ARTLETT SCHOOL OF GRADUATE STUDIES

UCL

REFURBISHMENT OF A VICTORIAN TERRACED HOUSE FOR ENERGY EFFICIENCY

by

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Abstract

The impacts of global warming are now obvious. The international community has committed itself to reduce CO_2 emissions, the main contributor to the greenhouse effect, both at international and national levels. In the Kyoto Protocol signed in 1997, countries have committed to reduce their greenhouse gases emissions below their 1990 levels by the period 2008-2012. The UK specifically should reduce those emissions by 12.5%. For that reason, the UK has introduced a package of policies, which promote not only the use of renewable energy resources, but most importantly the reduction in energy use, with energy efficiency. Refurbishment of existing houses has and will contribute to the reduction of energy consumption.

A Victorian mid-terraced house was studied in this report, and different refurbishment measures were tested, using two software programmes: TAS and SAP. The targets were to achieve certain levels of thermal comfort, to comply with the Building Regulation for building thermal elements and to achieve a high SAP rating. Then, the cost of each measure was calculated and its CO_2 emissions were compared.

Heat losses were mainly through the walls and roof. Roof and mainly wall refurbishment measures reduce the heating loads the most. Ground floor insulation does not contribute to the reduction of the heating loads, on the contrary it has detrimental effect in summer, where the cooling effect coming from the ground is being reduced. Window replacement achieves a very good performance in summer resulting in the reduction of overheating.

Wall and roof insulation increase the SAP rating the most, between the building elements, but boiler replacement and upgrading of heating controls increase it more. According to the SAP rating, CO_2 annual emissions are reduced the most by boiler replacement and then by wall and roof. The results given by the two softwares concerning which measure is more leads more to energy efficiency, are the same.

Finally, if the measures which lead to the best energy performance are combined together, then the house could cut its energy bills by half, and could have 70% reduction in CO_2 emissions.

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1. Introduction

The impacts of global warming are now obvious. The developed industrial countries have signed commitments to reduce CO_2 emissions, the main contributor to the greenhouse effect, both at international and national levels. The UK, participating in those commitments has introduced a package of policies to achieve this aim.

Buildings' energy use accounts for half of the UK's energy consumption. Houses in particular are the main contributors to CO_2 emissions, and their overall energy consumption is one of the largest in the UK. This is due to the fact that generally the UK housing stock is old. Many houses were built before the Building Regulations for energy efficiency, Part L-'Conservation of heat and power'[1], and despite the fact that some of the old buildings have been partly or in a whole refurbished, many of them cannot meet today's increasingly strict Building Regulations, and therefore their contribution to the reduction of energy consumption is negligible. For that reason, there is an increasing concern in refurbishing a house, which gains ground against demolition and rebuild. This report covers the issue of designing a refurbishment scheme, and an outline is given next.

[1] Office of the Deputy Prime Minister (ODPM); The Building Regulations 2006-Approved document L1-Conservation of fuel and power

2. Report Outline

The aim if this report is to study:

- Global warming and its causes, the policies that are taken both at an international and national level in the UK to reduce its impacts.

- The condition of the English housing stock, laying emphasis on the fabric of the stock (levels of insulation, SAP rating) and the reasons why refurbishment should be considered or not.

- The change in the energy consumption of a base house due to each measure applied, using TAS and calculating the resultant SAP rating of each measure.

- The cost of each measure, by breaking down each measure into the parts that is consisted of, and the payback period is calculated, using the heating savings from TAS analysis.

- CO_2 emissions and savings due to heating after the implementation of each measure.

3. Climate change

3.1 Greenhouse effect

Solar radiation enters the earth's atmosphere, where some of it is absorbed and some reemitted in the atmosphere as radiation in the near-infrared wavelength. This radiation is then trapped by the greenhouse gases, and a part of it is emitted to the space, while another part is radiated back to the earth, thus warming it. The natural greenhouse gases which contribute the most to this phenomenon are mainly water vapour, but also carbon dioxide (CO_2), methane (CH_4), and nitrous oxide (N_2O). Without these gases the earth would be 33°C colder[2]. But human activity, such as burning fossil fuels and deforestation, has enhanced this phenomenon by emitting more greenhouse gases, resulting in a climate change which is faster than the natural climate change rate.

3.2 Man's contribution to the greenhouse effect

The concentration of CO_2 in the atmosphere is the highest for a million years[3]. Before the Industrial Revolution the concentration of CO_2 in the atmosphere was 270 ppmv, and by 2003 it had increased to 380 ppmv[4]. Since 1990 the global temperature has increased by 0.2 °C[5], making it the warmest decade since climate records began[6], during this time the CO_2 concentration in the atmosphere has risen from 354 ppm to 380 ppm[7]. The 10 hottest years recorded have happened since 1983[8]. Due to the CO_2 already emitted, the temperature is expected to rise between 1.4 and 5.8 °C during this century[9].

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[2] Flewitt, Ian; *The role of residential refurbishment in reducing CO_2 emissions in the UK*, Thesis 2000, p 7.
[3] Royal Commission on Environmental Pollution; *Twenty-second Report, Energy-the changing climate.* Chairman: Sir Tom Blundell, June 2000, p 1.
[4] Washington Worldwatch Institute, taken from "Smith, Peter F.; *Eco-refurbishment: a guide to saving and producing energy in the home*, p..."
[5] HM Government; *Climate change – The UK programme 2006*, March 2006, p iii.
[6] Department for Trade and Industry (DTI); *Energy White Paper: our energy future-creating a low carbon economy*, 2003, p 6.
[7] HM Government; *Climate change – The UK programme 2006*, March 2006, p iii.
[8] Flewitt, Ian; *The role of residential refurbishment in reducing CO_2 emissions in the UK*, Thesis 2000, p 8.
[9] Department for Trade and Industry (DTI); *Energy White Paper: our energy future-creating a low carbon economy*, 2003, p 21.

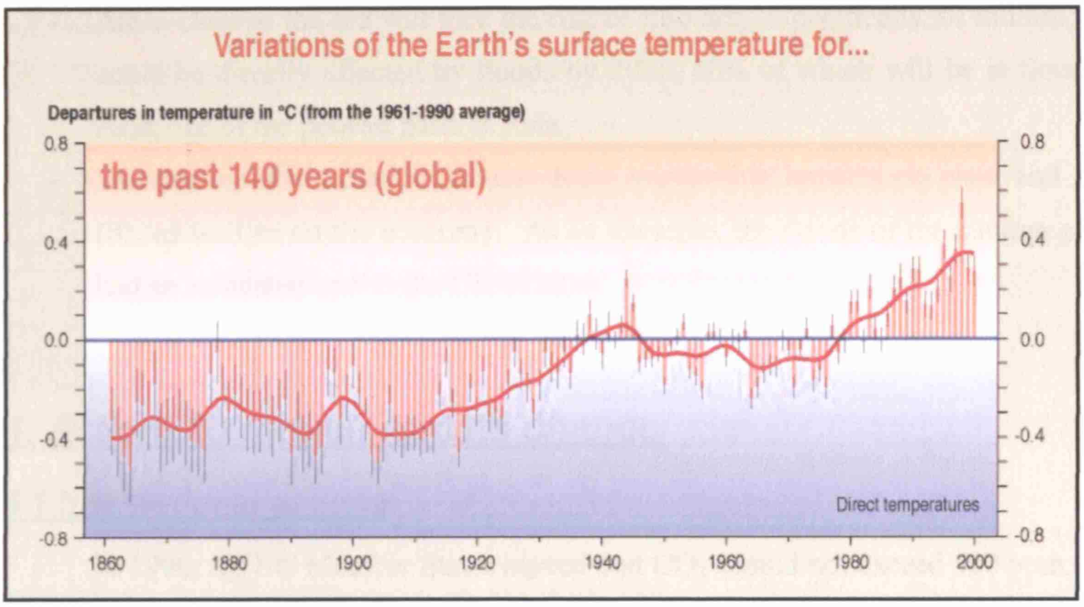

Figure 3.1. Variations on the earth's global temperature sine the industrial revolution (produced by the Intergovernmental Panel on Climate Change (IPCC)[10])

3.3 Consequences of climate change

Some of the evidence for the climate change is given below[11]:

- the ice on the peaks of mountains, like in Kilimanjaro, is being reduced.
- average sea level has risen by 1-2 cm during the last century.
- since the 1960's the snow cover on the earth has decreased by 10%
- increase of droughts in Asia and Africa during the last decades[12].
- 0.5-1% increase of precipitation in mid and high level areas in the northern hemisphere[13].

If the climate keeps changing at the same rate, its impact on life will be disastrous.

In particular:

- By 2080 the global temperature will be increased by 3°C[14].

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[10] http://www.grida.no/climate/ipcc_tar/slides/05.16.htm

[11] Department for Trade and Industry (DTI); *Energy White Paper: our energy future-creating a low carbon economy*, 2003, p 7.

[12] BBC website for Climate Change http://www.bbc.co.uk/climate/

[13] BBC website for Climate Change http://www.bbc.co.uk/climate/

[14] Flewitt, Ian; *The role of residential refurbishment in reducing CO_2 emissions in the UK*, Thesis 2000, p 7.

- Areas close to the sea will face the risk of flooding. Specifically 80 million people could be directly affected by floods by 2080, 60% of which will be in South East Asia, one of the poorest parts in Asia.
- Extreme weather conditions could have irreversible impacts on plant and animal life, as well as on the economy. As an example, the floods of the autumn of 2000 had an estimated cost to the UK of £1bn.

4. Actions to reduce climate change

4.1 International actions

In 1990, the EU Member States agreed that CO_2 should not exceed 550 ppm, which is double the concentration before the industrial revolution, and that the global temperature should not increase beyond 2°C compared to pre-industrial revolution era[15].

In 1992 a treaty was signed by the United Nations Framework Convention on Climate change, where 153 countries took part. According to this treaty, the developed countries should, by 2000, return the emission of their greenhouse gases to their 1990 levels. In the latest convention the Kyoto Protocol was signed in December 1997 in Kyoto, Japan, under which the developed countries should reduce their emissions of greenhouse gases by 5.2% below the 1990 levels, by the period 2008-12. The Kyoto basket, as the greenhouse gases that it includes are called, includes: carbon dioxide (CO_2), methane (CH_4), nitrous oxide (N_2O), hydrofluorocarbons (HFCs), perfluorocarbons (PFCs) and sulphur hexafluoride (SF_6). The EU agreed to reduce them by 8%, which would be shared out between the Member States. Under this agreement, the UK should reduce its CO_2 emissions by 12.5% compared to 1990 levels by the period 2008-2012.

The European Climate Change Programme (ECCP) started in 2000 and its aim is to set the essential elements for the EU countries to meet the Kyoto protocol. Its package of measures includes the EU Emissions Trading Scheme (Directive 2003/87/EC), the promotion both of biofuels (Directive 2003/30/EC) and of electricity produced by renewable energy resources (Directive 2001/77/EC) and the energy performance of buildings[16] (Directive 2002/91/EC). The first phase of the Emissions Trading Scheme started in 1 January 2005 and will last until 2007. The only greenhouse gas yet included in

[15] Department for Trade and Industry (DTI); *Energy White Paper: our energy future-creating a low carbon economy*, 2003, p 23.
[16] HM Government; Climate change – The UK programme 2006, March 2006, p 20.

the Scheme is CO_2. Four countries out of the 25 EU states – Italy, the Czech Republic, Greece and Poland- have not yet taken part to the Scheme.

4.2 The UK Energy Situation

The UK's energy demand is rising steadily, due to the growth of population, the increasing number of dwellings, the increasing travel and the economic growth which results in an increase of goods produced[17]. However, although since the 1970's the UK economy has doubled, the energy consumption has increased only by 15%[18], but still the energy consumption should be decreased.

The UK is responsible for 2% of global greenhouse gas emissions. Its national goal goes beyond the Kyoto Protocol and it is to reduce the emission of greenhouse gases by 20% by 2010 and by 60% by 2050. This challenge will be met by increasing the use of renewable energy resources, but more efficiently it will be met by a package of policies and regulations to reduce energy demand, by increasing the energy efficiency[19]. It is expected that half of the reduction in energy consumption by 2010 will come from energy efficiency, which is 10MtC[20]. In 2002, only 3% of the UK's electricity was generated by renewable resources, and 23% was generated in nuclear power stations, which is also a carbon-free technology, but there is the issue of nuclear waste[21]. The UK national goal is to provide 10% of energy from renewable sources by 2010.

4.3 UK actions to reduce climate change

Apart from the international commitments, the UK has set some national commitments and goals. Some of them are:

- The *UK Climate Change Programme 2006*[22] was published on 28 March 2006 and it is a review of the already existing programme. This programme summarises the

[17] Royal Commission on Environmental Pollution; *Twenty-second Report, Energy-the changing climate*. Chairman: Sir Tom Blundell, June 2000, p 4.
[18] Department for Trade and Industry (DTI); *Energy White Paper: our energy future-creating a low carbon economy*, 2003, p 26.
[19] HM Government; Climate change – The UK programme 2006, March 2006, p iii.
[20] Department for Trade and Industry (DTI); *Energy White Paper: our energy future-creating a low carbon economy*, 2003, p 32.
[21] Department for Trade and Industry (DTI); *Energy White Paper: our energy future-creating a low carbon economy*, 2003, p 8, taken from DTI estimates for 2002 on gross supplied basis based on Digest of UK Energy Statistics, table 5.6.
[22] HM Government; *Climate change – The UK programme 2006*, March 2006.

effects of global warming, the actions that the UK has taken and actions that it should take.

- In the 2003 *Energy White Paper*, the UK reinforces its commitment to sustainable policy[23] and sets four long-term goals[24]:

- To reduce CO_2 emissions by 60% by 2050.
- To reinforce the economy by developing the competitiveness of the market
- To reassure the energy supply
- To eliminate fuel poverty

- *Energy Efficiency Commitment (EEC)*, which is a package of policies and its aim is to encourage and assure the increasing energy efficiency in buildings. Its first phase started in April 2002 and ended in March 2005, and a saving of 0.37 MtC per annum is expected by 2010. The second phase started in April 2005 and it will last until March 2008, and the carbon savings are expected to be 0.62 MtC annually by 2010[25].
- *Building Regulations.* Each version of the Building Regulations introduces tighter measures to apply to new and existing buildings. The same Building regulations do note apply to the whole of the UK. England and Wales have the same Building Regulations, whereas Scotland and North Ireland have different ones.

  The latest version of the Building Regulations (2006 revision) will reduce the fuel bills of new-built houses by up to 40% and improve their efficiency by the same amount[26], compared to houses built before the Regulations of April 2002. Since 1990 the new buildings have been 70% more energy efficient[27]. The Building Regulations 2006 have increased the energy efficiency by a further 22% for houses, 27% for non-domestic buildings and 18% for flats, and are expected to save 0.75MtC carbon by 2010[28].
- *Code for Sustainable Homes*

It applies to all buildings, but it focuses at homes in particular and it will introduce standards which are voluntary and go beyond the Building Regulations, thus contributing to a further increase of energy efficiency in housing. The minimum standards in this Code, which include water and energy efficiency, are higher than those in Building

[23] As it is described in *A better quality of life: a strategy for sustainable development in the UK, May 1999.*
[24] HM Government; *Climate change – The UK programme 2006*, March 2006, p 34.
[25] HM Government; *Climate change – The UK programme 2006*, March 2006, p 78.
[26] HM Government; *Climate change – The UK programme 2006*, March 2006, p 80.
[27] HM Government; *Climate change – The UK programme 2006*, March 2006, p 80.
[28] HM Government; *Climate change – The UK programme 2006*, March 2006, p 80.

Regulations[29]. Houses can gain more Code points by having electricity generation from renewables, such as wind turbine. This Code will, also, set the foundations for the next revision of the Building Regulations.

- *EU Energy Performance of Buildings Directive (EUPD)*

It sets minimum energy standards for the performance of new buildings and for large existing buildings which will be renovated[30]. It includes the regular inspection of boilers and air-conditioning systems, which could deliver 0.2MtC carbon savings by 2010. Moreover, in buildings with an area more than 1000sqm, the use of renewables and CHP should be considered.

- *Renewables Obligation*[31], signed in April 2002, by which suppliers in England and Wales should rely more and more their electricity generation on renewable resources.
- *Climate Change Levy*

It was introduced in April 2001 and its aim is to reduce the emissions from business. Any money gained from the levy is given back to the firms as grants to promote energy saving measures. Moreover, firms which use renewable energy can avoid the levy.

- SAP, as explained in a next chapter (Chapter 7).

4.4 Future UK actions

- *Home Information Packs*[32]

It will be introduced in June 2007, and it will provide the possible buyers of a property with the 'Home Condition Report', which will include a survey about the energy performance of the house, as well as actions that could be taken to increase the energy efficiency further.

[29] HM Government; Climate change – The UK programme 2006, March 2006, p 81.
[30] HM Government; Climate change – The UK programme 2006, March 2006, p 82.
[31] Department for Trade and Industry (DTI); *Energy White Paper: our energy future-creating a low carbon economy*, 2003, p 12.
[32] HM Government; Climate change – The UK programme 2006, March 2006, p 82.

5. Refurbishing the UK housing stock

Houses account for the 27% of the UK's CO_2 emissions and for the 30% of its energy consumption[33] most of which is used for water and space heating (up to 60%[34]). A possible action to improve the UK response to climate change is to refurbish some of the housing stock. In that way houses are more energy efficient, so they will reduce energy consumption and gas emissions. This report considers the possibilities of this action.

5.1 The UK housing stock

Every five years the condition of the English housing stock is being surveyed. The latest English House Condition survey was held in 2001. According to the Survey there were 21.1 million dwellings in England in 2001, 0.8 million more than in the previous survey in 1996, with semi-detached houses accounting for 28% of the stock, which makes them the most common type of dwelling. In this 5 years period 99 thousand dwellings were demolished, whereas most of the new dwellings were new-built and 100 thousand were from building conversions. Moreover, there are 20.5 million households in England, whereas in 1996 there were 19.7 million.

There are 7 million non-decent homes[35] in England, one third of which was built before 1919, and the most common reason that they are characterized as non-decent, is that they cannot provide the occupants with good levels of thermal comfort. Specifically, a 26% of the housing stock fails to do this. Terraced houses have more probabilities to be non-decent, compared to other types of dwellings. There are 416000 small terraced houses in England[36].

7 million dwellings have solid walls, most of which have not been insulated in a refurbishment process. More houses have loft insulation compared to 1996 figures. In particular 93% of them had loft insulation in 1996, compared to 95% in 2001.

