures as at 1996)		
	Those that have to spend 10% or more of income on fuel	Those that are officially not fuel poor
Elderly that lack central heating	42,000	7,000
Tenants in the social rented sector that lack central heating	85,000	23,000
Total	127,000	30,000
Increase in NHER	Up from an average of 2.4 to 5.4.	
Number taken out of fuel poverty as a result of new programme	114,000	

3.2 The Warm Deal

The Warm Deal was introduced on 1 July 1999. It provides households dependent on Benefit with a package of insulation measures up to the value of £500. They are: loft, cold tank and pipe insulation, cavity wall insulation, hot tank insulation, draughtproofing, energy advice and 4 low-energy lightbulbs.

Over 38,000 low-income households benefited in the first year of the scheme. A further 60,000 will benefit by March 2003.

3.3 Investment in Local Authority Housing

In 1999/00, Scottish councils spent £345 million on their own stock. Within that sum, expenditure on works to improve energy efficiency, and the number of dwellings benefiting, was as shown in the Table**.** In 2000/01 they have projected to spend a further £343 million on their stock.

Scottish local authorities investment in improving energy efficiency – 1999/2000		
Programme	1999-2000	
	Number of Dwellings	Expenditure (£m)
Window Replacement	22,601	55.0
Central Heating	16,539	37.0
Insulation	12,125	10.0
Total	51,265	102.0

3.4 Housing Associations

Housing associations are responsible for almost all new build in the social rented sector. In 1999/00, 97% of all associations included energy efficiency measures in designs for new build. From September 2000 all new housing association stock will be expected to achieve a NHER rating of between 8.5-9.0 and all rehabilitated housing to achieve a NHER of between 6.5-7.5.

3.5 New Housing Partnerships

It is estimated that by 2002 some 8,000 new and improved dwellings will be delivered by the regeneration and development partnerships funded under the NHP initiative, through a combination of public and private investment. In addition, NHP resources have been earmarked to support transfer to community ownership, subject to tenants' approval, of up to 150,000 of the existing council housing stock in Scotland. It is possible that these transfers could generate private investment of up to £2 billion to improve house conditions.

3.6 The Affordable Warmth Programme

The Scottish Executive is working with Transco on its Affordable Warmth Programme for Scotland. This aims to provide a package of insulation and heating measures to those deemed to be at risk from fuel poverty. Transco consequently have to work in conjunction with the local authorities to receive this information. They have already entered into agreement with one local authority, covering 3,500 dwellings.

3.7 Improvement and Repair Grants System

The improvement and repair grant system in Scotland has extended its remit to cover insulation and space and water heating. Grants are targeted on low-income households and will be available at rates of up to 100%. A “Care and Repair” scheme helps elderly and disabled owner occupiers carry out repairs, improvements and adaptations allowing them to remain in their own homes. There are 33 schemes operating in 27 local authority areas. Capital funding for works comes mainly from local authority improvement and repair grants.

3.8 Home Energy Conservation Act – 1997

Many Local Authorities have integrated HECA into their wider responsibilities, such as Local Agenda 21 initiatives, their sustainable development strategies, as well as their Housing Plans. Internal arrangements have been complemented by a wide array of external partnerships with other local authorities, fuel utilities, and private or community sector agencies to assist in the delivery of HECA across all tenure groups.

Total reported expenditure on energy efficiency activities in Scotland amounted to over £370 million for this period. This expenditure resulted in:

1) the replacement of windows in over 77,000 dwellings
2) the replacement of over 64,000 old heating systems or the installation of whole house heating for the first time
3) the provision of low energy light bulbs to over 44,000 households
4) the carrying out of draughtproofing in over 36,000 dwellings
5) the fitting of loft insulation in over 27,000 dwellings
6) the installation of cavity wall insulation in over 20,000 dwellings
7) the fitting of hot water cylinder jackets in over 9,000 dwellings
8) the provision of energy advice directly to over 24,000 households
9) the completion of over 15,000 energy efficiency home visits
10) the issue of over 10,000 home energy survey reports.

In addition to these improvements:

1) over 25,000 dwellings receiving a 'package' of insulation measures
2) over 30,000 households benefited from work under HEES and the Warm Deal programmes
3) almost 2,500 households benefited from work funded by the two electricity utilities under the Energy Efficiency Standards of Performance schemes

As a result of this energy efficiency-related activity, it was calculated that:

1) energy consumption across the Scottish domestic sector fell by 6.6 PJ, which represents a 2.86% improvement in energy efficiency on the 1997 figures
2) average energy consumption per dwelling fell by 3.2 GJ (or 889.6 kWh), leaving every Scottish household on average, almost £26 better off
3) carbon dioxide emissions fell by 0.7 million tonnes, representing an overall reduction of 4.07% on 1997 figures
4) this investment would have supported 9,250 installation jobs directly, and another 5,285 jobs elsewhere
5) a reduction of 1,790 tonnes in SO_x emissions into the atmosphere
6) a reduction of 858 tonnes in NO_x emissions into the atmosphere.

Chapter 4
Modelling and Simulation

4.1 Introduction

The findings of the survey into the factors surrounding fuel poverty threw up a number of interesting facts. Principal among these was a possible causal link between excess winter deaths and internal temperatures.

If it is assumed that this is one of the causes, then any future policy initiative should attempt to increase mean internal temperature in Scottish homes to some benchmark figure above which no excess winter deaths are recorded.

The mean internal temperature that would have to be achieved to render Scottish statistics unremarkable in this respect is unknown but can be assumed to be at least the 17.8°C recorded in Denmark.

In order to investigate the effect of ensuring this mean internal temperature is achieved, a model was created using building simulation software, esp-r, to link NHER rating to energy per degree.

4.2 Relationship between NHER Rating and Energy Use

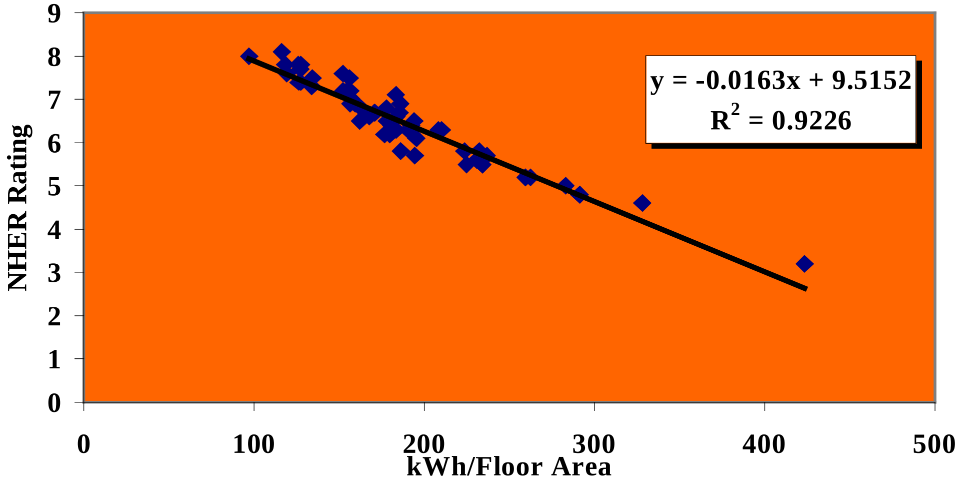
In order to carry out this task, data from a Scottish Local Authority survey into fuel poverty, not yet published, was made available. The survey investigated the CO_2 emissions, NHER rating, predicted energy costs and made comments concerning the type of heating system used and the state of the building fabric.

The first task was to link energy usage to NHER value. The NHER system is derived from the BRE'^{s} home energy rating model, BREDEM-12 and provides an energy rating for domestic properties based on a 1-10 scale (1=extremely poor and 10=excellent).

The data was used in this study to develop a relationship between energy usage in kWh/m^2 and NHER rating. The data was screened prior to use to remove anomalies associated with occupancy rating both low and high and to remove those occupancies that relied on peak electricity for their heating requirement. It is recognised that this is a pressing issue, particularly with the elderly, who often heat only one room in the house and will not use central heating for fear of high bills. 72

households were subsequently used to develop the relationship. The data is shown in Figure 10.

Figure 10 Relationship between NHER and Energy Delivered



The regression equation developed describes 92% of the data and was used in the subsequent analysis of the subject.

4.3 Esp-r Model

Full details of the esp-r model are given in Appendix II. The model was based on a standard Housing Association Type 2-bedroomed house. The house was situated in Glasgow. All data was generated using a Glasgow weather database. Five models were developed to provide a spread of energy use and these are described in the table below.

Model	Insulation	Glazing	Network Air Flow
1	None	Single 4mm Glazing	Set to esp-r default standards to indicate poor state of building fabric
2	Loft Insulation 250mm	Single 4 mm Glazing	Set to medium building fabric conditions
3	Loft Insulation 250mm Cavity Wall Insulation Under Floor Insulation	Single 4 mm Glazing	Set to medium building fabric conditions
4	Loft Insulation 250mm Cavity Wall Insulation Under Floor Insulation	Double 6mm Antisun Glazing	Set to medium building fabric conditions
5	Loft Insulation 250mm Cavity Wall Insulation Under Floor Insulation	Double 6mm Antisun Glazing	Set to minimum air flow characteristics to indicate excellent state of building fabric

For each model, the BRE method of calculating energy usage was used. This requires that the main living area of the house be set to 21°C and the remaining occupied areas of the house are set to 18°C. The model was ran for the month of January and degree-day calculations were then used to generate energy usage for the whole year. Details of degree day equations are given in Appendix I.

The results from the esp-r study are given in the table below:

Model	Energy Delivered - Jan	Energy Delivered – Yearly
1	4296 kWh	30,378 kWh
2	2511 kWh	17,756 kWh
3	2100 kWh	14,851 kWh
4	1784 kWh	12,617 kWh
5	230 kWh	1,625 kWh

It was now necessary to modify the results to allow for

- inefficiencies in the boiler operation
- losses from pumping hot water throughout the house

For simplicity, it was assumed that in all cases the boiler was a double condensing gas boiler that operates at a seasonal efficiency of 85%. The losses associated with pumping and usage inefficiencies were estimated to be a further 10%. The total efficiency of the operation was therefore assumed to be 75%.

The floor area of the house was 81.75 m^2. The yearly data was recalculated to reflect the inefficiencies and then expressed in the same terms as that from the Lanarkshire study.

Results are given in the table below.

Model	Energy Delivered With Inefficiencies	Energy Delivered/Floor Area (kWh/ m^2)
1	40,504 kWh	495
2	23,674 kWh	290
3	19,801 kWh	242
4	16,823 kWh	206
5	2,167 kWh	27

From the data thus generated it was possible to calculate the NHER rating for each condition based on the relationship derived from the Lanarkshire study.

Using the regression equation shown in Figure 10 ***(NHER = {-0.0163 x Energy Delivered} +9.5152)***

NHER values for the models studied were produced and are shown below

Model	NHER Rating
1	1.5
2	4.8
3	5.6
4	6.2
5	9.1

4.4 'Energy per Degree' Modelling

In order that the energy required to generate a specific mean internal temperature could be predicted, it was necessary that the energy used per degree be calculated.

To investigate this it was necessary to make a number of assumptions.

