University of Strathclyde Engineering

Department of Mechanical and Aerospace Engineering

ANALYSIS OF HOUSING UPGRADES FOR POLICY FORMULATION USING DYNAMIC SIMULATION TOOL

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Copyright Declaration

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Signed: Esan Kolade O. Date: 7/9/2012

Abstract

Upgrading existing building stock is no longer a debatable issue to improve the energy performance of existing building stock and reduce the carbon emission. It is believed that a minimum of 70% and above of the existing building will still be standing in 2050. Some sources are raising it to about 85%. For these buildings to be in existence in 2050, their current energy consumption and carbon emission cannot be acceptable in the nearest future. These will be negating the effort to reduce the carbon emission, meet the Kyoto protocol act and the 2050 target. Since the building sector is responsible for over 40% of the carbon emission in the UK, it will have a big impact Carbon Emission Reduction Target (CERT).

Government policy guidance and cost efficient approach that will hasten the retrofitting of existing building stock is a major challenge now. Policy makers are not generally technically inclined, but need sound results from building physics based computational environments, to base their decisions upon, when formulating policies regarding housing upgrade. The new build has a 1% penetration rate, which is too small to have a significant impact on the building stock by 2050.

This research describes the various upgrading approaches and analyses the approach to determine the best upgrading strategy. A dynamic simulation based tool was employed to carry out the simulation and analysis instead of conventional simple energy balance approach. The dynamic tool is meant to assess the various improvement options and compare them. This is meant to help policy makers to determine which approach best suit the building.

The tool was applied to stock average case models and to the South Ayrshire council housing. Improving the heating system alone gives a 37 % reduction in energy consumption. About 45 % reduction in energy occurs when improving the insulation alone. Combination of the two approaches with the introduction of LZCTs leads to about 87% reduction in energy consumption. In reality, saving will probably be lower and reasons for this are detailed in this report.

Acknowledgements

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To all my friends I met in Glasgow and my course mates, this is just the beginning. Better days are ahead of us, we see at the top.

ABBREVIATIONS

ASHP	Air Source Heat Pump
BEopt	Building Energy Optimization
CERT	Carbon Energy Reduction Target
CESP	Community Energy Saving Programme
CRC EES	Carbon Reduction Commitment Energy Efficient Efficiency Scheme
DECC	Department of Energy and Climate Change
DHW	Domestic Hot Water
EHS	English Housing Survey
EPA-ED	Energy Performance Assessment of Existing Dwellings
EPBD	Energy Performance of Buildings Directive
EPC	Energy Performance Certificate
ESRU	Energy System Research Unit
EU	European Union
EWI	External Wall Insulation
GHG	Green House Gas
GSHP	Ground Source Heat Pump
HUE	Housing Upgrading Evaluation
IWI	Internal Wall Insulation
LCC	Life Cycle Cost

LZCTs	Low and Zero Carbon Technologies
Mtoe	Metric Tonne of Oil Equivalent
$MtCO_2$	Metric Tonne Carbon Dioxide
NREL	National Renewable Energy Laboratory
UK	United Kingdom
UK-GBC	UK Green Building Council
PV	Photo Voltaic
SAP	Standard Assessment Procedure
SDHW	Solar Domestic Hot water
TFA	Total Floor Area
TREAT	Targeted Retrofit Energy Analysis Tool

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CHAPTER ONE

INTRODUCTION

1.1 Background.

Sustainability of energy is a major challenge in this present age. Energy is required for the existence of man. Virtually all sectors of economy consume energy. The sectors that consume substantial amount of energy are: power and industry, transport and the building stock (Clarke *et al*, 2008). Existing European Union (EU) building stock accounts for about 40% of the total EU's energy consumption (Energy Efficiency/linksDossier, 2012). UK energy consumption is a typical example of the EU energy consumption this is shown in figure 1.1 below. As an example 435 metric tonnes of oil equivalent (Mtoe) was consumed by the EU building sector in 2002, which amounts to 40.3% of the total EU energy consumption (Poel *et al*, 2007).

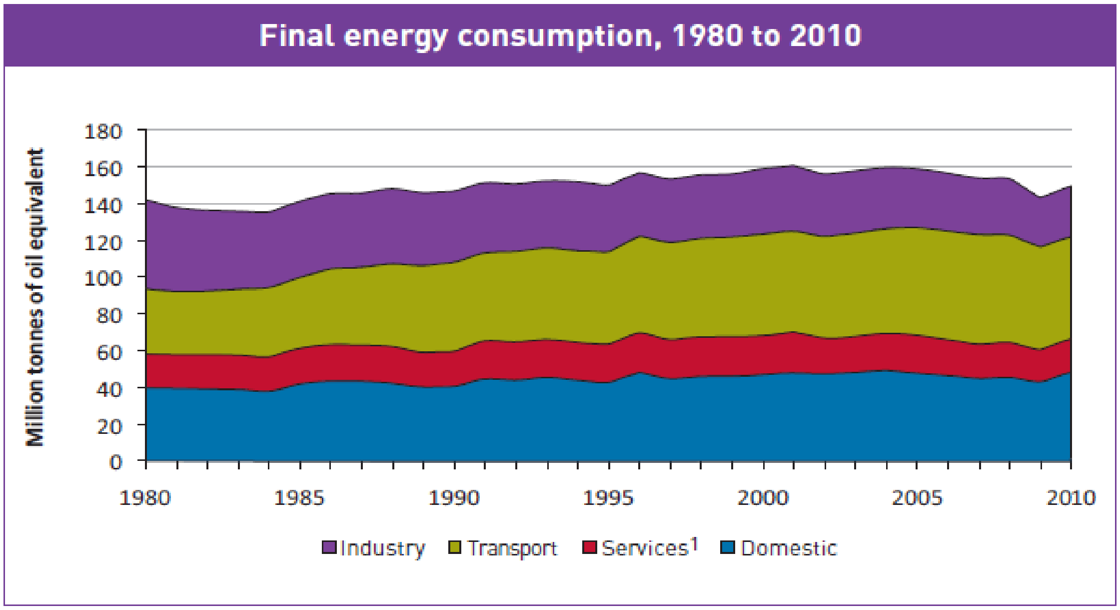


Figure 1.1: UK energy consumption 2010.
(Source: UK –energy-in-brief 2011)

There are about 196 million domestic buildings in the EU with approximately more than 50% being constructed before 1970 (Poel *et al*, 2007). About 26 million domestic buildings and 1.8 million non-domestic buildings are in existence in the UK and their energy consumption is accountable for 26% and 17% of the UK CO_2 emissions respectively (Our Priorities/Retrofit, 2012). The UK’s housing stock is among the least energy efficient buildings in the EU and is responsible for about a quarter of the annual carbon emissions (UK-GBC, 2012). Approximately 80% of the existing building stock is pre -1981 and its energy consumption is on the high side compared to new builds which have low energy consumption and are more energy efficient.

Approximately 75% of the existing building stock will still be standing by the year 2050 (National Statistics, 2012). It will require retrofitting of the existing stock on a massive scale to bring it up to applicable standards. Carbon Emissions Reduction Target (CERT) is a target to reduce the carbon emission level by 80% below 1990 levels as agreed to by the Kyoto protocol act for UN members’ state and to reduce their green gas emissions by 12.5% below 1990 levels by 2008-2012 (Department of Energy & Climate Change, 2009). 2050 is the deadline to achieve CERT. Almost all the members’ state of the UN have signed the Kyoto protocol act and have obligation to reduce their carbon emission levels. The source of energy generation plays an important role in CO_2 emission because conventional power plants burn fossil fuel to generate energy. Figure 1.2 below shows coal consumption across various sectors in the UK. During the generation of electricity from conventional plants CO_2 is emitted, therefore reducing energy consumption in buildings will reduce energy demand. There has been a gradual increase in electricity consumption in the domestic sector from the 80s which plays an important role in the carbon footprint of the UK this can be seen in figure1.3.

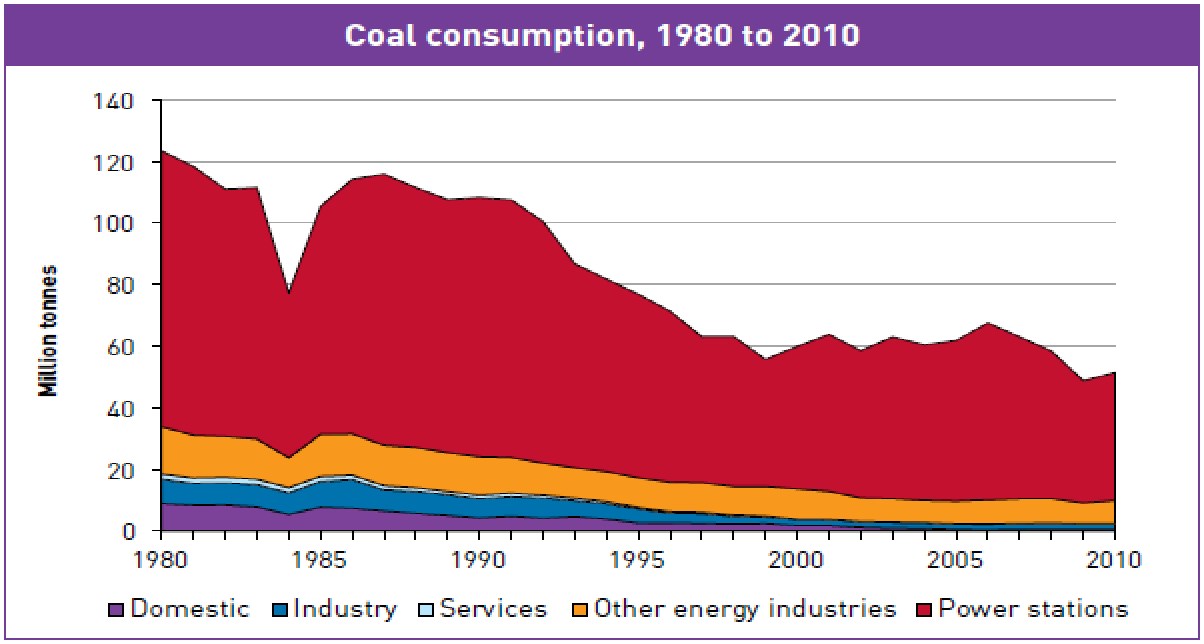


Figure 1.2: UK Coal consumption

(Source: UK –energy-in-brief 2011)

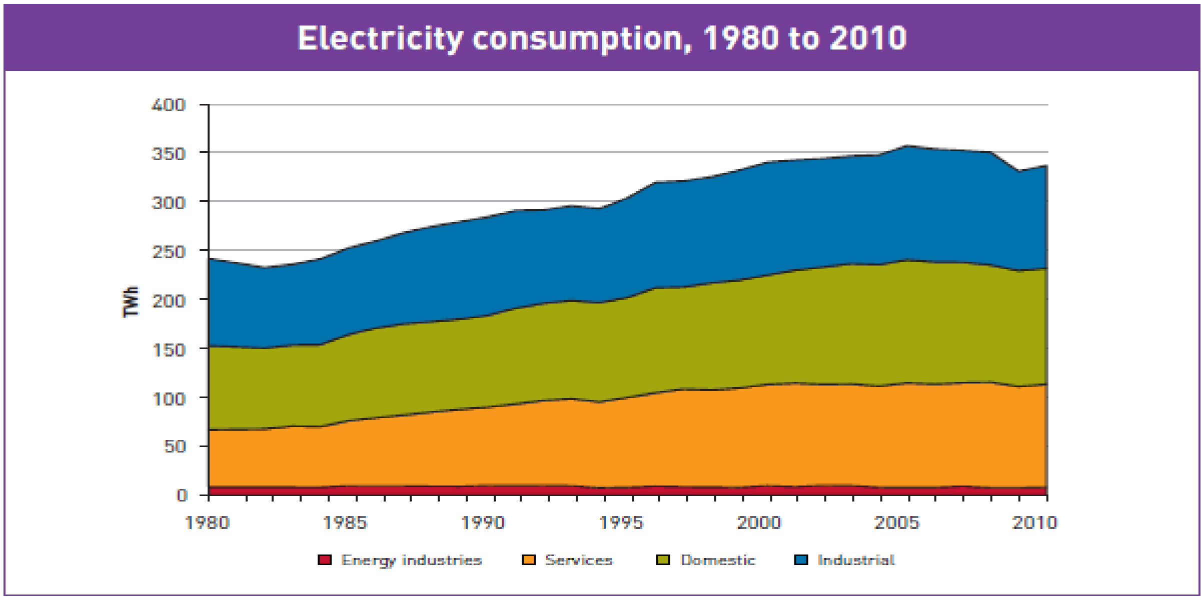


Figure 1.3: UK Electricity consumption

(Source: UK –energy-in-brief 2011)

Approximately 80% of the existing domestic stock comprises of buildings that have been in existence before 1980. Pre-1919 buildings have the highest percentile within the existing stock (National Statistics, 2012). Since the building sector is the largest consumer of energy and the domestic stock accounts for a high percentage of this (Clarke *et al*, 2008), retrofitting of existing buildings is the only viable option of achieving reduction in energy dependency and Green House Gases (GHGs) emission. A minimum of 20% energy reduction is achievable after retrofitting existing building (Biello, 2011).

Ever since the introduction of thermal insulation for building envelopes was introduced after the energy crisis in the 1970s, reduction in energy consumption is becoming predominant in new buildings. New buildings are aiming towards nearly zero energy buildings by 2016 and existing buildings are required to improve energy performance and conservation of fuel and power (European Union, 2010). This can be achieved by improving building fabric and/or energy systems. For the winter season, buildings should be able to trap heat for longer thereby requiring less energy to heat up the space. Similarly, summer time overheating should not be prevalent. This offers a unique challenge for refurbishment. Energy performance across the existing domestic stock varies and this is due to variance in the following:

- Age
- Size
- Dwelling type.

Climate change is due to the accumulation of GHGs in the atmosphere, which is thought to occur because of human activities. There are projections that the climate in the future will change; winters will be warmer while summers will be hotter (Arup, 2008). Comfort of the occupant must be taken into consideration when retrofitting existing building stock with respect to climate change. Increasing the insulation level and air tightness may at times lead to condensation, overheating and poor indoor air quality. Some challenges arise when retrofitting in buildings are not carried out to the required standard and regulations. For example, indoor air quality is affected by condensation from moisture air, damp rot and mould growth on walls due to dampness of the building.

There are various technologies available to improve the energy efficiency/ management of buildings some of the technologies are listed below:

- Improving air tightness
- Improving insulation levels
- Smart/green roofs
- Integrated energy equipment/systems
- More efficient energy systems
- Solid state lighting
- Efficient operations technologies.

It is important to retrofit the existing building stock because new built has a penetration rate of 1% per year. This means more than 70% of the existing stock will still be in existence by 2050 (Power, 2008). There is no exact figure about the buildings that will be in existence in 2050. There are about 26 million homes in the UK and at 1% penetration rate, it will take about 120 years to replace the existing domestic stock. Refurbishing the existing building stock to the current building standard is the only solution of reducing CO_2 emission levels of existing buildings to the projected figure for 2050. In addition, the benefits that will be achieved in carrying out the process are enormous. Some of the benefits are listed below:

- It helps the government to achieve the carbon emission reduction target
- Decreases energy costs of owner/occupier of the building
- Decreases CO_2 emission
- Decrease the usage of fossil fuel
- Reduces the energy consumption of the building
- Better Energy Performance Certificate (EPC) rating and market value

- It helps to sustain the earth and some of its energy resources
- Tackles fuel poverty

  There has been a steady increase in improvement of energy efficiency in existing domestic stock as shown in figure 1.4 below.

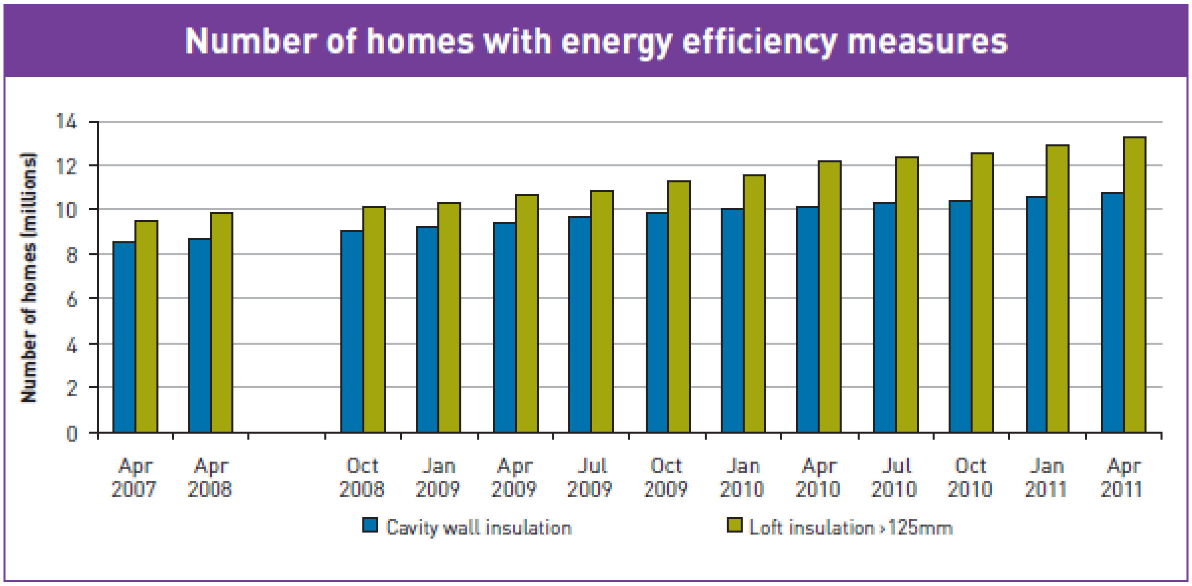


Figure 1. 4: Number of homes with energy efficiency measures (Source: UK –energy-in-brief 2011)

1.2 Objective of the project

The main objective of this research is to analyse different retrofitting measure using to help policy makers enforce the retrofitting of existing buildings. A dynamic simulation based upgrading tool was used for this purpose. There have being some burning issues about upgrading existing building, the major barriers against implementation of retrofitting are financial, policy formation and psychological barriers. Who should provide the capital to finance the retrofitting of the building, the owner or occupier? Who is benefitting from the retrofitting? The answer to these questions usually delays/stalls the process of retrofitting. There are not enough policies in place to enforce the upgrading of existing building in order to meet CERT. Simulation tools are mostly used in policy formation, but most tools applied are based on typical models rather than on a large building stock. During the analyses, the following will be looked into:

- Evaluation using the dynamic simulation tool
- Policy formation and implementation
- Cost and psychological barriers.