The average SAP rating has increased since the last survey in 1996 from 44 to 51[37]. Houses built before 1919 have the lowest average SAP rating of 41, whereas post 1980 have 63. The average cost to make a home decent is £7,200, resulting in a total cost of £50

[33] HM Government; *Climate change – The UK programme 2006*, March 2006, p 75.
[34] Smith, Peter; *Eco-refurbishment: a guide to saving and producing energy in the home*, 2004, p 2.
[35] Decent homes are described in the 'Office of the Deputy Prime Minister (ODPM); *English House Condition Survey: 2001 Key facts*' p 8, as the houses which "***meet the statutory minimum standard for housing (ie be fit), be in a reasonable state of repair, have reasonably modern facilities and services; and provide a reasonable degree of thermal comfort***".
[36] Office of the Deputy Prime Minister (ODPM); *English House Condition Survey: 2001 Key facts*, p 22.
[37] Office of the Deputy Prime Minister (ODPM); *English House Condition Survey: 2001 Key facts*, p 27.

billion. 40% would require less than £1,000, but 10% of the non-decent home would more than £20,000.

A 39% of the housing stock (8.1 million houses) was built before 1945, and 21% (4.4 million houses) was built before 1919[38], so the housing stock is generally old, especially in rural areas and in city and village centres (Picture 2). 68% of the stock built before 1919 is terraced houses or flats which have been converted.

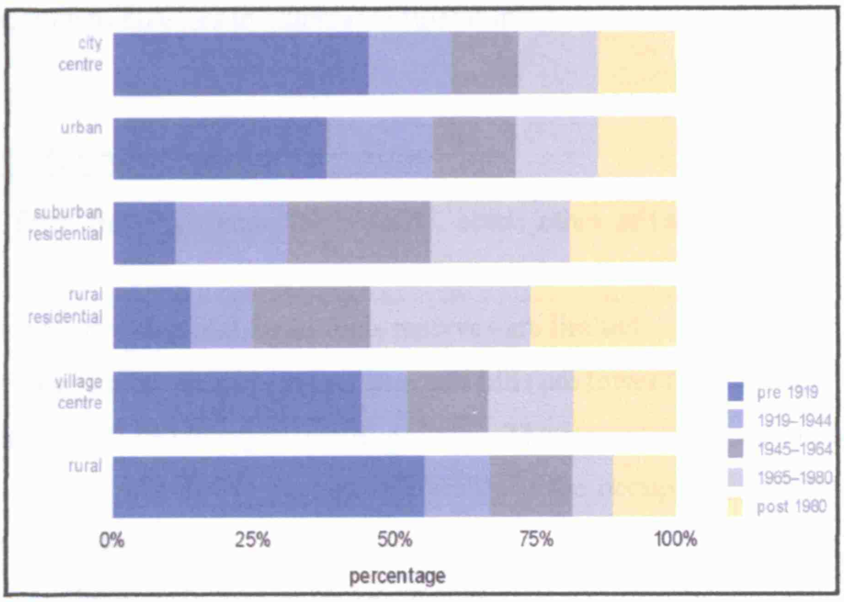

Figure 5.1. Age of dwellings by type of area[39].

In 2000, 68% of the houses were built before the implementation of the Building Regulations for minimum insulation requirements[40]. However, about 76% of the dwellings have double glazing, and 94% of them have central or programmable heating. 91% of the 86% of the houses that use central heating system are gas fuelled.

More than 85% of the houses which were built before 1965 do not have wall insulation. Most of the houses in England and Wales and almost all of them in Scotland, which were built before the 1940's have suspended timber ground floors which causes draughts from the void to the interior[41], and much of the UK housing stock is insulated well below the Building Regulations.

Reducing the energy consumption of a house contributes to the reduction of CO_2 mainly. The other 5 greenhouse gases covered by the Kyoto protocol are affected in a very

[38] Office of the Deputy Prime Minister (ODPM); *English House Condition Survey: 2001 Key facts,* p 4.
[39] The chart was taken from 'Office of the Deputy Prime Minister (ODPM); *English House Condition Survey: 2001 Key facts',* p 4.
[40] Flewitt, Ian; *The role of residential refurbishment in reducing CO_2 emissions in the UK*, Thesis 2000.
[41] Department of the Environment; *Energy efficient renovation of houses,* 1986, p 6.

small range, because these are mainly emitted by the manufacturing industry. But the production of buildings products contributes to their emission[42].

In 1990, the emission of greenhouse gases due to houses were 45.8 MtC and they were emitted due to electricity production and improved energy performance of houses, although without the increasing demand for warmer houses and more house entertainment the figures would be even lower. A smaller contribution to these changes was done by other factors, such as changes in external temperatures[43].

5.2 Reasons for refurbishing a house

Apart from the environmental benefits, some other advantages of refurbishing a house are:

-Oil prices are rising and fossil fuels reserves are limited.

-Refurbishing a house adds to its value and bills are lower (up to 50%)[44].

-Refurbishment discourages mould growth. The impact of houses with no or with poor insulation has a negative impact on the health of the occupants, and this is an issue which is often overlooked.

-Increased thermal comfort of the occupants.

-Financial benefits compared to demolition and reconstruction (50-80% of the cost), plus half to ¾ saving in time[45]. Not only it takes more time to demolish and rebuild a house, but also the design before the contract and the planning permission require more time.

5.4 Reasons for not considering refurbishment

However, in some cases refurbishment is not cost effective, for example when the use of the building should be changed or major alterations should take place. In that case demolition should be considered, unless the building is listed because of its historical or architectural value.

[42] Flewitt, Ian; *The role of residential refurbishment in reducing CO_2 emissions in the UK*, Thesis 2000, p 10.
[43] HM Government; *Climate change – The UK programme 2006, March 2006*, p 74.
[44] Smith, Peter; *Eco-refurbishment: a guide to saving and producing energy in the home*, 2004, p 2.
[45] Highfield, David; *Refurbishment and upgrading of buildings*, London, 2000, p 1.

5.5 Previous case studies

- *Liverpool, refurbishment of 25 pre-1919 terraced houses* by Merseyside Improved Houses in 1989[46]. Internal insulation was applied and special care was given to ventilation. The annual space heating savings due to refurbishment were £51 for every house. In addition, higher thermal comfort levels and the reduced condensation mould growth levels provided extra savings due to smaller requirement of frequent redecoration. The houses became more desirable, and there were aesthetic benefits. After monitoring for two years similar houses, insulated spent 20GJ (5555 kWh) annually for space heating, whereas uninsulated ones 31 GJ (8611 kWh) annually. Savings of £40 per year with 1989 gas prices £3.6 per GJ (£0.0036 per kWh). Insulated houses had average 10hrs per day heating on, and uninsulated ones 14 hrs.

- *Reading, refurbishment of Victorian houses*, started in 1999[47]. This was an EU-funded programme in West Reading, where fifty late Victorian terraced and semi-detached houses were refurbished. Walls, ground floor and roof were all insulated, windows were replaced with double-glazed ones, the heating system was upgraded and sunspaces were introduced. After monitoring in four of the houses, it was found that energy consumption was reduced by 38%, and that the houses provided the occypants with thermal comfort.

- *Nottingham 'Ecohome'*[48]. It is a refurbished Victorian house in West Bridgford, Nottingham which has very low U-values and integrated renewable energy. The walls were refurbished with a combination of internal and external wall insulation, insulation was introduced to ground floor and roof and the windows were replace either with double-glazed argon-filled, or triple glazed krypton-filled ones. Special care was given to ventilation and to prevent thermal bridging. The heating system was also upgraded and a solar panel for hot water was installed. There are not exact figures of the cut in energy consumption, but the occupiers expected to have electricity bills one fifth than the previous ones.

[46] Department of Energy; *Good Practice Case Study 4: Refurbishment of pre-1919 terraced housing*, Best Practice programme
[47] Part L1 (2002) in existing dwellings, *'Reading case study'*.
[48] Part L1 (2002) in existing dwellings, '*The Nottingham 'Ecohome''*.

6. Overview of refurbishment options

Commonly, there are some basic ways of refurbishing a building element and each of these ways has a wide range of options, the choice of which depends on several factors, such as the cost, the availability of materials and the suitability of the option in a particular case. The basic refurbishment options available are given next.

6.1 General about refurbishment options

6.1.1. External Walls

There are two methods of adding insulation in solid walls:

- Internal insulation (dry lining)
- External insulation (overcladding), which has higher capital cost[49]

Choosing between internal and external additional insulation depends, apart from whether the external surface has architectural value, on the periods that the building is being heated and the thermal capacity of the walls. In the case where the building is not heated continuously, internal insulation is more appropriate, so that it heats up quickly, although in this case heat is not stored and the risk of condensation is higher[50]. If the walls are thick and the building is heated continuously or when the walls are thin with low thermal capacity regardless the heating periods, then external insulation is appropriate. Another option is a combination of overcladding and internal insulation[51].

Some advantages of external insulation versus internal insulation are:

- Internal insulation reduces living space, which also leads to the economical disadvantage of the reduced value of the house. The U-value of the walls in the next revision of the Building Regulations in 2010 is expected to be 0.20 W/m^2K, which will be more difficult to achieve. It will require thicker wall insulation, thus choosing the option of internal insulation will reduce even more the internal area, unless the properties of the insulants are improved.
- During the installation of the internal insulation, the occupants should move out of the house, so more money should be spent on their temporary accommodation. During the installation of external insulation the building could be occupied.

[49] Department of the Environment; *Energy efficient renovation of houses*, 1986, p 23.
[50] Highfield, David; *Refurbishment and upgrading of buildings*, London, 2000, p 41.
[51] Smith, Peter F.; *Eco-refurbishment: a guide to saving and producing energy in the home*, p. 25.

- External insulation leaves the inside wall uninsulated which can act as a thermal mass, so it leads to better thermal performance.
- It protects the building fabric from external factors, such as weather conditions.
- It reduces thermal bridges which can lead to condensation and heat loss.
- Fast installation.

However, there are possible problems from external insulation, and these are:

- Alteration of the façade of the building. It should be checked whether the planning authorities allow this.
- The position of the windows should possibly be changed due to the increased thickness of the wall towards the external.
- If the ground floor is not suspended, then the additional insulation should be installed on the inside.

External walls - Internal insulation

Internal insulation can be installed by fixing the insulant on the wall, with a finishing of plasterboard with a plaster coat[52] [53], which can be done as follows[54]:

- with timber batten or metal fixing dry-linings on the internal surface of the wall and insulation between.
- with linings with pre-bonded insulation

It is generally accepted a reduction of less than 5% loss of the internal space area[55].

A vapour barrier, which is usually a polyethylene sheet or plastic membranes, is essential in order to eliminate the moisture penetration through the wall, thus reducing the risk of condensation. In cold and cool climate is placed between the insulant and the plasterboard, that is, closer to the internal side of the wall, because usually the internal temperature is higher than the external.

External walls - External insulation

There are two methods of installing external insulation[56] (overcladding):

- Fixing an insulation board and above it a waterproof render

[52] Smith, Peter F.; *Eco-refurbishment: a guide to saving and producing energy in the home*, p. 25.
[53] Highfield, David; *Refurbishment and upgrading of buildings, London*, 2000, p 42-45.
[54] Highfield, David; *Refurbishment and upgrading of buildings, London*, 2000, p 42-45.
[55] The Building Regulations 2006, p 29.
[56] Smith, Peter F.; *Eco-refurbishment: a guide to saving and producing energy in the home*, p 19

- Spray or trowel a thick render coat containing an insulant on the external face of the wall.

There are many render systems, but the most common are either a cement/sand render placed on a wire mesh, or a polymer cement render on a fibre mesh[57].

6.1.2. Internal walls

If they are not in a bad condition, they usually require only a cover of paint or wallcovering. In cases where the building fabric is old, demolition of the walls may be required. Plaster finishes or dry linings could be applied[58].

6.1.3. Floors

For solid ground floors an insulation layer is placed either above or below the concrete slab. When it is placed above the slab, then further work should be done due to the rise of floor level, such as relocating doors. A damp-proof membrane should be placed above the existing concrete layer, to prevent any moisture escaping from the concrete to the insulation[59].

In the case of internal floors, insulation can be introduced between joists.

6.1.4. Roof

For pitched roof the best option is mineral wool, although from an environmental point of view cork, cellulose and sheep's wool are preferred, but cellulose can only be used when moisture is not a problem and cork is expensive. Polyurethane (PUR) foam and extruded polystyrene are not recommended, due to the damage to the ozone layer[60]. The insulants that are approved by the British Standards are: blown mineral wool, mineral quilt and blown cellulose fibre.

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[57] Energy Saving Trust; *CE184 - Practical refurbishment of solid wall houses*, p 11.
[58] Highfield, David; *Refurbishment and upgrading of buildings, London*, 2000, p 33-37.
[59] Energy Saving Trust; *CE184 - Practical refurbishment of solid wall houses*, p 9.
[60] Anink, David; Boonstra, Chiel; Mak, John; *Handbook of sustainable building, an environmental preference method for selection of materials for use in construction and refurbishment*, London, 1996, p 50.

6.1.5. Windows

All single glazed windows should be replaced with double or triple glazed ones, preferably with a low e-coating to keep the heat inside and argon-filled, to reduce further the U-value.

6.1.6. Lighting

Existing low-energy lamps should be replaced with energy efficient ones.

6.1.7. Ventilation

Controlled ventilation should be introduced to replace draughts and uncontrolled ventilation. This can be provided by trickle ventilators on the windows. Extract fans should be placed in kitchen and bathroom and unused fireplaces should be closed with air-bricks.

6.2 Insulants

The insulants tested were:

Table 6.1 – Insulants used in the report

Type of insulation	*Specific heat (J/kgC)*	*Density (kg/m3)*	*Conductivity (W/mK)*
Polystyrene expanded (closed cell)	1200	25	0.03
Glass fibre	833	12	0.04
Mineral wool board	1050	240	0.05
Polyurethane board	1400	30	0.03
Cork boards	1800	130	0.04

6.3 Detailed discussion of refurbishment options

The options that were tested are shown next. For each option, apart from windows and lighting, a basic structure was made and then different kinds and thicknesses of insulants were applied, in order to simplify the comparison process and to gather conclusions about the insulants more easily.

6.3.1. Wall Options – Internal insulation

The basic structure of the options of internal insulation is as follows, and the options tested are given next (Table 6.2.):

Table 6.2 - Internal insulation options – Basic construction

Material	**Specific heat (J/kgC)**	**Density (kg/m³)**	**Conductivity (W/mK)**	**Width (mm)**
White paint flat	0	0	1000	0.1
Plasterboard, foiled backed	837	960	0.18	15
Insulation layer	-	-	-	-
Common brick*	920	1790	0.72	225

* Already existing

Table 6.3. – External walls - Internal insulation options

Options		**U-value (W/m^2K)**
Internal 1a -	80 mm expanded polystyrene	0.334
Internal 1b -	90 mm expanded polystyrene	0.304
Internal 2a -	100 mm glass fibre	0.328
Internal 2b -	120 mm glass fibre	0.282
Internal 3a -	120 mm mineral wool board	0.328
Internal 3b -	120 mm mineral wool board and 20 mm cavity upward flow	0.312

In order to test if the loss in the floor area due to internal insulation is accepted by the Building Regulations, the next Table was constructed.

Table 6.4. Internal area of external walls, and total floor area.

Length of external walls (measured internally) (m)			
Ground floor	**First floor**	**Total**	**Total Floor Area (m2)**
16.428	15.166	31.594	103.173

The reduction of the floor area due to the internal insulation is calculated in the next Table. All option result in a loss of floor area of less than 5%, so it is accepted by the Building Regulations.

Table 6.5. – Loss of floor area, due to internal insulation

	Thickness (m)	Area of internal insulation (m^2)	Proportion of total area of the house
Internal1a	0.093	2.922	0.028
Internal1b	0.105	3.317	0.032
Internal2a	0.113	3.554	0.034
Internal2b	0.133	4.186	0.041
Internal3a	0.133	4.186	0.041
Internal3b	0.153	4.818	0.047

6.3.2. Wall Options – External insulation

The method that was tested was the one with the render above the insulant. The basic structure of the options can be found in the next Table.

Table 6.6. - External insulation options - Basic construction

Material	Specific heat (J/kgC)	Density (kg/m3)	Conductivity (W/mK)	Width (mm)
White paint flat	0	0	1000	0.1
Plasterboard, foiled backed	837	960	0.18	12.5
Common brick*	920	1790	0.72	225
Insulation layer	-	-	-	-
Cement rendering	739	1300	0.5	20
White paint flat	0	0	1000	0.1

*Already existing

The options here are:

Table 6.7. External walls – External insulation options

Options		U-value (W/m2K)
External 1a -	80 mm expanded polystyrene	0.332
External 1b -	100 mm expanded polystyrene	0.276
External 2a -	120 mm mineral wool board	0.323
External 2b -	140 mm mineral wool board	0.285
External 3a -	100 mm glass fibre	0.328
External 3b -	120 mm glass fibre	0.282

6.3.3. Ground floor options – insulation above concrete slab

The basic construction of the ground floor options and the insulation layers tested are shown next.

Table 6.8 - Ground floor options - insulation above concrete slab-base construction

Material	Specific heat (J/kgC)	Density (kg/m^3)	Conductivity (W/mK)	Width (mm)
Carpet	1360	186	0.06	10
Softwood	1760	500	0.14	20
Insulation	-	-	-	-
Concrete 3% m.c.*	920	2200	1.45	100
Crashed brick aggregate*	1057	1580	0.55	70
Dark clay*	1840	1280	0.7	1000

*Already existing

Table 6.9. - Ground floor options - insulation above concrete slab

Options		U-value (W/m^{2}K)
Ground 1a -	90 mm mineral wool boards	0.249
Ground 1b -	100 mm mineral wool boards	0.237
Ground 2a -	80 mm expanded polystyrene	0.219
Ground 2b -	100 mm expanded polystyrene	0.193
Ground 3a -	80 mm glass fibre	0.241
Ground 3b -	100 mm glass fibre	0.215

6.3.4. Ground floor options – insulation below concrete slab

This option is better, in south facing rooms, because the concrete can act as a thermal mass, and stabilise internal temperatures, both in summer and in winter, but only if the new concrete slab is exposed, without any covering, such as carpet, on it.

Insulating below a new concrete slab will result in a rise of the floor level. The doors on that floor should be accordingly adjusted by reducing their heights, but again it could cause problems, like uneven height of staircases.

The damp-proof membrane can be placed either above or below the new concrete slab.

Table 6.10 - Ground floor options - insulation below concrete slab-base construction

Material	Specific heat (J/kgC)	Density (kg/m^3)	Conductivity (W/mK)	Width (mm)
Carpet	1360	186	0.06	10
Concrete screed	1000	2100	1.28	100
Insulation	-	-	-	-
Concrete 3% m.c.*	920	2200	1.45	100
Crashed brick aggregate*	1057	1580	0.55	70
Dark clay*	1840	1280	0.7	1000

*Already existing

Table 6.11. - Ground floor options - insulation below concrete slab

Options	U-value (W/m^{2}K)
Ground 4a - 100 mm mineral wool boards	0.24
Ground 4b - 120 mm mineral wool boards	0.22

6.3.5. Roof options

The insulation was inserted at rafter level, with one layer of insulation between joists and another layer under them. There is also a ventilated cavity above the insulation and a bitumen felt, which acts as a waterproof layer and prevents the penetration of moisture.