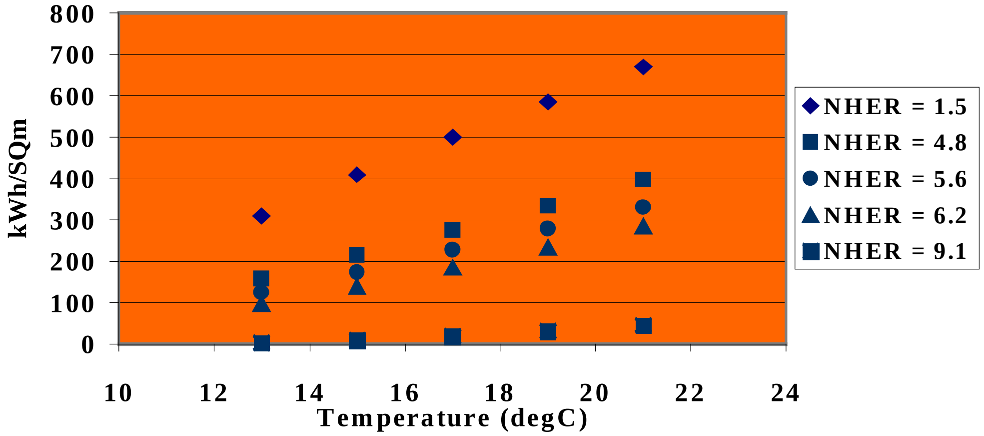
1. Not all heating criteria and regimes could be investigated in the course of this experimentation due to time constraints.
2. The BRE approach was rejected, as it required different temperatures in different zones of the house. While this fits in with studies conducted to establish adequate levels of comfort it would have made the identification of energy per degree hazardous.
3. It was therefore decided that the occupied rooms of the house would represent one zone.
4. This would be heated according to a weekday/weekend pattern. Saturday and Sunday were judged to be equivalent.
5. On weekdays, the heating system was set to operate between the hours of 7:00 and 9:00 in the morning. It then came on again at 5:00 in the evening and remained on until midnight. At weekends, the heating system came on at 8:00 in the morning and went off again at 11:00 at night.
6. All data used the Glasgow climate files and the location was Glasgow
7. The model was set to uncontrolled humidity
8. To investigate the energy required to elevate the temperature the occupied zones were set to hit a target temperature
9. Five temperature settings were investigated for each model.
10. These were 21, 19, 17, 15 and 13 °C.

The energy required to heat the house to each target temperature, for the periods detailed was then calculated for the month of January.

The yearly energy requirement was then calculated using degree-day method in conjunction with efficiency measures. This was repeated for each model.

The energy required to raise the temperature of the occupied space for each model is shown in Figure 11.

Figure 11 : Energy Delivered to Elevate Temperature



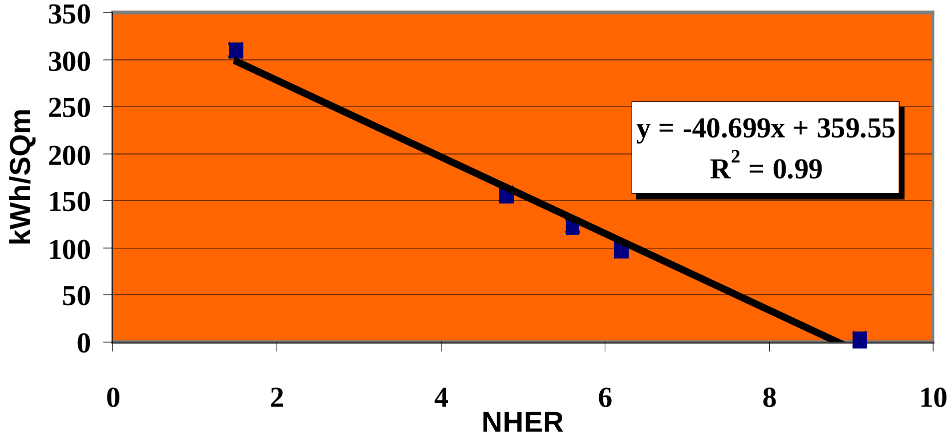
The data was then used to create a model to describe energy requirement for households with different NHER ratings.

While adequate linearity was found to exist within the experimental space it was thought unlikely that this would hold true across wider temperature ranges. It was evident from the data generated that more energy was required to move the temperature of the house from 20°C to 21°C compared to that required to move the temperature of the house from 15°C to 16°C.

In order to produce an energy per degree relationship, the following procedure was therefore adopted.

1. The relationship between NHER and energy required to heat the house to 13°C was first calculated. The data is shown in Figure 12.

Figure 12: Energy Required to heat House to 13 DegreesC

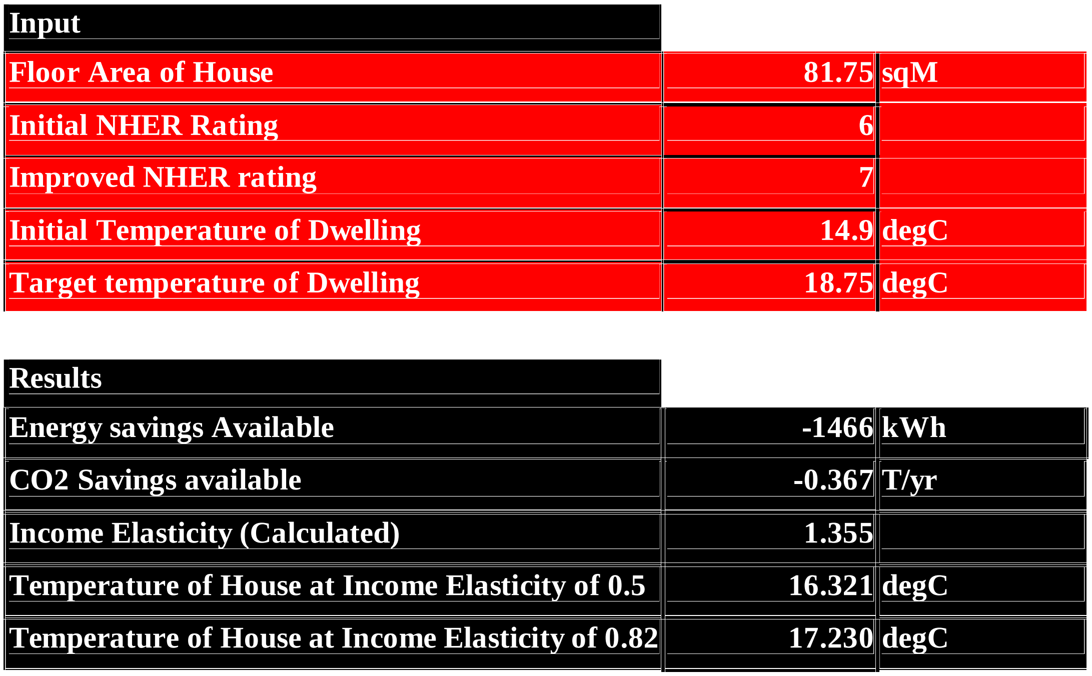


2. At each NHER level, the regression equation linking energy to temperature attained was calculated. This was effectively by drawing a line of best fit through the data as presented in Figure 11.
3. For each NHER level, it was possible therefore to generate an energy requirement to achieve 13°C and energy per degree requirement for temperatures above that.

A model was written in Microsoft Excel using the equations derived in the esp-r study. The front sheet of the model is shown in Figure 14.

By inputting the floor area of the house, the initial and improved NHER$^{'s}$ and the initial and target temperature of the house it was possible to calculate the Energy and CO2 savings available. It was also possible to predict an elasticity that would be required to deliver the target temperature.

Figure 13: Front Sheet of excel Model



Input		
Floor Area of House	81.75	sqM
Initial NHER Rating	6	
Improved NHER rating	7	
Initial Temperature of Dwelling	14.9	degC
Target temperature of Dwelling	18.75	degC

Results		
Energy savings Available	-1466	kWh
CO2 Savings available	-0.367	T/yr
Income Elasticity (Calculated)	1.355	
Temperature of House at Income Elasticity of 0.5	16.321	degC
Temperature of House at Income Elasticity of 0.82	17.230	degC

4.5 Results From the Modelling Studies

Calculating the Mean Internal Temperature After Energy Efficiency Improvements

The mean internal temperature of the dwelling was predicted given the following assumptions.

- The initial NHER rating for the dwelling was taken as 6 as this was the mean figure found from the Scottish Local Authority study
- The improved NHER figure was taken to be 7. That was found to be the upper limit of the target indicated by the Housing Association for refurbished property.
- The initial temperature was taken to be 14.9°C.
- The floor area of the dwelling used in the esp-r study was used
- Mean Internal temperature was predicted for an elasticity of 0.5 and again for an elasticity of 0.82.

The results are shown in Figure 14 and 15. The dwelling would achieve a temperature increase of 1.4°C if an income elasticity of 0.5 is applied to the savings accrued from the efficiency improvements. This would result in a saving in CO2 emissions of 0.516T/yr.

Figure 14: Effect of Income Elasticity on Mean Internal Temperature

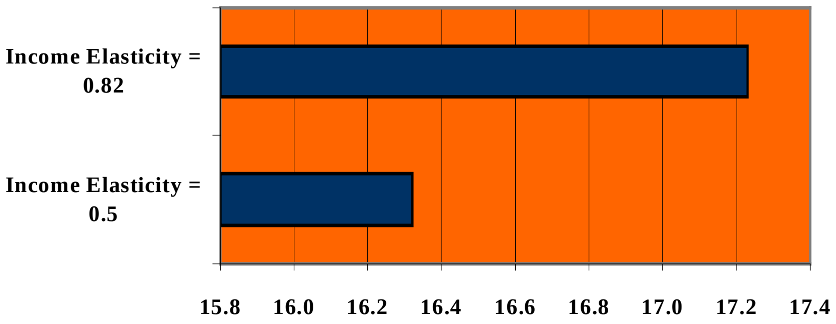
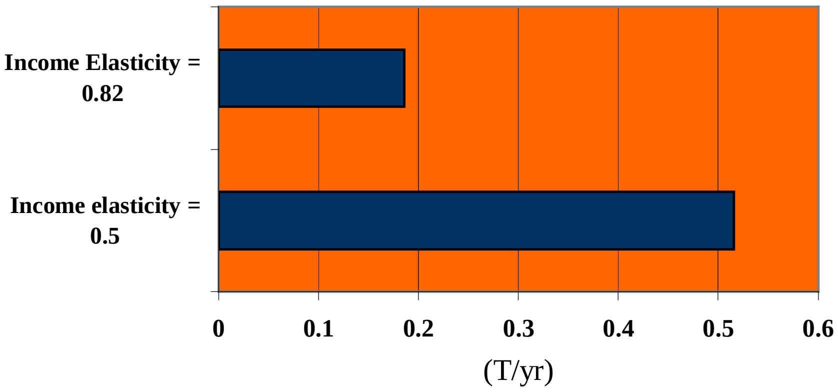


Figure 15: Effect of Income Elasticity on CO2 Emission Reductions



Calculating the Energy Used to Generate Adequate Mean Internal Temperatures

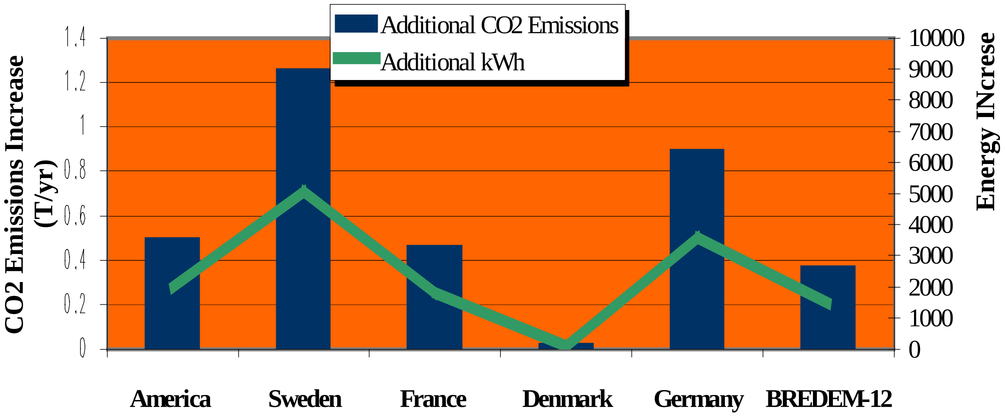
The mean internal temperature was recorded for a range of countries. The data is shown in the table below.

Country	Mean Internal Temperature
USA	19.1°C
Sweden	21.2°C
France	19.0°C
Denmark	17.8°C
Germany	20.2°C
Scotland	14.9 °C
BREDEM – 12	18.75°C

None of these countries has excess winter deaths of the magnitude of Scotland. The energy that would have to be used to generate these mean internal temperatures was then calculated together with resultant CO_2 emission data. It was assumed that the dwelling had been upgraded to NHER rating of 7.0.