CHAPTER TWO

Literature Review

2.1 Retrofitting of existing buildings

This chapter reviews research work that has been carried out on retrofitting of existing domestic stock in the EU. What is being done? Which policy makers/estate developers are effecting the improvements and the guidance they are using?

We are living in an era where the world is going green, measures are been put in place and implemented to ensure the sustainability of the earth and its natural resources for the existence of humanity. High priority issues for Member states of the EU have always been to seek out solutions to energy efficiency improvement across all sectors and to increase the awareness of renewable energy sources (Poel et al, 2007). Most countries around the globe are making effort to cut down on their greenhouse gas emissions. CO_2 is a major member of greenhouse gases and is generated by the combustion of fossil fuel. Reducing energy consumption in existing buildings reduces the energy generation so also the CO_2 emission. About 33% of total global emissions are attributed to the existing building stock (Urge-Vorsatz *et al*, 2007).

The building sector is the largest consumer of all energy sectors (Clarke *et al*, 2008). EU member states are obliged to reduce their energy consumption by 20% by the year 2020 and by 80% by the year 2050 (European Commission, 2011). The penetration rate of building new buildings is about 1% and more than two-thirds of the existing building stock will still be in existence by the year 2050. Most of the present buildings were built when energy efficiency and management were not taken into considerations; therefore, the focus is on retrofitting and improving the existing building stock to reduce its energy consumption. (Clarke *et al*, 2008).

The main aim of retrofitting existing building stock is to reduce energy consumption and increase the energy efficiency of the buildings. This simultaneously reduces the carbon footprint, saves cost and helps sustain the environment. It is possible to reduce energy consumption in existing buildings without neglecting important services and amenities. This can be done following the three main improvement measures listed below (can still be further categorised):

- Retrofitting the building fabric and its sub-systems;
- Replacing archaic systems with modern and efficient systems;
- Better operation and maintenance.

The existing building and its immediate environment are taken into consideration before any appropriate retrofitting measures are determined for the building. A building comprises of many subsystems with various and specific operational modes therefore, it is important to analyse each specific building domain when selecting a retrofitting measure. There are various methods of retrofitting existing building stock, to determine an appropriate, efficient and cost effective method is a challenging issue (Poel *et al*, 2007). An appropriate method will be one that will utilize the least non-renewable energy, have low air pollution and construction waste, improved indoor quality and works carried out within an affordable and cost effective budget (Clarke *et al* , 2009).

2.2 What is being done?

2.2.1 Transforming the Built environment

Member states of the EU are working earnestly to improve the energy efficiency of the existing building stock by formulating policies and new regulations (Poel *et al*, 2007). The Scottish government as an example is promoting a low carbon economic strategy for Scotland (Scottish Goevernment, 2010). Legislation has being put in place to achieve this to improve building energy performance. Research and development of innovative techniques of improving the environmental performance of buildings are being encouraged. From 1 October 2010 new domestic building are expected to emit 70 % less CO_2 than an equivalent building built in 1990. In the EU, the EPBD is a directive that all new domestic buildings are expected to be a near zero carbon building by 2016 and non-domestic by 2018 (Kelly, 2009). It is mandatory that all large buildings greater than

1000m^2 being retrofitted should be brought up to the current low energy standard. A minimum standard of ‘BREEAM Excellent’ for all new buildings has been set by the office of Government Commerce since 2003. Insulation of existing buildings is been promoted by the UN as one major solution to tackle climate change (Rockwool, 2009).

EPBD requires all EU member states’ building stock should have an EPC before they are being sold or rented out. The EPC shows the energy performance rating of the building, by calculating energy consumption of the building and the carbon emission rate. The energy performance is determined by analysing the following factors of the building (Poel *et al*, 2007):

- Geometry of the building with respect to climate, solar exposure and interaction of nearby structures
- Source of energy generation
- Insulation level of the building
- Technical and installation characteristics of the building
- Indoor Air Quality (IAQ) and the energy consumption.

The analyses are been graded and used to determine how efficient a building is. The figure 2.1 below shows the implementation level across the EU member states. Draft documents are available for implementation for all most all the member state except Slovakia and Sweden. There is no laid down procedure in implementing the directive, each country is free to develop an approach suited for her. Eleven countries have had their draft documents been reviewed by the public. Just Two countries have their work completed and waiting for legislative approval to enforce it. Only Two countries have their legislative work completed. Twelve countries have practical software/tools available to implement the EPBD directive. Eight countries have a pilot project to gain practical experience of the EPBD directive.

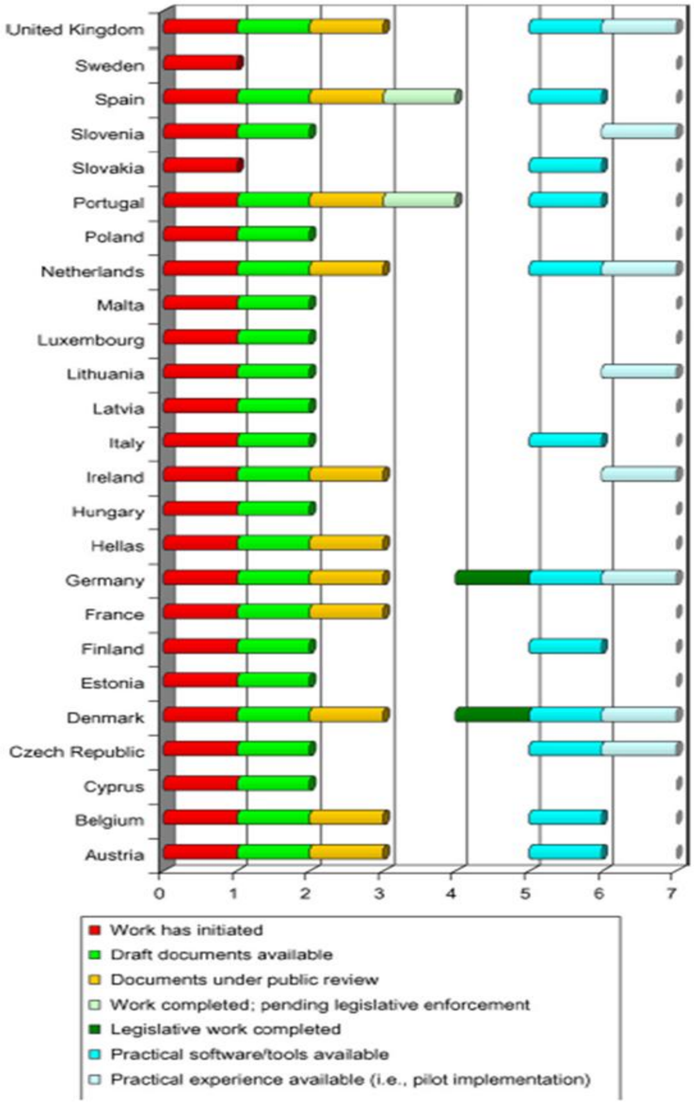


Figure 2.1: Implementation level of EPBD directive across the EU states.

(Source: Bart P. et al 2007)

There are various drivers and barriers affecting the energy performance of built environment some of them are listed below:

Drivers

- Energy savings
- Improved comfort
- Health benefits

Barriers

- Lack of information
- Investment cost
- Focus on initial cost rather than the whole cost
- Multiple ownership delays agreement to retrofit

Various technologies and methods are employed to reduce the energy demand in buildings

- Installation of energy efficient lighting and controls
- Installation of energy efficient boilers
- Insulation for domestic and non-domestic properties
- Smart metering
- Renewable energy systems.

With respect to sustainability policies and principles, it is cheaper to retrofit a building than to demolish and reconstruct a new building. Ageing dilapidated buildings are transformed into energy efficient and environmentally friendly buildings with improved market value by spending about one-third to half of the demolition and reconstruction cost (Poel *et al*, 2007).

The EPBD is developing a general framework for the calculation of Energy for the European Committee for Standardization (CEN) for member state of the EU (Hogeling, 2010). The new technique for energy performance assessment of existing dwellings (EPA-ED) employs a software tool to carry out the energy performance assessment of the building. The software is flexible and can adapt to any kind of scenario since there is standardized process for assessment. The software allows the user to carry out the following function:

- Evaluate energy performance(EP)
- Calculate the energy required for space loads, lighting and hot water

- Develop an EPC
- Generate different scenarios to evaluate various energy saving measures and determine the payback time of the investments
- Determine consumption and CO_2 emissions.

The figure 2.2 below shows the structure of the software.

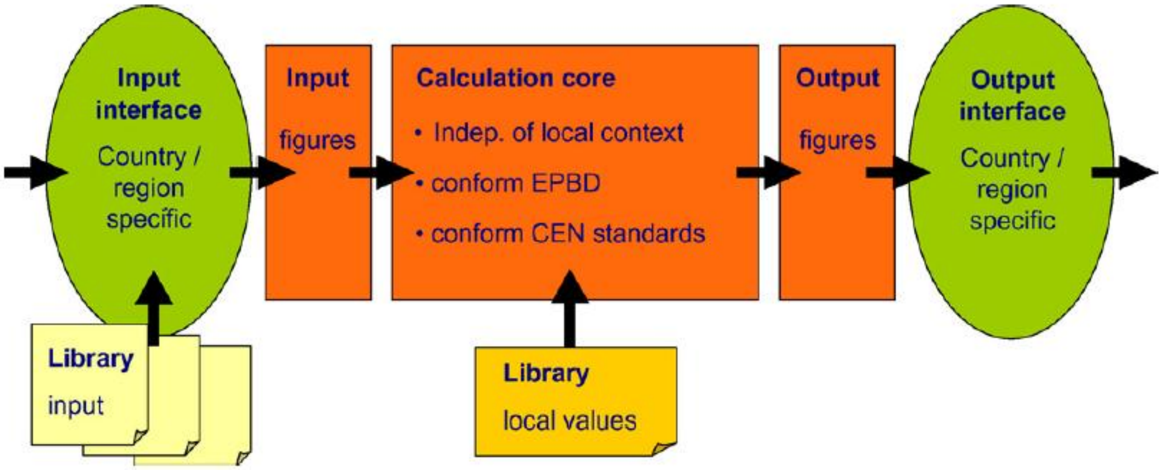


Figure 2.2: General structure of the software.

(Source: Bart P. et al 2007)

<u>Input interface:</u> The user chooses the country and region where the building is located from the embedded data in the library. The building type will determine the values of the building parameters to be used for calculation.

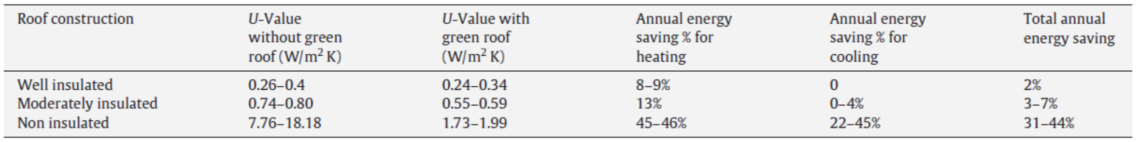
<u>Calculation core:</u> The calculation is based on the EPBD procedure. The following properties are used to for the calculation: orientation and position of the building, the building envelope, indoor climatic conditions, ventilation, thermal characteristics, and solar systems, heating and cooling. Acceptable statistics are CEN, ISO, any relevant statistic standards are adaptable to European and international standard, and at the same time the national standard can be applied.

Output interface The output interface can be adapted to suit the user and its local need like different languages.

Thermal performance of existing building stock should be able to measure up with current and projected regulation. One major challenge will be overheating which will arise from the increased insulation level of the building and higher temperature and warm weather, which is projected to occur in the future (Roberts, 2008). Another problem is IAQ with lower air leakage.

Green roofs are a method for reducing energy consumption and carbon emission in existing building stock. Since most of the existing buildings were constructed before roof, insulation came into play. It has being proved that existing buildings have the potential for green roof retrofit in making the buildings energy efficient (Castleton *et al* 2010). The table 2.1 and figure 2.4 below show the potential for energy saving using green roofs and evaluation of different types of roof with their annual energy consumption.

Table 2.1: Potential for energy saving using green roof



Roof construction	*U*-Value without green roof (W/m^2 K)	*U*-Value with green roof (W/m^2 K)	Annual energy saving % for heating	Annual energy saving % for cooling	Total annual energy saving
Well insulated	0.26–0.4	0.24–0.34	8–9%	0	2%
Moderately insulated	0.74–0.80	0.55–0.59	13%	0–4%	3–7%
Non insulated	7.76–18.18	1.73–1.99	45–46%	22–45%	31–44%

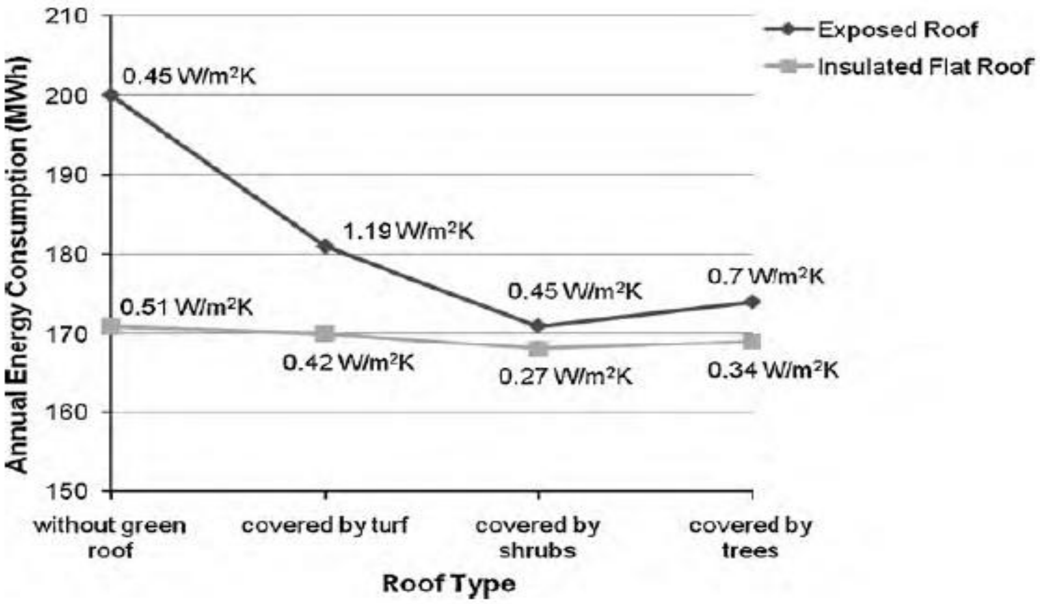


Figure 2.3 Roof types with annual energy consumption
Sourced from: (Castleton *et al*, 2010)

Determining energy implications of retrofitting existing buildings can be done in various ways. These can be called scenarios cases or packages application. The measures are related to energy systems of the building and the technique employed for the efficient use of energy. An assessment is usually carried out using a computational simulation model to compare each measure, scenario and package in respect to energy conservation and economic viability (Santamouris & Dascalaki, 2002).

Life Cycle Cost (LCC) can be employed as an optimization tool used to determine the retrofit measure of a building. For example the optimum level of insulation required by the building depends on the optimum level and efficiency of the heating system (Gustafsson, 2000).

2.3 Who is doing the retrofitting?

The EPBD resulted in the development of the UK National Calculation Methodology (NCM). For non-domestic buildings this used for calculating energy consumption in buildings by comparing, it with a notional building subject to NCM rules and conventions compares it with existing one. It is used to provide energy certificates and assess building compliance for non-domestic buildings. UK's Standard Assessment Procedure (SAP) is used for domestic buildings and follows a similar procedure. The Energy Saving Trust helps promote energy efficiency awareness in domestic building (Clarke, *et al* 2008).

Building owners who support green energy, wishing to save cost on energy consumption and promoting sustainability of the earth are retrofitting buildings (BE, 2012).