Table 6.12. - Roof insulation options - Basic construction

Material	Specific heat (J/kgC)	Density (kg/m^3)	Conductivity (W/mK)	Width (mm)
Plaster	837	1200	0.42	12.5
Insulation layer	-	-	-	-
Cavity (upward flow)	-	-	-	50
Bitumen felt	1000	1055	0.16	1.5
Cavity (upward flow)	-	-	-	20
Grey slate*	753	2700	2	30

*Already existing in the base model

Table 6.13. - Roof insulation options

Options	U-value (W/m^{2}K)
Roof 1a - 160 mm expanded polystyrene	0.187
Roof 1b - 180 mm expanded polystyrene	0.168
Roof 2a - 120 mm polyurethane boards	0.188
Roof 2b - 140 mm polyurethane boards	0.163
Roof 3a - 180 mm cork boards	0.2
Roof 3b - 200 mm cork boards	0.181
Roof 4a - 220 mm mineral wool boards	0.196

6.3.6. Opening options

All the windows were replaced first with double-glazed ones and then with triple-glazed and low-e coated (Table 6.14 and detailed in Appendix B). Those options were tested again with argon filling. The external pane of the South-facing windows was selected to have good solar properties, and the frame thickness was increased from 25mm to 60mm with a U-value of 1.653 kg/m^{2}K. The method used to assess the windows was the U-value method, which is included in the Building Regulations. A newer approach is by the British Fenestration Rating Council (BFRC), which takes into account, not only the heat losses through the openings, but also the solar gains and heat losses from infiltration, thus giving a better view of their performance.

Table 6.14. Windows options

Options		**U-value (W/m^{2}K)**	
Windows1 -	Double glazed	South	1.953
		Others	1.757
Windows2 -	Double glazed, argon filled	South	1.637
		Others	1.417
Windows3 -	Triple glazed, low-e coating	South	1.088
		Others	1.025
Windows4 -	Triple glazed, low-e coating, argon filled	South	0.854
		Others	0.790

6.3.7. Ventilation

Although ventilation is a crucial part during a refurbishment, in the present project it was not tested, since the aim is not the air quality, but the thermal performance of the building.

6.3.8. Lighting

All Tungsten Filament lamps (GLS) were replaced with Compact Fluorescent (CFL) ones. CFL lamps are more efficient, they use less electricity for the same light output and their heat gains are less.

6.3.9. Heating options

The Building Regulations of the 2006 revision introduced changes to the boiler specifications. According to those changes, any new-installed boiler, either for new-build houses or replacement of an existing boiler, should be a condensing one. The boiler that was tested was a condensing combi boiler, 1998 or later, with automatic ignition, and it was tested for different options of controls.

7. Methodology

7.1. Building Simulation

Two software programmes were used for the comparison of the options. A simulation programme (TAS), and a programme which assesses the energy efficiency of a house (SAP). Both of them are presented next.

7.1.1. TAS

TAS is a software package which analyses the thermal performance of a building. There are three stages in the use of the software. At the first stage the building is being designed in 2D, or it can be imported from AutoCAD. Inserting the appropriate data, TAS can display the building in 3D. The building is zoned, so that the internal conditions can be different from zone to zone. At the second stage the building can be defined in more detail, such as the constructions of the building elements, the internal conditions (heat gains from occupants, lighting and equipment, infiltration and ventilation rates, heating and/or cooling controlled by a thermostat), aperture types and climate data. The third and final stage is a system and controls simulation. The output includes the conditions (such as internal temperature, humidity and relative humidity) in every zone, in an hourly basis.

TAS also includes a 2D Computational Fluid Dynamics (CFD) modeling programme, which was not used in this report. This modeling programme simulates the flow of the air within a room, and gives results for the microclimate of the room.

7.1.2. SAP

SAP is the Government's Standard Assessment Procedure for the evaluation of the energy performance of a house. The SAP rating is between 1 and 120, with energy efficiency increasing as the rating increases, and is based on the cost for space and water heating and it is adjusted to floor area, so it is not dependent on the size of the dwelling. For the calculation of SAP rating the occupancy levels and the heating regime are assumed, according to the floor area. The Carbon Index (CI) can be between 1 and 10, and it expresses an evaluation of the CO_2 emissions due to space and water heating. The SAP and CI ratings take into account the characteristics of the building, which are thermal insulation, solar gains, ventilation characteristics, fuel used control and efficiency of the heating system, but they are not affected by the individual characteristics of the occupants, such as size of the household, appliances and individual heating regimes. In SAP version 2001, the CI rating was introduced, highest SAP rating was increased from 100 to 120 and some other changes were made, in order to make the rating more independent of the floor area.

7.2. Refurbishment measure targets

The targets of the refurbishment were:

- To comply with the Building Regulations 2006 revision, regarding thermal properties of building elements and features of building services.
- To achieve a SAP rating of 75[61] or higher.
- To achieve the comfort levels for dwellings recommended by the CIBSE Guide A for winter and summer temperatures (Table 7.1).

Table 7.1. Recommended winter and summer temperatures[62].

Space type	Recommended winter dry bulb temperatures (°C)	Recommended Summer dry bulb temperatures (°C)
Bathroom	20-22	23-25
Bedroom	17-19	23-25
Hall/stairs/landings	19-24	21-25
Kitchen	17-19	21-23
Living room	22-23	23-25
Toilets	19-21	21-23

- To have the least possible cost, and the smallest possible payback period.
- To have the lowest possible CO_2 emissions due to space heating.

[61] Energy efficiency best practice in housing; *Good practice guide 155 – Energy efficient refurbishment of existing housing, p 7.*
[62] CIBSE; *CIBSE Guide A – Environmental Design*, Table 1.5, p 1-8.

7.3. Base case

Initially, a base model was constructed, and then its performance was compared with several options. Two software programmes were used: SAP version 2001, and TAS version 9.0.7. The options were chosen so that they would satisfy the requirements of the Building Regulations 2006 considering the U-values of the building elements.

According to the Regulations, renovation of a building element should be done especially to those elements which U-value is worse than the threshold U-value (Table 7.2) and trying to achieve the recommended U-values, but only if this is 'technically and functionally' possible and would payback in 15 years with a simple payback period. In cases where this is not possible, the U-value should be improved as close as possible to the recommended one[63].

Table 7.2. - Upgrading retained thermal elements[64]

Element	(a)Threshold value W/m^2K	(b)Improved value W/m^2K
Other wall type (than cavity wall)	0.70	0.35
Floor	0.70	0.25
Pitched roof - insulation at ceiling level	0.35	0.16
Pitched roof – insulation at rafter level	0.35	0.20

Table 7.3. - Reasonable provision when working on controlled fittings[65]

Fittings	Standard for replacement fittings in an existing dwelling
Windows, roof window and rooflight	U-value=2.00W/m^2K or Window energy rating=BandE; or Centre-pane U-value=1.2W/m^2K
Doors (less than 50% glazed)	3.0W/m^2K

The options tested include upgrading of the external walls, ground floor, openings and roof, as well as replacement of the light fittings. Specifically:

- External walls – insulation introduced (internal and external)
- Ground floor – insulation introduced
- Openings – replacement of glazing and frames

[63] The Building Regulations 2006 revision, part L1b, p 23.
[64] The Building Regulations 2006 revision, part L1b, p 23.
[65] The Building Regulations 2006 revision, part L1b, p 20.

- Roof – insulation introduced
- Lighting – replacement of existing lamps with more energy efficient ones

7.4 Assumptions

- In TAS simulations the vapour barrier was not taken into account, because after some simulations it was noticed that it does not affect the results in internal temperature or humidity. However, it is considered in the cost estimation
- No insulation was added between joists of the floors, since there are no heat losses through internal elements.
- In the ground floor constructions the damp-proof membrane was ignored in the TAS simulations, since it was noticed that it does not make any difference to the U-value of the construction
- Although the resultant U-value of the walls is less in the case of timber framing, compared to having plain insulation, in TAS simulations this was not taken into account in the cases where the insulation is installed with timber battens, that is for glass fibre and mineral wool boards.

8. Case study: Refurbishing a Victorian terrace house

8.1. Presentation of the house

The building under investigation is situated on No 19, Truro road, in Wood Green, N22 8EH, London. The latitude of the house is 51.60 (51° 36') and the longtitude is -0.11 (0° 6') (Source: http://world.maporama.com/idl/maporama/drawadress.aspx). It is a Victorian mid-terraced house, built in the late 19th century. 27% of the England's housing stock is terrace houses[66], so of a total of about 21,613 thousands houses, 5,835 of them are terraced.

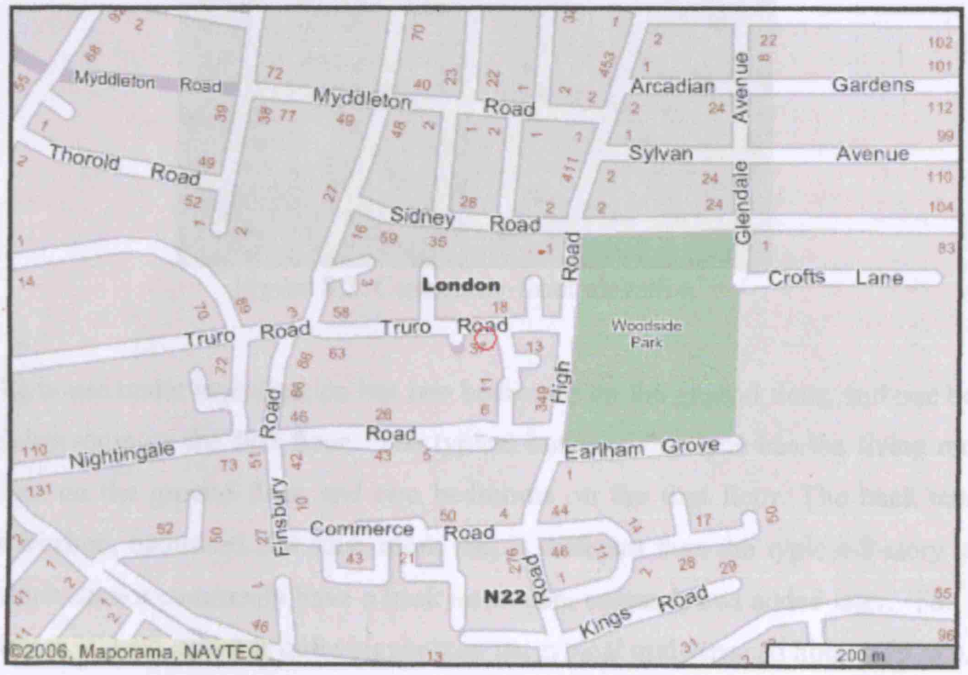
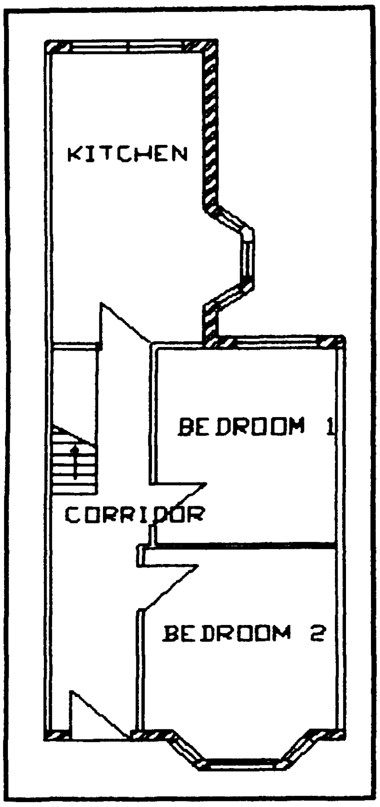


Figure 8.1. Location of the house (red circle) (Source: Maporama website http://world.maporama.com/idl/maporama/drawadress.aspx)

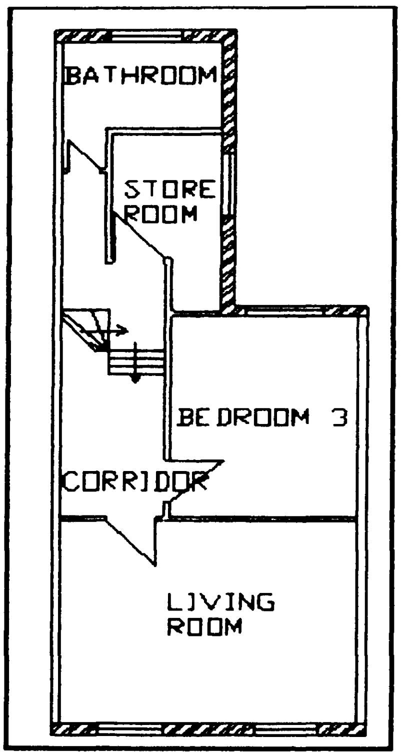
[66] ODPM, Survey 2005, table 117

Figure 8.2. Case study-front elevation

The house under investigation has two bedrooms on the ground floor, and one bedroom and the living room on the first floor. The typical house of this type has the living room and dining room on the ground floor and two bedrooms on the first floor. The back extension, where the kitchen, bathroom and store room are, is different than the typical 2-story terraced houses, which do not commonly have a back extension, unless it was added later. The area of the dwelling is 103 m^2, and it is quite bigger than the typical mid-terraced house (79 m^2).



Ground floor floorplan



First floor floorplan

The characteristics of the building, the building elements and services are as follows.

		U-value (where appropriate)
Orientation	North-South	
External walls	Exposed and party walls, are of 225 mm thick brick construction, which forms Flemish bond (double brick construction without cavity).	Exposed walls - 2.073 kg/m^{2}K
Ground floor	Solid concrete floor covered with floorboards and carpet, no insulation.	0.46 kg/m^{2}K
Internal walls	110 mm thick brick construction with plaster on both sides	2.175 kg/m^{2}K
Stud partition internal walls	Two layers of 12.5 mm thick plasterboard, with 100 mm air cavity between them, supported with 63 mm timber studs	2.52 kg/m^{2}K
Internal floors	Joisted, with 200mm air cavity	1.589 kg/m^{2}K
Roofs	No roof insulation, grey slates, 30 mm thick, supported on wooden rafters, 100 mm thick. Below the slates, there is a layer of bitumen felt and 20 mm cavity.	2.124 kg/m^{2}K
Windows	Single glazed 6 mm clear pane (optifloat clear) and wooden frame, no visible gaps around them, no draughtstripping	Pane - 5.753 kg/m^{2}K Frame - 2.848 kg/m^{2}K
Doors	20 mm thick softwood, no visible gaps around them, no draughtstripping	3.196 kg/m^{2}K
Lighting	Provided by tungsten filament lamps	
Extract fans	One, located in the bathroom.	
Chimneys	All chimneys blocked	
Central heating	Provided by a pre-1979 floor gas boiler, with an efficiency of 65%, (is a typical efficiency for old boilers). The heat is distributed via wall mounted radiators and the heating controls are programmer and roomstat.	
Hot water tank	Uninsulated, cylinder size 140 lt, hot water comes directly from the heating boiler.	

8.2. Heat losses

The house benefits from the fact that it is mid-terraced, so there are no heat losses from the side wall to the attached buildings.

The formula to calculate the heat losses from the building is:

$$\text{Fabric Heat Loss (F.H.L.)} = \Sigma(U \cdot A) \cdot \Delta T \qquad (1)$$

Where U, is the U-value of the building element (kg/m^{2}K)

A, is the area of the building element (m^2)

ΔT, is the difference between internal and external temperature (^{o}C)

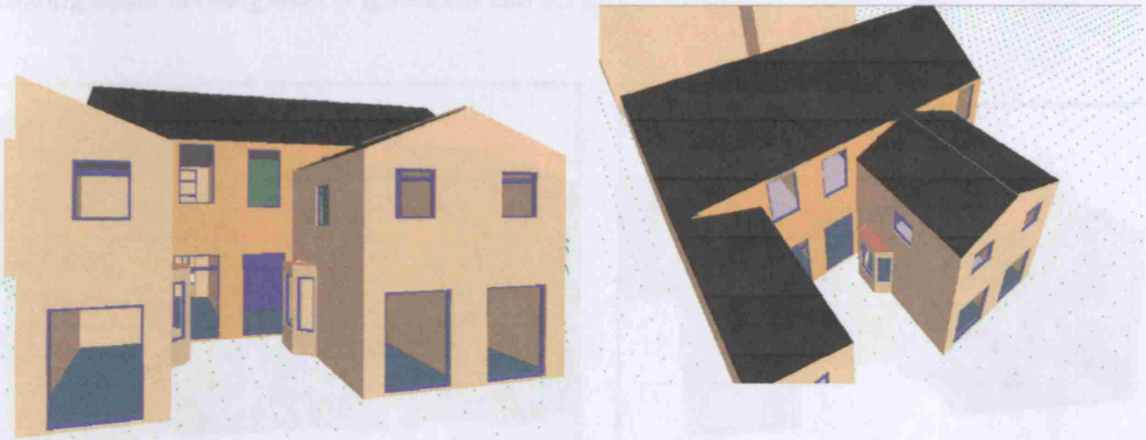
It is assumed that the internal temperature is maintained at 20 °C and the external is 6 °C, which is a typical temperature during the heating period. The results are summed up in the next Table. Roof accounts for the biggest proportion of heat losses (46%), with walls being second (26%). Estimating heat losses is useful to make an initial estimation on which element stress should be laid. In this case, external walls, roof and windows, are those which if altered correctly will reduce substantially the heat losses.

Table 8.1. Heat losses of the base building

	U-values (kg/m2K)	*Area(m2)*	*F.H.L.(kW)*	*Proportion*
External walls	2.073	57.46	1667.60	0.26
Ground floor	0.46	52.43	337.66	0.05
Windows	5.753	17.98	1447.90	0.22
Roof	2.124	100.63	2992.45	0.46
External door	3.196	1.87	83.67	0.01
		Total	6529.29	

8.3. Description of base case model

The 3d model of the building designed in TAS is shown in Figures 8.3-8.4.