The results are shown in Figure 16.

Figure 16: Effect on Energy Use of Higher Internal Temperatures



The data shows that in order to achieve the mean internal temperatures recorded in other countries, the fuel poor in Scotland would have to forgo all the savings accrued to them as a result of energy efficiency improvements and spend additional sums of income.

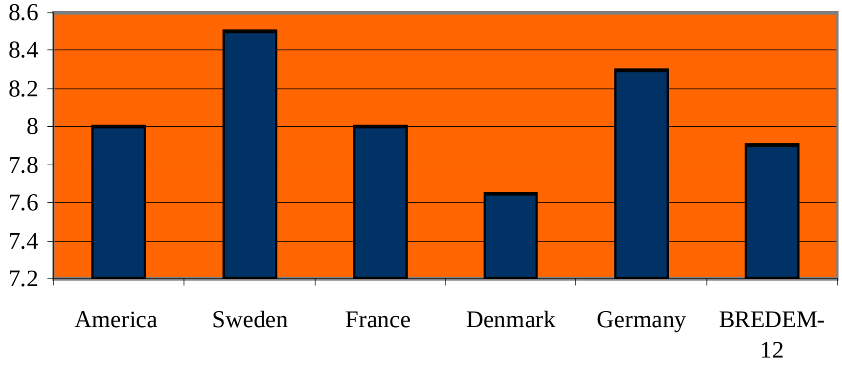
If mean internal temperatures equivalent to those seen in other countries where the spectre of excess winter deaths does not cast its ghoulish cloak across the land are to be realised than it would result in a significant increase in the amount of energy consumed in the domestic sector.

Calculating NHER Levels Necessary to Generate Adequate Mean Internal Temperatures

The NHER level necessary to produce the mean internal temperatures for each of the countries detailed above were then calculated.

An elasticity of 0.5 was assumed, i.e. for every 1kWh saved at the NHER level in question, an additional 0.5kWh was purchased. (This actually lowers the target NHER Rating required.)

Figure 17: NHER to Achieve Income Elasticity of 0.5



As shown, the figures range from 7.65 to 8.5 depending on the standard required. If we assume Denmark is to provide the ‘benchmark’ figure then an NHER rating 0.65 higher than that stipulated for refurbished property would have to be achieved.

4.6 Conclusions from Modelling Studies

A relationship has been derived between NHER and energy per degree. This relationship was used to write a model in excel. This in turn was used to identify the following:

The effect of improving the fuel poor housing stock to NHR rating 7 is to increase the mean internal temperature by 1.4°C to 16.3°C. This is still some way below the mean internal temperature for Denmark that was used in this study as a benchmark (17.8°C).

In order to increase the mean internal temperature to this benchmark would require either significant increase in energy usage or an NHER rating 0.65 above that recommended for refurbished property.

Chapter 5

Evaluation of the Current Policy

Any policy designed to address fuel poverty would ideally attack all the factors surrounding this most intractable of problems. It is worthwhile at this point to pause and review the situation in the light of findings to date.

There is a causal link between mean internal temperature and excess winter deaths. The fuel poor are more likely to live in cold accommodation and are therefore excess winter deaths are likely to come from the ranks of the fuel poor. If the fuel poor did not live in cold accommodation, the figures for excess winter deaths would plummet.

The aim of any program should therefore be to provide a benchmark mean internal temperature which low income groups can afford and which does not result in excess winter deaths.

As its central aim this pretty much sums up the core of the problem. If, however, the policy were to embrace the ideals of sustainable development best summed up by the philosophy emanating from the architectural profession then a number of other matters would have to be considered.

Principal among these would be the desire to reduce primary energy consumption and to foster some connection between energy provider and the community in which they are operating. Any technology employed would have to meet best life-cycle criteria.

These criteria are summarised in the table below.

Criteria	Description
1	Provide benchmark mean internal temperature
2	Ensure that this does not exceed 10% of income of the ‘30% lowest income group’
3	Reduce primary energy use
4	Ensure technology meets best life-cycle analysis
5	Endeavour to foster connection between energy provider and the community in which they are operating

The approach of the Scottish Executive was then measured against these criteria.

Criteria 1

The modelling work carried out suggested that the energy efficiency measures proposed would increase the mean internal temperature of the Scottish home by 1.4°C to 16.3°C.

The identification of a benchmark figure has not been made and a great deal of confusion as to the concept of ideal comfort level exists. One person's warm room is a freezer to another.

The best approach may be to trust that there is a causal link between mean internal temperature and excess winter deaths and therefore assume that those countries that have a low co-efficient of variation are heating their homes adequately. If this is the case then the lowest benchmark figure that could be used is Denmark at 17.8°C. The Scottish Executive proposals do not provide this benchmark figure and they are therefore not adequate.

Criteria 2

The cost of heat is not directly addressed by the Scottish Executive proposals. The warmth is made more affordable by the improvement in energy efficiency. The Scottish Office responded to this question by commenting that:

'In fact, once the measures from the programme are installed our research suggests that the average householder will typically see the cost of heating their home halved.'

This would certainly see the removal of the majority of participants in the scheme removed from fuel poverty. However, the research which has been published by Macintyre et al suggest that only 1 in 2 households would be removed from fuel poverty even if all households were included in the government programme.

The simple answer to this is that the government does not ensure that those household included in the programme will pay less than 10% of income to receive benchmark mean internal temperature.

Criteria 3

The proposals will undoubtedly see a reduction in primary energy use. However, there are a number of ambiguities surrounding the data. The Scottish executive use an elasticity of 0.5 whereas work by Harrow et al quoted by Boardman et al suggested an elasticity of 0.82.

The other ambiguity comes back to the question of benchmark mean internal temperature. The proposals do not ensure that this is delivered. Modelling predicts that the temperature generated from the proposals will be lower than the benchmark. If those households affected by the proposals are suddenly catapulted up the income ladder, it is likely that they will put there heating on for longer to achieve this benchmark. This would result in an increase in the primary energy usage.

Criteria 4

A detailed life-cycle study on the proposal was beyond the remit of this exercise.

Criteria 5

There are a number of encouraging programs being carried out by energy providers in addressing the fuel poverty. These, in some cases, address the issues of bill payment by setting up simple bank accounts so that the benefits accrued to direct debit customers could be offered to low income groups currently paying by cash. There are also programmes that offer a flat rate charge regardless of use to simplify budgeting.

However, the use of pre-payment meters has increased by almost 80% in the last decade[20]. The number of customers using pre-payment meters was 5.12 million in 1998. There is a concern that the use of pre-payment meters hides the rate of disconnection. When the money runs out the power goes off and no records are kept. Data showing reduced levels of disconnection by the energy providers is a delectable twist of sophistry.

There is no attempt in the proposals to bring the energy provider more in focus with the community.

Chapter 6
Alternative Approaches

6.1 Introduction

These are presented in the form of best-case examples. Two examples are given of council activity that has met most if not all of the criteria defined in Chapter 5.

A review is also given of the current technology surrounding micro-CHP. This is presented as a result of communications with the Housing Department at Edinburgh City Council regarding the implementation of large-scale district heating schemes.

They had found difficulty implementing such schemes in existing properties as a result of mixed tenure within one street or block of housing. While the private owner may have been interested the housing association tenant may not have been and the like. The Shetland Heat and Light Company who have been operating a waste to energy district heating scheme in Lerwick also raised these concerns. They have taken 4 years to establish a customer base in the streets in which they have provided hot water. This length of time can prevent many ventures from getting off the ground.

The advantage of micro-CHP is that it provides for one household only and so the ownership issue is minimised somewhat. The status of the technology is presented and an indication of the costs associated in comparison with a traditional boiler.

The attempt to address fuel poverty by supplying the required energy in a ‘renewable’ form also addresses one of the key criteria indicated above. The reduction in primary energy usage is essential if GHG emissions are to be reduced and energy security is to be maintained in the long-term.

It should be stressed that fuel poverty is an energy problem. Development of CHP technology would be rapid if fuel poverty were used as a vehicle for its implementation. The UK Government target of 10,000 MW_e of installed CHP by the year 2010 would be met, one feels, with consummate ease. This approach also fits neatly with the commitment made by the UK Government to involve itself with ‘joined-up thinking.’

6.2 Woking Borough Council (21)

A strategy was devised in 1990 one of the key points being the improvement in energy efficiency in all buildings in Woking. After a successful; period of building stock improvement it soon became clear that further improvements in energy efficiency could only be attained by controlling the production and distribution of the energy in the first place. To facilitate this a number of CHP private-wire networks were designed to supply heat, hot water and electricity to local residents and businesses.

Use of CHP increases efficiency to 80-85% and approximately 6% of electricity is saved through the elimination of distribution losses in transmission systems. In addition, the system charges levied by the national Grid and local distribution companies were avoided by making use of the licence exemptions and private-wire networks under the Electricity (Class Exemptions from the Requirement for a Licence) Orders 19995 and 1997. Thus the full benefit of embedded generation can be passed on to consumers. This substantially alters the return on investment calculations.

There are six separate sites operating under this principal. Natural gas fired CHP plants supply heat, hot water and electricity.

Priors Croft is a 33 elderly persons residential home comprising 33 one bed roomed flats, common rooms and landlords services and living areas. A CHP unit that is sized to produce base load heat requirement (thus satisfying full load operating conditions) is used. The unit comprises 33kW e and 50kW thermal loading backed up by 6 x 50kW modular boiler.

Total costs of the system including cost of installing private wire and community heating system, boiler house, CHP unit, modular boiler and heating systems, controls, Building Energy Management System (BEMS), and electricity meters was £165,000. Savings in annual energy consumption amounted to 500,000 kWh per year that equated to a reduction of 178.5 T CO_2 emissions per annum.

The average combined heating bill for a one bed roomed flat in Priors Croft is approximately 6-7% of a single pensioner’s income. The BEMS controls the internal temperatures of all rooms in the complex to a minimum of 16°C.

6.3 Hutchestown Multi-Storey Blocks (22)

Hutchestown is a housing development in Glasgow of four, 24 storey blocks of flats. Each block contains 138 flats making 553 in total. The blocks have an in-situ concrete frame with precast cladding panels.

In 1992 a large-scale refurbishment programme was started on the site. This encompassed re-roofing, overcladding (including thermal insulation), replacement windows, enclosure of balconies, LPHW district heating scheme, replacement sanitary fittings and installation of CCTV security system.

Scottish Homes conducted a study in 1996/97 to assess the effectiveness of the energy efficiency measures and also the effectiveness of the design solution in terms of value for money.

The key findings were as follows:

1. The temperatures recorded in the flats indicated that pre-improvement, they were generally below minimum acceptable levels. After improvement the temperatures were above acceptable temperature levels.
2. During the same period the average annual cost to tenants of adequate space and hot water heating fell by 68% (from £350 to £120 pa).
3. Common areas such as corridors and stairs had temperatures significantly higher following refurbishment.
4. Level of tenant's satisfaction with the new heating system was 97%.
5. Only 2% of tenants required any other form of energy for space heating.
6. Total cost of the refurbishment per dwelling was £3900 for building fabric improvement and £3950 for the heating systems. The previous heating systems were due to have been replaced in any case at a cost of £2000 per dwelling. The payback period for the district heating system was 7.6 years. The payback period for the building fabric improvements was 15.8 years and the payback for the whole package was 23.4 years. Simple payback methods were used to calculate this.
7. It was concluded that these paybacks were outwith measures commonly accepted for value for money.

8. The system was therefore deemed to be not value for money unless other improvements resulting from the refurbishment were included.
9. A further study investigated the possibility of installing a CHP plant for supplying landlord electrical supplies to the four blocks. It was found to have a payback period of 12.5 years and was therefore deemed to be less sustainable than the alternative – a heat only district heating system.

These included.

- CO2 emissions reduced by 380 tonnes per year per block
- Reduced use of fossil fuels
- Improved levels of comfort for tenants.
- Greater control of heat output by tenants.
- More affordable heating for tenants
- Reduced management and maintenance costs to housing association

Scottish Homes regarding future development of multi-storey blocks of this nature made the following recommendations:

As good practice, option appraisals should always be undertaken to inform the design of energy efficiency measures in high rise blocks. The appraisals should address the following issues:

The simple payback periods associated with various fuel/heating systems options.