Estate developers providing building services, houses and recognizes the financial gains of retrofitting existing buildings. That offers maximum value and resilience on upgrading of existing/listed building (Arup, 2012b).

Government agencies and departments are fomualting policies to ensure the 2050 CERT is achieved. EPBD directive(2002/91/EC) is an example.

2.4 What kind of guidance are they using?

There are various guidance, packages and regulations governing the retrofit of existing building stock. To reduce the consumption of thermal energy in buildings the overall heat transfer coefficient of the building's envelope must be reduced (add insulation, use double pane windows). The two most important measures are insulation improvement and air tightness improvement. Old buildings are prone to infiltration, high rate of air leakage through pores, cracks and openings. This leads to excessive heat loss, This is mitigated by weather stripping: blocking of glass panels joints, caulking of cracks, windows, doors and openings being ensured they are sealed and air tight. External doors should also be weather-stripped.

It is mandatory in the EU for large buildings (greater than 1000 m^2) undergoing refurbishing to be brought up to low contemporary energy standards (Rockwool, 2009).

Community Energy Saving Programme (CESP) is a policy that is meant to replace CERT, which is due to end in December 2012. CERT has an obligation on energy supplier to deliver overall lifetime CO_2 savings of 293 $MtCO_2$ through various measures but most importantly by installing insulation in buildings. CESP focuses on the whole house retrofits achieved by the partnership between community groups, local authority and energy companies (UK-GBC, 2012).

Green Deal is a new policy due to be launched in autumn 2012, it is a framework meant to drive energy efficiency improvements in millions of UK homes and businesses (UK-GBC, 2012).

The European Directive (EPBD) (2002/91/EC) on the energy performance of buildings has the obligation of all EU member state to improve their building regulations and introduce energy certification (EPC) scheme for all buildings. EPC rates how energy efficient a building is and it is focused to reduce energy import dependency and CO_2 emissions. Concerted Action (CA) EPBD is a legislation which was established to assist the European directive by encouraging dialogue and best practice between EU member states (EPBD, 2012).

EPBD (Directive 2010/31/EU) member states have a new directive on improving existing domestic building stock to nearly zero energy buildings by 2020 and 2018 for public buildings. This includes the use of a cost efficient method to determine the minimum requirements for both the technical systems and envelope of the building (EPBD, 2012).

SAP is the approved method used by the UK Government to assess the energy performance of domestic buildings. The assessment is based on the energy cost of the building and rated on a scale of 1-100 with lower numbers representing higher running cost. Above 40% of pre 1919 building stock has a SAP rating of lower than 41. Two-third of all existing building stock has SAP rating between 41 and 70 (CLG, 2006).

New building regulations requires a thickness of about 250mm of insulation where laid between joists. New buildings are required to have a U –value of 0.1 and 0.14W/m^{2}K for roof and walls respectively. (SAP, 2005)

There is a new labelling scheme proposed to rate and improve the efficiency of buildings by taken into consideration the indoor air quality, the environmental impact and the energy consumption of the building. It will have three labels A, B and C.

Label A is assigned to techniques, which use the environmental impact, indoor environmental quality and energy use to rate the building.

Label B is assigned to techniques, which use the definition of energy use from statistical data, and employs the definition of Fuzzy C-means algorithm from statistical data in respect to energy use of building clusters.

Label C is used to classify buildings by analysing technique the principal component of a variety of buildings from a particular stock with respect to energy use and the environment (Santamouris & Dascalaki, 2002).

2.5 Government Initiatives

The UK government introduced the green deal in 2012 Green Deal initiative is meant to encourage house owners and builders to install energy efficient measures in existing domestic buildings and businesses to reduce the wastage of energy linked to hot water and space heating.(About two-thirds of the energy consumed in domestic buildings is required for this purpose. By introducing loft insulation and boiler insulating jackets energy wastage can be reduced. There are other measures as well). The owner/occupier of the building requires no initial capital as it is financed from the savings made from the energy that would have been wasted (Retrostructure, 2012).

Carbon Reduction Commitment Energy Efficient Efficiency Scheme (CRC EES) is a mandatory scheme put in place by the government in achieving improved energy efficiency and lowering emissions in large public and private sector organizations. The scheme employs a range of financial incentives directed to motivate organizations to develop energy management plans that contribute to better analysis and conservation of energy consumption (DECC, 2010).

BUILD UP initiative is targeted at reducing the use of energy in buildings across Europe by transferring best practices to the market and fostering their acceptance (Institue for Building Efficiency, 2009).

A forum on European rebuilding was launched to expedite the energy efficient retrofitting of Europe's existing building stock (Survey, 2011).

2.6 TOOL APPLICATION

Software tools have been and are being developed to help assist in the assessment of retrofitting of different building stocks depending on the use of the building, the structural condition, weather condition, energy performance, indoor air quality etc. Some of the available software tools are:

- BEopt
- EPIQR- Used for residential
- TOBUS- Used for offices
- TREAT
- HUE- Used for stock modelling
- SAP

2.6.1 Building Energy Optimization (BEopt)

BEopt is a modelling tool designed by NREL used to analyse retrofit measures in new and existing domestic buildings and determine the optimal cost effective package to achieve a net zero energy building. It is based on the specific characteristics of the building like type, size, architecture, occupancy, energy use and location of the building. The simulation is based on the Building America House Simulation Protocols (NREL, 2011).

2.6.2 Energy performance Indoor Environmental Quality Retrofit (EPIQR)

EPIQR is another tool used to evaluate the retrofitting and refurbishment of existing building stock. The tool divides the building into various descriptive segments like heating system, roofs and facades. The four main aspects used to analyse the retrofitting are (Jaggs & Palme, 2000):

- Energy use
- IEQ
- Costs
- Retrofit measures

Certain factors are required to be considered for the successful retrofitting of existing building and there are many perspectives to this. The social, economic, cultural and physical factor of a building determines how a building can be refurbished and how long its life can be prolonged for (Ravetz, 2008).

2.6.3 Tobus

This is an evaluation tool developed to assess the retrofitting of office buildings in the EU and to estimate the cost required to meet the improved energy performance and indoor environment standard. It is a decision making tool which proposes the most efficient improvement measures with a reliable estimate of the financial implication (Caccavelli & Gugerli, 2002). The software has being structured into four processes in analysing the retrofitting process they are:

- Indoor environmental quality;

- Energy demand;

- Current state of degradation of building envelope;
- Functionality of building services.

Figure 2.4 shows the decision making process.

1. Object box describes the building type.
2. Diagnosis box analyse the current state of the building with respect to its functionality, energy consumption, deterioration and indoor environment quality (IEQ).
3. Actions box defines the type of retrofitting and upgrading that are available and their cost implications.
4. Decision making box analyses both action and diagnosis box to come up with the most efficient and cost effective measure.

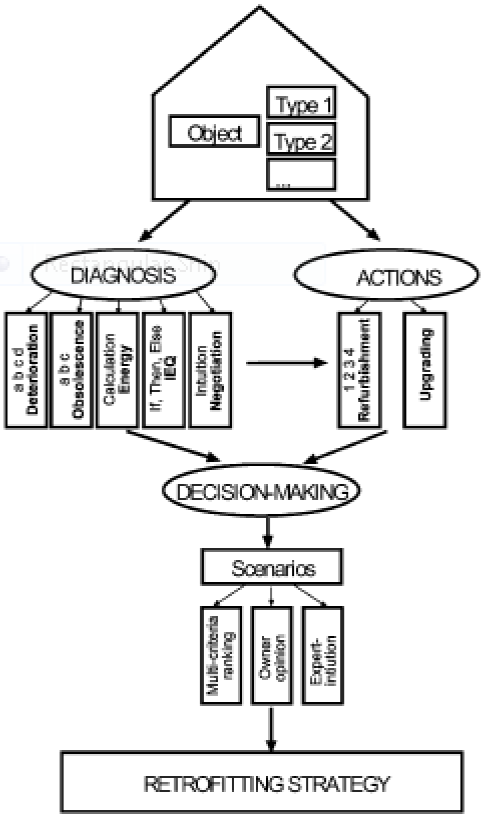


Figure 2.4: The TOBUS decision- making process.

Source: (Caccavelli, D. & Gugerli, H., 2002)

2.6.4 Targeted Retrofit Energy Analysis Tool (TREAT)

TREAT is a comprehensive tool used for evaluating various domestic housing types for both single and multifamily residences. It evaluates the building envelope (insulation and infiltration), HVAC, lighting, appliances etc. Its results take into consideration the local weather, solar heat gain, waste heat and the prospective energy savings calculation it has a clientele base of over 1000. The following types of organizations make use of its results:

- Home Energy Raters
- Insulation and Mechanical Contractors
- Mechanical /Energy Engineers
- Home Performance with Energy star Contractors

It has a limitation of not been compatible with non-domestic building with complex HVAC systems (US Department of Energy, 2011).

2.6.5 SAP

Standard Assessment Procedure (SAP) is the tool used by DECC for evaluating the performance of domestic buildings with respect to the energy they consume and the impact it has on the environment. The Building Research Establishment (BRE) developed SAP. The current SAP calculation method is based on simple energy balance methods that do not fully account for the dynamic characteristics of buildings and climates.

2.7 HUE Software Application

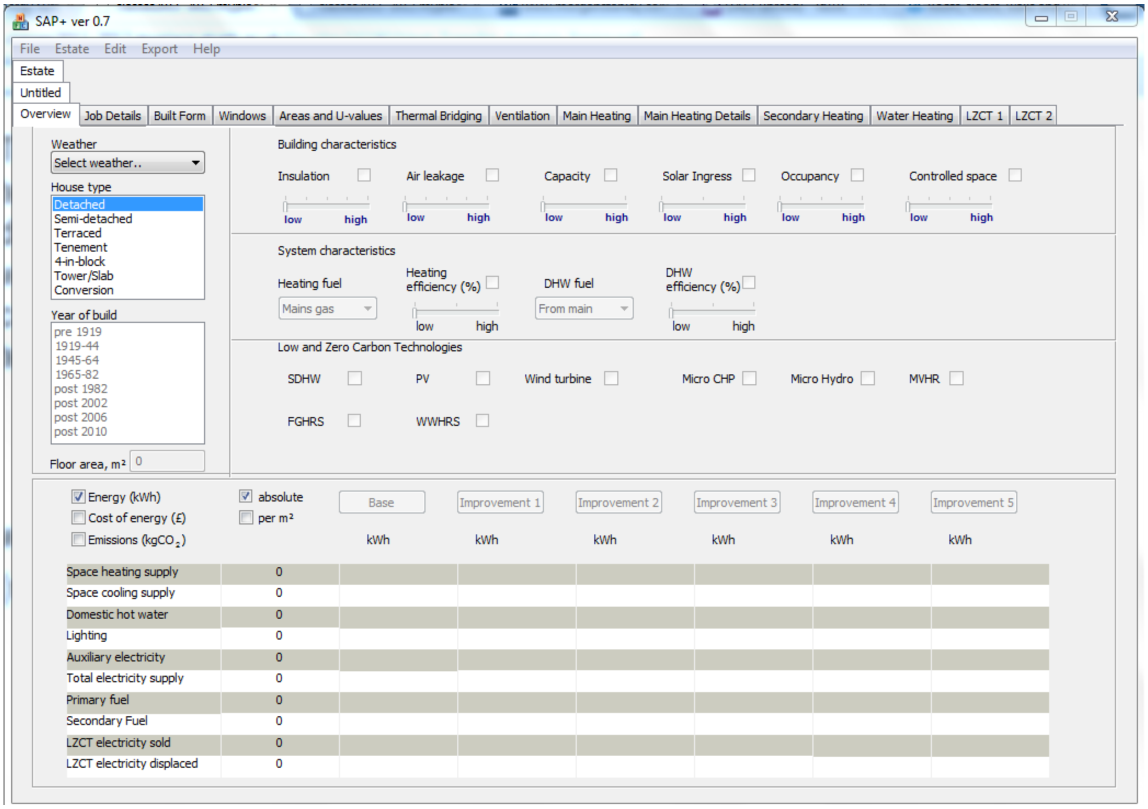
Energy System Research Unit (ESRU) of University of Strathclyde developed this software. It is used to assess the retrofitting of existing domestic stock and has the option of scaling it up to an estate level. Weather data for different locations, thermal properties and other buildings parameters of different building types have been embedded into the software tool. As each improvement is carried out on the base case building the outcome of the energy consumption, cost of energy and carbon emission can be seen and analysed.

The result of each improvement is compared on the reduction made on energy consumption, carbon emission and the cost of energy. The software has provision for Low and Zero Carbon Technologies (LZCT) that helps to reduce carbon emission and encourage on site generation of energy. The HUE tool allows for variation of the floor area especially below 1000m^2. For the purpose of this research, the HUE tool was chosen because:

- It is a dynamic simulation-based study, which is a more accurate representation of the real case study, demand management approaches, proposed energy efficiency measure and local generation options.
- It does not require extensive data input, it has a large pre-simulated data set embedded in the tool. This is based on the housing type, location and year of build.
- It is more representatives of reality than steady state methods and can accommodate high-level information about building stock. The pre-simulated models used are based on national housing survey and representation of the it is a representative of the variation between the current and future stock is accommodated.

Using the software involves defining a base case model and then improving it by introducing one or more improvements. These improved models can then be compared with each other and the base case to guide on suitable retrofit application. The process can be extended to refurbishment policy formulation for estate level. This is by extending the above procedure to multiple dwellings. Similar thermodynamic characteristics of different houses are mapped into distinct thermodynamic prototypes. The design parameters are used to govern energy performance of the building due to variation in stock. This maps the real world domain to a thermodynamic domain.

These design parameters are used to define a dwelling thermodynamically (Each combination of design parameters is linked to a simulation model). The process of refurbishment just alters this definition and the underlying simulation model. Results from both the base case and improvement retrofit model can be compared immediately because the underlying data base hold pre simulated results. The governing design parameters in HUE are divided into two aspects: the building parameters, and the energy system parameters. Research work is on going on energy system parameters to extend its approach. Figure 2.5 below shows a screenshot of the tool



Weather: Select weather..

House type: Detached

Floor area, m²: 0

Heating fuel: Mains gas

DHW fuel: From main

☑ Energy (kWh)
☐ Cost of energy (£)
☐ Emissions (kgCO₂)

☑ absolute
☐ per m²

Space heating supply	0
Space cooling supply	0
Domestic hot water	0
Lighting	0
Auxiliary electricity	0
Total electricity supply	0
Primary fuel	0
Secondary Fuel	0
LZCT electricity sold	0
LZCT electricity displaced	0

Figure 2.5: Screen Shot of HUE Software application

The design building parameters used for selecting prototypes are:

2.7.1 Exposure

This is the exposed area within the prototype; it is expressed as a fraction of the total floor area. It has a range of 0.5 to 3 for the exposure parameter.

2.7.2 Insulation

This is the area weighted sum of the exposed surfaces U-values normalized by the total floor area. The insulation parameter range is from 0.19 to 6.05.

2.7.3 Air tightness

This is derived from the number of openings and terrain type following guidance available from SAP. It has a range of 0.1 to 1.5 air changes per hour.

2.7.4 Capacity position

This governs the thermal capacity position within the construction. The parameter has two values, one represents the internal insulation layer and the other represents the external insulation layer.

2.7.5 Solar ingress

This represents the different levels of heat gain and loss due to fenestration systems. This is achieved by normalizing the total roof and window light area by floor area. It has a range from 0.15 to 0.3

2.7.6 Occupancy

This parameter regulates the level of internal gains, small power loads, hot water use and fresh air requirements. It uses the SAP approach where gains are a function of total floor area. It has a range from 0.7 to 2.2 W/m$^{2.}$

2.7.7 Living area fraction

Dwelling models are designed to have two zones representing a living and sleeping area. These zones have different temperature, occupancy and profile use. It has a range from 0.25 to 0.75

CHAPTER THREE

3.0 STOCK OVERVIEW

This chapter assesses the existing English building stock and modelling tool used for building upgrade analysis.

3.1 BUILDING STOCK

The Survey of English Housing (SEH) and the English House Condition Survey (EHCS) were combined to form the English Housing Survey (EHS) in April 2008 (Communities and Local Government, 2012). EHS regularly carry out a sampling survey on the existing domestic buildings to have an up to date record of the status of the buildings. There are about 22.4 million domestic buildings in England, 66% of these are owner-occupier. They can be classified using various factors such as age, size, type, purpose etc. Table 3.1 and figure3.1 below shows a breakdown of the English domestic stock as of 2010

Table 3.1: Domestic Stock Profile

	Private sector			Social sector			
	Owner occupier	Private rented	All private sector	Local authority	Housing association	All social sector	
thousands of dwellings **Dwelling age**							
Pre 1919	3,126	1,482	4,608	68	189	257	4,865
1919-44	2,819	456	3,275	289	187	476	3,751
1945-64	2,816	398	3,214	685	498	1,183	4,397
1965-80	2,978	505	3,483	626	492	1,118	4,602
1981-90	1.243	274	1,518	109	253	362	1,880
post 1990	1,879	591	2,469	24	399	422	2,892
Dwelling type							
End terrace	1,469	367	1,836	197	218	415	2,251
Mid terrace	2,609	862	3,471	275	359	634	4,105

Small terraced house	1,238	521	1,758	198	214	412	2,171
Medium/large terraced house	2,840	709	3,549	274	363	637	4,185
All terraced	4,078	1,229	5,307	472	577	1,049	6,356
Semi-detached house	4,590	580	5,170	313	377	690	5,860
Detached house	3,517	268	3,785	*	*	*	3,796
Bungalow	1,439	166	1,606	185	205	391	1,996
Converted flat	295	549	844	*	80	104	948
Purpose built flat, low rise	874	803	1,677	642	720	1,362	3,039
Purpose built flat, high rise	68	109	177	164	49	213	390
Floor area							
Less than 50 m^2	665	792	1,457	496	563	1,058	2,515
50 to 69m^2	2,805	1,170	3,976	701	709	1,410	5,386
70to 89 m^2	4,382	932	5,274	486	582	1,067	6,341
90 to 109m^2	2,505	374	2,879	97	118	214	3,093
110sqm or m^2	4,543	438	4,981	*	46	69	5,050

Notes: 1) * indicates same size too small for reliable estimate

Sourced: English Housing Survey, Homes 2010.