Figures 8.3 and 8.4. Back views of the house and the houses attached

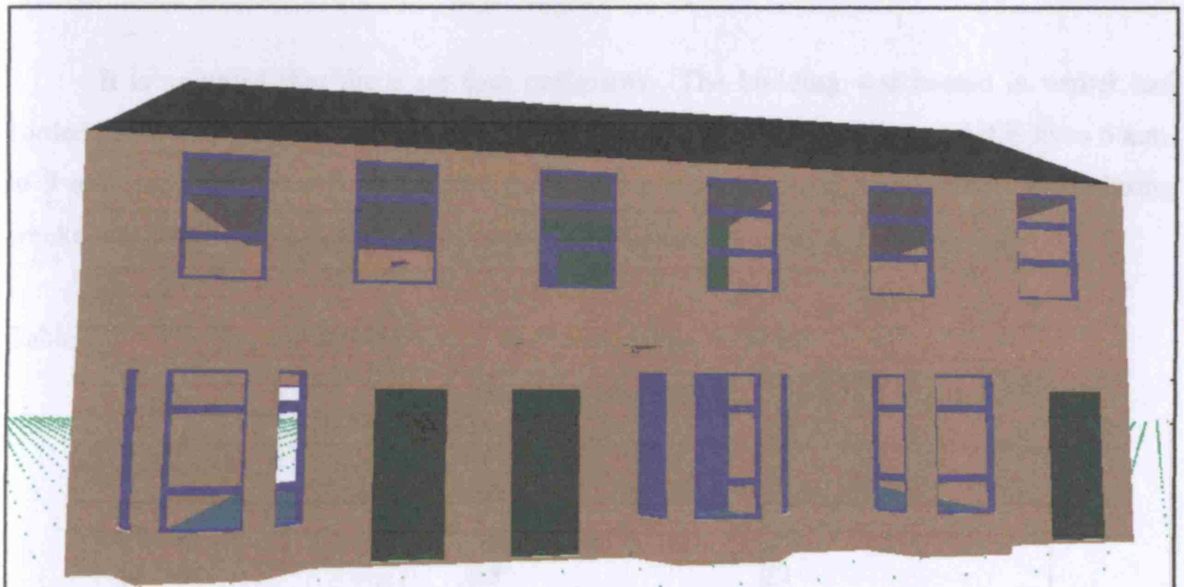
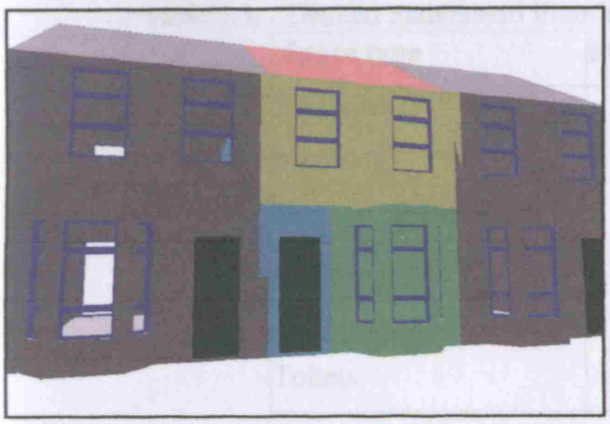
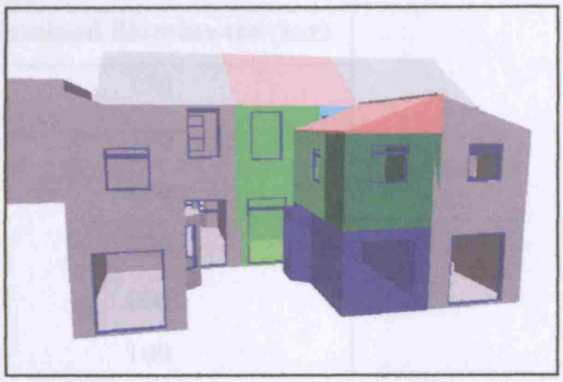


Figure 8.5. Front view of the house

The initial model was divided into 11 zones, namely, bedrooms 1-3, bathroom, kitchen, living-room, store room, corridor/ground floor, corridor/upper floor, front loft and rear loft. The attached buildings were not zoned, since there are no heat losses from the side walls of the building under investigation (Figures 8.6 and 8.7).





Figures 8.6 and 8.7. Front and back views of zones (grey-unzoned, green-bathroom, light green-bedrooms, blue-kitchen, light blue-corridors, pink-roofs)

It is assumed that there are four occupants. The building was heated in winter and cooled in summer. The schedule is the same for both heating and cooling and it is from 6 a.m. to 9 a.m. and then from 6 p.m. to 11 p.m. during weekdays and 8 a.m. to 11 p.m. during weekends. Each zone was heated and cooled at a different temperature (Table 8.2).

Table 8.2. – Heating and cooling temperatures according to zones.

Zone	Heating temperature (°C)	Cooling temperature (°C)
Bathroom	21	24
Bedrooms	18	24
Corridors	20	23
Kitchen	18	22
Living room	22	24
Store room	Unheated	Not cooled
Lofts	Unheated	Not cooled

The heat gains from lighting were calculated by knowing the desired illuminance of each zone and the luminous efficacy of Tungsten Filament lamps[67]. It is assumed that there are no heat gains from lighting in the corridors, since those lights are usually turned on intermittently.

Table 8.3. - Desired maintained illuminance

Space type	**Maintained illuminance (lux)**
Bathroom	150
Bedroom	100
Hall/stairs/landings	100
Kitchen	300
Living room	200
Toilets	100

The infiltration rates were set to be the highest recommended by the CIBSE Guide A, as shown in the next table.

Table 8.4. Recommended air infiltration allowances

Space type	**Recommended air infiltration allowances (ACH)**
Bathroom	2
Bedroom	0.5
Corridor	1.5
Entrance	1.5
Living room	1

[67] Mc Mullan, Randall; *Environmental Science in Building*, p 147.

The heat gains are those in the next table.

Table 8.5. – Occupants and equipment heat gains

Type of source	Sensible Heat emissions (W)	Latent heat emissions (W)
Occupancy		
Person	70	45
Equipment in the kitchen		
Freezer	540	-
Refrigerator	310	-
Oven	1520	-
Equipment in the living room		
Colour television	100	-
Desktop computer	150	-

Assumptions

- Heat gains from some kitchen equipment such as toaster and microwave oven were ignored, because they are not usually turned on for a long time.
- Printer, scanner and similar office equipment were also ignored, because they are not usually used in a regular basis in a house.

9. TAS Results

In order to compare the performance of the building in each refurbishment option, a comparison is made between the heating loads for winter and cooling loads for summer. It is assumed that the heating period starts on the 1st October and ends on the 30th July, and the cooling period is during the rest of the year. While cooling is unlikely in such a house, by modeling a notional cooling load this gives a good idea of how the house will perform in summer, if there is a high cooling load, there will be a larger number of hours of overheating. According to the Building Regulations[68], in order to estimate the annual energy savings, the cost of gas should be taken as 1.63 p/kWh, which is for 2005.

9.1. Results of base case model

The annual heating loads for the base model are 9691.94 kWh. The boiler efficiency is not taken into account in TAS, so the actual annual heating loads would be greater.

9.2. Heating loads

9.2.1. Annual heating loads and cost savings - internal and external insulation options

A summary of the annual heating loads and the cost savings is given overleaf.

[68] The Building Regulations 2006, p 25.

Table 9.1. – Annual heating loads and cost savings according to external wall insulation options

	External walls U-value (kg/m^{2}K)	Annual heating load(kWh)	Cost (£/year)	Savings (£/year)
Base	2.073	9691.94	157.98	
Int 1a	0.334	7307.86	119.12	38.86
Int 1b	0.304	7260.85	118.35	39.63
Int 2a	0.328	7289.79	118.82	39.16
Int 2b	0.282	7219.86	117.68	40.29
Int 3a	0.328	7306.96	119.10	38.88
Int 3b	0.312	7284.23	118.73	39.25
Ext 1a	0.332	7274.26	118.57	39.41
Ext 1b	0.276	7187.29	117.15	40.83
Ext 2a	0.323	7316.96	119.27	38.71
Ext 2b	0.285	7255.63	118.27	39.71
Ext 3a	0.328	7258.77	118.32	39.66
Ext 3b	0.282	7187.01	117.15	40.83

External insulation has higher energy savings than the internal insulation for the same U-values. Its performance would be better if the building was not heated intermittently, because the internal surface of the walls acts as a thermal mass, so when the building is heated its response is slow, although looking at the RH and temperature charts, the internal conditions are more stabilized, something which cannot be tested using only the heating loads.

100 mm expanded polystyrene or 120 mm fibre glass applied on the external surface of the walls (Options Ext1b and Ext 3b respectively) offer the highest savings (40.83 £/year). On the other hand, 120 mm mineral wool results in the lowest savings (38.71 £/year). The 20 mm cavity in the external insulation option 3b manages to increase the savings by about £0.40 annually, with no additional installation cost, so this should be considered when the budget is limited.

9.2.2. Annual heating loads and cost savings - ground insulation options

The annual heating loads and cost savings from ground insulation options are shown below.

Table 9.2. – Annual heating loads and cost savings according to ground floor insulation options.

Option	Ground floor U-value (kg/m^{2}K)	Annual heating load(kWh)	Cost (£/year)	Savings (£/year)
Ground1a	0.249	9647.04	157.25	0.73
Ground1b	0.237	9643.54	157.19	0.79
Ground2a	0.219	9640.39	157.14	0.84
Ground2b	0.193	9634.21	157.04	0.94
Ground3a	0.241	9646.00	157.23	0.75
Ground3b	0.215	9639.49	157.12	0.85
Ground4a	0.240	9636.95	157.08	0.90
Ground4b	0.220	9631.46	156.99	0.99

Ground insulation has the smallest savings, since the heat losses are less through the ground floor, than through any other building element, as it was found in Chapter 8.2. Despite the fact that the concrete in options 4a and 4b is not exposed but covered with carpet which leads to a limited thermal mass potential, those option appear to have higher savings, even compared to options with lower U-value.

9.2.3. Annual heating loads and cost savings - roof insulation options

Table 9.3. – Annual heating loads and cost savings according to roof insulation options.

Option	Roof U-value (kg/m^2K)	Annual heating load(kWh)	Cost (£/year)	Savings (£/year)
Roof1a	0.187	8992.49	146.58	11.40
Roof1b	0.168	8975.02	146.29	11.69
Roof2a	0.188	8994.21	146.61	11.37
Roof2b	0.163	8971.11	146.23	11.75
Roof3a	0.200	9004.42	146.77	11.22
Roof3b	0.181	8988.08	146.51	11.47

150 mm of polyurethane boards (option 2b) lead to the best energy performance, and 220 mm cork boards (option Roof3a) to the worst.

9.2.4. Annual heating loads and cost savings - openings options

Table 9.4. – Annual heating loads and cost saving according to windows replacement options

Option	Windows U-value (kg/m^2K)		Annual heating load(kWh)	Cost (£/year)	Savings (£/year)
	South	1.953			
Windows1	Others	1.757	8431.32	137.43	20.55
	South	1.637			
Windows2	Others	1.417	8249.49	134.47	23.51
	South	1.088			
Windows3	Others	1.025	8409.98	137.08	20.90
	South	0.854			
Windows4	Others	0.79	8298.08	135.26	22.72

Due to the improvement of the U-values in the argon filled options, the savings are at least 3 £/year for every option. Surprising is the fact that the argon filled triple glazed window with low-e coating (Option Window4) has lower savings than the argon filled double glazed one (Option Window2). Looking at the summary of the annual heating loads broken down in the zones, it is noticed that all the zones have lower loads in the case of Windows4 than in the Option Window2, apart from the ground floor corridor, which has higher.

9.2.5. Lighting option

Table 9.5. – Annual heating loads and cost savings due to lights replacement.

	Annual heating load(kWh)	**Cost (£/year)**	**Savings (£/year)**
Base	9691.94	157.98	
Lighting	9999.40	162.99	-5.01

The installation of more energy efficient lights leads to additional cost for heating, 5.01 £/year, because the heat gains are reduced.

9.3. Cooling loads

9.3.1. Annual cooling loads – internal and external wall insulation options

Table 9.6. – Annual cooling loads according to external wall insulation options

	External walls U-value (kg/m²K)	Annual cooling load(kWh)
Base	2.073	553.65
Int 1a	0.334	550.13
Int 1b	0.304	550.05
Int2a	0.328	550.72
Int2b	0.282	550.62
Int3a	0.328	544.93
Int3b	0.312	544.94
Ext 1a	0.332	582.10
Ext 1b	0.276	584.81
Ext 2a	0.323	540.86
Ext 2b	0.285	541.17
Ext 3a	0.328	583.22
Ext 3b	0.282	585.34

During summer, the performance of the different measures for external wall insulation is quite reversed. Option Ext 2a seems to have the highest savings, although it had the smallest during heating period, and Option Ext 3b, has the worst performance, worse than the original, although previously had the best. This can be attributed to the thermal mass effect, and to the slow response of internal temperature change. In the case of internally applied insulation, 120 mm mineral wool boards (Option Int3a) seem to be the best option and 100 mm glass fibre (Option Int2a) the worst.

9.3.2. Annual cooling loads – ground floor insulation options

Table 9.7. – Annual cooling loads due to ground floor insulation options

	Ground floor U-value (kg/m²K)	Annual cooling load(kWh)
Base		553.65
Ground1a	0.249	604.78
Ground1b	0.237	607.00
Ground2a	0.219	613.15
Ground2b	0.193	618.15
Ground3a	0.241	608.72
Ground3b	0.215	613.99
Ground4a	0.240	582.26
Ground4b	0.220	585.86

Insulating the ground floor results in increased cooling loads for all the options, due to the loss of the cooling effect coming from the ground. This may cause overheating problems. The measure with the least insulation (Option 1a) has the smallest cooling loads required among the options with insulation above concrete. Options Ground4a and Ground4b, which are those with the insulation below the slab, have more savings, because the concrete slab, although covered with carpet, acts like a heat storage, preventing the space to heat up quickly.

9.3.3. Annual cooling loads – openings options

Table 9.8. – Annual cooling loads according to windows replacement options.

	Pane U-value (kg/m^2K)		Annual cooling load(kWh)
Base			553.65
Windows1	South	1.953	422.89
	Others	1.757	
Windows2	South	1.637	423.13
	Others	1.417	
Windows3	South	1.088	388.54
	Others	1.025	
Windows4	South	0.854	389.91
	Others	0.79	

Replacing the windows leads to the lowest required cooling loads, especially because the South facing windows have low solar transmittance. Surprising is the fact that although argon-filled glazing has lower U-value, the cooling load required is higher, for both pair of options.

9.3.4. Annual cooling loads – roof options

Table 9.9. - Annual cooling loads according to roof insulation options.

	Roof U-value (kg/m^2K)	Annual cooling load(kWh)
Base		553.65
Roof1a	0.187	500.55
Roof1b	0.168	499.44
Roof2a	0.188	500.58
Roof2b	0.163	499.16
Roof3a	0.200	498.79
Roof3b	0.181	497.87

In this case, again, the options which performed better in winter do not have equal performance in summer time. 200 mm cork boards seems to be the best options, although previously, it was one of the worst.

9.3.5. Annual cooling loads – lighting option

Table 9.10. Annual cooling loads due to lights replacement

	Annual cooling load(kWh)
Base	553.65
Lighting	533.10

Replacing the lights with more energy efficient ones reduces the risk of overheating, and the loads are similar to wall options.

9.4. Overall TAS results

The savings are generally lower than expected. The difference in actual with simulated savings, can be attributed to weaknesses of the software. For example in the case of external wall alteration, TAS does not take into account the age of the base wall and the adhesive used, which cause can lead to higher heat losses. Moreover, it calculates the U-value in one dimension and does not take into account that the heat flows towards different directions.

All external wall insulation options provide the highest savings, between £38 and £41 annually, compared to the rest of the refurbishment measures. 100 mm expanded polystyrene or 120 mm fibre glass result in the best performance if applied externally, but if external insulation is not possible either because of its high cost or because it is not allowed by the local authorities, then 120 mm of glass fibre is the next preferable option. But during summer, the mineral wool option leads to the smallest required cooling loads, and glass fibre to the largest.

Insulating the ground floor leads to the lowest savings. Placing the insulation below a concrete slab appears to be the best solution, but it should be checked if this is possible, due to the rise of the floor level. During the cooling period, ground floor insulation reduces the cooling effect coming from the ground, and the risk of overheating is higher. Again, insulation below concrete slab leads to the lowest cooling loads.

Surprising is the fact that triple glazed windows perform worse in winter than double glazed ones, as well as the fact that argon filled glazing performs worse during summer than the equivalent non-argon filled ones.

10. Results from SAP Analysis

This chapter takes a look on the resulting SAP rating due to the refurbishment measures. Apart from the measures tested already in TAS, boiler is being replaced and the impact of different heating controls is being examined.

10.1. Base case

The SAP rating of the base model is 33, and it is much lower than the average SAP rating of mid-terraced houses, which is 53[69], according to the 2001 English House condition survey. Of course, many of those houses had already undergone refurbishment, or had recently their heating system upgraded. The useful energy requirement for space heating is 70.66 GJ, that is, 19628 kWh, more than double than TAS calculated, 9691 kWh, but close to relevant research results[70], which also used SAP. Taking into account the efficiency of the boiler, then the space heating requirements are 117.77 GJ (32,713 kWh). The C.I. rating of the base building is 1.8. The annual CO_2 emissions for water and space heating are 8756.98 kg, 72.6% of which (6359.56 kg) are for space heating.

10.2.1. External wall options

Since there are small variations in the U-values of the options, there are also small variations in the SAP rating. All the options increase the SAP rating to between 40, which was achieved by walls with a U-value more than 0.32 kg/m^{2}K, and 41 and CI to 2.4. SAP does not take into account the thermal mass, which is important in the case of external insulation, and for that reason, although external insulation may lead to a more energy efficient house, the resultant SAP rating is the same as if the insulation was internal and of the same U-value.

[69] Office of the Deputy Prime Minister (ODPM); *English House Condition Survey: 2001 Key facts*, p 19.
[70] Energy Saving Trust; CE189 – Refurbishing dwelling – A summary of best practice, September 2000, revised June 2006, p 7.

10.2.2. Ground floor

Accordingly to TAS results, where both the improvement of the building and the variations between the options were very small, SAP rating is increased only by 1 and it is 34 for all the options. CI remains the same, to 1.8.

10.2.3. Windows

An overall U-value of the openings, including both pane and frame, should be calculated, manually since this cannot be done in TAS. The formula used was:

$$U_T=(U_p \cdot A_p + U_e \cdot A_e + U_f \cdot A_f)/A_T \quad (2)$$

Where, U_T, U_p, U_e, U_f are the U-values of the whole of the opening, the pane, the edges and the frame respectively, and

A_T, A_p, A_e, A_f are the areas of the whole of the opening, the pane, the edges and the frame respectively.

The procedure of the calculation, as well as the resultant U-values, can be found in Appendix D. The U-value of the edges was ignored in the calculation, since it was not known.

For all the options, SAP rating is increased to 37 and CI to 2.1.