The simple payback periods associated with various options for structural thermal efficiency improvements.

6.4 Review of Micro-CHP

In conventional energy supply systems, electricity is generated at a central power station and distributed as a unique product. Heat is generated at the local site either from a primary fuel or from electricity. Any rejected heat from either the generating or the heating process generally goes to waste. The overall efficiency of each system has traditionally been considered separately due to the economies of scale offered by centralised power stations and the low cost of transporting electricity in comparison to heat.

This situation has resulted in the construction of large-scale power stations, remote from centres of population and the development of individual heating systems. The EU Green Paper investigating energy security issues facing Europe in the first 30 years of the century concluded that there is a need for 600GW of electricity capacity needing built in Europe in the next 30 years. 300GW of this are growth and 300GW are to replace obsolete power stations.

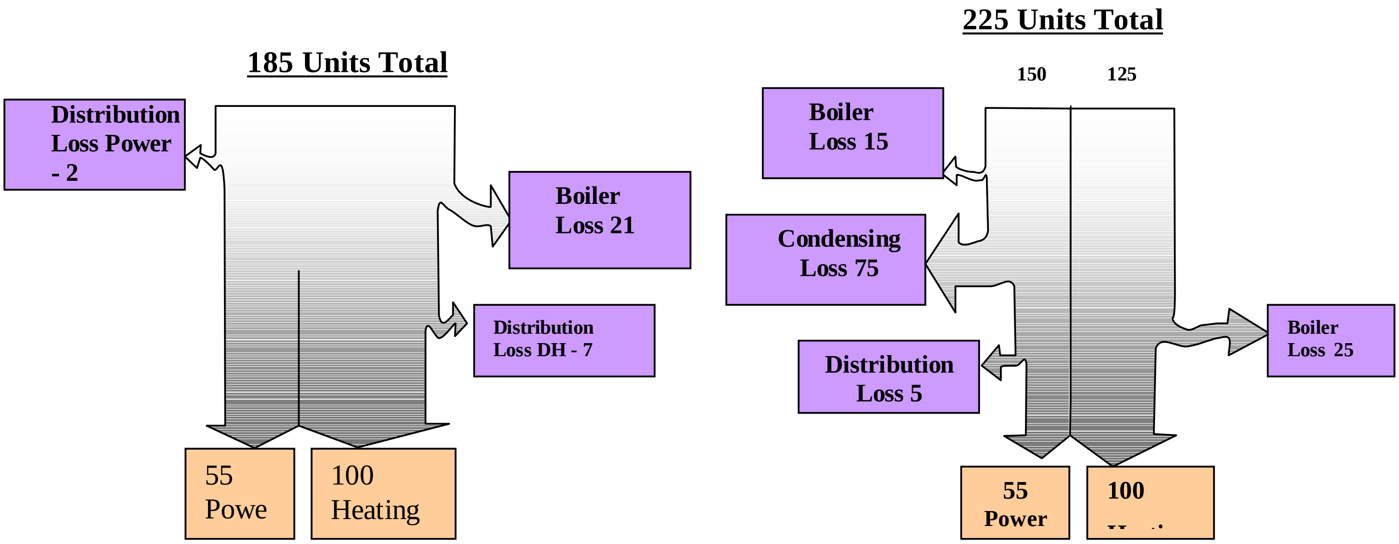
This represents a power station the size of Cockenzie being built somewhere in Europe every 16 days for the next 20 years.

The debate on the source of primary fuel has started in earnest, with British Energy making a sustainable claim for nuclear energy. It is instrumental that the debate centres on the certainties of the current situation. The possibility that an alternative method of supplying different sectors of the market is not being considered. Renewable alternatives to the use of primary fuels are counted against precisely because of their inability to produce electricity on a large enough scale.

This chapter looks at the potential of micro-CHP to address some issues surrounding the provision of electricity and heat. The fuel poverty bill at its core is an energy bill. The provision of energy is ignored, it only being concerned with the use of the energy once produced. Residential energy demand accounts for 35% of total national consumption of electricity and approximately 45% of the peak power demand. There are substantial improvements to be achieved by introducing CHP to the domestic sector. These are summarised in Figure 6.

In the conventional system, 225 units are used to produce the 155 units of combined heat and power. In the CHP only 185 units are used representing an efficiency of primary energy use of 83% compared to 56%. If the fuel is assumed to be gas for all operations then the reduction in CO2 emissions associated with using the CHP unit would be 40%.

Figure 18 Comparison between CHP and Standard Methods of Heat/Electric Production



Combined Heat and Power (CHP)
185 units input produces 155 units output

Separate Heat and Power
275 units input produces 155 units output

There are therefore four main advantages resulting from the widespread application of micro-CHP systems in the domestic sector. These are:

1. The utilisation of rejected heat from the electricity generation will result in a reduction in the rate of fossil fuel production.
2. The reduction in the rate of fossil fuel production will have a positive impact on the national objective of reducing CO_2 emissions.
3. The reduction in fossil fuel consumption will have an impact on the amount of primary fuel required to be imported and therefore will help to allay energy security fears.
4. The reclaimed heat and generated electricity will offset significant proportions of the costs associated with satisfying the thermal and electrical demands of the households. The unit cost of CHP generated electricity is much less than the delivered cost of grid electricity provided that the rejected heat can be usefully employed.

However, two problems are dominant if the application of a CHP solution is feasible both technically and feasibly. These are:

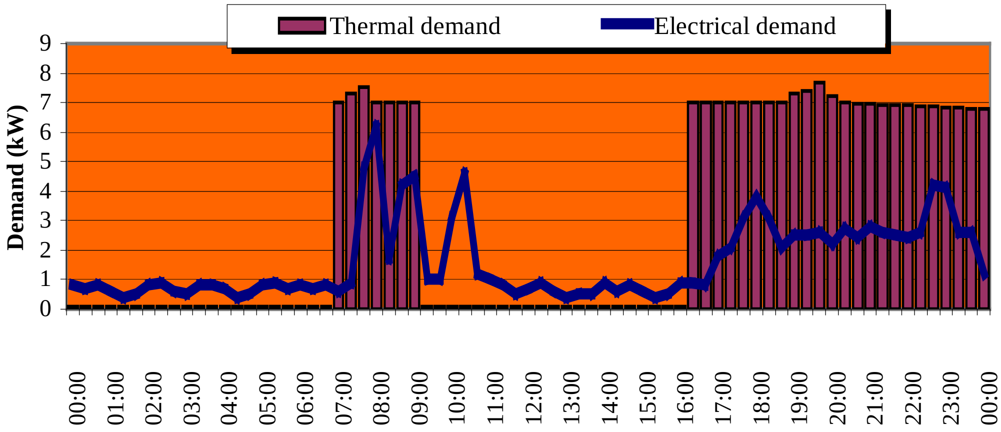
1. Achieving high load factors for both the generated electricity and the recovered heat.
2. Generating the electricity at a location close to the thermal demand.

Traditional thinking has it that the base load for both the heat and the electricity must occur simultaneously for at least 5000 hours of the year and the heat: power ratio should be 3:1 to ensure an economic payback[23].

If reliable and economic systems are to be developed there is therefore a need to develop an understanding of the time-related relationship between domestic electrical and heat requirements. This will have an impact on the characteristics of the prime mover.

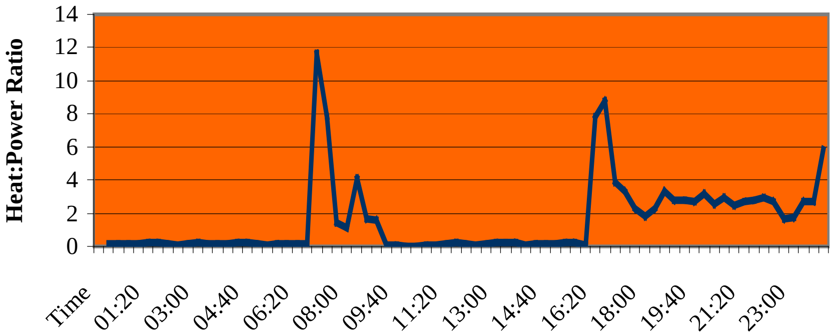
The demands for electricity and heat are neither simultaneous nor constant. The daily heat and power demand profiles are given in Figure 19 for a dwelling that is unoccupied for several hours during the day[24].

Figure 19: Domestic Electrical and Thermal Demand



The wide range of heat:power ratio is also evident from this data and is described in figure 20. The ratio ranges from practically 0 to greater 12. In practice the ratio can exceed 100:1 momentarily.

Figure 20:Typical Heat:Power Ratio for Domestic Sector



The daily electrical demand profile exhibits a low base load consisting mainly of refrigeration unit, security lighting and stand by power for audio-visual equipment or microwave ovens.

The thermal demand of a dwelling consists of three main components:

- Water heating,
- Space heating
- Cooking

Of these, only water heating represents a year round base load usually requiring between 5 and 15 kWh per day.

Space heating is generally the largest thermal load. The actual demand profiles for heat are naturally related to personal comfort requirements. There is consequently widespread variation in the daily space-heating requirement of an individual home.

There is no defined thermal condition to describe ‘comfort’. Different families in identical buildings may have widely varying space-heating requirements. The recommendations for new housing require an achievable indoor temperature of 21°C in living rooms and 18°C in bedrooms.

These values correspond with World Health Organisation levels established for comfort and heath. Temperatures of 18-24°C are required with air speeds less than 0.2 ms^{-1} and a relative humidity of 50%.

Integration of CHP into the Domestic Sector

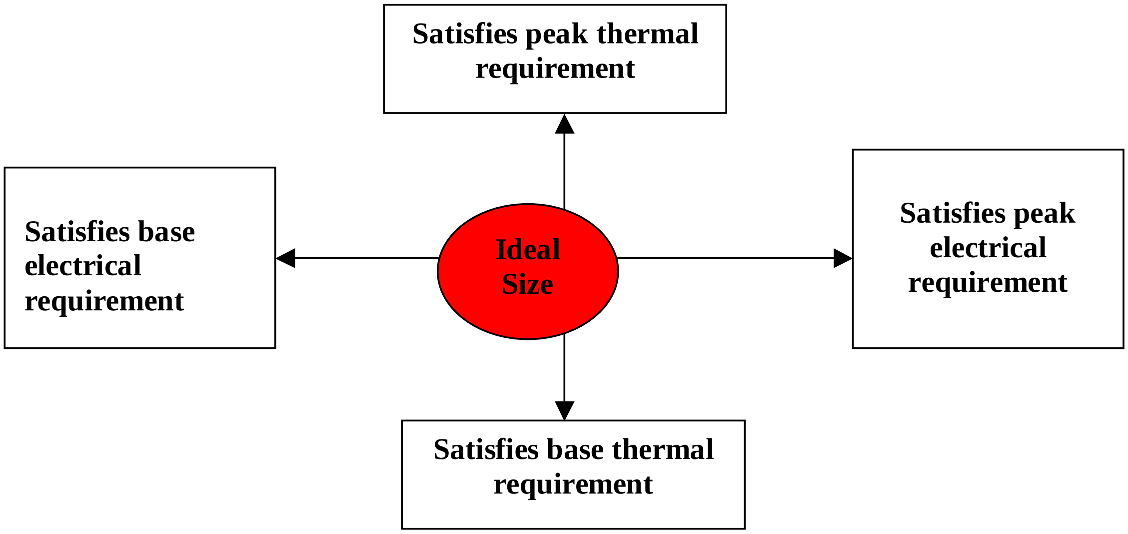
In most daily load profiles, some synchronisation of the thermal and electrical demand can be observed. Space, water and electrical peaks tend to occur when the house is occupied. However, the variability exhibited in the heat:power ratio suggests that no prime mover will be capable of supplying all of a dwellings heat and power requirements as they occur.

Indeed the variability of the heat:power ratio makes defining a specific ratio for design purposes difficult.