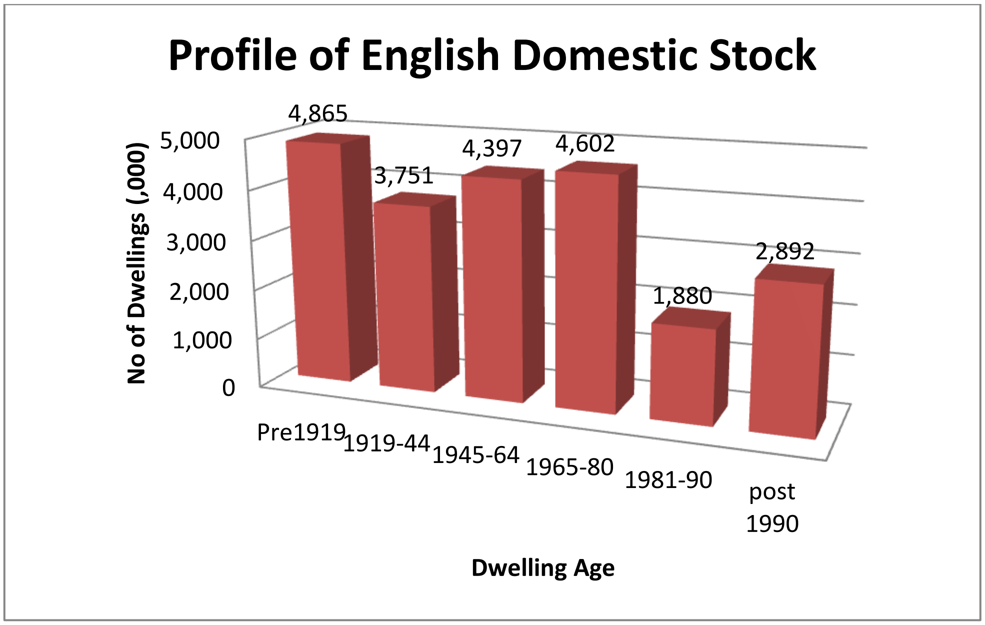


Figure 3.1: Profile of English Domestic Stock

From the graph above pre-1919 and 1965-80 buildings represents the highest number of dwellings with 22% and 21 % respectively of the existing stock. Figure 3.2 below shows the age of housing stock by tenure.

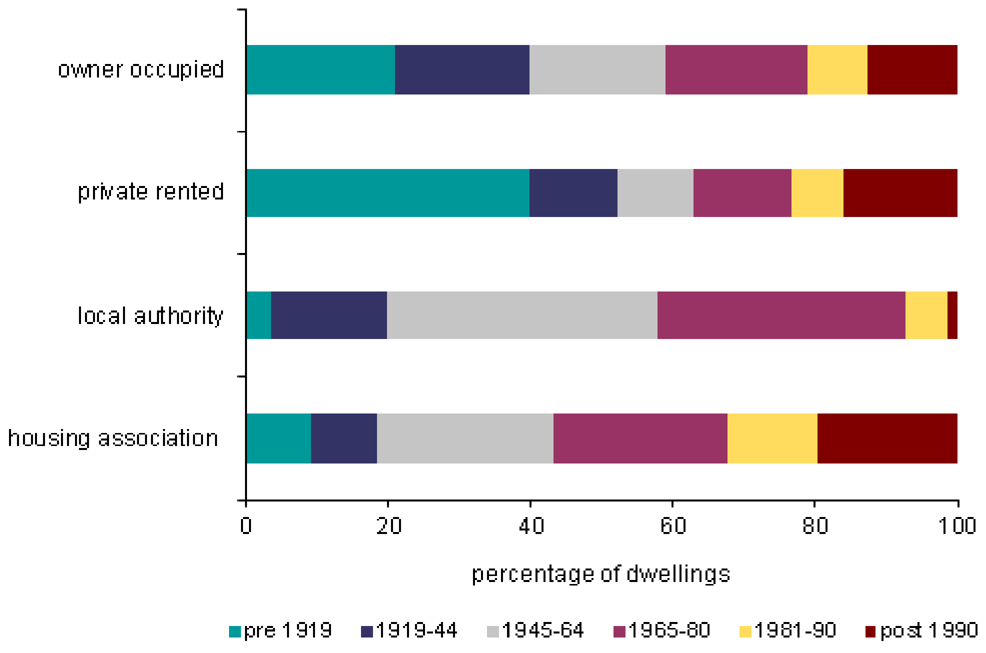


Figure 3.2: Percentage of dwellings in each tenure by dwelling age, 2010.
(Source: English Housing Survey, Homes 2010)

6.9 million buildings do not have cavity walls and 15.5 million have cavity walls. Solid walls can be improved by adding internal or external insulation whereas cavity walls can be filled with loft insulation.

It is not always possible to do so because of space restriction for external wall insulation. For cavity walls typical issues include presence of conservatories, wall finishing is not masonry pointing, the building has more than four floors and the building was built using a metal, concrete or timber framed construction. Figure 3.3 below.

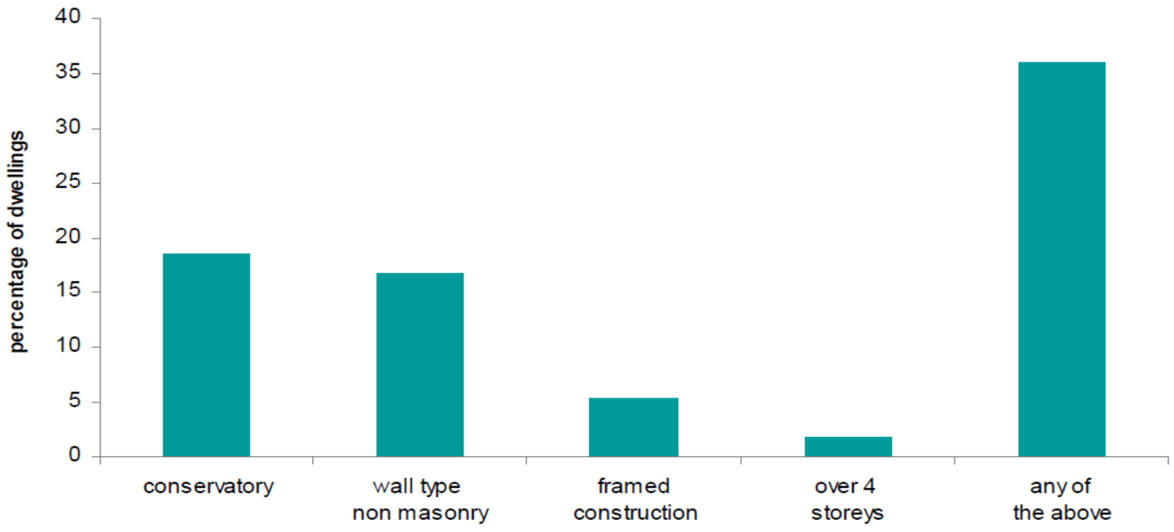


Figure 3.3: Percentage of dwellings with cavity walls with key features

(Source: English Housing Survey, 2010)

The usable floor area of a home depends on the type of building. Overall, average floor area is 92 m^2, but pre-1919 has a mean floor area of 103m^2 and is the largest buildings. Floor area of new buildings in the UK is getting smaller compared with their EU member states. Figure 3.4 below shows the analysis of the building by floor area and building age.

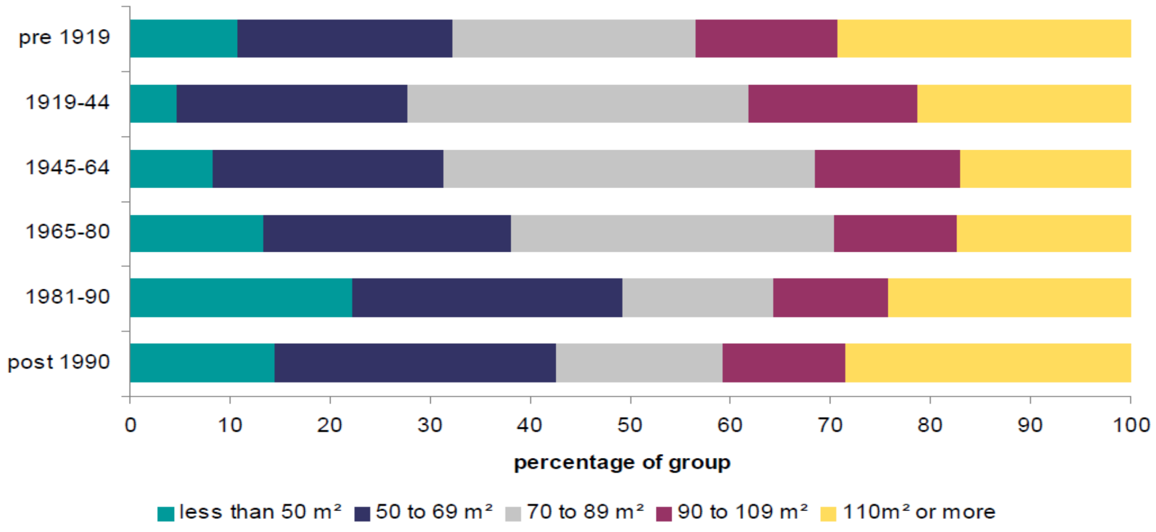


Figure 3.4: Percentage of dwellings by age and floor area

(Source: English Housing Survey, 2010)

Improving the energy efficiency of the building can be carried out through various measures, cavity wall insulation and full double-glazing seems to be the most common measures employed to improve the energy efficiency across all tenures. Figure 3.5 below shows the percentage of buildings with efficient insulation measures by tenures.

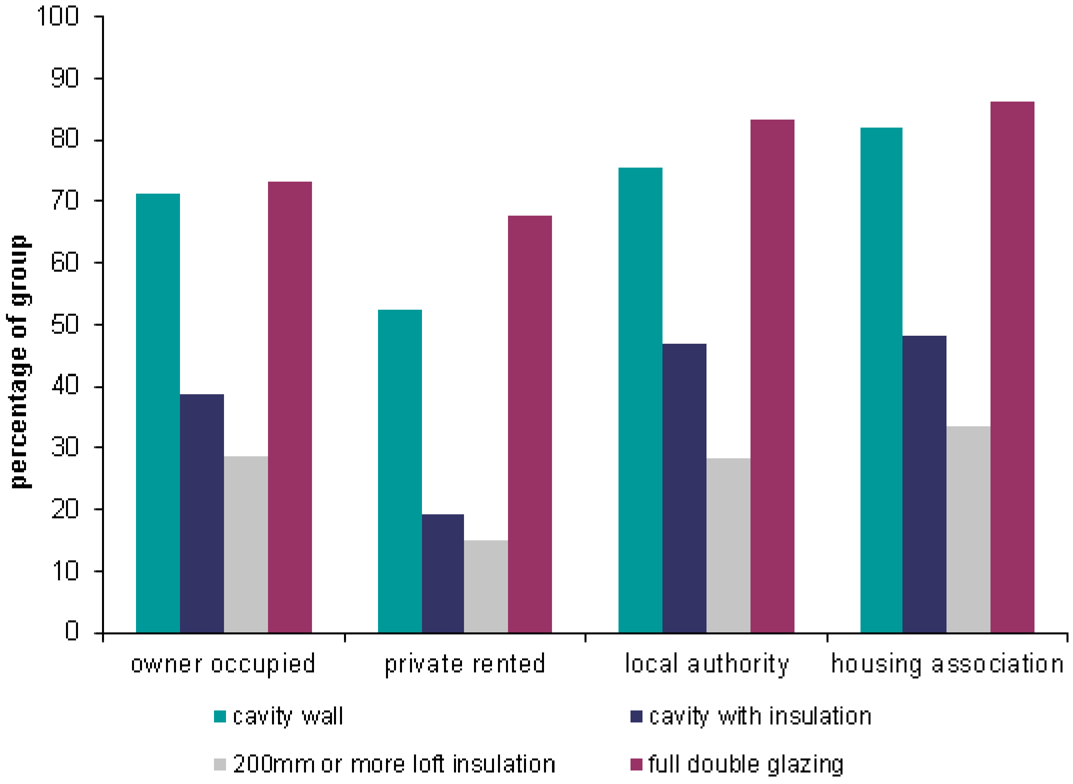


Figure 3.5: Percentage of dwellings with efficient insulation measures by tenure.

(Source: English Housing Survey, 2010)

Dampness occurs in buildings due to a number of reasons. If left untreated the dampness causes mould growth. This has an adverse effect on the building and the occupants. Figure 3.6 below shows the distribution of dampness in buildings across the tenures.

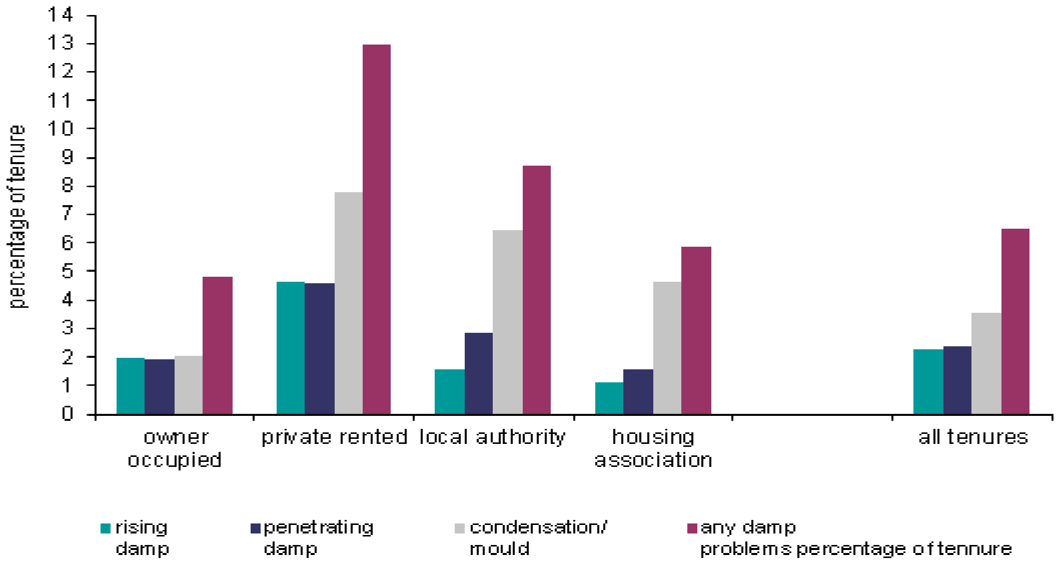


Figure 3.6: Percentage of homes with damp problems, by tenure

(Source: English Housing Survey, 2010)

Figure 3.7 below shows the gradual increase of energy improvement measures in domestic building with double-glazing taking the lead.

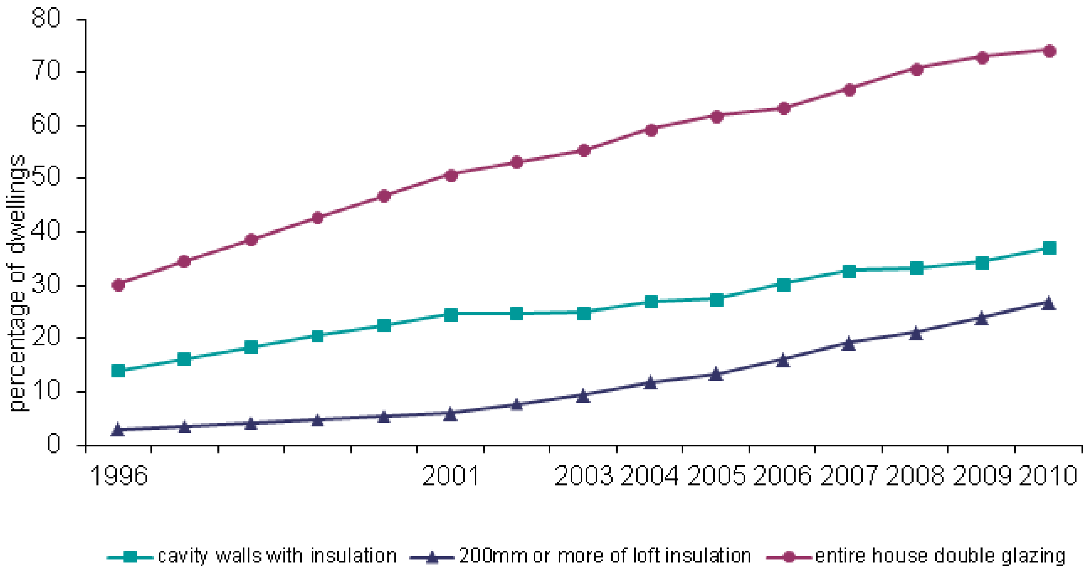


Figure 3.7: Insulation measures 1996-2010

(Source: English Housing Survey, 2010)

From the statistics of the existing domestic stock, pre-1919 and 1965-80 age bands have the highest percentage of stock terraced and semi-detached houses are most prevalent at “18% and 17% respectively. These two types of existing building and age band were selected to be used to analyze the retrofitting measures.