10.2.4. Roof

Roof options have relevant results with the wall options. The SAP rating is increased to between 40 and 41 for all the options, and CI to 2.4.

10.2.5. Low energy lights

Fitting low energy lights does not make a difference in SAP ratings.

10.2.6. Heating

The boiler that was tested was a condensing combi one, 1998 or later (automatic ignition) with an efficiency of 86% and boiler interlock.

The controls tested were:

1) roomstat and programmer (already existing in the house)

2) roomstat, programmer and TRVs

3) Full zone control

Boiler replacement leads to the best improvement of SAP rating. Just replacing the boiler with no change in control systems gives a SAP rating of 53. TRVs' installation improves it by a further 1 point, whereas full zone control gives a SAP rating of 58.

10. Economic evaluation results

In this section each measure's cost is calculated, as well as its one's payback period, using heating loads calculated from TAS simulations. Windows options cost was not calculated, since it was difficult to find the cost for the exact glazing used in the simulations.

10.1 Spon's Architect's and Builders' Price

In order to estimate the economic evaluation of each measure, prices indicated in Spon's[71] were used, unless otherwise indicated. Spon's is most common source used by the building industry for the cost of building schemes. The cost is broken down in labour and material cost. The section of minor works was used in the present project, which includes schemes which cost is less than £65,000.

10.2 Assumptions

- In the choice of plasterboard and in order to simplify the calculation of its cost it was assumed that all floors have the same height of 2.7 m.
- Timber battens in internal walls insulation are at 600 mm centres. For the calculation of the total battens needed, again an average height of 2.7 m was taken for the stories.

[71] Spon's Architects' and Builders' Price Book, edited by Davis Langdon, 2006.

10.3 Costs and payback periods

10.3.1. Costs and payback periods from building elements refurbishment measures

A summary can be found in next Table.

Table 10.1. Cost of refurbishment measures and payback periods

Element	Cost (£)	Savings (£/year) *	Payback period (years)
Walls			
Internal 1a	2486.36	38.86	63.98
Internal 1b	2550.71	39.63	64.37
Internal 2a	1553.78	39.16	39.68
Internal 2b	1826.14	40.29	45.32
Internal 3a	1967.49	38.88	50.61
Internal 3b	1967.49	39.25	50.13
External 1a	2913.22	39.41	73.92
External 1b	3157.57	40.83	77.34
External 2a	2614.72	38.71	67.54
External 2b	2687.77	39.71	67.68
External 3a	2161.30	39.66	54.49
External 3b	2459.80	40.83	60.24
Ground floor			
Ground1a	1563.99	0.73	2137.17
Ground1b	1563.99	0.79	1982.50
Ground2a	2189.48	0.84	2605.73
Ground2b	2364.07	0.94	2512.22
Ground3a	1334.34	0.75	1781.91
Ground3b	1364.75	0.85	1596.40
Ground4a	2566.45	0.90	2863.19
Ground4b	2941.85	0.99	2984.27
Roof			
Roof1a	1386.36	11.40	121.60
Roof1b	1586.25	11.69	135.74
Roof2a	1519.50	11.37	133.61
Roof2b	1588.46	11.75	135.19
Roof3a	2101.85	11.21	187.55
Roof3b	2745.79	11.47	239.33

*Savings are according to TAS results

The payback period is very long for all the refurbishment options. This is due to the fact that the savings from calculated from TAS results were very low. If these results are to be taken as accurate, then none of the measures is viable. However, a comparison between the different options according to their payback period can be made.

External insulation has longest payback period than the internal insulation, and it is double in some cases. The most economical solution appears to be option internal 2a, which is 100 mm glass fibre. Due to the high capital cost of expanded polystyrene, its payback period is the longest.

Ground floor insulation has very long payback period and the longest between the different measures and, therefore, should not be considered in such a small scale scheme. Placing the insulation below a concrete slab may have good performance during the heating period and the best of the options in the cooling period, but because of its increased cost due to the concrete slab, it is not feasible.

Option Roof1a is the best economic solution among roof options, because both polyurethane boards and, especially, cork boards have higher capital cost.

10.3.2. Lighting replacement savings

Replacing the Tungsten Filament lamps with Compact Fluorescent ones, the heat gains are less, because for the same illuminance, more watts are required when using tungsten lamps. This results in an increase in fuel bills, but it also reduces the risk of overheating. From the TAS simulation it was found that £5.01 is the additional amount of money that should be spent in fuel, after the replacement. However, Compact Fluorescent lamps have longer nominal life, 8000 hours, as opposed to the 1000 hours for Tungsten Filament lamps, and, also, their light output is higher for the same amount of electricity. Specifically, they can use up to 80% less electricity than Tungsten lamps. The total savings from the replacement can be calculated as follows:

Table 10.2. Savings from lamp fittings replacement.

	Area (m^2)	Total lighting hours (yearly)[72]	Power output needed (W/m^2)		Electricity output needed (KWh)	
			Tungsten Filament	Compact Fluorescent	Tungsten Filament	Compact Fluorescent
Bathroom	4.54	1825	12.5	2.5	103.57	20.71
Bedroom1	11.19	365	8.33	1.67	34.02	6.82
Bedroom2	11.37	365	8.33	1.67	34.57	6.93
Bedroom3	11.15	365	8.33	1.67	33.9	6.80
Kitchen	14.45	1560	25	5	563.55	112.71
Living room	17.64	1560	16.67	3.33	458.73	91.64
				TOTAL	11481.77	245.61
				SAVINGS	11236.16	

So the energy savings are 11236.16 kWh/year, and if the cost of electricity is 3.65 p/kWh, as recommended by the Building Regulations 2006[73] to use when calculating the energy savings, then the annual cost savings are £410.12. Plus the Tungsten need more frequent replacement.

10.3.3. Heating

The estimated boiler output was around 21 kW[74]. Since boiler replacement could not be tested in TAS, the savings in heating were taken from TAS. (Table 10.3)

Table 10.3. Cost and payback periods from boiler options.

Element	Cost (£)	Savings (£/year)*	Payback period (years)
Boiler1	1299	127.9097	10
Boiler2	1974	138.0067	14
Boiler3	2549	172.4631	15

*calculated from SAP, using gas cost 0.0163 £/kWh, according to the Building Regulations

[72] According to the lighting schedules in TAS

[73] The Building Regulations 2006, p 25.

[74] Calculated according to the size of the building in *Boiler sizing method for houses and flats*, *http://www.boilers.org.uk*. For the estimation of the boiler size, the programme makes some assumptions. Those assumptions, as well as the factors it uses, can be found in Appendix F.

Boiler1 has the smallest payback period, whereas boilers 2 and 3 will start to pay off the capital cost after 14 and 15 years respectively. But Boiler3 has the highest savings. Eventually, over the lifetime of the boiler (around 25 years), the calculated heating savings are £3175 for Boiler1, £3450 for Boiler2, £4300 for Boiler3, and their difference with the initial cost is £1876, £1476 and £1751, respectively. So, again Boiler1 is the most economical solution, followed by Boiler3.

11. Combination of options

The key fields in a refurbishment are insulation, heating system and ventilation. There should be an integrated approach towards these, otherwise other problems may rise. For example, if the insulation levels and heating system are upgraded and no care has been taken for ventilation, then condensation may occur[75]. The same problem may occur if single glazed windows are replaced with double glazed ones, without further insulation of the walls, because the walls become the coldest building element and are vulnerable to condensation and mould growth[76]. In the present report one combination was tested, but further research should always be done to check which of the combinations is the best one.

The combination of the options was done according to the best thermal performance of the options for each building element. The summary of the alterations is given in Table 1.11. Cost savings were not taken into account in the choice of options. Ground floor remained unaltered, due to the restricted benefits mentioned.

Table 11.1. Combination of options

Building element	**Choice**	
External walls	External 3b	120 mm glass fibre
Ground floor	Unaltered	-
Roof	Roof2b	140 mm polyurethane boards
Windows	Windows2	Double glazing, argon filled
Lighting		Fluorescent lamps
Boiler	Option3	Condensing combi 1998 or later, 86% efficiency, full zone control

[75] Energy Efficiency; *Good Practice Guide 179: Energy efficient refurbishment of low rise solid wall housing,* Best Practice Programme, p 2.
[76] Energy Efficiency; *Good Practice Guide 179: Energy efficient refurbishment of low rise solid wall housing,* Best Practice Programme, p 3.

11.2 TAS RESULTS

The results from TAS analysis are shown below (Table 11.2)

Table 11.2. Annual heating and cooling loads for options combination

	Annual heating load(kWh)	Cost(£)	Savings(£)	Annual cooling load(kWh)
Base	9691.94	157.98		553.6525
Combination	4505.49	73.44	84.54	287.5436

The refurbishment measure combined can save 84.54 £/year, and reduce the heating loads to more than half. The hours of overheating during the summer will also be substantially less, as the cooling load required is almost 50% less than in the base model.

11.3 SAP RESULTS

SAP rating is increased to 86, 11 points higher than the target SAP rating and CI to 6.6.

12. CO_2 emissions

The C.I. rating calculated in TAS is an indicator of the CO_2 emissions that the house is responsible for. After all, one of the aims of a refurbishment scheme is to reduce the CO_2 emissions and contribute to the reduction of the climate change phenomenon. CO_2 emissions savings is another way to compare the refurbishment options. Calculating embodied energy in the measures is also important. This report does not study the embodied energy, but general about it can be found in Appendix G. A summary of the CO2 emissions, as calculated in SAP, and CO2 savings are given next (Table 12.1 and Charts 12.1-12.5).

Table 12.1. CO_2 emissions and savings according to refurbishment measure

	Total CO_2 (kg/year)	**CO_2 due to space heating (kg/year)**	**Total CO_2 savings (kg/year)**
BASE	8756.98	6359.56	
Internal 1a	7425	5027.65	1331.98
Internal 1b	7400.67	5003.24	1356.31
Internal 2a	7420.2	5022.77	1336.78
Internal 2b	7382.74	4985.31	1374.24
Internal 3a	7420.2	5022.77	1336.78
Internal 3b	7407.18	5009.76	1349.8
External 1a	7423.45	5026.02	1333.53
External 1b	7377.85	4980.42	1379.13
External 2a	7416.13	5018.71	1340.85
External 2b	7385.18	4987.76	1371.8
External 3a	7416.13	5018.71	1340.85
External 3b	7379.48	4982.06	1377.5
Ground1a	8629.12	6231.69	127.86
Ground1b	8620.61	6223.18	136.37
Ground2a	8609.27	6211.85	147.71
Ground2b	8590.53	6193.1	166.45
Ground3a	8624.76	6227.33	132.22
Ground3b	8609.27	6211.85	147.71
Ground4a	8624.76	6227.33	132.22
Ground4b	8609.27	6211.85	147.71
Roof1a	7418.09	5020.66	1338.89
Roof1b	7404.13	5006.71	1352.85
Roof2a	7418.82	5021.4	1338.16
Roof2b	7400.46	5003.04	1356.52
Roof3a	7427.63	5030.2	1329.35
Roof3b	7413.68	5016.26	1343.3
Windows1	8077.35	5679.93	679.63
Windows2	8022.53	5625.11	734.45
Windows3	8075.26	5677.84	734.45
Windows4	8039.27	5641.84	734.45
Boiler1	5508.1	4834.3	3248.88
Boiler2	5387.64	4713.84	3369.34
Boiler3	4976.71	4302.91	3780.27