It is therefore important that other methods are considered when sizing the unit and that design parameters should be introduced in the confidence that shortfalls in power and heat requirements will be met from an alternative source.

Consideration of the electrical and thermal demand characteristics suggest four corners to the heat:power envelope which will effectively define the sizing limits for the micro-CHP system. This is shown in Figure 21.

Figure 21: Heat:Power Envelope for Micro-CHP Unit



Meeting Thermal Peak Demand

This size of the micro CHP unit would provide heat at a rate sufficient to supply the peak space heating and water loads. This would necessitate employing a very high heat:power ratio prime mover so as to restrict the electrical output. Outside the peak-heating season, the use of the unit would be seriously curtailed. This would result in an extremely low load factor over a period of a year and a fantastically uneconomic situation.

Meeting Electrical Peak Demand

This unit would aim to satisfy all the electrical demand of the dwelling. This would imply grid autonomy. The electrical output of the unit would have to be high and the heat:power ratio very low. The result would be an under-utilised unit that would only reach maximum load factors for short periods during the day. Its capital expenditure would be difficult to justify.

Meeting Electrical Base Demand

Such a unit would supply only base electrical load at a constant output without attempting to meet any of the peak loads. The electrical output will be very low (≈200W) to match the low base load expected in a domestic situation. However, the operating period will be almost 100%. To make a useful contribution to the thermal demand it would be necessary to maximise the heat:power ratio of the prime mover. Assuming that heat:power ratio for prime movers are in the range 1:1 to 1:10 this implies a heat rejection rate of between 200W and 2kW. This would give daily outputs of 4.8 and 48kWh respectively assuming that the unit runs for 100%.

The economic case for such a unit is weakened by the competition offered by off-peak tariffs. This could result in the unit being switched off during the night. This would severely restrict the available thermal provision and would probably render the unit uneconomic.

Meeting the Thermal Base Demand

This unit would aim to satisfy the hot water requirement of 5-15 kWh per day. The prime mover would be operated for several hours per day so as to span the peak electrical demand periods. This would appear to be the most useful system if the prime mover can supply a significant proportion of the electrical demand during these periods.

By analysing these positions it is possible to arrive at the conclusion that the optimal operating window will lie towards the left-hand area of the graph.

The operating duration in all cases is defined by the thermal demand. If all available thermal storage is saturated than the CHP unit must cease operation.

It is clear that as the electrical power output of the prime mover increases the feasible operating period decreases.

The utilisation of any system that has been sized to meet a level somewhere between base and peak requirement will be significantly improved if storage can be integrated into the system. Current technology favours thermal storage but electrochemical storage may also be favourable.

Problems Surrounding Embedded Generation

The UK Government has implemented policy objectives that will see a significant increase in renewable plant and CHP generation of electricity. They have also expressed a wish to see various types of generating plant in generating networks. The effect of this will be to see a significant rise in the amount of generating plant embedded in distribution networks.

This will give rise to a number of problems that will have to be addressed if the situation is to be realised.

Commercial and regulatory frameworks have clouded the requirements for research and development in this area. The major group who need to define these requirements, the Distribution Network Operators (DNOs), are reluctant to pursue embedded generation as an option.

A number of companies in the UK have technology under development that they believe could assist in embedded generation playing a more significant part in helping the DNOs operate a safe and cost effective network. However without clear indications of interest from DNOs these technology providers are reluctant to invest in developing potential solutions.

The technology issues, which must be addressed if additional network capacity can be developed for embedded generation, can be split into two groups:

(i) mitigation of technical issues on existing systems (for example fault levels, voltage control, demand management systems (DMS) and

(ii) future system design and operation

Network Management and Control

Distribution Management Systems (DMS) would enable a controller to assess the network in terms of real and reactive power, transformer tap positions etc.

Changes could be made automatically to adjust the network to maintain parameters within the required limits. This would include the despatch of embedded plant, providing real and reactive power to the controller's requirements.

Current Fault Limiters

The presence of embedded generation connection to the network generally increases the current fault level. This can be reduced by the introduction of impedance but this would increase losses. Higher fault levels require network switchgear upgrades at a cost that acts as a barrier to the up-take of embedded generation. The development of new limiters such as 'super-conducting current fault limiters' (SCFL) could provide an economic solution.

Power Conditioning

Embedded generation plant can, for example, cause transient voltage variations and harmonic distortion by their presence on the network. PV and micro-CHP may deliver its input to the network through power electric interfaces that may distort network parameters. Power conditioning equipment can be used to overcome these effects.

Network and Generator Protection

Although generator protection is fairly well understood the impact of a faulty generator on the network is more difficult to analyse and manage. Loss of mains and its detection is a particular issue of concern and can lead to unacceptable accidental islanding where after a fault, unknown to the DNO, a section of the network remains live.

Modelling and Simulation Tools

Modelling the network is required to assess, for example, power flows, faults and system stability. As the network becomes more active with the addition of multi-generator connections more complex modelling and simulation tools will be required to evaluate their impact.

In the near term probably the most important technical areas to address are those which offer help in the integration of embedded plant by the automation of the present networks. DMS is a technique that could make a sizeable impact on the ability of networks to accept growth in embedded plant. With better modelling to understand the network condition, DMS could be central to accommodating embedded generation growth. Improved fault limiters, protection techniques and power conditioning all have a role to play, as does energy storage, if it can be demonstrated to have the potential to be cost-effective.

Commercial Trading of Electricity

By reducing the need for supply from the Grid, a small generator, that is not required to be licensed, will avoid Grid and wholesale dealing costs. This means that in many cases a supplier, providing electricity generated by an embedded generator to its customers, can reduce costs. This is the principal cause of the 40% reduction in bills indicated in the best case studies detailed in Chapter 11.

Previous programme studies have show that the increased supply value of embedded generation, through these avoided costs, could be worth as much as £7 per MWh to the plant operator. [25]

Regulatory Framework

When a developer of an embedded generation project seeks a connection to the distribution network a contractual agreement is required with the DNO. As an excluded cost to the distribution price control the connectee is required to pay the full cost of the connection (so called 'deep' connection costing). This may include any infrastructure changes needed to the network in the location of the connection point to accommodate the generation plant.

This condition leads to inconsistencies in charging for connection.

In some cases, where capacity exists, the cost of connection can be low. In other cases where the capacity is constrained, the cost of connection can result in a scheme being uneconomic.

Rationale

The majority of generation plant construction that will be catalysed by Government policies and targets[26] for renewables and CHP will be connected to the regional distribution networks.

If Government targets for CHP and renewables are to be met, the rate at which new generation must be connected to the distribution systems will need to increase by a factor of 4 or 5 over that which has been achieved in recent years.

The existing technical and commercial rules and regulations that govern the operation of the electricity supply industry have been developed in the context of power generated by large, remote, National Grid connected coal, nuclear and gas fired plants.

The various arrangements have not yet been revised to recognise the changing electricity marketplace that will be driven by the development of cost effective modular generation plant that can be sited close to sites of demand and the increasing awareness of the environmental impact of power generation.

In its recent report, 'Energy - the Changing Climate' (published in June 2000)[27], the Royal Commission on Environmental Pollution called on the government to review how electricity networks can best be financed, managed and regulated in order to stimulate and accommodate large contributions to energy supplies from CHP plants and renewable sources. The reliability and quality of supply would, naturally, have to be maintained

Prime Movers

The search for a suitable prime mover is of overwhelming importance to the success of the system described. Several companies are in production with micro CHP units based on Stirling Engine, solid-polymer fuel cell and solid-oxide fuel cell technology. Technologies, which have potential to be developed over the longer term, are detailed in the table below

Prime Mover Type	**Development status**	η_p
Internal Combustion Engine (spark ignition)	Widespread technology mass-produced in all sizes. Mechanically complex and noisy	0.1-0.25
Gas Turbine	Not available in small sizes. Simple principal but very high rotational speeds would be required to raise efficiency	<0.2
Stirling Engine	Proven technology has been produced in large quantities. Latest developments are emerging from prototype stage **28**	0.1–0.25
Fuel cell – Solid Polymer Electrolyte	No moving parts – very simple device. Low temperature of operation (<85°C) results in small amount of rejected heat. Prototypes are operating **29,30**	0.5-0.7
Fuel cells – Solid Oxide Electrolyte	No moving parts will run on natural gas. High temperature of operation. Prototypes in operation**31**	0.5-0.7
Thermoelectric generation	Differential temperatures in material causes electrical potential. Semiconductor technology. Prototypes have been built (160W_e)**32**	<0.1
Alkali metal thermoelectric converter	Rankine cycle device with liquid sodium as working fluid. No moving parts. Prototypes being developed**33**	0.18 predicted
Thermionic Energy Conversion	Electrons driven of a heated electrode travel to a cooler electrode. Currently the temperature required is in excess of 1300°C and the	0.2 predicted

	Inter-electrode gap of the region of 10µm. i.e. the gap to be maintained is less than the thermal expansion of the electrode materials over the temperature range.**34**	
Thermo photovoltaic generation	Similar to a solar cell, but rather than being stimulated by sunlight, the cell is stimulated by the radiation emitted by a heat source. Developed for space applications and has all the attendant material cost implications**35**	0.2 predicted

System Economics

At present it would be difficult to make a full economic analysis of the implementation of a micro-CHP systems. There would be, contained in the analysis, many assumptions as the market and the technology are not yet fully developed to proffer this solution on the marketplace.

The capital costs of the prime movers are uncertain and are subject to substantial change due to the nature of economies of scale if a large movement towards this method of generation were to be adopted.

There are also considerable connection costs that at present would be costed to the householder. This situation is likely to change in the near future as a result of discussions being held by the DTI embedded generation group.

It should also be noted that a dwelling would constitute too small a generating capacity to be applicable for consideration under the Renewable Obligation. The power companies would therefore not benefit by having a large number of domestic generators contributing to their ‘renewable total.’

Assuming, however, that a micro-CHP unit has been installed, the overall running coasts can be estimated and compared to traditional provision to generate a saving.

This consists of three operational savings which maybe expressed as:

Savings in electricity costs by self-generation of a portion of the electrical demand

Savings in the heating costs by utilising rejected heat from the CHP unit to satisfy a portion of the domestic heat demand

Savings in heating costs by using the electricity diverted from the output of the prime mover.

These three savings can be expressed as an overall saving per kW_e size, per hour of operation, of any prime mover as:

$$S = G \left[f\,(r-1) + \frac{(\eta_s - 1)}{\eta_p} \right]$$

S	Hourly savings (p)
G	Unit price of natural gas (p/kWh)
f	Utilisation factor. The average electrical output of the CHP unit divided by the maximum power output for the available unit.
r	Unit price ratio between grid electricity and natural gas
η_s	Overall system efficiency
η_p	Prime mover efficiency

Large savings will occur when a high price differential occurs between electricity and gas, and a high utilisation factor of the prime mover is realised during its period of operation.

Conclusions

Residential CHP has several potential advantages:

- It reduces the need for primary fuels.
- It reduces the emissions of GHG
- It offers a considerable cost saving to the householder.

It is however, inhibited as a result of the demand profiles. The implementation of massive demand side reduction techniques and/or the implementation of cost effective thermal and electrical storage devices would herald the coming of this particular new dawn.

Implementation of an effective micro CHP system depends on several factors, all of which contribute to lower costs and higher availability.

During the summer the system will be heat limited due to the lack of adequate thermal storage. In winter when thermal demands are much greater, the operating period will be much less constrained.

Of the various candidate technologies, no single one offers a complete solution to the design criteria as they present themselves at present.

The prime candidate is however the Stirling Engine which has the added advantage of being able to accept multiple fuel streams. The development of fuel cell technology would appear to be some 5-7 years from providing a suitable alternative but offers true potential.

The potential market is obviously huge. The consideration of such a device as part of a fuel poverty bill is to politicise the provision of energy. 506,000 households are experiencing fuel poverty in Scotland. The Scottish Executive proposes to address the plight of 140,000 households with the Fuel Poverty bill. This will provide a package of insulation measures together with a gas central heating system. The provision of micro CHP instead of gas central heating would result in a boost to this industry that would cause the costs to plummet.