3.2 Retrofitting Existing Domestic Stock

Retrofitting of Buildings can be categorized into two major aspects using the HUE tool: building envelope and building systems characteristics. The existing domestic buildings are embedded in the modelling tool. The user inputs type of building, age and location only. The tool then finds the relevant model and populates building parameters from it this represent the base model. The planned retrofitting is designed and the user uses the HUE tool to select a model that represents the retrofitted prototype by improving the governing design parameters listed earlier at 2.7.1 to 2.7.7. The performance of the base case model and the retrofitted prototype is displayed; the difference in their parameter value shows how efficient an upgrade is. The parameters can be altered to determine which retrofitting measure suit the user based on energy consumption, cost and carbon emission.

3.3. Upgrading approach

A dwelling stock average with four case models of different building type and age band were simulated. The selection is based on the statistics of been the highest percentage of availability within the building stock. Pre 1919 and 1965-82 have the highest occurrence amongst the age band. So also terraced and semi-detached within the building type band.

This case study is based on a refurbishment carried out on the South Ayrshire stock. South Ayrshire stock comprises 8,796 dwellings as at 2005, 89.5 % dwelling of different type were simulated to determine the energy performance and carbon foot print of the stock. Data used is available from (Tuohy *et al*, 2006).

Each building type is improved by increasing the insulation level and reducing the air leakage rate separately and then later together to get an optimum result. Reducing the air leakage rate is not as efficient as increasing the insulation only. The improvements are carried out in four steps. These are listed in the next chapter:

- Building characteristics only
- Systems characteristics only
- Building and system characteristics
- LZCT is employed in the building +building and system characteristics.

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CHAPTER FOUR

4.0 RESULTS ANALYSIS

Four different types of buildings were simulated using the HUE software:

- Pre-1919 Terraced
- Pre-1919 Semi-Detached
- 1965-1982 Terraced
- 1965-1982 Semi-Detached

4.1 Pre-1919 terrace building

The Pre-1919 terrace building has the building properties as shown in table 4.1 below.

Table 4.1: Pre-1919 Terraced building properties

	U-value (W/m^2K)	**Total Floor Area (m^2)**
Doors	3.00	90
Windows	5.60	
Ground Floor	0.40	
Walls Type 1	1.80	
Roof Type1	1.80	

4.1.1 Base Case

The base case has an energy consumption of 265kWh/m^2 for space heating because it has a low insulation level and high air leakage rate. 32kWh/m^2 was consumed for domestic hot water (DHW).

4.1.2 Improvement 1(Heating system)

This improvement is by improving the energy efficiency to a higher level. The energy consumption for space heating reduced to 194 kWh/m^2 and DHW consumption reduced to 24 kWh/m^2.

4.1.3 Improvement 2(Air tightness)

This improvement is by further improving the air tightness. The energy consumption reduced to 146 kWh/m^2. DHW consumption remained constant at 24 kWh/m^2.

4.1.4 Improvement 3(Super air tightness)

This improvement is by further improving the air tightness. The energy consumption reduced to 146 kWh/m^2. DHW consumption remained constant at 24 kWh/m^2.

4.1.5 Improvement 4(Insulation)

This improvement is by improving the insulation the energy consumption reduced to 101 kWh/m^2. DHW consumption remained at 24 kWh/m^2.

4.1.6 Improvement 5(Super insulation)

This improvement is by further improving the insulation. The energy consumption reduced to 57 kWh/m^2. DHW consumption remained at 24 kWh/m^2.

4.1.7 Improvement 6(A+B+SDHW+PV)

This involved improving insulation and air tightness still further. LZCTs: Solar Domestic Hot Water (SDHW) and Photo Voltaic (PV) were also introduced into the retrofitting measures. The energy consumption reduced further, DHW consumption remained constant at 24kWh/m^2. Due to local generation, grid dependence was reduced and some DHW energy was provided from solar energy. The values are tabulated in table 4.2 and represented graphically in figures 4.1 and 4.2

Table 2.2: Pre-1919 Terrace building data

Imp Type	Base	Imp 1	Imp 2	Imp 3	Imp 4	Imp 5	Imp 6
Energy (kWh/m^2)	265	194	166	146	101	57	26
Carbon foot print (T CO_2 pa)	4.68	3.42	2.97	2.61	1.8	0.99	0.45
DHW (kWh/m^2)	32	24	24	24	24	24	24

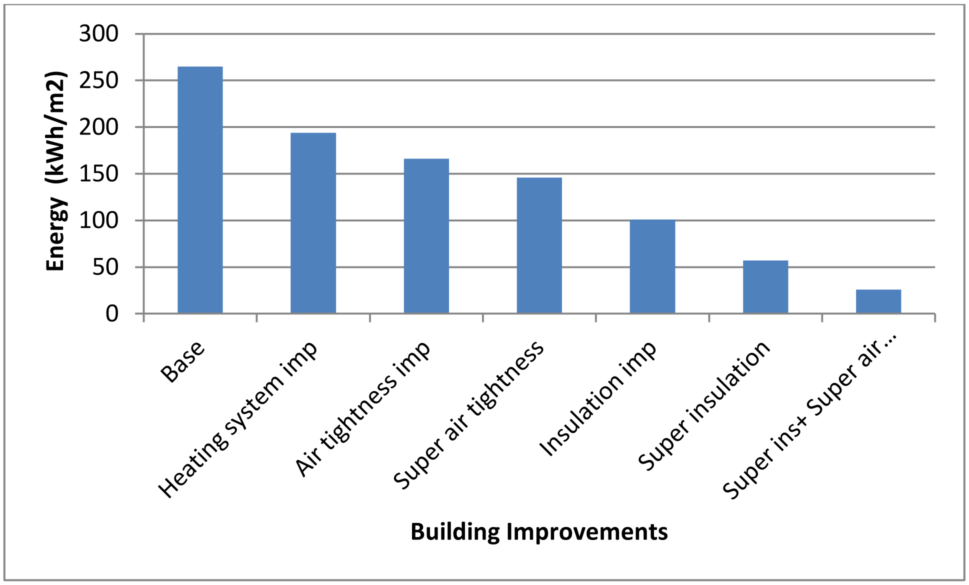

Figure 4.1: Energy Consumption for a pre-1919 Terraced Building

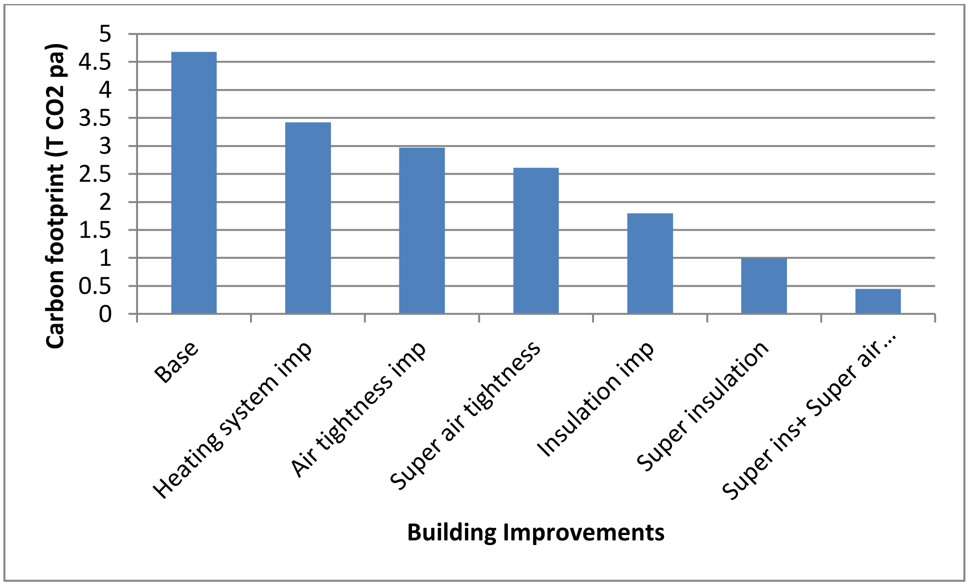

Figure 4.2: CO2 emission level for a pre-1919 Terraced Building

4.2 Pre-1919 Semi-Detached Building

The pre 1919 semi-detached building has the following properties as shown in table 4.3 below.

Table 4.3: Pre-1919 Semi-detached building properties

	U-value (W/m^{2}K)	Total Floor Area (m^2)
Doors	3.00	88
Windows	5.60	
Ground Floor	0.40	
Walls Type 1	1.80	
Roof Type1	1.80	

The same improvement 1-6 carried out on the terraced building is repeated for the semi-detached building. The results are tabulated in table 4.4 and represented graphically in figures 4.3 and 4.4.

Table 4.4: Pre-1919 Semi-detached data

Imp type	Base	Imp 1	Imp 2	Imp 3	Imp 4	Imp 5	Imp 6
Energy (kWh/m^2)	252	185	181	170	99	60	27
Carbon foot print (T CO2 pa)	4.4	3.3	3.2	2.9	1.8	1.1	0.4
DHW(kWh/m^2)	32	25	25	25	25	25	25

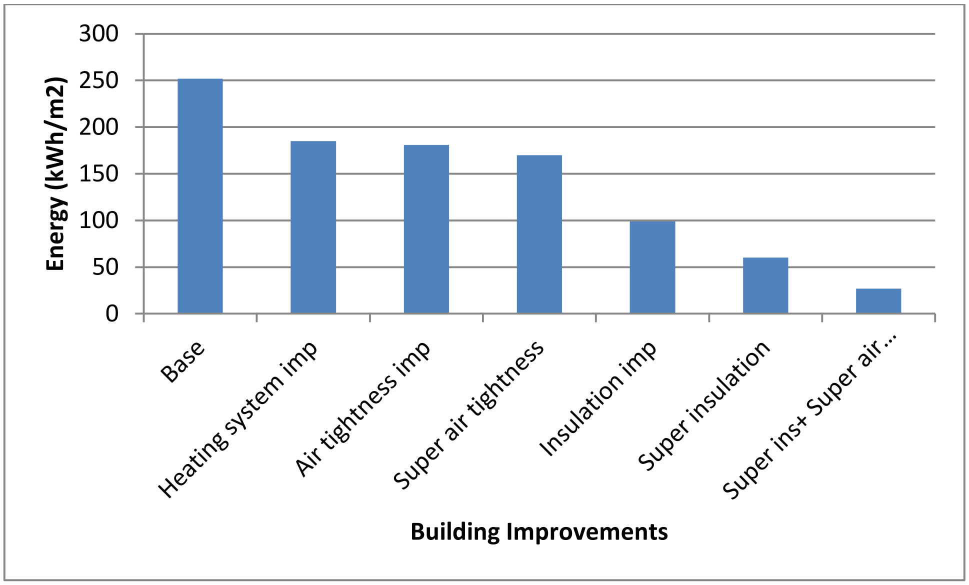

Figure 4.3: Energy Consumption for a pre-1919 semi-detached Building

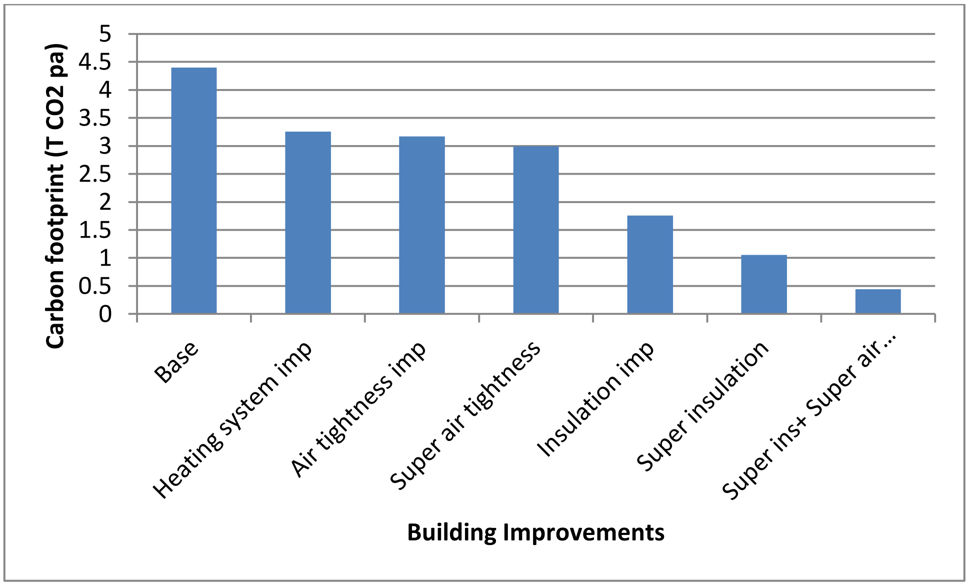

Figure 4.4: CO2 emission level for a pre-1919 semi- detached Building

4.3 65-82 Terraced Buildings

The 65-82 terraced building has the following properties as shown in table 4.5.

Table 4.5: 65-82 Terraced building properties

	U-value (W/m^2K)	Total Floor Area (m^2)
Doors	3.00	90
Windows	3.40	
Ground Floor	0.40	
Walls Type 1	0.80	
Roof Type1	0.80	

The same improvement 1-6 carried out on the pre 1919 terraced building is repeated for the 65-82 terraced building. The results are tabulated in table 4.6 and represented graphically in figures 4.5 and 4.6

Table 4.6: 65-82 Terraced data

Imp type	Base	Imp 1	Imp 2	Imp 3	Imp 4	Imp 5	Imp 6
Energy (kWh/m^2)	200	179	157	109	62	38	28
Carbon foot print (T CO2 pa)	3.6	3.2	2.8	2.0	1.1	0.6	0.5
DHW(kWh/m^2)	27	24	24	24	24	24	22

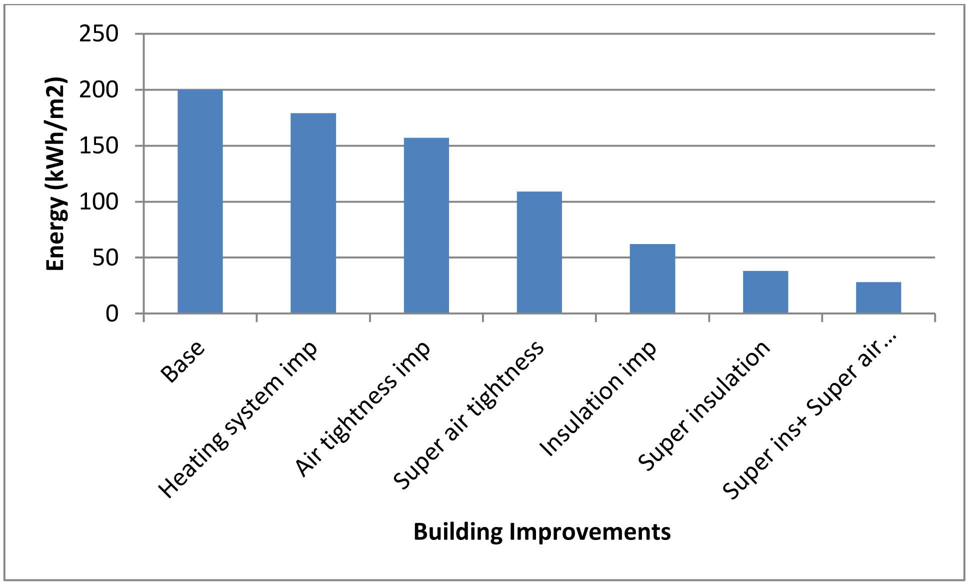

Figure 4.5: Energy Consumption for a 65-82 Terraced Building

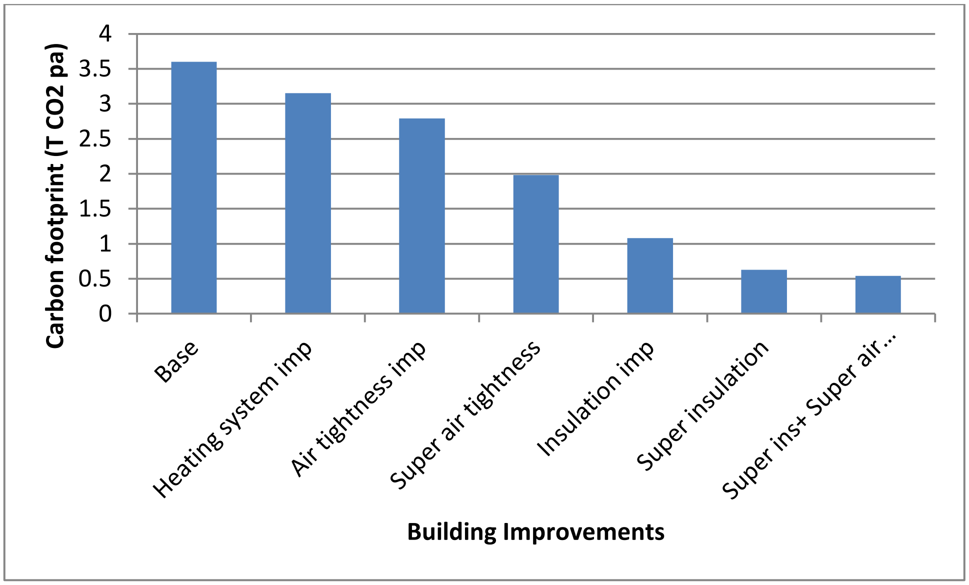

Figure 4.6: CO2 emission level for a 65-82 Terraced Building

4.4 65-82 Semi- Detached

The pre 1919 terrace building has the following building properties as shown in table 4.5 below.