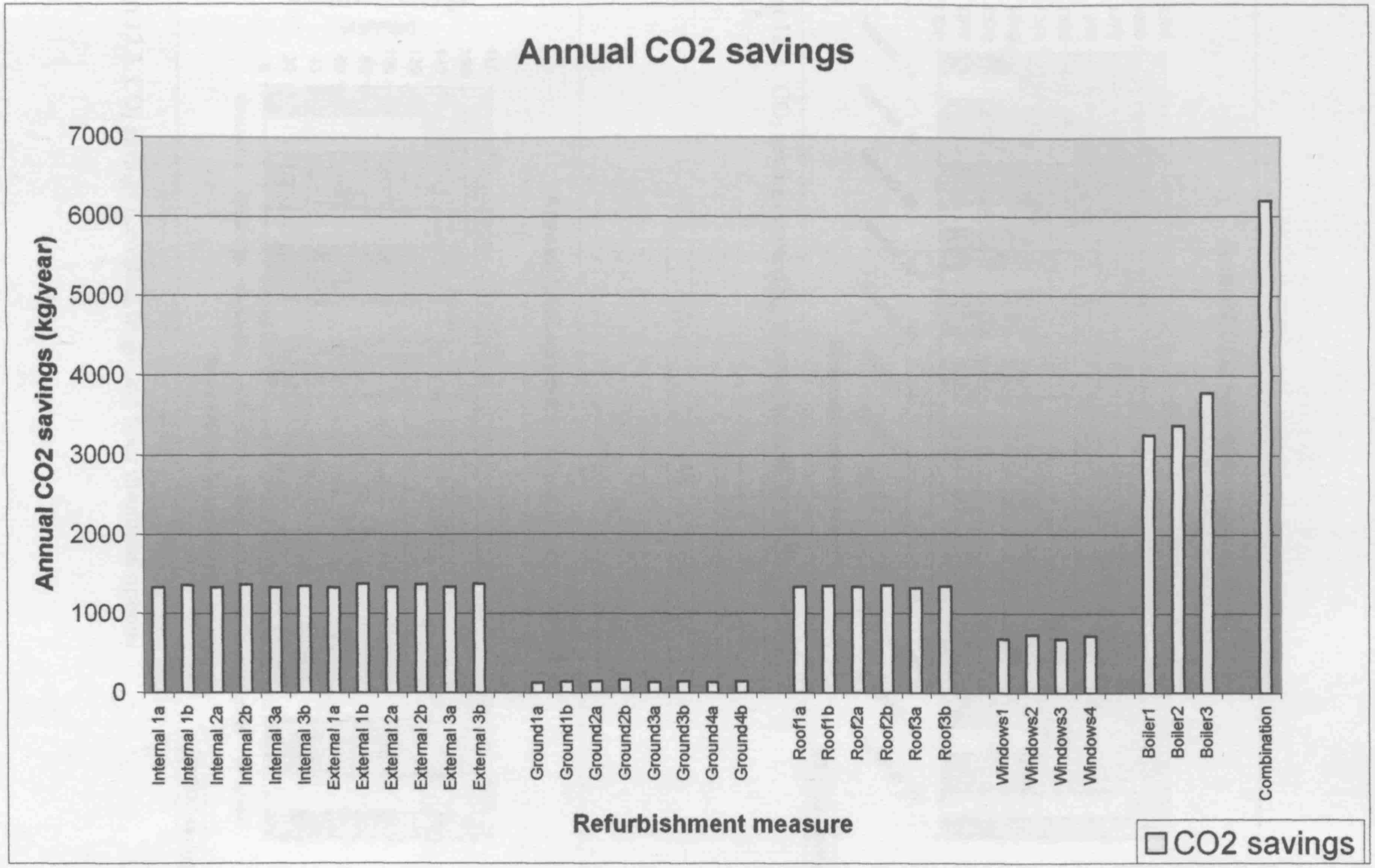


Chart 12.1. CO_2 savings according to refurbishment measure

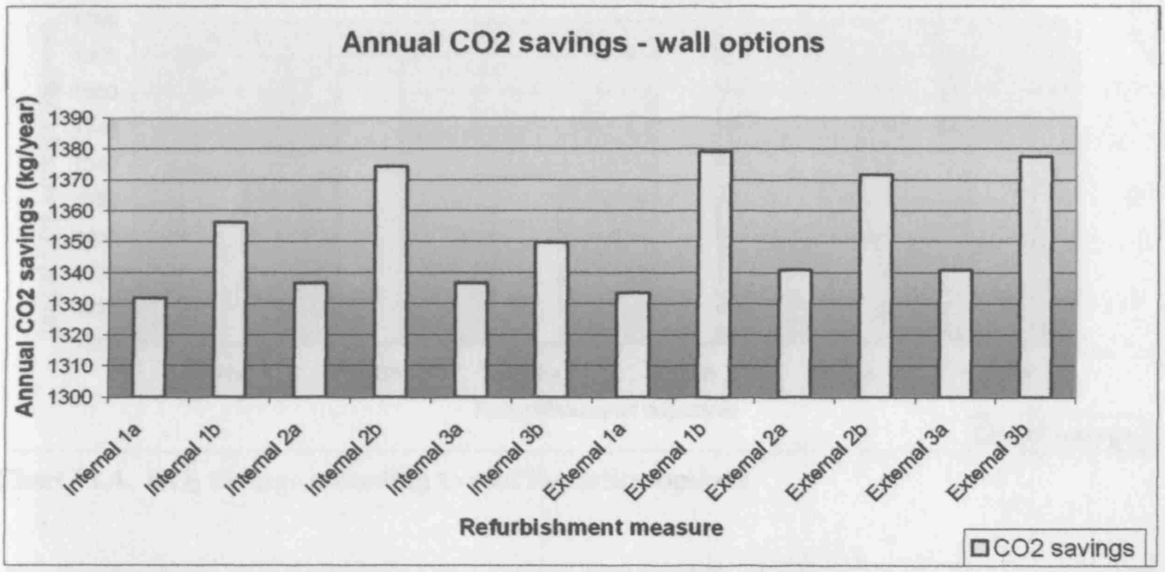


Chart 12.2. CO_2 savings according to external wall insulation options

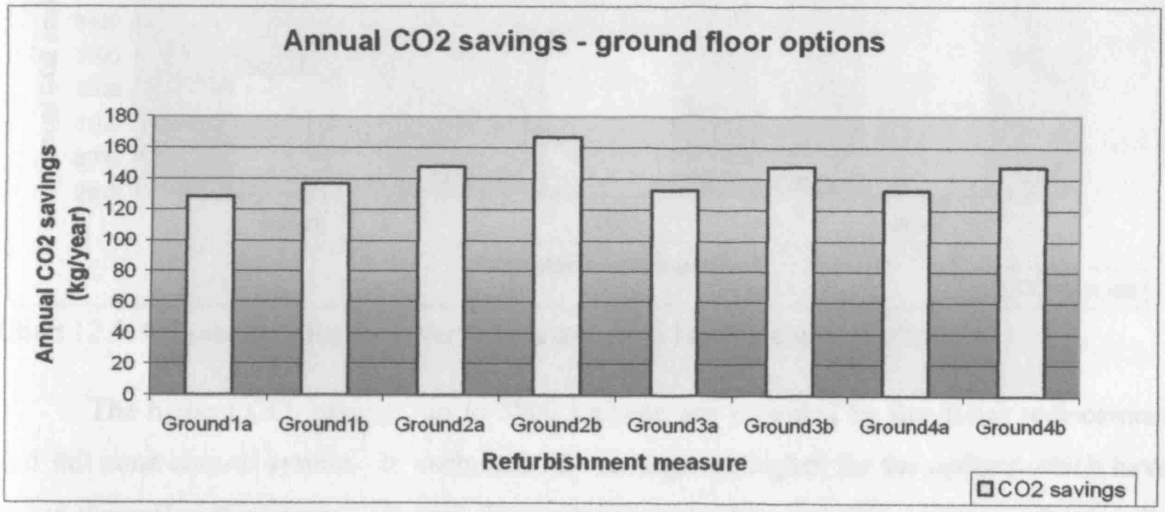


Chart 12.3. CO_2 savings according to ground floor insulation options

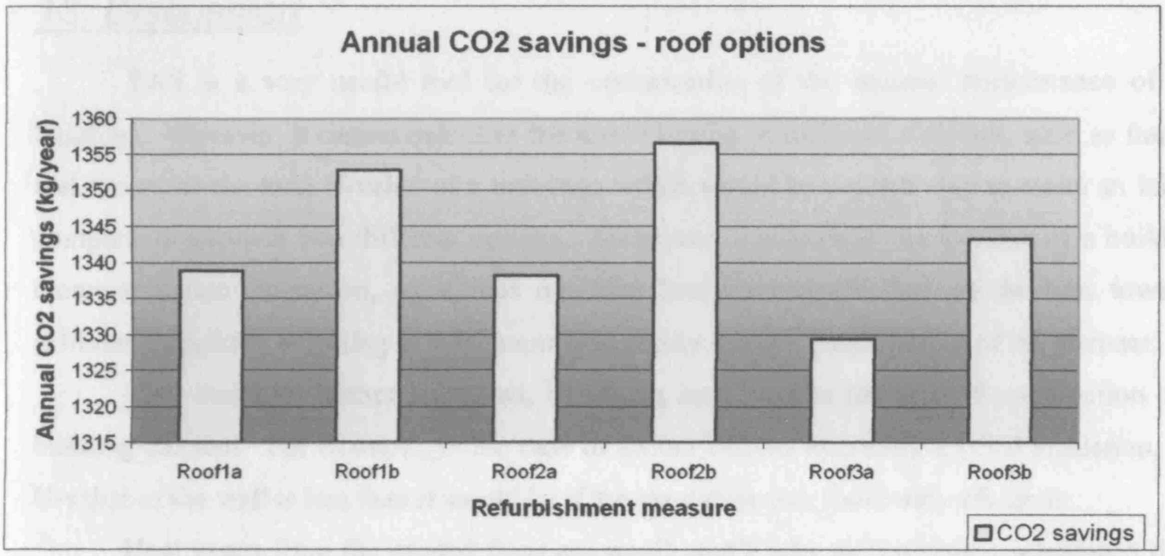


Chart 12.4. CO_2 savings according to roof insulation options

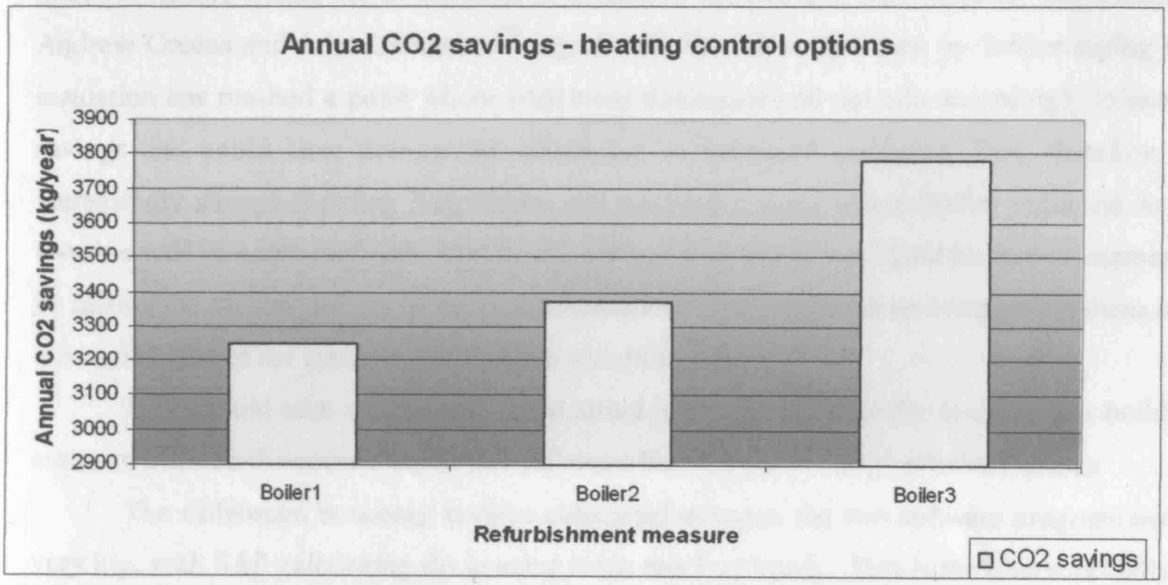


Chart 12.5. CO_2 savings due to boiler replacement and heating control options

The highest CO_2 savings, up to 3800 kg/year, are provided by the boiler replacement and full zone control system. In each case, the savings are higher for the options which have better thermal performance. Ground floor alterations lead to low CO_2 savings, whereas the combination of the options saves 6197 kg/year, that is, 70% of the emissions of the base building.

13. Discussion

TAS is a very useful tool for the optimization of the thermal performance of the building. However, it cannot calculate the total U-value of different elements, such as frames and panes, or the total U-value of a building, which would be a quick way to make an initial comparison between two different options. Moreover, it calculates the U-value of a building element in one dimension, so it does not take into account the flow of the heat towards different directions, resulting in a different than reality thermal performance of the element.

TAS could be further improved, by taking into account the way of construction of a building element. For example, in the case of timber battens internally applied insulation, the U-value of the wall is less than it would be if the insulation was fixed with adhesive.

Heat losses from the ground floor are small, that's why the insulation introduced does not result in significantly better performance. Combined with the long payback period, this kind of measure should not be considered, at least in such a small scale scheme. Mike George, Andrew Greens and John Littlewood[77], agree with this view, and they go further saying that insulation has reached a point where additional thicknesses do not add accordingly to energy savings and could have detrimental effect due to increased embodied CO_2, therefore the increasingly stricter Building Regulations are reaching a point where further reduction in the U-value will be non-beneficial. The insulation levels in this report could be further examined, by testing the carbon savings of many thicknesses of each insulation and comparing them with the capital cost of the measure and the embodied CO_2.

SAP should take into account the thermal mass and not only the U-value of a building element, because the correct use of thermal mass leads to more energy efficient houses.

The difference in energy savings calculated between the two software programmes, is very big, with SAP calculating the heating loads twice as much. This is the case especially in the roof insulation options, and this could be attributed to the fact that in TAS, although the insulation was installed at rafter level, the loft was left unheated, whereas in SAP is being heated, plus target temperatures and occupancy levels are different. Moreover, SAP calculates primary energy, so the calculated heating loads should have been less, which is not the case here.

[77] Building for a future; *Beware the blanket approach!*, by Mike George, Andrew Greens and John Littlewood, Winter 2005/2006, p 62-65.

Refurbishment of houses is held back due to high cost. Although measures could be not cost-effective, from environmental point of view they are beneficial, because they pay back the embodied CO_2 in a few years time. So, if the obstacle of high cost is overcome, then all houses would benefit from energy efficient refurbishment.

Thermal comfort should also be checked, aiming at the stabilization of the internal conditions, and not only in the reduction of the energy consumed, and different combinations should be checked to achieve the optimum result.

14. Conclusions

For the UK government to meet the Kyoto protocol commitment and its national goals in reducing energy consumption, it should take and has taken measures to reduce the energy consumption in the building sector which accounts for half of the UK's energy needs. Generally, its housing stock is old, and it should be refurbished to improve not only their energy performance, but their thermal performance as well.

The house studied in this report, would benefit from external wall insulation, and the best option appears to be external insulation, although it may lead to more overheating hours during the summer. To meet the tougher Building Regulation standards the insulation should be thicker. There should be research in the improvement of the insulation materials (so that thinner insulation will be required) so that the choice of the internally applied insulation will not reduce the space area. Most heat losses are through the roof, so stress should be laid on the insulation there. Since there are not significant savings from insulating the ground floor, this should be considered only in major works. Although argon filled triple glazing with low-e coating has lower U-value than argon filled double glazed one, the latter's performance is better in winter. Moreover, in summer, argon filled ones lead to higher overheating risk.

The findings from this report for ground floor insulation, support the view of Mike George, Andrew Greens and John Littlewood[78], who also used TAS for their findings, and they state that ground floor insulation should not be considered, since not only it does not reduce significantly the energy consumption, but it may also have a detrimental effect.

From SAP analysis, SAP rating is increased the most by boiler replacement. Boiler replacement, as well as wall and roof insulation also increase the SAP rating more than the other refurbishment measures. Heating loads calculated in SAP are almost double than those calculated in TAS. However, if a comparison is made between the measures by using each programme's loads, then the results about which measure is better, are the same.

CO_2 emissions are reduced also by boiler replacement the most, and then by wall and roof insulation. Ground floor again, has the lowest CO_2 savings. Although it was not taken into account in this report, when calculating the CO_2 savings the embodied energy each

[78] Building for a future; *Beware the blanket approach!*, by Mike George, Andrew Greens and John Littlewood, Winter 2005/2006, p 62-65.

measure has should not be overlooked, and the CO_2 payback period should always be taken into account.

After economic evaluation of each measure it is concluded that no measure is viable, if TAS results for required heating loads are taken as accurate. However, wall insulation had the lowest payback period.

If the measures which lead separately to the best thermal performance are combined, then the house could cut its energy consumption and CO_2 emissions to more than half, but several combinations should be tested, because some measures may contradict each other and reduce the benefits of other measures when applied together. Upgrading only the heating system and installing loft insulation, cannot provide the occupants with desired comfort levels and condensation problems still occur. Occupants use other forms of heating, like paraffin heaters which add to the condensation problems[79].

[79] Department of Energy; *Good Practice Case Study 4: Refurbishment of pre-1919 terraced housing*, Best Practice programme

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Appendix A - Tas initial constructions

Table A1. Initial construction

Material	***Conductivity (W/m2C)***	***Width (mm)***
External walls		
White paint flat	1000	0.1
Common brick	0.72	225
	U-value (W/m^{2}K)	2.073

Internal walls		
Plaster	0.42	9.5
London stock	0.45	110
Plaster	0.42	9.5
	U-value (W/m^{2}K)	2.175

Internal walls-stud partition		
Plaster	0.42	12.5
Air (upward flow)	-	50
Plaster	0.42	12.5
	U-value (W/m^{2}K)	2.52

Ground floor		
Carpet	0.06	10
Softwood	0.14	20
Concrete 3% m.c.	1.45	100
Crashed brick aggregate	0.55	70
Clay (dark)	0.7	1000
	U-value (W/m^{2}K)	0.46

Ceilings		
Timber smooth planed	0.14	15
Air (upward flow)	-	200
Timber smooth planed	0.14	25
	U-value (W/m^{2}K)	1.589

Roof		
Softwood	0.14	40
Grey slate	2	30
	U-value (W/m^{2}K)	2.124

Windows-pane		
Optifloat clear	1	6
	U-value (W/m^{2}K)	5.753

Windows-frame		
Pine	0.14	25
	U-value (W/m^{2}K)	2.848

Doors

Softwood	0.14	20
	U-value (W/m^{2}K)	3.196

Appendix B- Windows TAS options

Table B1. Windows options

Windows-Frame

Material	Conductivity (W/mK)	Width (mm)
Pine	0.138	60
	U-value (W/m²K)	1.653

Windows-OPTION1

Material	Conductivity (W/mK)	Width (mm)
K glass	1	6
Air (upward flow)	-	12
Pilkington K	1	10
	U-value (W/m²K)	1.757

Windows-OPTION1/South

Material	Conductivity (W/mK)	Width (mm)
K glass	1	6
Air (upward flow)	-	15
Eclipse 33/50 clear	1	6
	U-value (W/m²K)	1.953

Windows-OPTION2

Material	Conductivity (W/mK)	Width (mm)
K glass	1	6
Argon (downward flow)	-	12
Pilkington K	1	10
	U-value (W/m²K)	1.417

Windows-OPTION2/South

Material	Conductivity (W/mK)	Width (mm)
K glass	1	6
Argon (downward flow)	-	12
Eclipse 33/50 clear	1	6
	U-value (W/m²K)	1.637

Windows-OPTION3

Material	Conductivity (W/mK)	Width (mm)
SC planitherm, low-e	1	6
Air (upward flow)	-	15
K glass	1	6
Air (upward flow)	-	15
Pilkington K	1	10
	U-value (W/m²K)	1.025

Windows-OPTION3/South

Material	***Conductivity (W/mK)***	***Width (mm)***
SC planitherm, low-e	1	6
Air (upward flow)	-	15
K glass	1	6
Air (upward flow)	-	15
Eclipse 33/50 clear	1	6
	U-value (W/m^2K)	1.088

Windows-OPTION4

Material	***Conductivity (W/mK)***	***Width (mm)***
SC planitherm, low-e	1	6
Argon (downward flow)	-	12
K glass	1	6
Argon (downward flow)	-	12
Pilkington K	1	10
	U-value (W/m^2K)	0.79

Windows-OPTION4/South

Material	***Conductivity (W/mK)***	***Width (mm)***
SC planitherm, low-e	1	6
Argon (downward flow)	-	12
K glass	1	6
Argon (downward flow)	-	12
Eclipse 33/50 clear	1	6
	U-value (W/m^2K)	0.854

Appendix C- Heating and cooling loads-TAS

Table C1. Heating loads

Heating loads (Wh) days 1-120 and 274-365

	Bathroom	Bedroom1	Bedroom2	Bedroom3	Corridor first floor	Corridor ground floor	Kitchen	Living room	TOTAL (kWh)
Base	2187165	752184	955126	731677	655470	1595549	637287	2177482	9692
Internal 1a	1513777	589856	678788	541215	552670	1327827	383645	1720085	7308
Internal 1b	1499645	586769	673716	537575	550397	1321855	378654	1712235	7261
Internal 2a	1507164	589276	676808	540485	552894	1327323	380851	1714988	7290
Internal 2b	1485997	584665	669159	535010	549531	1318786	373662	1703049	7220
Internal 3a	1515681	588929	678857	540126	550842	1325209	383780	1723540	7307
Internal 3b	1508596	587415	676294	538363	549970	1322605	381305	1719680	7284
External 1a	1521025	597799	690574	557344	530540	1290983	398281	1687711	7274
External 1b	1493509	592206	681084	550587	526772	1281026	388414	1673694	7187
External 2a	1519073	593070	681130	545442	549147	1322887	391195	1715012	7317
External 2b	1500234	589022	674513	540553	546261	1315297	384390	1705366	7256
External 3a	1516525	596966	689176	556504	529618	1288914	396676	1684390	7259
External 3b	1493942	592415	681463	551045	526486	1280427	388460	1672774	7187
Ground1a	2185819	741763	946894	729869	653341	1574783	639838	2174737	9647
Ground1b	2185707	741054	946355	729744	653223	1573512	639426	2174522	9644
Ground2a	2185627	740545	945602	729610	652993	1571108	640607	2174299	9640
Ground2b	2185434	739110	944496	729328	652697	1568516	640744	2173883	9634
Ground3a	2185817	741808	946533	729855	653265	1573338	640698	2174686	9646
Ground3b	2185609	740369	945420	729578	652968	1570669	640614	2174265	9639
Ground4a	2184842	740126	947505	728952	652609	1576102	633264	2173549	9637
Ground4b	2184696	738882	946543	728709	652352	1573860	633232	2173188	9631
Windows1	2111318	553597	721441	630837	622303	1407655	502395	1881777	8431
Windows2	2091240	526876	696838	615069	615510	1380777	470985	1852196	8249
Windows3	2110078	531688	718310	618824	624769	1460559	473466	1872284	8410
Windows4	2099185	512836	701438	607513	620256	1445448	459433	1851971	8298
Roof1a	2060125	726883	935513	581390	542440	1556045	628001	1962088	8992
Roof1b	2057252	726239	935030	577683	539618	1554885	627657	1956661	8975
Roof2a	2060385	726943	935559	581702	542685	1556158	628192	1962588	8994
Roof2b	2056641	726102	934920	576876	539015	1554641	627449	1955468	8971
Roof3a	2062318	727234	935766	583843	544353	1556591	628286	1966027	9004
Roof3b	2059598	726618	935299	580386	541675	1555591	627986	1960925	8988
Lighting	2282473	760274	965146	741410	660415	1601005	638241	2350432	9999
COMBINATION	1166930	250479	317729	191891	347529	958743	114060	1158126	4505

Table C2. Cooling loads

	Cooling loads (Wh) days 121-273								
	Bathroom	Bedroom1	Bedroom2	Bedroom3	Corridor first floor	Corridor ground floor	Kitchen	Living room	TOTAL (KWh)
Base	63384	19308	12639	34069	26752	18528	301745	77227	554
Internal 1a	64147	17886	11444	30635	23796	15885	309327	77007	550
Internal 1b	64134	17848	11419	30539	23742	15823	309580	76962	550
Internal 2a	64623	17919	11475	30662	23853	15916	309132	77136	551
Internal 2b	64642	17860	11438	30553	23736	15822	309460	77106	551
Internal 3a	62273	17657	11163	30186	23547	15664	308261	76180	545
Internal 3b	62289	17644	11143	30177	23524	15625	308366	76168	545
External 1a	58053	24597	13693	37794	32299	22794	303336	89530	582
External 1b	58386	24810	13793	37986	32502	23046	304199	90090	585
External 2a	60852	17798	11042	30254	23857	15777	304946	76338	541
External 2b	60958	17767	11019	30186	23767	15717	305397	76356	541
External 3a	58179	24708	13755	37902	32438	22954	303490	89797	583
External 3b	58464	24865	13828	38066	32594	23094	304173	90252	585
Ground1a	64768	27946	18566	35513	28210	26040	324542	79195	605
Ground1b	64826	28302	18830	35588	28307	26444	325399	79300	607
Ground2a	64970	29641	19669	35767	28457	27321	327823	79505	613
Ground2b	65094	30481	20295	35919	28627	28133	329895	79702	618
Ground3a	64857	28845	19126	35648	28334	26596	325963	79350	609
Ground3b	64991	29798	19781	35794	28488	27458	328147	79536	614
Ground4a	64241	23133	15798	35015	27765	23750	314014	78543	582
Ground4b	64344	23754	16225	35104	27862	24372	315541	78660	586
Windows1	48587	4566	5966	17790	18897	9195	252354	65539	423
Windows2	48679	4485	5904	17772	18950	9192	252646	65499	423
Windows3	43775	2916	4023	14583	16815	6831	238921	60671	389
Windows4	45057	2831	3961	14529	16832	6802	239229	60665	390
Roof1a	51974	18111	11900	23105	17461	16567	299671	61759	501
Roof1b	51758	18024	11878	22881	17311	16521	299635	61428	499
Roof2a	51985	18112	11900	23117	17471	16569	299654	61776	501
Roof2b	51702	18013	11875	22823	17264	16509	299639	61338	499
Roof3a	51437	18045	11877	22845	17295	16539	299635	61117	499
Roof3b	51275	18022	11860	22665	17130	16501	299587	60827	498
Lighting	56040	19242	12593	33764	26472	18387	294752	71851	533
COMBINATION	18553	1065	2014	2221	5066	2838	222042	33745	288