The current costs of micro CHP systems are roughly double that of installation of a gas fired boiler[36]. In the first instance then, only 70,000 dwellings would benefit from the Fuel Poverty bill.

The CO2 emission savings would be 40% greater than the original bill and the effect on the fuel bills of the householders would be to offer reductions of between 18 and 40%

The current debate on future energy requirement still retains the elements of debates conducted in the past in that the current situation of large-scale generation and transmission and distribution is considered sacrosanct. This presents a difficulty for governments, as emerging renewable technologies will find it difficult to compete at the GW size of generation. This is due to large extent to land-use restrictions.

For the government to meet its targets regarding decoupling economy and GHG emissions, an alternative method of generation is required.

Chapter 7
Conclusions

The factors surrounding fuel poverty were thoroughly reviewed. The data from a survey conducted by a Scottish Local Authority was analysed to establish the significant variations between the fuel poor and the not fuel poor. By combining the finding from these studies the principal causes of fuel poverty were found to be

- Cost of Fuel
- Energy Efficiency of Dwelling
- Income of Household
- External Temperature
- Occupancy Conditions

A model was written using esp-r and excel which developed a relationship between NHER rating and energy use. As a result it was possible to predict the mean internal temperature which would be achieved as a result of energy efficiency improvements proposed by the Scottish Executive to address fuel poverty.

This was found to be 16.3°C, an increase of 1.4°C on the current figure.

The concept of benchmark mean internal temperature was proposed. This defined the temperature that should be attained in order that excess winter deaths could be reduced by eliminating internal temperature as a cause.

The benchmark figure was taken to be that recorded by Denmark (17.8°C). This was the lowest figure found from a country that does not have excess winter deaths.

The NHER Rating that would have to be attained to achieve this benchmark figure was then calculated using the model. It was found to be 7.5. This is 0.5 above the upper level of the target for refurbished property in Scotland.

A number of criteria were then proposed with which to evaluate the Scottish Executive approach to addressing fuel poverty. These were developed both from the technical consideration surrounding the problem but also from a sustainable development perspective.

The current approach to fuel poverty is to concentrate solely on improvements to energy efficiency of the dwelling. This study confirmed findings of Macintyre et al in suggesting that an approach purely focussed on improving NHER rating would not fully address the problem of fuel poverty.

A number of best case examples are given to describe an alternative strategy for addressing this problem. These show the potential for large-scale district heating schemes. However, discussions with Edinburgh City Council suggested that this large-scale district heating schemes were not favoured as difficulties were encountered due to mixed tenure of housing stock.

The technological status of small-scale CHP units was therefore evaluated to offer an alternative alternative, if you will.

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Appendix I
Degree-day Method for Calculating the Yearly Energy Requirement

Degree Days show how far, for a given month, outside temperatures are, on average, below 15.5°C. (the control temperature). When the outside temperature is above this level it should not be necessary to heat a building in normal commercial occupation. The casual energy gains associated with the presence of people and office machinery should bring the temperature in the building up to 19°C.

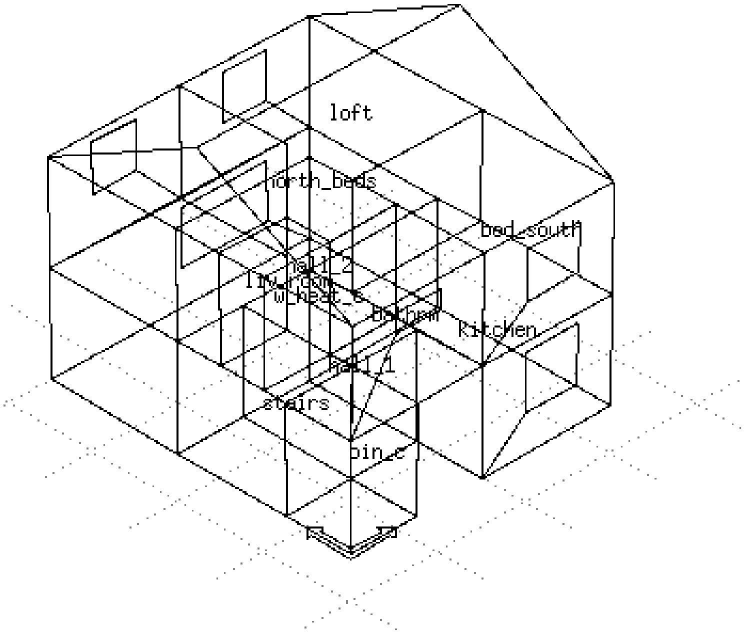
The more degree-days shown for a month the colder the month. For a 12-month period a point for each month should be plotted on a graph whose vertical axis shows the amount of fuel used for heating and whose horizontal axis shows degree-days per month. The usual result is a straight line, showing how much heating fuel is required for a given number of degree-days (or a given amount of 'cold').

Consequently, by calculating the energy used in one month of the year it is possible to estimate the energy that would be required for the whole year.

The degree-day method was used in the modelling study to calculate the yearly energy requirement for the 2-bedroomed house. Energy was provided for the month of January. Using the data set for the West of Scotland in the year 2000[37], the number of degree-days for the month of January was found to be 330.

The number for the whole year was found to be 2325. The energy used by the model for heating the house in January was thus multiplied by (2325/330) to produce the energy requirement for the year.

Appendix II
ESP-r Building Simulation Software QA Report



Description of the Control Strategy for one of the Models.

```
ID Zone             Volume|          Surface
   Name            m^3   | No. Opaque  Transp  ~Floor
 1 bin_c           5.0   6    17.7     0.0     2.2 attributed
 2 stairs          8.3   8    25.1     0.0     3.8 attributed
 3 hall_1          8.3   7    25.1     0.0     3.8 attributed
 4 kitchen        26.4   9    53.4     1.4    12.0 attributed
 5 liv_room       39.6   9    73.2     2.4    18.0 attributed
 6 bathrm         13.2  11    33.6     0.4     6.0 attributed
 7 bed_south      19.8   8    43.2     1.2     9.0 attributed
 8 w_heat_c        3.3   6    14.0     0.0     1.5 attributed
 9 hall_2          9.9  10    31.0     0.0     4.5 attributed
10 north_beds     46.2  14    95.0     2.0    21.0 attributed
11 loft           37.8   9   101.8     0.0    42.0 attributed
   all           218.   97    513.      7.    124.
```

Control description: proj cntrl

```
 Zones control: no descrip : 3 functions.

 The sensor for function  1 measures the temperature of the current
zone.
 The actuator for function  1 is air point of the current zone
 The function day types are Weekdays, Saturdays & Sundays

 Weekday control is valid during period: Sat  1 Jan to Sun 31 Dec,
2000 with  4 periods.
 Per| Start|Sensed   |Actuated   | Control law       | Data
 no.| time |property |property   |                   |
  1   0.00  db temp   > flux      free floating
  2   7.00  db temp   > flux      ideal control         3000.0 0.0
17.1 17.0 17.0 100.0 0.0
  3   9.00  db temp   > flux      free floating
  4  17.00  db temp   > flux      ideal control         3000.0 0.0
17.1 17.0 17.0 100.0 0.0

 Saturday control is valid during period: Sat  1 Jan to Sun 31 Dec,
2000 with  3 periods.
 Per| Start|Sensed   |Actuated   | Control law       | Data
 no.| time |property |property   |                   |
  1   0.00  db temp   > flux      free floating
  2   8.00  db temp   > flux      ideal control         3000.0 0.0
17.1 17.0 17.0 100.0 0.0
  3  23.00  db temp   > flux      free floating

 Sunday control is valid during period: Sat  1 Jan to Sun 31 Dec,
2000 with  3 periods.
 Per| Start|Sensed   |Actuated   | Control law       | Data
 no.| time |property |property   |                   |
  1   0.00  db temp   > flux      free floating
  2   8.00  db temp   > flux      ideal control         3000.0 0.0
17.1 17.0 17.0 100.0 0.0
  3  23.00  db temp   > flux      free floating


 The sensor for function  2 measures the temperature of the current
zone.
 The actuator for function  2 is air point of the current zone
 There have been  1 day types defined.

 Day type  1 is valid during period: Sat  1 Jan to Sun 31 Dec, 2000
with  4 periods.
 Per| Start|Sensed   |Actuated   | Control law       | Data
 no.| time |property |property   |                   |
  1   0.00  db temp   > flux      free floating
  2   7.00  db temp   > flux      ideal control         3000.0 0.0
21.1 21.0 21.0 100.0 0.0
  3   9.00  db temp   > flux      free floating
  4  17.00  db temp   > flux      ideal control         3000.0 0.0
21.1 21.0 21.0 100.0 0.0
```

```
 The sensor for function  3 measures the temperature of the current
zone.
 The actuator for function  3 is air point of the current zone
 There have been  1 day types defined.

 Day type  1 is valid during period: Sat  1 Jan to Sun 31 Dec, 2000
with  4 periods.
 Per| Start|Sensed   |Actuated   | Control law       | Data
 no.| time |property |property   |                   |
  1   0.00  db temp   > flux      free floating
  2   7.00  db temp   > flux      ideal control         3000.0 0.0
18.1 18.0 18.0 100.0 0.0
  3   9.00  db temp   > flux      free floating
  4  17.00  db temp   > flux      ideal control         3000.0 0.0
18.1 18.0 18.0 100.0 0.0

 Zone to contol loop linkages:
 zone ( 1) bin_c        << control  0
 zone ( 2) stairs       << control  1
 zone ( 3) hall_1       << control  1
 zone ( 4) kitchen      << control  1
 zone ( 5) liv_room     << control  1
 zone ( 6) bathrm       << control  1
 zone ( 7) bed_south    << control  1
 zone ( 8) w_heat_c     << control  0
 zone ( 9) hall_2       << control  1
 zone (10) north_beds   << control  1
 zone (11) loft         << control  0
```

Zone bin_c (1) is composed of 6 surfaces and 8 vertices.

```
 It encloses a volume of     5.0m^3 of space, with a total surface
 area of    17.70m^2 & approx floor area of    2.25m^2
 bin_c describes a...

 A summary of the surfaces in bin_c( 1) follows:

 Sur| Area  |Azim|Elev| surface    |geometry| multilayer
|environment
    | m^2   |deg |deg | name       |type|loc| constr name  |other
side
  1     3.30 180.   0. south        OPAQ VERT ext_wall     ||<
external
  2     3.30  90.   0. porch        OPAQ VERT int_doors    ||<
external
  3     3.30   0.   0. stairs       OPAQ VERT ext_part     ||<
bin:stairs
  4     3.30 270.   0. west         OPAQ VERT ext_part     ||<
identical environment
  5     2.25   0.  90. ceiling      OPAQ CEIL ceiling      ||<
bin_c:bathrm
  6     2.25   0. -90. floor        OPAQ FLOR grnd_floor   ||< ground
profile  1


 Solar radiation is focused on surface floor       .

 Description: nil_operations
 Control: no control of air flow

 Number of Weekday Sat Sun air change periods =  0  0  0


 Description : nil_operations
 Number of Weekday Sat Sun casual gains=  0  0  0
```

Zone stairs (2) is composed of 8 surfaces and 12 vertices.

```
 It encloses a volume of     8.3m^3 of space, with a total surface
 area of    25.10m^2 & approx floor area of    3.75m^2
 stairs describes a...

 A summary of the surfaces in stairs( 2) follows:

 Sur| Area  |Azim|Elev| surface    |geometry| multilayer
|environment
    | m^2   |deg |deg | name       |type|loc| constr name  |other
side
  1     3.30 180.   0. bin          OPAQ VERT ext_part     ||<
stairs:bin_c
  2     5.50  90.   0. hall         OPAQ VERT int_part     ||<
stairs:hall_1
  3     3.30   0.   0. livrm        OPAQ VERT int_part     ||<
stairs:liv_room
  4     5.50 270.   0. west         OPAQ VERT ext_part     ||<
identical environment
  5     0.75   0.  90. bathrm       OPAQ CEIL ceiling      ||<
stairs:bathrm
  6     3.75   0. -90. floor        OPAQ FLOR grnd_floor   ||< ground
profile  1
```

```
  7     1.50   0.  90. whc          OPAQ CEIL ceiling      ||<
floor:w_heat_c
  8     1.50   0.  90. north_beds   OPAQ CEIL ceiling      ||<
stairs:hall_2


 Solar radiation is focused on surface floor       .

 Description: nil_operations
 Control: no control of air flow

 Number of Weekday Sat Sun air change periods =  0  0  0


 Description : nil_operations
 Number of Weekday Sat Sun casual gains=  0  0  0
```