Table 4.7: 65-82 Semi-detached building properties

	U-value (W/m^2K)	Total Floor Area (m^2)
Doors	3.00	90
Windows	3.40	
Ground Floor	0.40	
Walls Type 1	0.80	
Roof Type1	0.80	

The same improvement 1-6 carried out on the pre 1919 terraced building is repeated for the 65-82 semi-detached building. The results are tabulated in table 4.8 and represented graphically in figures 4.7 and 4.8

Table 4.8: 1965-82 Semi-detached data

Imp type	Base	Imp 1	Imp 2	Imp 3	Imp 4	Imp 5	Imp 6
Energy (kWh/m^2)	215	192	171	146	71	35	27
Carbon foot print (T CO2 pa)	3.8	3.4	3.1	2.6	1.3	0.6	0.5
DHW(kWh/m^2)	27	25	25	25	25	25	22

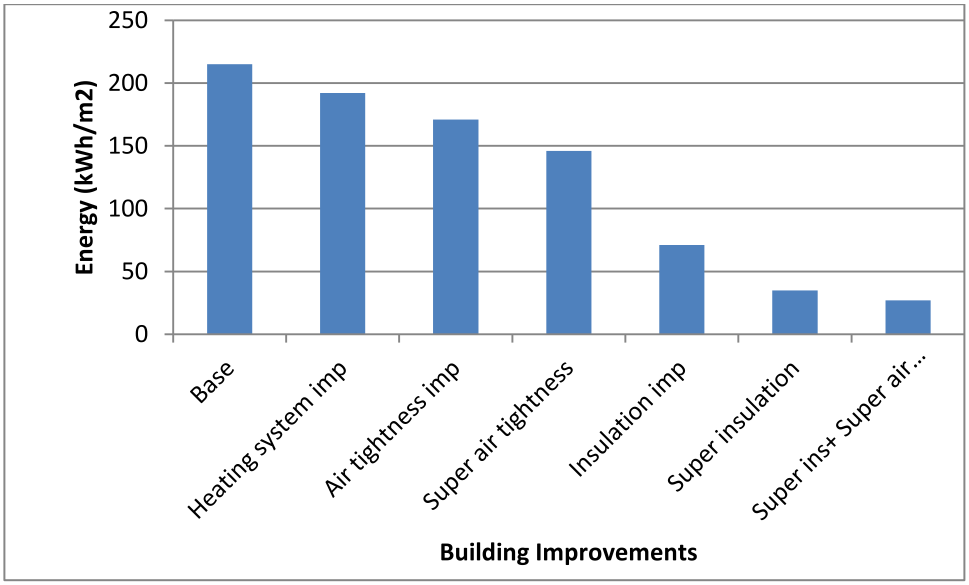

Figure 4.7: Energy Consumption for a 65-82 Semi-detached Building

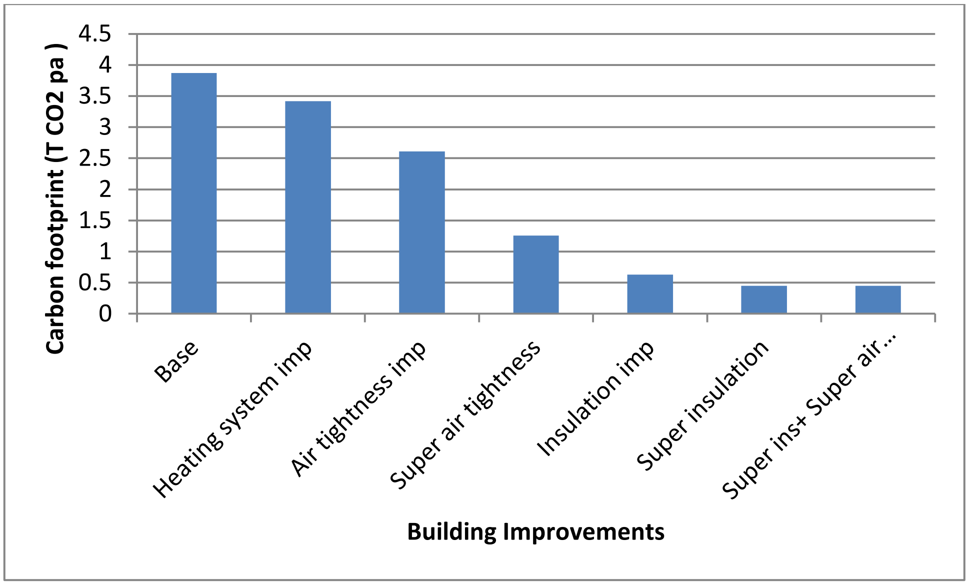

Figure 4.8: CO2 emission level for a 65-82 Semi-detached Building

4.5 South Ayrshire Council Housing Stock

The South Ayrshire Council Housing Stock is part of the Rurasu project sponsored by the European Commission's "Intelligent Energy- Europe "programme. The project is about the process of local design advice and support units to provide guidance and services in renewable energy, energy management and energy conservation (Tuohy *et al*, 2006).

The dwellings type in Ayrshire council housing stock was categorized into three major types, the full description can be seen in Appendix A

- Semi-detached- 1287dwellings
- Mid- terraced- 1946 dwellings
- Flat -4541 dwellings

Most properties have basic double glazing, 100mm loft insulation and cavity wall insulation. Eight upgrade measures were applied to the building stock in the project.

1. "As is"
2. "Low cost fabric improvement" (fabric upgrade A)
3. "Major fabric upgrade" (fabric upgrade B)
4. "2007 heating systems"
5. "Fabric upgrades A+B with 2007 heating systems
6. "Fabric upgrades A+B with 2007 systems plus solar hot water heating"
7. "Fabric upgrades A+B with 2007 systems plus solar hot water and renewable generation"
8. "Fabric upgrades A+B with CHP"
9. "Fabric upgrades A+B with Biomass"

The same improvements 1-5 used in the previous case model are applied to the Ayrshire housing council stock. HUE cannot accommodate some upgrade measures listed above, hence it was modified to suit the housing stock. Improvement 6 for this case was the introduction of wind turbines because of local availability. Table 4.5.1 and figure 4.9 represent the carbon footprint for each improvement scenario.

Table 4.5.1: Ayrshire housing stock data for carbon foot print T CO_2 p.a.

Imp type	Base	Imp 1	Imp 2	Imp 3	Imp 4	Imp 5	Imp 6
Semi Detached	4.5	3.7	3.2	2.8	1.5	0.9	0.5
Mid Terraced	4.8	4.0	3.4	2.8	1.5	0.9	0.5
Flat	2.9	2.4	2.1	1.8	1.0	0.6	0.4

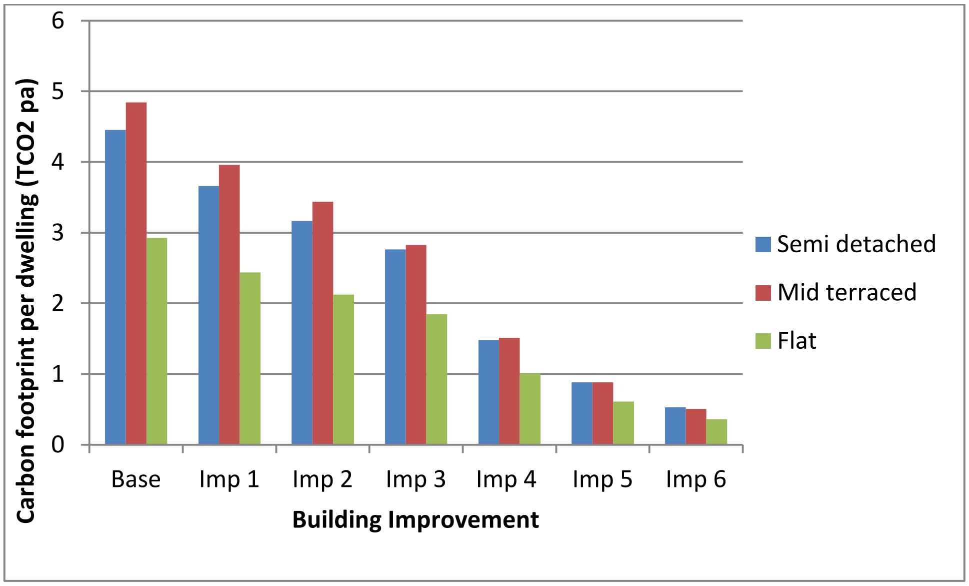

Figure 4.9: Carbon footprint for each improvement scenario

Table 4.5.2: Ayrshire housing stock data for energy consumption (kWh/m^2)

Imp type	Base	Imp 1	Imp 2	Imp 3	Imp 4	Imp 5	Imp 6
Semi Detached	255.4	210	182.4	158.4	85	50.6	30
Mid Terraced	272.4	222.2	193.6	158.4	84.2	48.8	28
Flat	246.6	205.8	179.4	156.4	84.4	50.8	30

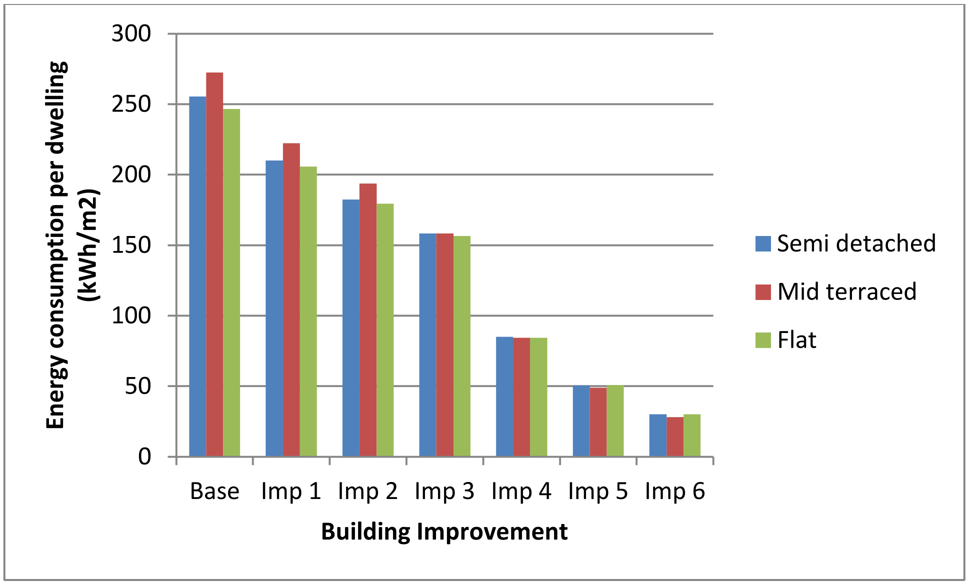

Figure 4.10: Energy Consumption for each improvement scenario per dwelling

4.6 Cost Benefit Analysis

4.6.1 For pre-1919 terraced building

The energy reduction achieved when making all the improvements 1-6 is

(265-26) kWh/m^2 = 239kWh/m^2

Gas cost 3.1 pence per kWh (SAP, 2009)

Savings made from energy reduction= $3.1p/kWh \times 239kWh/m^2$ =$740.9pence/m^2$

$$\frac{740.9.}{100} = \text{£}7.41/m^2$$

4.6.2 For pre 1919 semi-detached building

The energy reduction achieved is

(252-27) kWh/m^2 = 225kWh/m^2

Savings made from energy reduction = $3.1p/kWh \times 225kWh/m^2$ =$697.5pence/m^2$

$$\frac{697.5}{100} = \text{£}6.98/m^2$$

4.6.3 For a 65-82 terraced building

The energy reduction achieved is

(214-25) kWh/m^2 = 189kWh/m^2

Savings made from energy reduction =$3.1p/kWh \times 189kWh/m^2$ =$585.9pence/m^2$

$$\frac{585.9.}{100} = \text{£}5.86/m^2$$

4.6.4 For a 65-82 semi-detached building

The energy reduction using U-values is

(215-27) kWh/m^2 = 188kWh/m^2

Savings for U-values= $3.1p/kWh \times 188kWh/m^2$ =$582.8pence/m^2$

$$\frac{582.8.}{100} = \text{£}5.83/m^2$$

CHAPTER FIVE

5.0 FINDINGS

5.1 Stock average

Upgrading of the building models is limited to the building envelope and the heating energy system. Improving the performance of building envelope and heating system shows a reduction in energy consumption and carbon emissions. This is evident from figures 4.1- 4.8 shown in the previous chapter. Carrying out one improvement measure alone is usually not as efficient as a combined approach. Improving the heating system without improving the insulation level and air leakage rate amounts to wasted energy and capital because the heating system will be working at its optimal level but the building fabric will not be able to retain the heat. Hence, the heat escapes at a fast rate and frequent heating is required for the comfort of the occupants. Improving the insulation level to the maximum gives rise to an enhanced reduction in energy consumption.

Improving the insulation level alone has a high effect on energy reduction (it can reduce energy consumption by up to 37%) than improving the air tightness alone (appendix B) this is evident from improvements 3 and 4 described in chapter 4. Combining both insulation and air tightness gives a better improvement as is shown from improvement 6 (appendix B). Total floor area (TFA) of a building determines the amount of energy consumed and CO_2 emission. Semi-detached dwellings have a lesser TFA than terraced dwellings, tables 4.2 and 4.4 shows the reduction in data for terraced and semidetached dwellings respectively. Introduction of LZCTs reduces dependency due to local generation and increases the amount of energy displaced to grid.

The base case is the current stock average status for each of the buildings without any improvement. Pre-1919 terraced buildings have an energy consumption of 265 kWh/m^2 and the terraced building of 1965-82 consumed 200kWh/m^2. This is due to improvement in the building fabric; improved U value, increased heating efficiency reduced air leakage rate (appendix C) and lesser TFA. There is about 33% reduction in energy consumption between the two building types. This spread across the remaining models shows a similar pattern. Pre-1919 terraced building has a carbon footprint of 4.68 tonnes of carbon dioxide per year, 1965-82 building carbon footprint shows a 30% reduction. This can be attributed to less energy demand.

Improvement 1 is about upgrading the energy system in the building. Improving the efficiency of the heating system reduces the energy consumption by 37%. DHW reduces by 33 % because the boiler requires less energy to heat the space and water due to higher efficiency as shown in (appendix D). The carbon footprint reduction for this improvement is approximately 37% (appendix E).

Improvement 2 and 3 is carried out on the envelope by improving air tightness, the difference in reduction in energy consumption is not as high as improving the heating system. Improvements 2 and 3 reduce energy consumption and carbon footprint by 17% and 14% respectively. (appendix F).

Improvement 4 and 5 carried out on the envelope by improving insulation gives higher energy reduction. About 45% of energy reduction is achieved by improving the insulation level alone. Carbon foot print for pre 1919 terraced dwelling reduced by 82%, 64% for pre 1919 semi-detached, 83% for 1965-82 terraced and 54% for 1965-82 semi-detached dwelling.

Improvement 6 is a combination of all the previous improvements and includes a SDHW and PV system. Combining the two parameters gives a higher energy reduction. The DHW energy use was constant throughout because the energy system was improved just once. DHW energy depends only on the heating system, so it did not change except when the system was upgraded. The energy and carbon emission reduction is about 90% for the entire measures combined together (appendix A and G).

5.2 Rationale behind improvements approach

The heating system, air tightness, insulation and introduction of LZCTs are the main drivers of reduction in energy consumption and carbon emission. At least 90% of the current building stock has central heating system. (Utley & Shorrock, 2007). The heating system account for a high percentage of energy consumption in the building and the efficiency decreases the older the boiler gets. 76% of all central heating systems are mains gas fire systems and condensing boilers are generally the most efficient boiler type (BRE, 2005). Hence, the need to upgrade the heating system to the most efficient one.

Although majority of the existing building stock have some form of insulation and air tightness measure applied to them. They are not up to the current applicable standard, which leaves room for improvement. LZCTs helps to reduce grid dependency, it is mostly on site energy generation through PV, wind turbine, SDHW, air source heat pump(ASHP), ground source heat pump(GSHP), combined heat pump (CHP) etc.