Appendix D – Calculation of U-value of openings

Table D1. Calculation of overall U-value of openings (frame and pane) – initial windows constuction

	Frame U-value (kg/m²K)	Frame Area (m²)	Pane U-value (kg/m²K)	Pane area (m²)	Overall U-value (kg/m²K)	Area (m²)
Bathroom						
S	2.848	0.18	5.753	0.7	5.16	0.88
S	2.848	0.12	5.753	0.1	4.17	0.22
Bedroom1						
S	2.848	0.345	5.753	2.755	5.43	3.1
S	2.848	0.185	5.753	0.435	4.89	0.62
Bedroom2						
NW	2.848	0.09	5.753	0.16	4.71	0.25
NW	2.848	0.14	5.753	0.36	4.94	0.5
NW	2.848	0.09	5.753	0.16	4.71	0.25
N	2.848	0.135	5.753	0.34	4.93	0.475
N	2.848	0.185	5.753	0.765	5.19	0.95
N	2.848	0.135	5.753	0.34	4.93	0.475
NE	2.848	0.09	5.753	0.16	4.71	0.25
NE	2.848	0.14	5.753	0.36	4.94	0.5
NE	2.848	0.09	5.753	0.16	4.71	0.25
Bedroom3						
S	2.848	0.28	5.753	1.76	5.35	2.04
Corridor ground						
N (door)	2.848	0.315	3.196	1.87	3.15	2.185
N	2.848	0.14	5.753	0.382	4.97	0.522
Kitchen						
S	2.848	0.37	5.753	0.323	4.20	0.693
SW	2.848	0.185	5.753	0.585	5.06	0.77
W	2.848	0.22	5.753	1.04	5.25	1.26
NW	2.848	0.185	5.753	0.585	5.06	0.77
Living room						
N	2.848	0.32	5.753	1	5.05	1.32
N	2.848	0.32	5.753	1	5.05	1.32
N	2.848	0.3	5.753	0.8	4.96	1.1
Store room						
W	2.848	0.18	5.753	0.7	5.16	0.88
W	2.848	0.12	5.753	0.1	4.17	0.22

Table D2. Calculation of overall U-value of openings (frame and pane) in option Windows1

	Frame U-value (kg/m²K)	Frame Area (m²)	Pane U-value (kg/m²K)	Pane area (m²)	Overall U-value (kg/m²K)	Area (m²)
Bathroom						
S	1.653	0.18	1.953	0.7	1.89	0.88
S	1.653	0.12	1.953	0.1	1.79	0.22
Bedroom1						
S	1.653	0.345	1.953	2.755	1.92	3.1
S	1.653	0.185	1.953	0.435	1.86	0.62
Bedroom2						
NW	1.653	0.09	1.757	0.16	1.72	0.25
NW	1.653	0.14	1.757	0.36	1.73	0.5
NW	1.653	0.09	1.757	0.16	1.72	0.25
N	1.653	0.135	1.757	0.34	1.73	0.475
N	1.653	0.185	1.757	0.765	1.74	0.95
N	1.653	0.135	1.757	0.34	1.73	0.475
NE	1.653	0.09	1.757	0.16	1.72	0.25
NE	1.653	0.14	1.757	0.36	1.73	0.5
NE	1.653	0.09	1.757	0.16	1.72	0.25
Bedroom3						
S	1.653	0.28	1.953	1.76	1.91	2.04
Corridor ground						
N (door)	1.653	0.315	3.196	1.87	2.97	2.185
N	1.653	0.14	1.757	0.382	1.73	0.522
Kitchen						
S	1.653	0.37	1.953	0.323	1.79	0.693
SW	1.653	0.185	1.757	0.585	1.73	0.77
W	1.653	0.22	1.757	1.04	1.74	1.26
NW	1.653	0.185	1.757	0.585	1.73	0.77
Living room						
N	1.653	0.32	1.757	1	1.73	1.32
N	1.653	0.32	1.757	1	1.73	1.32
N	1.653	0.3	1.757	0.8	1.73	1.1
Store room						
W	1.653	0.18	1.757	0.7	1.74	0.88
W	1.653	0.12	1.757	0.1	1.70	0.22

Table D3. Calculation of overall U-value of openings (frame and pane) in option Windows2

	Frame U-value (kg/m²K)	Frame Area (m²)	Pane U-value (kg/m²K)	Pane area (m²)	Overall U-value (kg/m²K)	Area (m²)
Bathroom						
S	1.653	0.18	1.637	0.7	1.64	0.88
S	1.653	0.12	1.637	0.1	1.65	0.22
Bedroom1						
S	1.653	0.345	1.637	2.755	1.64	3.1
S	1.653	0.185	1.637	0.435	1.64	0.62
Bedroom2						
NW	1.653	0.09	1.417	0.16	1.50	0.25
NW	1.653	0.14	1.417	0.36	1.48	0.5
NW	1.653	0.09	1.417	0.16	1.50	0.25
N	1.653	0.135	1.417	0.34	1.48	0.475
N	1.653	0.185	1.417	0.765	1.46	0.95
N	1.653	0.135	1.417	0.34	1.48	0.475
NE	1.653	0.09	1.417	0.16	1.50	0.25
NE	1.653	0.14	1.417	0.36	1.48	0.5
NE	1.653	0.09	1.417	0.16	1.50	0.25
Bedroom3						
S	1.653	0.28	1.637	1.76	1.64	2.04
Corridor ground						
N (door)	1.653	0.315	3.196	1.87	2.97	2.185
N	1.653	0.14	1.417	0.382	1.48	0.522
Kitchen						
S	1.653	0.37	1.637	0.323	1.65	0.693
SW	1.653	0.185	1.417	0.585	1.47	0.77
W	1.653	0.22	1.417	1.04	1.46	1.26
NW	1.653	0.185	1.417	0.585	1.47	0.77
Living room						
N	1.653	0.32	1.417	1	1.47	1.32
N	1.653	0.32	1.417	1	1.47	1.32
N	1.653	0.3	1.417	0.8	1.48	1.1
Store room						
W	1.653	0.18	1.417	0.7	1.47	0.88
W	1.653	0.12	1.417	0.1	1.55	0.22

Table D4. Calculation of overall U-value of openings (frame and pane) in option Windows3

	Frame U-value (kg/m²K)	Frame Area (m²)	Pane U-value (kg/m²K)	Pane area (m²)	Overall U-value (kg/m²K)	Area (m²)
Bathroom						
S	1.653	0.18	1.088	0.7	1.20	0.88
S	1.653	0.12	1.088	0.1	1.40	0.22
Bedroom1						
S	1.653	0.345	1.088	2.755	1.15	3.1
S	1.653	0.185	1.088	0.435	1.26	0.62
Bedroom2						
NW	1.653	0.09	1.025	0.16	1.25	0.25
NW	1.653	0.14	1.025	0.36	1.20	0.5
NW	1.653	0.09	1.025	0.16	1.25	0.25
N	1.653	0.135	1.025	0.34	1.20	0.475
N	1.653	0.185	1.025	0.765	1.15	0.95
N	1.653	0.135	1.025	0.34	1.20	0.475
NE	1.653	0.09	1.025	0.16	1.25	0.25
NE	1.653	0.14	1.025	0.36	1.20	0.5
NE	1.653	0.09	1.025	0.16	1.25	0.25
Bedroom3						
S	1.653	0.28	1.088	1.76	1.17	2.04
Corridor ground						
N (door)	1.653	0.315	3.196	1.87	2.97	2.185
N	1.653	0.14	1.025	0.382	1.19	0.522
Kitchen						
S	1.653	0.37	1.088	0.323	1.39	0.693
SW	1.653	0.185	1.088	0.585	1.22	0.77
W	1.653	0.22	1.088	1.04	1.19	1.26
NW	1.653	0.185	1.088	0.585	1.22	0.77
Living room						
N	1.653	0.32	1.025	1	1.18	1.32
N	1.653	0.32	1.025	1	1.18	1.32
N	1.653	0.3	1.025	0.8	1.20	1.1
Store room						
W	1.653	0.18	1.025	0.7	1.15	0.88
W	1.653	0.12	1.025	0.1	1.37	0.22

Table D4. Calculation of overall U-value of openings (frame and pane) in option Windows3

	Frame U-value (kg/m²K)	Frame Area (m²)	Pane U-value (kg/m²K)	Pane area (m²)	Overall U-value (kg/m²K)	Area (m²)
Bathroom						
S	1.653	0.18	0.854	0.7	1.02	0.88
S	1.653	0.12	0.854	0.1	1.29	0.22
Bedroom1						
S	1.653	0.345	0.854	2.755	0.94	3.1
S	1.653	0.185	0.854	0.435	1.09	0.62
Bedroom2						
NW	1.653	0.09	0.79	0.16	1.10	0.25
NW	1.653	0.14	0.79	0.36	1.03	0.5
NW	1.653	0.09	0.79	0.16	1.10	0.25
N	1.653	0.135	0.79	0.34	1.04	0.475
N	1.653	0.185	0.79	0.765	0.96	0.95
N	1.653	0.135	0.79	0.34	1.04	0.475
NE	1.653	0.09	0.79	0.16	1.10	0.25
NE	1.653	0.14	0.79	0.36	1.03	0.5
NE	1.653	0.09	0.79	0.16	1.10	0.25
Bedroom3						
S	1.653	0.28	0.854	1.76	0.96	2.04
Corridor ground						
N (door)	1.653	0.315	3.196	1.87	2.97	2.185
N	1.653	0.14	0.79	0.382	1.02	0.522
Kitchen						
S	1.653	0.37	0.854	0.323	1.28	0.693
SW	1.653	0.185	0.79	0.585	1.00	0.77
W	1.653	0.22	0.79	1.04	0.94	1.26
NW	1.653	0.185	0.79	0.585	1.00	0.77
Living room						
N	1.653	0.32	0.79	1	1.00	1.32
N	1.653	0.32	0.79	1	1.00	1.32
N	1.653	0.3	0.79	0.8	1.03	1.1
Store room						
W	1.653	0.18	0.79	0.7	0.97	0.88
W	1.653	0.12	0.79	0.1	1.26	0.22

Appendix E – Costs evaluation and payback periods

Table E1. External Walls - Internal Insulation Option Internal 1a

Net wall area (without openings)=57.46 m^2

Element	Element Quantity	Labour cost (£/unit of element)	Material cost (£/unit of element)	Total Labour Cost (£)	Total material cost (£)	Total Cost (£)
Plasterboard (average height=2.7 for all the building)	21.86 m	16.08	12.49	351.5088	273.0314	624.5402
Expanded polystyrene 80 mm	57.46 m2	6.21	13.84	356.8266	795.2464	1152.073
Vapour barrier	57.46 m2	1.2	1.42	68.952	81.5932	150.5452
Skirting	21.86 m	1.83	3.59	40.0038	78.4774	118.4812
Gloss oil paint	57.46 m2	4.91	2.76	282.1286	158.5896	440.7182
			Total (excluding VAT)	1099.4198	1386.938	2486.3578

Table E2. External Walls - Internal Insulation Option Internal 1b

Net wall area (without openings)=57.46 m^2

Element	Element Quantity	Labour cost (£/unit of element)	Material cost (£/unit of element)	Total Labour Cost (£)	Total material cost (£)	Total Cost (£)
Plasterboard (average height=2.7 for all the building)	21.86 m	16.08	12.49	351.5088	273.0314	624.5402
Expanded polystyrene 90 mm	57.46 m2	6.51	14.66	374.0646	842.3636	1216.4282
Vapour barrier	57.46 m2	1.2	1.42	68.952	81.5932	150.5452
Skirting	21.86 m	1.83	3.59	40.0038	78.4774	118.4812
Gloss oil paint	57.46 m2	4.91	2.76	282.1286	158.5896	440.7182
			Total (excluding VAT)	1116.6578	1434.0552	2550.713

Table E3. External Walls - Internal Insulation Option Internal 2a

Net wall area (without openings)=57.46 m^2

Element	Element Quantity		Labour cost (£/unit of element)	Material cost (£/unit of element)	Total Labour Cost (£)	Total material cost (£)	Total Cost (£)
Timber framing	102.6	m	2.19	0.73	224.694	74.898	299.592
Plasterboard (average height=2.7 for all the building)	21.86	m	16.08	12.49	351.5088	273.0314	624.5402
Glass fibre 100 mm	57.46	m2	1.34	2.48	76.9964	142.5008	219.4972
Vapour barrier	57.46	m2	1.2	1.42	68.952	81.5932	150.5452
Skirting	21.86	m	1.83	3.59	40.0038	78.4774	118.4812
Gloss oil paint	57.46	m2	4.91	2.76	282.1286	158.5896	440.7182
				Total (excluding VAT)	819.5896	734.1924	1553.782

Table E4. External Walls - Internal Insulation Option Internal 1a

Net wall area (without openings)=57.46 m^2

Element	Element Quantity		Labour cost (£/unit of element)	Material cost (£/unit of element)	Total Labour Cost (£)	Total material cost (£)	Total Cost (£)
Timber framing	102.6	m	2.19	0.73	224.694	74.898	299.592
Plasterboard (average height=2.7 for all the building)	21.86	m	16.08	12.49	351.5088	273.0314	624.5402
Glass fibre (140 mm)	57.46	m2	2.81	5.75	161.4626	330.395	491.8576
Vapour barrier	57.46	m2	1.2	1.42	68.952	81.5932	150.5452
Skirting	21.86	m	1.83	3.59	40.0038	78.4774	118.4812
Gloss oil paint	57.46	m2	4.91	2.76	282.1286	158.5896	440.7182
				Total (excluding VAT)	904.0558	922.0866	1826.1424

Table E5. External Walls - Internal Insulation Option Internal 3a

Net wall area (without openings)=57.46 m^2

Element	Element Quantity		Labour cost (£/unit of element)	Material cost (£/unit of element)	Total Labour Cost (£)	Total material cost (£)	Total Cost (£)
Timber framing	102.6	m	2.19	0.73	224.694	74.898	299.592
Plasterboard (average height=2.7 for all the building)	21.86	m	16.08	12.49	351.5088	273.0314	624.5402
Mineral wool 125mm	57.46	m2	3.88	7.14	222.9448	410.2644	633.2092
Vapour barrier	57.46	m2	1.2	1.42	68.952	81.5932	150.5452
Skirting	21.86	m	1.83	3.59	40.0038	78.4774	118.4812
Gloss oil paint	57.46	m2	4.91	2.76	282.1286	158.5896	440.7182
				Total (excluding VAT)	965.538	1001.956	1967.494

Table E6. External Walls - Internal Insulation Option Internal 3b

Net wall area (without openings)=57.46 m^2

Element	Element Quantity		Labour cost (£/unit of element)	Material cost (£/unit of element)	Total Labour Cost (£)	Total material cost (£)	Total Cost (£)
Timber framing	102.6	m	2.19	0.73	224.694	74.898	299.592
Plasterboard (average height=2.7 for all the building)	21.86	m	16.08	12.49	351.5088	273.0314	624.5402
Mineral wool 125 mm	57.46	m2	3.88	7.14	222.9448	410.2644	633.2092
Vapour barrier	57.46	m2	1.2	1.42	68.952	81.5932	150.5452
Skirting	21.86	m	1.83	3.59	40.0038	78.4774	118.4812
Gloss oil paint	57.46	m2	4.91	2.76	282.1286	158.5896	440.7182
				Total (excluding VAT)	965.538	1001.956	1967.494

Table E7. External Walls - External Insulation Option External 1a

Net external wall area (without openings)=67.85 m^2

Element	Element Quantity	Labour cost (£/unit of element)	Material cost (£/unit of element)	Total Labour Cost (£)	Total material cost (£)	Total Cost (£)
Expanded polystyrene 75mm	62.975 m2	3.65	12.11	229.85875	762.62725	992.486
Metal lathing	62.975 m2	4.98	10.5	313.6155	661.2375	974.853
Concrete screed	62.975 m2	0	10.11	0	636.67725	636.67725
Paint	62.975 m2	3.79	1.12	238.67525	70.532	309.20725
			Total (excluding VAT)	782.1495	2131.074	2913.2235

Table E8. External Walls - External Insulation Option External 1b

Net external wall area (without openings)=67.85 m^2

Element	Element Quantity	Labour cost (£/unit of element)	Material cost (£/unit of element)	Total Labour Cost (£)	Total material cost (£)	Total Cost (£)
Expanded polystyrene for 100 mm	62.975 m2	3.84	15.8	241.824	995.005	1236.829
Metal lathing	62.975 m2	4.98	10.5	313.6155	661.2375	974.853
Concrete screed	62.975 m2	0	10.11	0	636.67725	636.67725
Paint	62.975 m2	3.79	1.12	238.67525	70.532	309.20725
			Total (excluding VAT)	794.11475	2363.45175	3157.5665

Table E9. External Walls - External Insulation Option External 2a

Net external wall area (without openings)=67.85 m2

Element	Element Quantity	Labour cost (£/unit of element)	Material cost (£/unit of element)	Total Labour Cost (£)	Total material cost (£)	Total Cost (£)
Mineral wool 120 mm	62.975 m2	3.88	7.14	244.343	449.6415	693.9845
Metal lathing	62.975 m2	4.98	10.5	313.6155	661.2375	974.853
Concrete screed	62.975 m2	0	10.11	0	636.67725	636.67725
Paint	62.975 m2	3.79	1.12	238.67525	70.532	309.20725
			Total (excluding VAT)	796.63375	1818.08825	2614.722

Table E10. External Walls - External Insulation Option External 2b

Net external wall area (without openings)=67.85 m2

Element	Element Quantity	Labour cost (£/unit of element)	Material cost (£/unit of element)	Total Labour Cost (£)	Total material cost (£)	Total Cost (£)
Mineral wool 150mm	62.975 m2	4.02	8.16	253.1595	513.876	767.0355
Metal lathing	62.975 m2	4.98	10.5	313.6155	661.2375	974.853
Concrete screed	62.975 m2	0	10.11	0	636.67725	636.67725
Paint	62.975 m2	3.79	1.12	238.67525	70.532	309.20725
			Total (excluding VAT)	805.45025	1882.32275	2687.773