Zone hall_1 (3) is composed of 7 surfaces and 10 vertices.

```
 It encloses a volume of     8.3m^3 of space, with a total surface
 area of    25.10m^2 & approx floor area of    3.75m^2
 hall_1 describes a...

 A summary of the surfaces in hall_1( 3) follows:

 Sur| Area  |Azim|Elev| surface    |geometry| multilayer
|environment
    | m^2   |deg |deg | name       |type|loc| constr name  |other
side
  1     3.30 180.   0. door         OPAQ VERT int_doors    ||<
external
  2     5.50  90.   0. kitchen      OPAQ VERT int_part     ||<
hall:kitchen
  3     3.30   0.   0. livroom      OPAQ VERT int_doors    ||<
hall_1:liv_room
  4     5.50 270.   0. stairs       OPAQ VERT int_part     ||<
hall:stairs
  5     3.00   0.  90. hall_2       OPAQ CEIL ceiling      ||<
hall1:hall_2
  6     3.75   0. -90. floor        OPAQ FLOR grnd_floor   ||< ground
profile  1
  7     0.75   0.  90. bathrm       OPAQ CEIL ceiling      ||<
hall_1:bathrm


 Solar radiation is focused on surface floor       .

 Description: nil_operations
 Control: no control of air flow

 Number of Weekday Sat Sun air change periods =  0  0  0


 Description : nil_operations
 Number of Weekday Sat Sun casual gains=  0  0  0
```

```
 Zone kitchen ( 4) is composed of  9 surfaces and 16 vertices.
 It encloses a volume of    26.4m^3 of space, with a total surface
 area of    54.80m^2 & approx floor area of   12.00m^2
 kitchen describes a...

 A summary of the surfaces in kitchen( 4) follows:

 Sur| Area  |Azim|Elev| surface    |geometry| multilayer
|environment
    | m^2   |deg |deg | name       |type|loc| constr name  |other
side
  1     5.16 180.   0. south        OPAQ VERT ext_wall     ||<
external
  2     8.80  90.   0. east_part    OPAQ VERT ext_part     ||<
identical environment
  3     6.60   0.   0. liv_r        OPAQ VERT int_part     ||<
kitch:liv_room
  4     5.50 270.   0. hall         OPAQ VERT int_part     ||<
kitchen:hall_1
  5     9.00   0.  90. bed_1        OPAQ CEIL ceiling      ||<
floor:bed_south
  6    12.00   0. -90. floor        OPAQ FLOR grnd_floor   ||< ground
profile  1
  7     3.00   0.  90. north_beds   OPAQ CEIL ceiling      ||<
kitch:north_beds
  8     3.30 270.   0. Ext          OPAQ VERT ext_wall     ||<
external
  9     1.44 180.   0. window       TRAN VERT single_glaz  ||<
external


 Solar radiation is focused on surface floor       .
 Casual gains are controlled in this zone.

 Description: nil_operations
 Control: no control of air flow

 Number of Weekday Sat Sun air change periods =  0  0  0


 Description : nil_operations
 Number of Weekday Sat Sun casual gains=  2  2  2
Day Gain Type   Period Sensible  Latent    Radiant   Convec
    No.  labl   Hours  Magn.(W)  Magn. (W) Frac    Frac
Wkd  1 EquiptW    5 -  6   4160.0   2890.0       0.50       0.50
Wkd  2 EquiptW    7 -  8   1870.0   1300.0       0.50       0.50
Sat  1 EquiptW    5 -  6   4160.0   2890.0       0.50       0.50
Sat  2 EquiptW    7 -  8   1870.0   1300.0       0.50       0.50
Sun  1 EquiptW    5 -  6   4160.0   2890.0       0.50       0.50
Sun  2 EquiptW    7 -  8   1870.0   1300.0       0.50       0.50
```

```
 Zone liv_room ( 5) is composed of  9 surfaces and 16 vertices.
 It encloses a volume of    39.6m^3 of space, with a total surface
 area of    75.60m^2 & approx floor area of   18.00m^2
 liv_room describes a...

 A summary of the surfaces in liv_room( 5) follows:

 Sur| Area  |Azim|Elev| surface    |geometry| multilayer
|environment
    | m^2   |deg |deg | name       |type|loc| constr name  |other
side
  1     3.30 180.   0. stairs       OPAQ VERT int_part     ||<
livrm:stairs
  2     6.60  90.   0. east_ext     OPAQ VERT ext_part     ||<
identical environment
  3    10.80   0.   0. north_ext    OPAQ VERT ext_wall     ||<
external
  4     6.60 270.   0. west_part    OPAQ VERT ext_part     ||<
identical environment
  5    18.00   0.  90. north_beds   OPAQ CEIL ceiling      ||< Surf-
11:north_beds
  6    18.00   0. -90. floor        OPAQ FLOR grnd_floor   ||< ground
profile  1
  7     3.30 180.   0. hall_1       OPAQ VERT int_doors    ||<
livroom:hall_1
  8     6.60 180.   0. kitch        OPAQ VERT int_part     ||<
liv_r:kitchen
  9     2.40   0.   0. window       TRAN VERT single_glaz  ||<
external


 Solar radiation is focused on surface floor       .
 Casual gains are controlled in this zone.

 Description: nil_operations
 Control: no control of air flow

 Number of Weekday Sat Sun air change periods =  0  0  0


 Description : nil_operations
 Number of Weekday Sat Sun casual gains=  1  1  1
Day Gain Type   Period Sensible  Latent    Radiant   Convec
    No.  labl   Hours  Magn.(W)  Magn. (W) Frac    Frac
Wkd  1 OccuptW   17 - 23    380.0    180.0       0.70       0.30
Sat  1 OccuptW   17 - 23    380.0    180.0       0.70       0.30
Sun  1 OccuptW   17 - 23    380.0    180.0       0.70       0.30
```

Zone bathrm (6) is composed of 11 surfaces and 18 vertices.

```
 It encloses a volume of    13.2m^3 of space, with a total surface
 area of    34.00m^2 & approx floor area of    6.00m^2
 bathrm describes a...

 A summary of the surfaces in bathrm( 6) follows:

 Sur| Area  |Azim|Elev| surface    |geometry| multilayer
|environment
    | m^2   |deg |deg | name       |type|loc| constr name  |other
side
  1     6.20 180.   0. south_ext    OPAQ VERT ext_wall     ||<
external
  2     4.40  90.   0. s_bed        OPAQ VERT int_part     ||<
bathrm:bed_south
  3     3.30   0.   0. wh_cup       OPAQ VERT int_part     ||<
bathrm:w_heat_c
  4     4.40 270.   0. west         OPAQ VERT ext_part     ||<
identical environment
  5     6.00   0.  90. roof         OPAQ CEIL loft_ceil    ||<
first:loft
  6     2.25   0. -90. porch        OPAQ FLOR upper_flor   ||<
external
  7     2.25   0. -90. bin_c        OPAQ FLOR upper_flor   ||<
ceiling:bin_c
  8     0.75   0. -90. stairs       OPAQ FLOR upper_flor   ||<
bathrm:stairs
  9     0.75   0. -90. hall_1       OPAQ FLOR upper_flor   ||<
bathrm:hall_1
 10     3.30   0.   0. hall_2       OPAQ VERT int_doors    ||<
bathrm:hall_2
 11     0.40 180.   0. window       TRAN VERT single_glaz  ||<
external


 Solar radiation is focused on surface porch       .

 Description: nil_operations
 Control: no control of air flow

 Number of Weekday Sat Sun air change periods =  0  0  0


 Description : nil_operations
 Number of Weekday Sat Sun casual gains=  1  1  1
Day Gain Type   Period Sensible  Latent    Radiant   Convec
    No.  labl   Hours  Magn.(W)  Magn. (W) Frac    Frac
Wkd  1 EquiptW    7 -  9    500.0    160.0       0.50       0.50
Sat  1 EquiptW    7 -  9    500.0    160.0       0.50       0.50
Sun  1 EquiptW    7 -  9    500.0    160.0       0.50       0.50
```

```
 Zone bed_south ( 7) is composed of  8 surfaces and 14 vertices.
 It encloses a volume of    19.8m^3 of space, with a total surface
 area of    44.40m^2 & approx floor area of    9.00m^2
 bed_south describes a...

 A summary of the surfaces in bed_south( 7) follows:

 Sur| Area  |Azim|Elev| surface    |geometry| multilayer
|environment
    | m^2   |deg |deg | name       |type|loc| constr name  |other
side
  1     5.40 180.   0. south        OPAQ VERT ext_wall     ||<
external
  2     6.60  90.   0. east         OPAQ VERT ext_part     ||<
identical environment
  3     6.60   0.   0. north_bed    OPAQ VERT int_part     ||<
bed_s:north_beds
  4     4.40 270.   0. bathrm       OPAQ VERT int_part     ||<
s_bed:bathrm
  5     9.00   0.  90. roof         OPAQ CEIL loft_ceil    ||<
Loft_sbed:loft
  6     9.00   0. -90. floor        OPAQ FLOR upper_flor   ||<
bed_1:kitchen
  7     2.20 270.   0. hall_2       OPAQ VERT int_part     ||<
south_beds:hall_2
  8     1.20 180.   0. window       TRAN VERT single_glaz  ||<
external


 Solar radiation is focused on surface floor       .
 Casual gains are controlled in this zone.

 Description: nil_operations
 Control: no control of air flow

 Number of Weekday Sat Sun air change periods =  0  0  0


 Description : nil_operations
 Number of Weekday Sat Sun casual gains=  1  1  1
Day Gain Type   Period Sensible  Latent    Radiant   Convec
    No.  labl   Hours  Magn.(W)  Magn. (W) Frac    Frac
Wkd  1 OccuptW    0 -  7    180.0     90.0       0.70       0.30
Sat  1 OccuptW    0 -  7    180.0     90.0       0.70       0.30
Sun  1 OccuptW    0 -  7    180.0     90.0       0.70       0.30
```

```
 Zone w_heat_c ( 8) is composed of  6 surfaces and  8 vertices.
 It encloses a volume of     3.3m^3 of space, with a total surface
 area of    14.00m^2 & approx floor area of    1.50m^2
 w_heat_c describes a...

 A summary of the surfaces in w_heat_c( 8) follows:

 Sur| Area  |Azim|Elev| surface    |geometry| multilayer
|environment
    | m^2   |deg |deg | name       |type|loc| constr name  |other
side
  1     2.20  90.   0. hall2        OPAQ VERT int_doors    ||<
whc2:hall_2
  2     3.30   0.   0. hall2_2      OPAQ VERT int_part     ||<
whc:hall_2
  3     2.20 270.   0. west_part    OPAQ VERT ext_part     ||<
identical environment
  4     3.30 180.   0. bathrm       OPAQ VERT int_part     ||<
wh_cup:bathrm
  5     1.50   0.  90. ceiling      OPAQ CEIL loft_ceil    ||<
wh_cup:loft
  6     1.50   0. -90. floor        OPAQ FLOR upper_flor   ||<
whc:stairs


 Solar radiation is focused on surface floor       .

 Description: nil_operations
 Control: no control of air flow

 Number of Weekday Sat Sun air change periods =  0  0  0


 Description : nil_operations
 Number of Weekday Sat Sun casual gains=  1  1  1
Day Gain Type   Period Sensible  Latent    Radiant   Convec
    No.  labl   Hours  Magn.(W)  Magn. (W) Frac    Frac
Wkd  1 EquiptW    0 - 24    200.0      0.0       0.50       0.50
Sat  1 EquiptW    0 - 24    200.0      0.0       0.50       0.50
Sun  1 EquiptW    0 - 24    200.0      0.0       0.50       0.50
```