All these technologies have low or nearly zero emission while operational, alternative source of energy is been generated and reduces demand on the conventional plant which in return reduces the carbon emission. The combination of all the improvements shows about 74% reduction in carbon footprint for the 1965-82 tenure. For buildings up to 1965-82 standards achieving 80% reduction in CO_2 by 2050 looks feasible applying the improvement approach.

5.2.1 PV/SDHW

Solar PV is a technology that is well understood and has been around for a while. It captures the sun’s energy and converts it to electricity with photovoltaic cells. Direct sunlight is not necessarily required for the panel to work. Tilt angle and direction of placement that are of paramount importance. Introducing PV into the approach helps to reduce the carbon footprint of the building. It is a green energy and does not emit any carbon emission while operational. It is possible to save over a tonne of CO_2 per year when PV system is been installed in the building (EST, 2012). PV system is commercially mature, and various types of PV panels are produced on a large scale, which has brought the price down. Income can be generated from the Feed-in Tariff scheme if the building is eligible and at the same time save cost on electricity bill due to local generation. Savings made from the reduced electricity bill can be used to implement the upgrade approach. The flexibility of the PV panels to be installed as a standalone system in a building or collectively in a farm is an added advantage for including it in the upgrade approach.

Introducing SDHW reduces energy consumption for DHW, and it will reduce the energy consumption and carbon emission level of the building.

5.3 Ayrshire Housing stock

The Ayrshire housing stock constitutes mainly semi-detached, mid terraced houses and flats. Flats account for the highest percentage of the existing stock, being more than half of all the dwellings. Precise data for the housing stock is not available, data is sourced from (Tuohy *et al*, 2006). The flat was generalised as a ground floor flat . As shown in figure 4.9 & 4.10 respectively the carbon foot print and energy consumption of the mid terrace is higher than the other two building types. This is due to colder temperatures around the mid terrace building and requires more energy for heating the space. The base case is the current stock without upgrade measures applied. Improvement 1 shows the reduction in carbon foot print and energy consumption per dwelling after improving the heating system. Improvement 3 and 4 brought the reduction for the three dwelling types to a close range, which involves reducing the air leakage and increasing the insulation level. The base case is the current stock with no upgrade measure applied. Semi detached buildings improvement from base to improvement 1 shows a 22 % reduction in the energy consumption. Fot the mid terrace and flat is 23% and 20% respectively.

Improvement 2 is about reducing the air leakage rate. Semi detached, mid terrace and flat type all have the same saving of 15 % respectively for energy reduction and carbon footprint.

Improvement 3 shows that reducing air leakage, semi detached, mid terrace and flat have a 15 % , 22% , 15 % reduction in energy consumption & carbon emission respectively.

Improvement 4 is increasing the insulation level of the buildings further, semi detached, mid terrace and flat have the following vaules 87%, 88% & 85% respectively

Improvement 5 is increasing the insulation level of the buildings, semi detached, mid terrace and flat have the following reduction in energy consumption and emission 68%,73% &66 % respectively.

Improvement 6 is combining all the measures together and introducing SDHW and wind turbine as a LZCT. SDHW reduces the DHW consumption, and increases the amount of electricity displaced and sold to the grid. Semi detached, mid terrace and flat have the vaules 67%,74 % &69. % respectively

5.4 Practical challenges

There are practical issues that will prevent achieving these figures with actual refurbishment. This is because there is a limit to which improvement can be carried out. Reducing air leakage rate and increasing insulation level might lead to overheating in summer, especially with the projection of future summers getting hotter. In most cases insulation of existing buildings cannot be as high as a new building due to practical issues. The practical challenges include; planning restraints, accessibility and cost.

Condensation in buildings takes place when warm moist air in buildings comes in contact with cold surfaces. Due to heat transfer the temperature of the air is cooled down below its saturation level which causes a phase change from vapour to liquid. The condensed liquid which is usually water appears as droplets on non-permeable surfaces like tiles and windows. Generation of moist warm air is the major cause of condensation, this is produced from various activities like cooking, washing, drying and bathing. The detrimental effects of this are mould growth and deterioration of the building.

Retrofitting buildings usually means putting in double glazed windows improved insulation levels removal of fireplace and less natural ventilation. The building is sealed up in order to trap heat for a long time. This encourages condensation to occur, when winter season comes and the heating is more frequent the probability of warm moisture air being exposed to the cold surface is high there by encouraging condensation.

5.4.1 Planning issues

These constraints can occur in various formats:

- Building infrastructure- will determine the kind of retrofitting scheme that will take place. Buildings with no cavity wall will be filled with Internal Wall Insulation (IWI). External Wall structure Insulation (EWI) is recommended where IWI is not practicable. Can the building accommodate the extra load caused by the proposed retrofitting scheme?
- Building status- Listed buildings and conservation areas have historic significance. These buildings and areas will have restrictions on what can be done to the building in order to preserve the building in its original state.
- Occupation – Will the building required to be vacated during the duration of retrofitting works? Occupants staying back will restrict the kind of retrofitting that can be carried out.
- Building design- terraced buildings and blocks of flats will be difficult to change the design to suit the retrofitting process. Buildings with narrow side are not suitable for EWI. Accessibility will be major challenge; erecting scaffolding between narrow walls might not be possible.

Thermal Bridges become important as the U value decreases. It is difficult to eradicate thermal bridging when retrofitting existing buildings but it can be reduced to minimum. The use of specialised modelling software to analyze the thermal bridges in retrofitting measure helps identify thermal bridges and how best to reduce heat loss.

5.4.2. Implementation issues

This involves some constraints that stall the process of retrofitting of the buildings. Some are listed below:

- Finance - The availability of and access to funds post a major challenge in implementing refurbishing measure.
- Technology- Lack of adequate knowledge and expertise required to carry out retrofit in buildings
- Policy- Lack of government regulations and incentives to enforce the retrofitting measure.
- Role play- Lack of organisation and directive
- Commercial- How viable is the retrofitting, what money can be made from it, what is the payback time of the investment?

5.4.3 Stock degradation

Penetration rate for new built is about 1 % per year, and demolition rate is even lesser. At this rate about 87% of the current existing stock will still be standing (Power, 2008). There is no other choice than to upgrade the existing building stock to the current building regulations. Demolishing existing building has its own challenges, like the embodied energy used to carry out the demolition, applicability of renovating and cost.

5.4.4 Challenges

- Refurbishing existing building is subject to a 17.5 % VAT and new built is tax free
- Lack of trained personnel/skilled workers that will be able to refurbish buildings without giving rise to thermal bridges, condensation or other aforementioned issues.
- Local residents should be informed and enlightened before the refurbishment starts.

5.5 Software limitation/assumption

- Two different weather data were assumed for the model cases. SAP weather data was used for the pre1919 building and Thames was used for the 1965-82 models.
- The energy system is limited to only the heating the system for now.
- The input parameters are fixed and restricted.
- There is no room to differentiate between traditional and non-traditional dwellings,
- An average over the dwelling type was calculated to determine the building parameters. This was derived and used to run the simulation.

CHAPTER SIX

CONCLUSIONS AND RECOMMENDATIONS

6.1 Conclusions

This research work is carried out to help assist policy makers/ formation in achieving the CERT for 2050. The best attainable solution is retrofitting existing buildings, instead. of demolition and rebuild Since the penetration rate of retrofitting existing building is around 1%, better measures to hasten this process are required. To be able to meet the 2050 target aggressive refurbishing of existing stock must be employed by implementing policy that will enforce all dwellings with low EPC to be upgraded.

The policy should lay down the improvement measure to be carried for each building type and provide financial incentive and assistance.

A software tool based on a detailed dynamic simulation tool has been applied to the stock average case from the simulations carried out on the stock average case it was observed that various upgrading measures give different reduction and impact on the environment. The tool will help policy makers to choose appropriate measures when upgrading a particular type of building. The tool was chosen over other tools because of the following characteristics

- It is a dynamic simulation-based tool, it has a more accurate representation of a real and future case study, demand management approaches, proposed energy efficiency measure and local generation options.
- It does not require extensive data input, because there is a large pre-simulated data base embedded in the tool. This is based on the housing type, location, and year of build.
- It is more representatives of reality than steady state methods and can accommodate high-level information about building stock. The pre-simulated models used are based on national housing survey information.

Policy makers are not generally technically educated, but they need results from sound building physics based computational environment. The tool should have a simplified graphical user interface (GUI) for the policy makers to interpret the results and formulate an effective policy.

There are quite a lot of similar buildings that represent a housing stock, an average model can be modelled and scaled up to an estate level. The alternative to model a large representation is extremely resource intensive and not possible with current technology. This was applied using South Ayrshire Council housing stock. The carbon foot print per dwelling from the stock is 4.1 tonnes of $CO_{2.}$ Improvement measures arrived at reduce it to below 1 tonne, similar to figure achieved from the initial report.

The tool accommodates the introduction of LZCTs. The location will determine the type of LZCTs to be applied and the building type will determine the heat recovery system.

6.2 Further work

The following areas are recommended for further research & development:

- There is room for improvement in including Heating Ventilation and Air-condition, (HVAC) within the tool.
- The improvement measure should have a high penetration rate and require less capital cost.
- Awareness for retrofitting should be promoted to investors
- Promoting the use of dynamic simulation tools by policy makers.

Upgrading of existing buildings should allow future technical advancement to be introduced. Dynamic simulation should be employed more by policy makers in making decisions on upgrading existing buildings.

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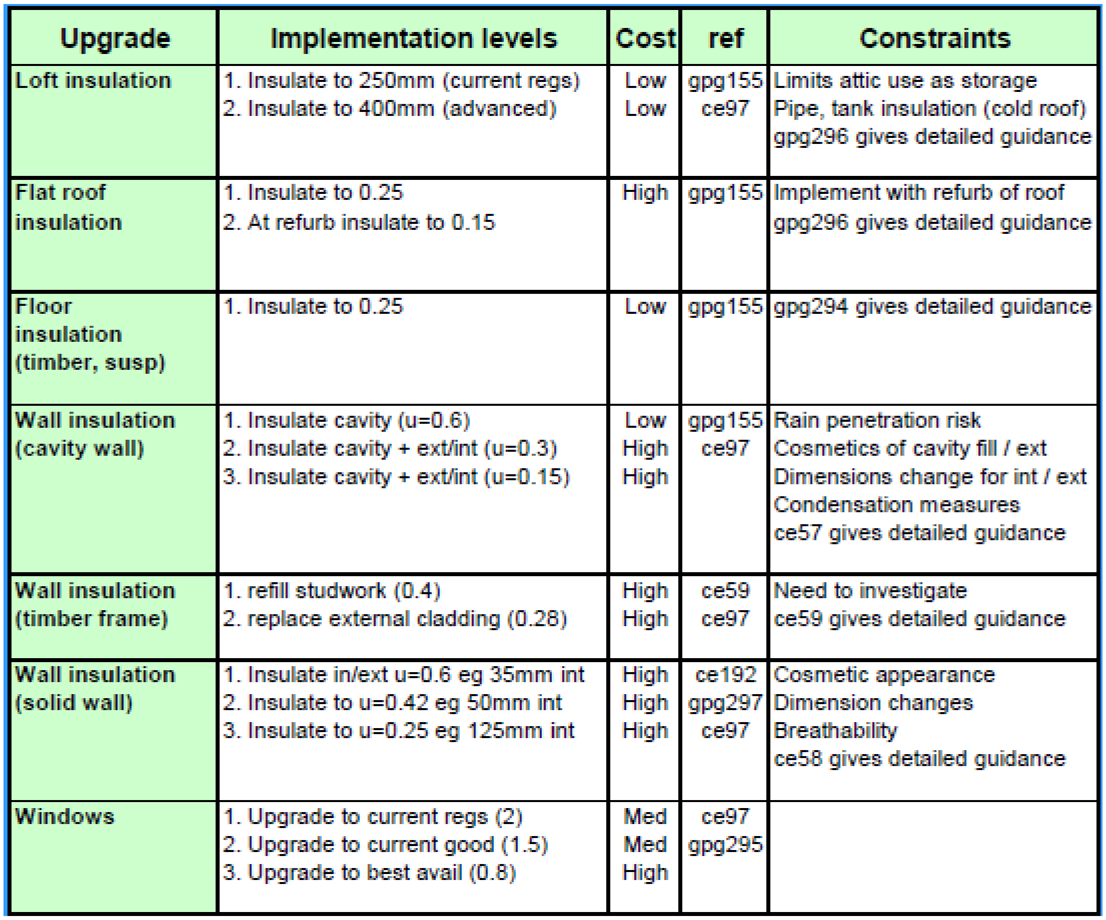
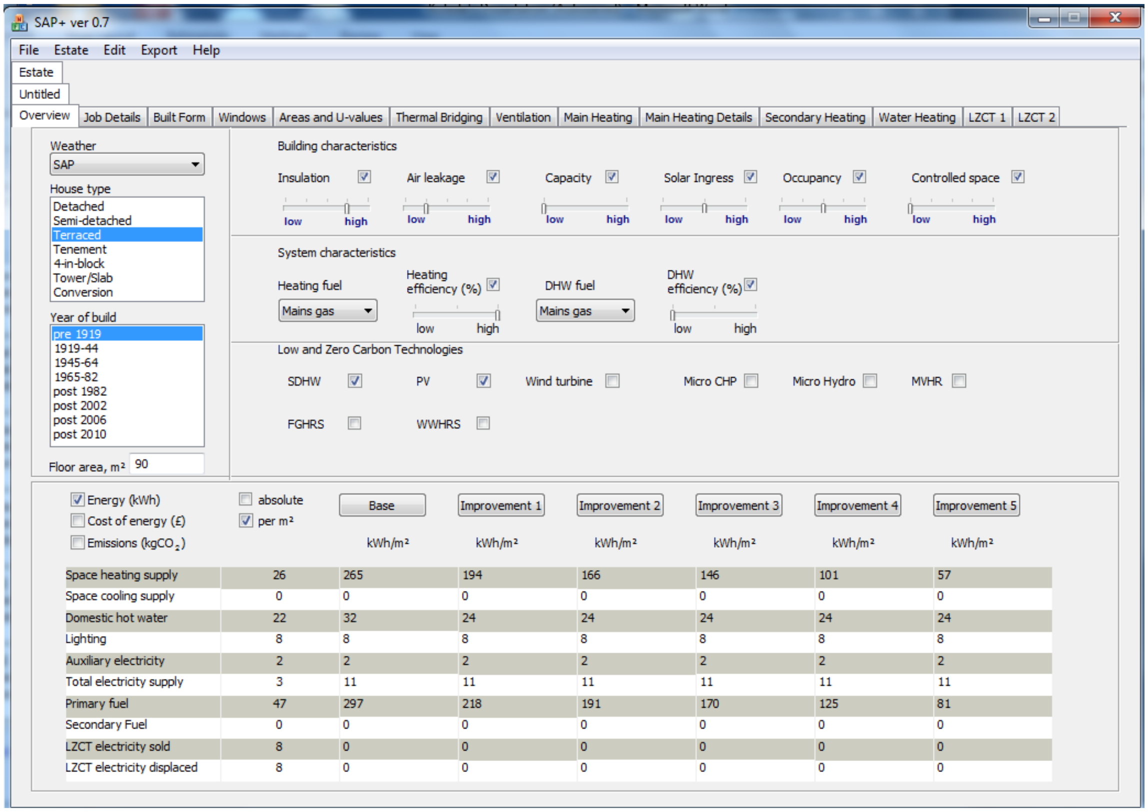
Appendix A: Detailed guidance on improvement on Ayrshire housing stock



Upgrade	Implementation levels	Cost	ref	Constraints
Loft insulation	1. Insulate to 250mm (current regs) 2. Insulate to 400mm (advanced)	Low Low	gpg155 ce97	Limits attic use as storage Pipe, tank insulation (cold roof) gpg296 gives detailed guidance
Flat roof insulation	1. Insulate to 0.25 2. At refurb insulate to 0.15	High	gpg155	Implement with refurb of roof gpg296 gives detailed guidance
Floor insulation (timber, susp)	1. Insulate to 0.25	Low	gpg155	gpg294 gives detailed guidance
Wall insulation (cavity wall)	1. Insulate cavity (u=0.6) 2. Insulate cavity + ext/int (u=0.3) 3. Insulate cavity + ext/int (u=0.15)	Low High High	gpg155 ce97	Rain penetration risk Cosmetics of cavity fill / ext Dimensions change for int / ext Condensation measures ce57 gives detailed guidance
Wall insulation (timber frame)	1. refill studwork (0.4) 2. replace external cladding (0.28)	High High	ce59 ce97	Need to investigate ce59 gives detailed guidance
Wall insulation (solid wall)	1. Insulate in/ext u=0.6 eg 35mm int 2. Insulate to u=0.42 eg 50mm int 3. Insulate to u=0.25 eg 125mm int	High High High	ce192 gpg297 ce97	Cosmetic appearance Dimension changes Breathability ce58 gives detailed guidance
Windows	1. Upgrade to current regs (2) 2. Upgrade to current good (1.5) 3. Upgrade to best avail (0.8)	Med Med High	ce97 gpg295	

Appendix B- Improving Insulation level only



Weather: SAP

House type: Detached, Semi-detached, **Terraced**, Tenement, 4-in-block, Tower/Slab, Conversion