Table E11. External Walls - External insulation Option External 3a

Net external wall area (without openings)=67.85 m2

Element	Element Quantity		Labour cost (£/unit of element)	Material cost (£/unit of element)	Total Labour Cost (£)	Total material cost (£)	Total Cost (£)
Glass fibre 100 mm	62.975	m2	1.34	2.48	84.3865	156.178	240.5645
Metal lathing	62.975	m2	4.98	10.5	313.6155	661.2375	974.853
Concrete screed	62.975	m2	0	10.11	0	636.67725	636.67725
Paint	62.975	m2	3.79	1.12	238.67525	70.532	309.20725
				Total (excluding VAT)	636.67725	1524.62475	2161.302

Table E12. External Walls - External insulation Option External 3b

Net external wall area (without openings)=67.85 m2

Element	Element Quantity		Labour cost (£/unit of element)	Material cost (£/unit of element)	Total Labour Cost (£)	Total material cost (£)	Total Cost (£)
Glass fibre 140 mm	62.975	m2	2.81	5.75	176.95975	362.10625	539.066
Metal lathing	62.975	m2	4.98	10.5	313.6155	661.2375	974.853
Concrete screed	62.975	m2	0	10.11	0	636.67725	636.67725
Paint	62.975	m2	3.79	1.12	238.67525	70.532	309.20725
				Total (excluding VAT)	729.2505	1730.553	2459.8035

Table E13. Ground floor-Option Ground1a

Ground floor area=52.431 m2

Element	Element Quantity	Labour cost (£/unit of element)	Material cost (£/unit of element)	Total Labour Cost (£)	Total material cost (£)	Total Cost (£)
Remove carpet	52.43 m2	1.47	0	77.0721	0	77.0721
Remove floorboards	52.43 m2	9.23	0	483.9289	0	483.9289
Mineral wool board 100 mm	52.43 m2	2.68	5.44	140.5124	285.2192	425.7316
Refit Floorboard	52.43 m2	4.89	0.5	256.3827	26.215	282.5977
Refit carpet	52.43 m2	5.62	0	294.6566	0	294.6566
			Total (excluding VAT)	1252.5527	311.4342	1563.9869

Table E14. Ground floor-Option Ground1a

Ground floor area=52.431 m2

Element	Element Quantity	Labour cost (£/unit of element)	Material cost (£/unit of element)	Total Labour Cost (£)	Total material cost (£)	Total Cost (£)
Remove carpet	52.43 m2	1.47	0	77.0721	0	77.0721
Remove floorboards	52.43 m2	9.23	0	483.9289	0	483.9289
Mineral wool board 110 mm	52.43 m2	2.68	5.44	140.5124	285.2192	425.7316
Refit Floorboard	52.43 m2	4.89	0.5	256.3827	26.215	282.5977
Refit carpet	52.43 m2	5.62	0	294.6566	0	294.6566
			Total (excluding VAT)	1252.5527	311.4342	1563.9869

Table E15. Ground floor-Option Ground1a

Ground floor area=52.431 m2

Element	Element Quantity	Labour cost (£/unit of element)	Material cost (£/unit of element)	Total Labour Cost (£)	Total material cost (£)	Total Cost (£)
Remove carpet	52.43 m2	1.47	0	77.0721	0	77.0721
Remove floorboards	52.43 m2	9.23	0	483.9289	0	483.9289
Expanded polystyrene 80 mm	52.43 m2	6.21	13.84	325.5903	725.6312	1051.2215
Refit Floorboard	52.43 m2	4.89	0.5	256.3827	26.215	282.5977
Refit carpet	52.43 m2	5.62	0	294.6566	0	294.6566
			Total (excluding VAT)	1437.6306	751.8462	2189.4768

Table E16. Ground floor-Option Ground1a

Ground floor area=52.431 m2

Element	Element Quantity	Labour cost (£/unit of element)	Material cost (£/unit of element)	Total Labour Cost (£)	Total material cost (£)	Total Cost (£)
Remove carpet	52.43 m2	1.47	0	77.0721	0	77.0721
Remove floorboards	52.43 m2	9.23	0	483.9289	0	483.9289
Expanded polystyrene 100 mm	52.43 m2	6.58	16.8	344.9894	880.824	1225.8134
Refit Floorboard	52.43 m2	4.89	0.5	256.3827	26.215	282.5977
Refit carpet	52.43 m2	5.62	0	294.6566	0	294.6566
			Total (excluding VAT)	1457.0297	907.039	2364.0687

Table E17. Ground floor-Option Ground1a

Ground floor area=52.431 m2

Element	Element Quantity	Labour cost (£/unit of element)	Material cost (£/unit of element)	Total Labour Cost (£)	Total material cost (£)	Total Cost (£)
Remove carpet	52.43 m2	1.47	0	77.0721	0	77.0721
Remove floorboards	52.43 m2	9.23	0	483.9289	0	483.9289
Glass fibre 80 mm	52.43 m2	1.47	2.27	77.0721	119.0161	196.0882
Refit Floorboard	52.43 m2	4.89	0.5	256.3827	26.215	282.5977
Refit carpet	52.43 m2	5.62	0	294.6566	0	294.6566
			Total (excluding VAT)	1189.1124	145.2311	1334.3435

Table E18. Ground floor-Option Ground1a

Ground floor area=52.431 m2

Element	Element Quantity	Labour cost (£/unit of element)	Material cost (£/unit of element)	Total Labour Cost (£)	Total material cost (£)	Total Cost (£)
Remove carpet	52.43 m2	1.47	0	77.0721	0	77.0721
Remove floorboards	52.43 m2	9.23	0	483.9289	0	483.9289
Glass fibre 100 mm	52.43 m2	1.61	2.71	84.4123	142.0853	226.4976
Refit Floorboard	52.43 m2	4.89	0.5	256.3827	26.215	282.5977
Refit carpet	52.43 m2	5.62	0	294.6566	0	294.6566
			Total (excluding VAT)	1196.4526	168.3003	1364.7529

Table E19. Ground floor-Option Ground1a

Ground floor area=52.431 m2

Element	Element Quantity	Labour cost (£/unit of element)	Material cost (£/unit of element)	Total Labour Cost (£)	Total material cost (£)	Total Cost (£)
Remove carpet	52.43 m2	1.47	0	77.0721	0	77.0721
Remove floorboards	52.43 m2	9.23	0	483.9289	0	483.9289
Mineral wool board (50+50)	52.43 m2	2.68	5.44	140.5124	285.2192	425.7316
Cement screed	52.43 m2	10.84	8.28	568.3412	434.1204	1002.4616
Refit Floorboard	52.43 m2	4.89	0.5	256.3827	26.215	282.5977
Refit carpet	52.43 m2	5.62	0	294.6566	0	294.6566
			Total (excluding VAT)	1820.8939	745.5546	2566.4485

Table E20. Ground floor-Option Ground1a

Ground floor area=52.431 m2

Element	Element Quantity	Labour cost (£/unit of element)	Material cost (£/unit of element)	Total Labour Cost (£)	Total material cost (£)	Total Cost (£)
Remove carpet	52.43 m2	1.47	0	77.0721	0	77.0721
Remove floorboards	52.43 m2	9.23	0	483.9289	0	483.9289
Mineral wool board 125 mm	52.43 m2	3.88	7.14	203.4284	374.3502	577.7786
	52.43 m2	6.58	16.8	344.9894	880.824	1225.8134
Refit Floorboard	52.43 m2	4.89	0.5	256.3827	26.215	282.5977
Refit carpet	52.43 m2	5.62	0	294.6566	0	294.6566
			Total (excluding VAT)	1660.4581	1281.3892	2941.8473

Table E21. Roof - Option Roof1a

Roof area =36.881 m2

Element	Element Quantity	Labour cost (£/unit of element)	Material cost (£/unit of element)	Total Labour Cost (£)	Total material cost (£)	Total Cost (£)
Expanded polystyrene 160 mm	36.881 m2	7.31	25.67	269.60011	946.73527	1216.33538
Bitumen felt	36.881 m3	0.83	1.44	30.61123	53.10864	83.71987
Breather membrane	36.881 m2	0.83	1.51	30.61123	55.69031	86.30154
			Total (excluding VAT)	330.82257	1055.53422	1386.35679

Table G22. Roof - Option Roof1b

Roof area =36.881 m2

Element	Element Quantity	Labour cost (£/unit of element)	Material cost (£/unit of element)	Total Labour Cost (£)	Total material cost (£)	Total Cost (£)
Expanded polystyrene 175 mm	36.881 m2	7.49	30.91	276.23869	1139.99171	1416.2304
Bitumen felt	36.881 m3	0.83	1.44	30.61123	53.10864	83.71987
Breather membrane	36.881 m2	0.83	1.51	30.61123	55.69031	86.30154
			Total (excluding VAT)	337.46115	1248.79066	1586.25181

Table G23. Roof - Option Roof2a

Roof area =36.881 m2

Element	Element Quantity		Labour cost (£/unit of element)	Material cost (£/unit of element)	Total Labour Cost (£)	Total material cost (£)	Total Cost (£)
Polyurethane boards 130 mm	36.881	m2	36.59	0	1349.47579	0	1349.47579
Bitumen felt	36.881	m3	0.83	1.44	30.61123	53.10864	83.71987
Breather membrane	36.881	m2	0.83	1.51	30.61123	55.69031	86.30154
				Total (excluding VAT)	1410.69825	108.79895	1519.4972

Table E24. Roof - Option Roof2b

Roof area =36.881 m2

Element	Element Quantity		Labour cost (£/unit of element)	Material cost (£/unit of element)	Total Labour Cost (£)	Total material cost (£)	Total Cost (£)
Polyurethane boards 150 mm	36.881	m2	38.46	0	1418.44326	0	1418.44326
Bitumen felt	36.881	m3	0.83	1.44	30.61123	53.10864	83.71987
Breather membrane	36.881	m2	0.83	1.51	30.61123	55.69031	86.30154
				Total (excluding VAT)	1479.66572	108.79895	1588.46467

Table E25. Roof - Option Roof3a

Roof area =36.881 m2

Element	Element Quantity		Labour cost (£/unit of element)	Material cost (£/unit of element)	Total Labour Cost (£)	Total material cost (£)	Total Cost (£)
Cork boards 180 mm	36.881	m2	52.38	0	1931.82678	0	1931.82678
Bitumen felt	36.881	m3	0.83	1.44	30.61123	53.10864	83.71987
Breather membrane	36.881	m2	0.83	1.51	30.61123	55.69031	86.30154
				Total (excluding VAT)	1993.04924	108.79895	2101.84819

Table E26. Roof - Option Roof3b

Roof area =36.881 m2

Element	Element Quantity		Labour cost (£/unit of element)	Material cost (£/unit of element)	Total Labour Cost (£)	Total material cost (£)	Total Cost (£)
Cork boards 240 mm	36.881	m2	69.84	0	2575.76904	0	2575.76904
Bitumen felt	36.881	m3	0.83	1.44	30.61123	53.10864	83.71987
Breather membrane	36.881	m2	0.83	1.51	30.61123	55.69031	86.30154
				Total (excluding VAT)	2606.38027	108.79895	2745.79045

Table E27. Heating Option 1

Element	Element Quantity		Labour cost (£/unit of element)	Material cost (£/unit of element)	Total Labour Cost (£)	Total material cost (£)	Total Cost (£)
Remove existing boiler and fit the new one#	1	nr	475	0	475	0	475
Condensing Combi boiler*	1	nr	0	824	0	824	824
				Total (excluding VAT)	0	824	1299

#Figure after personal communication with a heating company

*The Condensing Combi Boiler cost is for an "Alpha CD24C Condensing Combi boiler", up to 24 kW, SEDBUK band 'A'
(www.discountedheating.co.uk/shop/acatalog/Alpha_Condensing_Combi_Boilers, (3/9/2006))

Table E28. Heating Option 2

Element	Element Quantity		Labour cost (£/unit of element)	Material cost (£/unit of element)	Total Labour Cost (£)	Total material cost (£)	Total Cost (£)
Condensing Combi boiler	1	nr	0	824	0	824	824
Remove existing boiler and fit the new one	1	nr	475	0	475	0	475
TRVs#	9	nr	60	15	540	135	675
				Total (excluding VAT)	1015	959	1974

*The Condensing Combi Boiler cost is for an "Alpha CD24C Condensing Combi boiler", up to 24 kW, SEDBUK band 'A' (www.discountedheating.co.uk/shop/acatalog/Alpha_Condensing_Combi_Boilers, (3/9/2006))

Price for "Danfoss Randall" Ras-D2 15, 10, or 8 mm (http://www.discountedheating.co.uk/shop/acatalog/Online_Catalogue_Danfoss_Randall_Thermastat_Radiator_Valves_175.html, (3/9/2006))

Table E29. Heating Option 3

Element	Element Quantity		Labour cost (£/unit of element)	Material cost (£/unit of element)	Total Labour Cost (£)	Total material cost (£)	Total Cost (£)
Condensing Combi boiler*	1	nr	0	824	0	824	824
Remove existing boiler and fit the new one	1	nr	475	0	475	0	475
Full zone control, install control system#	5	nr	100	150	500	750	1250
				Total (excluding VAT)	975	1574	2549

*The Condensing Combi Boiler cost is for an "Alpha CD24C Condensing Combi boiler", up to 24 kW, SEDBUK band 'A'
(http://www.discountedheating.co.uk/shop/acatalog/Alpha_Condensing_Combi_Boilers, (3/9/2006))

#Price for 2000, taken from "Flewitt, Ian; The role of residential refurbishment in reducing CO2 emissions in the UK, UCL Thesis 2000, Appendix, p G91"

Appendix F - Boiler sizing

(The assumptions and the factors are presented as seen in the calculator, http://www.boilers.org.uk/, Boiler sizing method.)

Assumptions:

- a design internal temperature of 21°C (included in location factor).
- design external temperatures, dependant on the location of the property (included in the location factor).
- an allowance of 10% for intermittent heating (included in the location factor).
- an allowance of 5% for pipe losses (included in the location factor).
- a ventilation rate of 0.7 air changes per hour (included in the 0.25 ventilation factor).
- an allowance of 2 kW for heating hot water.

TABLES

Factors used

Window Factors

Detached	0.17
Semi-detached	0.2
Mid terrace	0.25
Flat	0.25

Window U-values

Double glazed wood/plastic	3.0
Double glazed metal frames	4.2
Single glazed wood/plastic	4.7
Single glazed metal frames	5.8

Wall U-values

Filled cavity wall	0.45
Unfilled cavity wall	1.6
Solid wall 220mm	2.1

Roof U-values

Pitched < 50mm insulation	2.6
Pitched 50-75mm insulation	0.99
Pitched > 75mm insulation	0.44
Flat uninsulated	2.0
Flat 50mm insulation	0.54

Location Factors

North & Midlands	29
Northern Ireland	26.5
Scotland	28.5
South East & Wales	27
South West	25

Appendix G – Embodied CO_2 of insulation materials

One more thing that should be considered during a refurbishment is the embodied energy of the materials. Previous research[80] has shown that embodied CO_2 in refurbishment measures similar to the ones that were tested in this report, can be paid back in a period of 8 years for every measure, apart from double glazing, which can be recovered in less than 3 years. Triple glazing was not tested in that research. From the tables below it is obvious that expanded polystyrene has the highest embodied CO_2, so it would take the longest to pay it back. However, polystyrene has better insulation properties than other insulation materials with lower embodied CO_2, so less of this material is essential to achieve the desirable U-value. In any case, embodied CO_2 and its payback period should be examined and calculated so that the refurbishment will achieve the optimum energy saving performance.

Table F1. Embodied CO_2 from insulants[81]

Insulation Type	***Insulation Product Name***	***Use***	***Conductivity W/mK***	***Density (kg/m3)***	***Embodied Energy (GJ/tonne)#***	***CO2 emissions (kg/tonne)^***
Mineral Wool	Rockwool Flexible Slab RW2	Floor & wall	0.035	33	15.1	1
Mineral Wool	Rockwool Cavity Wall Batts	wall	0.036	24	15.1	1
Blown Mineral Wool	Rockwool Energysaver	wall	0.039	24	15.1	1
Mineral Wool	Rollbatts	Roof	0.037	24	15.1	1
Cellulose		Wall & roof	0.05	24	1.75	0
Cellular Glass	Foamglas	Floor, wall, roof	0.038	120	27.9	2
Polyisocyanurate	Trymer	Floor, wall, roof	0.027	29	69.8	5
Perlite	Sproule Perlite	Floor, wall, roof	0.056	192	-	-
Phenolic foam	Tarec	Floor, wall, roof	0.019	40	-	-
Expanded Polstyrene	-	Floor, wall, roof	0.037	21	111.6	8

Data generally from manufacturer's
literature, except;

#Embodied Energy Data from Environmental Building News (1) for generic type of insulation
listed in column 1
^Embodied energy converted to CO2 emissions using BRE figure of 0.069 kgC/kWh(1996) (2)
for C production per kWh
then DETR conversion figure 44/12 for conversion of C to CO2 full
molecular weight basis

(1) Insulation Materials: Environmental Comparisons, Environmental Building News, Building

[80] Flewitt, Ian; The role of residential refurbishment in reducing CO2 emissions in the UK, UCL Thesis 2000, 'Abstract'.
[81] Copied from Flewitt, Ian; The role of residential refurbishment in reducing CO2 emissions in the UK, UCL Thesis 2000, p 43.

Green, January 1995.
(2) A Better Quality of Life, DETR (UK), The Stationary Office, 1998.

Table F2. Insulation materials and embodied CO_2 (Source: Insulation materials: Environmental Comparisons, Environmental Building News, Building Green, January 1995, *(https: www.buildinggreen.com auth article.cfm?fileName=040101a.xml, 5 9 2006)*)

Material	Embodied Energy in Btu/lb. (MJ/kg)	Weight per insulating unit[1] in lbs. (kg)	Embodied Energy per insulating unit in Btu (MJ)
Cellulose[2]	750 (1.75)	0.812 (0.37)	600 (0.6)
Fiberglass[3]	12,000 (27.9)	0.379 (0.17)	4,550 (4.8)
Mineral wool[2]	6,500 (15.1)	0.458 (0.21)	2,980 (3.1)
EPS[3]	48,000(111.6)	0.375 (0.17)	18,000(19.0)
Polyiso[3]	30,000 (69.8)	0.476 (0.22)	14,300(15.1)

1. "Insulating unit" refers to the mass of insulation required to provide R-20 (RSI-3.52) over one ft^2 (0.093m) at standard density.

2. Figures from personal communication with manufacturers.

3. Figures from the final report: "Comparative Energy Evaluation of Plastic Products and Their Alternatives for the Building and Construction and Transportation Industries," 1991, Franklin Associates, Ltd., prepared for The Society of the Plastics Industry.