Zone hall_2 (9) is composed of 10 surfaces and 15 vertices.

```
 It encloses a volume of     9.9m^3 of space, with a total surface
 area of    31.00m^2 & approx floor area of    4.50m^2
 hall_2 describes a...

 A summary of the surfaces in hall_2( 9) follows:

 Sur| Area  |Azim|Elev| surface    |geometry| multilayer
|environment
    | m^2   |deg |deg | name       |type|loc| constr name  |other
side
  1     3.30 180.   0. bathrm       OPAQ VERT int_doors    ||<
hall_2:bathrm
  2     2.20  90.   0. south_beds   OPAQ VERT int_part     ||<
hall_2:bed_south
  3     6.60   0.   0. north_beds   OPAQ VERT int_part     ||<
hall2:north_beds
  4     2.20 270.   0. west         OPAQ VERT ext_part     ||<
identical environment
  5     3.30 180.   0. whc          OPAQ VERT int_part     ||<
hall2_2:w_heat_c
  6     2.20 270.   0. whc2         OPAQ VERT int_doors    ||<
hall2:w_heat_c
  7     4.50   0.  90. ceiling      OPAQ CEIL loft_ceil    ||<
hall:loft
  8     3.00   0. -90. hall1        OPAQ FLOR upper_flor   ||<
hall_2:hall_1
  9     2.20  90.   0. north_beds   OPAQ VERT int_part     ||<
hall_2_2:north_beds
 10     1.50   0. -90. stairs       OPAQ FLOR upper_flor   ||<
north_beds:stairs


 Solar radiation is focused on surface hall1       .

 Description: nil_operations
 Control: no control of air flow

 Number of Weekday Sat Sun air change periods =  0  0  0


 Description : nil_operations
 Number of Weekday Sat Sun casual gains=  0  0  0
```

Zone north_beds (10) is composed of 14 surfaces and 27 vertices.
It encloses a volume of   46.2m^3 of space, with a total surface
area of   97.00m^2 & approx floor area of   21.00m^2
north_beds describes a...

```
 A summary of the surfaces in north_beds(10) follows:

 Sur| Area  |Azim|Elev| surface    |geometry| multilayer
|environment
    | m^2   |deg |deg | name       |type|loc| constr name  |other
side
  1     6.60 180.   0. hall2        OPAQ VERT int_part     ||<
north_beds:hall_2
  2     2.20 270.   0. hall_2_2     OPAQ VERT int_part     ||<
north_beds:hall_2
  3     6.60 180.   0. bed_s        OPAQ VERT int_part     ||<
north_bed:bed_south
  4     8.80  90.   0. east         OPAQ VERT ext_part     ||<
identical environment
  5     5.60 360.   0. north1       OPAQ VERT ext_wall     ||<
external
  6     5.50 270.   0. Surf-6       OPAQ VERT int_part     ||<
adiabatic
  7     5.50  90.   0. Surf-7       OPAQ VERT int_part     ||<
adiabatic
  8     5.60 360.   0. north2       OPAQ VERT ext_wall     ||<
external
  9     6.60 270.   0. east         OPAQ VERT ext_part     ||<
identical environment
 10    21.00   0.  90. Surf-10      OPAQ CEIL loft_ceil    ||<
Loft_nbed:loft
 11    18.00   0. -90. Surf-11      OPAQ FLOR upper_flor   ||<
north_beds:liv_room
 12     3.00   0. -90. kitch        OPAQ FLOR upper_flor   ||<
north_beds:kitchen
 13     1.00 360.   0. window1      TRAN VERT single_glaz  ||<
external
 14     1.00 360.   0. window2      TRAN VERT single_glaz  ||<
external


 Solar radiation is focused on surface Surf-11     .
 Casual gains are controlled in this zone.

 Description: nil_operations
 Control: no control of air flow

 Number of Weekday Sat Sun air change periods =  0  0  0


 Description : nil_operations
 Number of Weekday Sat Sun casual gains=  1  1  1
Day Gain Type   Period Sensible  Latent    Radiant   Convec
    No.  labl   Hours  Magn.(W)  Magn. (W) Frac    Frac
Wkd  1 OccuptW    0 -  7    180.0     90.0       0.70       0.30
Sat  1 OccuptW    0 -  7    180.0     90.0       0.70       0.30
Sun  1 OccuptW    0 -  7    180.0     90.0       0.70       0.30
```

Zone loft (11) is composed of 9 surfaces and 17 vertices.

```
 It encloses a volume of    37.8m^3 of space, with a total surface
 area of   101.83m^2 & approx floor area of   42.00m^2
 loft describes a...

 A summary of the surfaces in loft(11) follows:

 Sur| Area  |Azim|Elev| surface    |geometry| multilayer
|environment
    | m^2   |deg |deg | name       |type|loc| constr name  |other
side
  1     6.00   0. -90. first        OPAQ FLOR loft_floor   ||<
roof:bathrm
  2     6.30 270.   0. West_ext     OPAQ VERT ext_part     ||<
identical environment
  3     6.30  90.   0. East_ext     OPAQ VERT ext_part     ||<
identical environment
  4    23.61 180.  63. South_roof   OPAQ SLOP roof         ||<
external
  5    23.61   0.  63. North_roof   OPAQ SLOP roof         ||<
external
  6    21.00   0. -90. Loft_nbed    OPAQ FLOR loft_floor   ||< Surf-
10:north_beds
  7     9.00   0. -90. Loft_sbed    OPAQ FLOR loft_floor   ||<
roof:bed_south
  8     4.50   0. -90. hall         OPAQ FLOR loft_floor   ||<
ceiling:hall_2
  9     1.50   0. -90. wh_cup       OPAQ FLOR loft_floor   ||<
ceiling:w_heat_c


 All surfaces will receive diffuse insolation.

 Description: nil_operations
 Control: no control of air flow

 Number of Weekday Sat Sun air change periods =  0  0  0


 Description : nil_operations
 Number of Weekday Sat Sun casual gains=  0  0  0

 _
```

Multi-layer constructions used

```
 Details of opaque composite: grnd_floor

 Layer|Prim|Thick |Conduc-|Density|Specif|IR  |Solr|Diffu|Descr
      |db  | (m)  |tivity |       |heat  |emis|abs |resis|
    1  263 0.2500     1.280  1460.   879. 0.90 0.85     5. Common
earch
    2  262 0.1500     0.520  2050.   184. 0.90 0.85     2. Gravel
based
    3   32 0.1500     1.400  2100.   653. 0.90 0.65    19. Heavy mix
concrete
    4    0 0.0500     0.000     0.     0. 0.99 0.99     1. air  0.17
0.17 0.17
    5   67 0.0190     0.150   800.  2093. 0.91 0.65    96. Chipboard
    6  221 0.0060     0.060   186.  1360. 0.90 0.60    10. Wilton
 Standardised U value =    0.86

 Details of transparent composite: single_glaz  with SC_8985_04nb
optics.

 Layer|Prim|Thick |Conduc-|Density|Specif|IR  |Solr|Diffu|Descr
      |db  | (m)  |tivity |       |heat  |emis|abs |resis|
    1  243 0.0040     1.050  2500.   750. 0.83 0.05 19200. 4mm clear
float
 Standardised U value =    5.50

 Details of opaque composite: roof

 Layer|Prim|Thick |Conduc-|Density|Specif|IR  |Solr|Diffu|Descr
      |db  | (m)  |tivity |       |heat  |emis|abs |resis|
    1  141 0.0100     0.850  1900.   837. 0.90 0.60    52. Clay tile
    2  161 0.0020     0.500  1700.  1000. 0.90 0.90  1000. Bitumen
felt
    3   67 0.0250     0.150   800.  2093. 0.91 0.65    96. Chipboard
 Standardised U value =    2.77

 Details of opaque composite: int_doors

 Layer|Prim|Thick |Conduc-|Density|Specif|IR  |Solr|Diffu|Descr
      |db  | (m)  |tivity |       |heat  |emis|abs |resis|
    1   69 0.0250     0.190   700.  2390. 0.90 0.65    12. Oak
(radial)
 Standardised U value =    3.23

 Details of opaque composite: ext_wall

 Layer|Prim|Thick |Conduc-|Density|Specif|IR  |Solr|Diffu|Descr
      |db  | (m)  |tivity |       |heat  |emis|abs |resis|
    1  125 0.0030     0.500  1300.  1000. 0.91 0.50    19. White dry
render
    2    4 0.1100     0.960  2000.   650. 0.90 0.93    25. Outer leaf
brick
    3    0 0.2500     0.000     0.     0. 0.99 0.99     1. air  0.17
0.17 0.17
    4    3 0.1100     0.620  1800.   840. 0.93 0.70    29. Inner leaf
brick
    5  104 0.0130     0.420  1200.   837. 0.91 0.50    11. Gypsum
plaster
 Standardised U value =    1.48
```

```
 Details of opaque composite: ext_part

 Layer|Prim|Thick |Conduc-|Density|Specif|IR  |Solr|Diffu|Descr
      |db  | (m)  |tivity |       |heat  |emis|abs |resis|
    1  104 0.0130     0.420  1200.   837. 0.91 0.50    11. Gypsum
plaster
    2   28 0.1000     0.510  1400.  1000. 0.90 0.65    10. Block
inner (3% mc)
    3  104 0.0130     0.420  1200.   837. 0.91 0.50    11. Gypsum
plaster
 Standardised U value =    2.29

 Details of opaque composite: int_part


 Layer|Prim|Thick |Conduc-|Density|Specif|IR  |Solr|Diffu|Descr
      |db  | (m)  |tivity |       |heat  |emis|abs |resis|
    1  102 0.0250     0.160   600.  1000. 0.91 0.50     8. Light
plaster
    2    0 0.1500     0.000     0.     0. 0.99 0.99     1. air  0.17
0.17 0.17
    3  102 0.0250     0.160   600.  1000. 0.91 0.50     8. Light
plaster
 Standardised U value =    1.51

 Details of opaque composite: ceiling

 Layer|Prim|Thick |Conduc-|Density|Specif|IR  |Solr|Diffu|Descr
      |db  | (m)  |tivity |       |heat  |emis|abs |resis|
    1  221 0.0250     0.060   186.  1360. 0.90 0.60    10. Wilton
    2   65 0.0250     0.140   600.  1210. 0.91 0.65    14. Flooring
    3    0 0.1500     0.000     0.     0. 0.99 0.99     1. air  0.17
0.17 0.17
    4  102 0.0250     0.160   600.  1000. 0.91 0.50     8. Light
plaster
 Standardised U value =    0.91

 Details of opaque composite: upper_flor

 Layer|Prim|Thick |Conduc-|Density|Specif|IR  |Solr|Diffu|Descr
      |db  | (m)  |tivity |       |heat  |emis|abs |resis|
    1  102 0.0250     0.160   600.  1000. 0.91 0.50     8. Light
plaster
    2  216 0.1500     0.040   105.  1800. 0.90 0.60     1. Mineral
fibre
    3   65 0.0250     0.140   600.  1210. 0.91 0.65    14. Flooring
    4  221 0.0250     0.060   186.  1360. 0.90 0.60    10. Wilton
 Standardised U value =    0.21

 Details of opaque composite: loft_ceil

 Layer|Prim|Thick |Conduc-|Density|Specif|IR  |Solr|Diffu|Descr
      |db  | (m)  |tivity |       |heat  |emis|abs |resis|
    1   67 0.0200     0.150   800.  2093. 0.91 0.65    96. Chipboard
    2  102 0.0050     0.160   600.  1000. 0.91 0.50     8. Light
plaster
 Standardised U value =    2.92
```

```
 Details of opaque composite: loft_floor

 Layer|Prim|Thick |Conduc-|Density|Specif|IR  |Solr|Diffu|Descr
      |db  | (m)  |tivity |       |heat  |emis|abs |resis|
    1  102 0.0050     0.160   600.  1000. 0.91 0.50     8. Light
plaster
    2   67 0.0200     0.150   800.  2093. 0.91 0.65    96. Chipboard
 Standardised U value =    2.92
```