Year of build: **pre 1919**, 1919-44, 1945-64, 1965-82, post 1982, post 2002, post 2006, post 2010

Floor area, m²: 90

Insulation ☑ Air leakage ☑ Capacity ☑ Solar Ingress ☑ Occupancy ☑ Controlled space ☑

Heating fuel: Mains gas

Heating efficiency (%) ☑

DHW fuel: Mains gas

DHW efficiency (%) ☑

SDHW ☑ PV ☑ Wind turbine ☐ Micro CHP ☐ Micro Hydro ☐ MVHR ☐

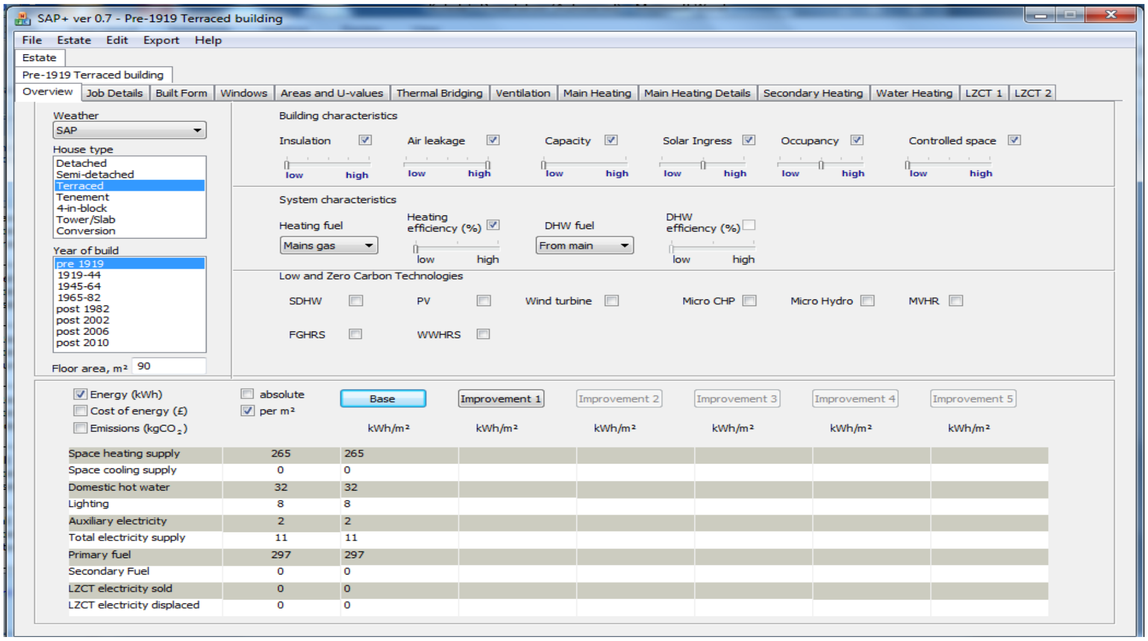
FGHRS ☐ WWHRS ☐

☑ Energy (kWh)
☐ Cost of energy (£)
☐ Emissions (kgCO$_2$)

☐ absolute
☑ per m²

		Base	Improvement 1	Improvement 2	Improvement 3	Improvement 4	Improvement 5
		kWh/m²	kWh/m²	kWh/m²	kWh/m²	kWh/m²	kWh/m²
Space heating supply	26	265	194	166	146	101	57
Space cooling supply	0	0	0	0	0	0	0
Domestic hot water	22	32	24	24	24	24	24
Lighting	8	8	8	8	8	8	8
Auxiliary electricity	2	2	2	2	2	2	2
Total electricity supply	3	11	11	11	11	11	11
Primary fuel	47	297	218	191	170	125	81
Secondary Fuel	0	0	0	0	0	0	0
LZCT electricity sold	8	0	0	0	0	0	0
LZCT electricity displaced	8	0	0	0	0	0	0

Appendix C- Improved heating efficiency and air leakage level



SAP+ ver 0.7 - Pre-1919 Terraced building

Pre-1919 Terraced building

Weather: SAP

House type: Detached, Semi-detached, **Terraced**, Tenement, 4-in-block, Tower/Slab, Conversion

Year of build: **pre 1919**, 1919-44, 1945-64, 1965-82, post 1982, post 2002, post 2006, post 2010

Floor area, m²: 90

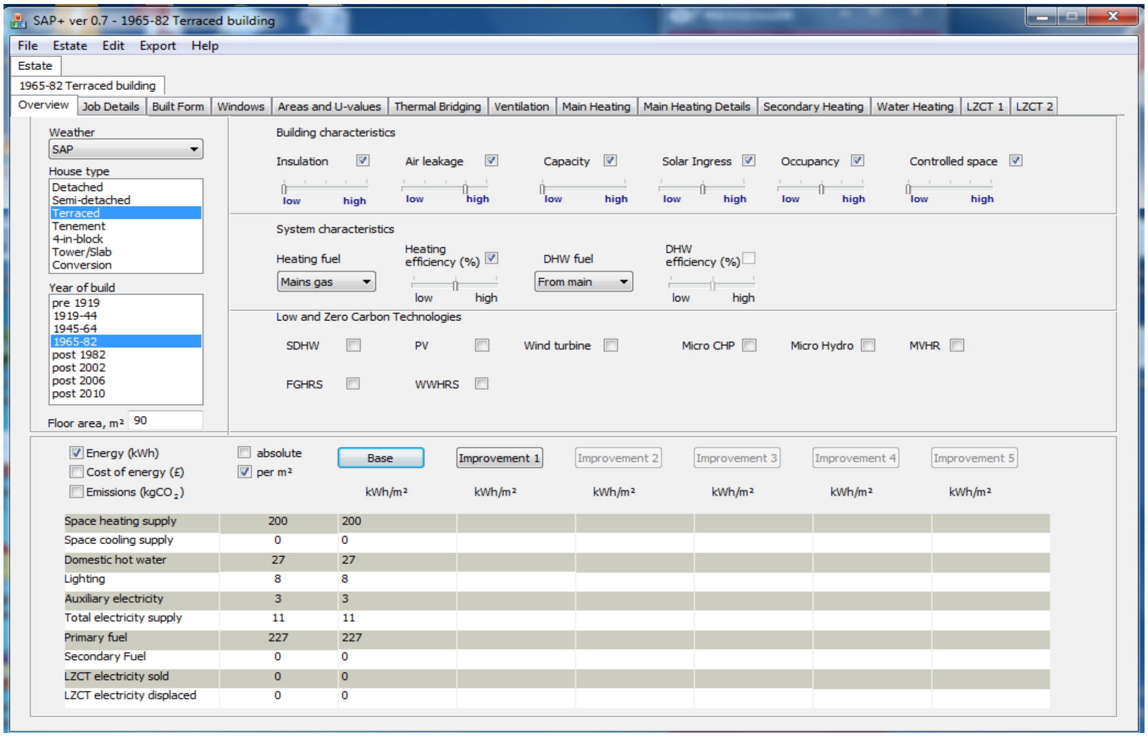
Building characteristics: Insulation ☑ Air leakage ☑ Capacity ☑ Solar Ingress ☑ Occupancy ☑ Controlled space ☑

System characteristics: Heating fuel: Mains gas; Heating efficiency (%) ☑; DHW fuel: From main; DHW efficiency (%) ☐

Low and Zero Carbon Technologies: SDHW ☐ PV ☐ Wind turbine ☐ Micro CHP ☐ Micro Hydro ☐ MVHR ☐ FGHRS ☐ WWHRS ☐

☑ Energy (kWh) ☐ Cost of energy (£) ☐ Emissions (kgCO$_2$) ☐ absolute ☑ per m²

	Base	Improvement 1	Improvement 2	Improvement 3	Improvement 4	Improvement 5
	kWh/m²	kWh/m²	kWh/m²	kWh/m²	kWh/m²	kWh/m²
Space heating supply	265	265				
Space cooling supply	0	0				
Domestic hot water	32	32				
Lighting	8	8				
Auxiliary electricity	2	2				
Total electricity supply	11	11				
Primary fuel	297	297				
Secondary Fuel	0	0				
LZCT electricity sold	0	0				
LZCT electricity displaced	0	0				



SAP+ ver 0.7 - 1965-82 Terraced building

1965-82 Terraced building

Weather: SAP

House type: Detached, Semi-detached, **Terraced**, Tenement, 4-in-block, Tower/Slab, Conversion

Year of build: pre 1919, 1919-44, 1945-64, **1965-82**, post 1982, post 2002, post 2006, post 2010

Floor area, m²: 90

Building characteristics: Insulation ☑ Air leakage ☑ Capacity ☑ Solar Ingress ☑ Occupancy ☑ Controlled space ☑

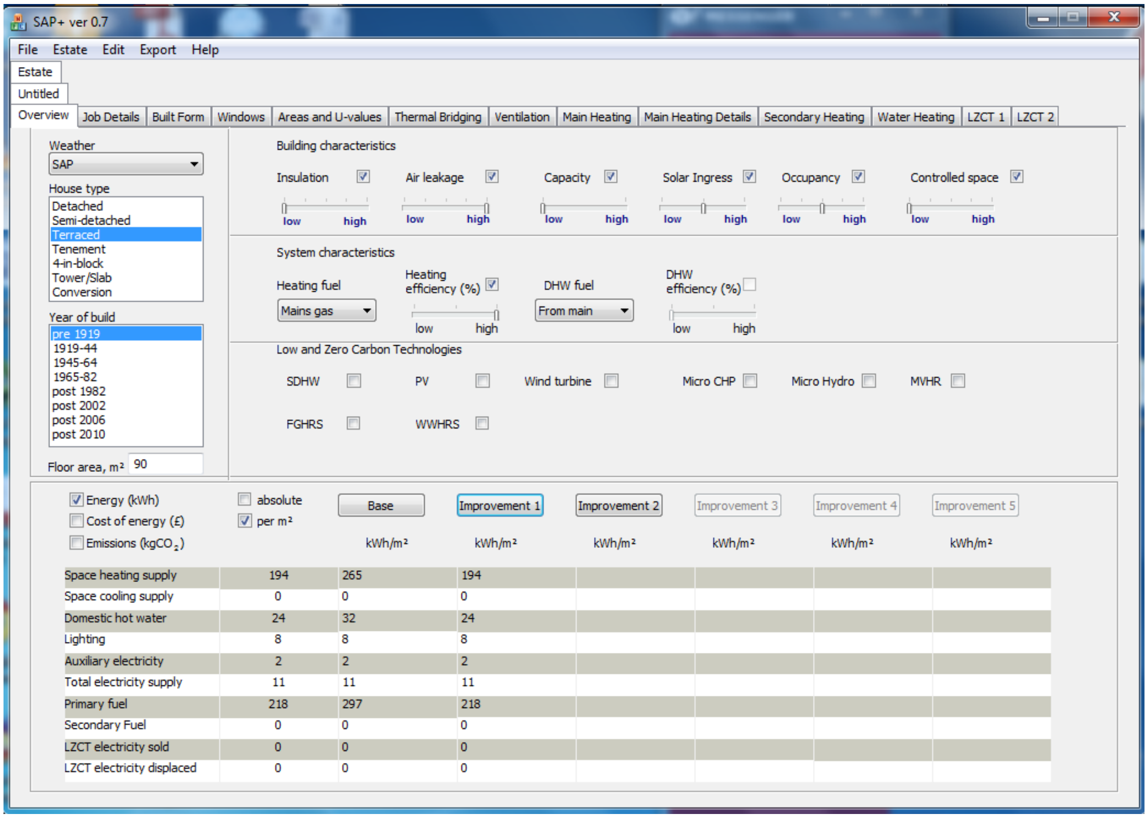
System characteristics: Heating fuel: Mains gas; Heating efficiency (%) ☑; DHW fuel: From main; DHW efficiency (%) ☐

Low and Zero Carbon Technologies: SDHW ☐ PV ☐ Wind turbine ☐ Micro CHP ☐ Micro Hydro ☐ MVHR ☐ FGHRS ☐ WWHRS ☐

☑ Energy (kWh) ☐ Cost of energy (£) ☐ Emissions (kgCO$_2$) ☐ absolute ☑ per m²

	Base	Improvement 1	Improvement 2	Improvement 3	Improvement 4	Improvement 5
	kWh/m²	kWh/m²	kWh/m²	kWh/m²	kWh/m²	kWh/m²
Space heating supply	200	200				
Space cooling supply	0	0				
Domestic hot water	27	27				
Lighting	8	8				
Auxiliary electricity	3	3				
Total electricity supply	11	11				
Primary fuel	227	227				
Secondary Fuel	0	0				
LZCT electricity sold	0	0				
LZCT electricity displaced	0	0				

Appendix D: Pre- 1919 Terraced building Improvement 1



Weather: SAP

House type: Detached, Semi-detached, **Terraced**, Tenement, 4-in-block, Tower/Slab, Conversion

Year of build: **pre 1919**, 1919-44, 1945-64, 1965-82, post 1982, post 2002, post 2006, post 2010

Floor area, m² 90

Building characteristics

Insulation ☑ low high
Air leakage ☑ low high
Capacity ☑ low high
Solar Ingress ☑ low high
Occupancy ☑ low high
Controlled space ☑ low high

System characteristics

Heating fuel: Mains gas
Heating efficiency (%) ☑ low high
DHW fuel: From main
DHW efficiency (%) ☐ low high

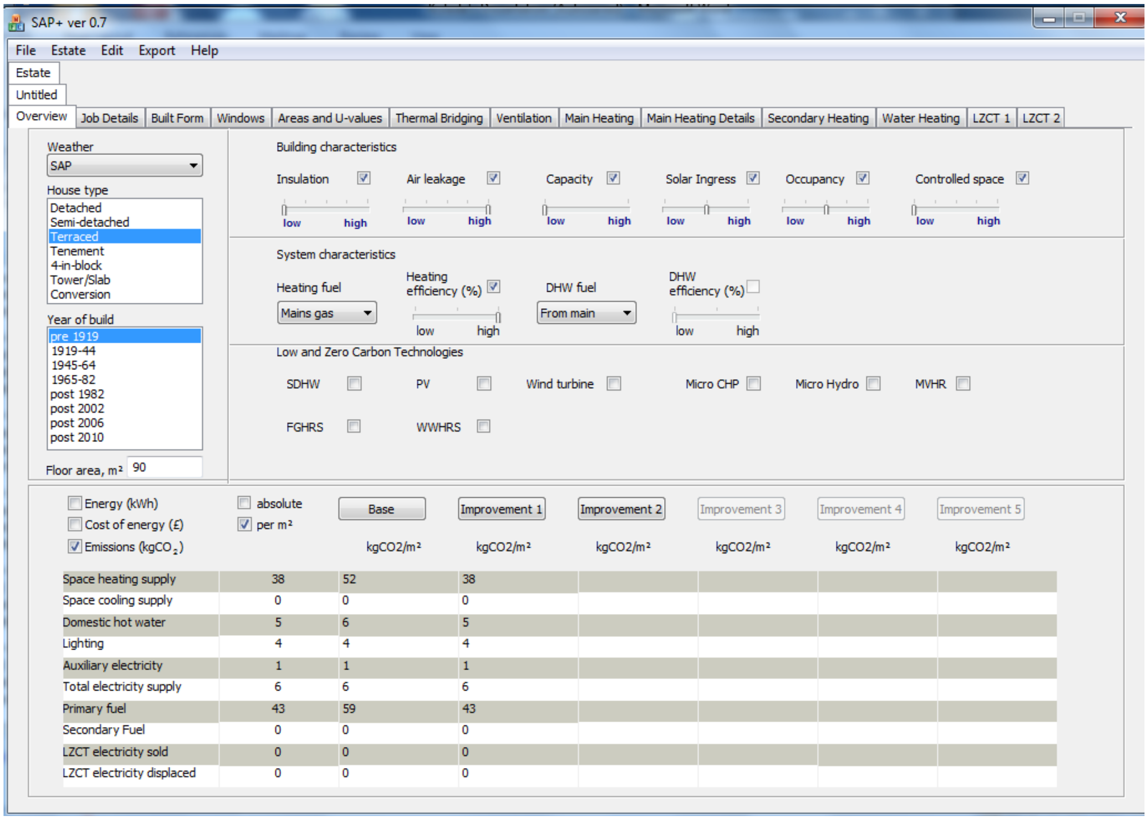
Low and Zero Carbon Technologies

SDHW ☐
PV ☐
Wind turbine ☐
Micro CHP ☐
Micro Hydro ☐
MVHR ☐
FGHRS ☐
WWHRS ☐

☑ Energy (kWh)
☐ Cost of energy (£)
☐ Emissions (kgCO$_2$)
☐ absolute
☑ per m²

		Base	Improvement 1	Improvement 2	Improvement 3	Improvement 4	Improvement 5
		kWh/m²	kWh/m²	kWh/m²	kWh/m²	kWh/m²	kWh/m²
Space heating supply	194	265	194				
Space cooling supply	0	0	0				
Domestic hot water	24	32	24				
Lighting	8	8	8				
Auxiliary electricity	2	2	2				
Total electricity supply	11	11	11				
Primary fuel	218	297	218				
Secondary Fuel	0	0	0				
LZCT electricity sold	0	0	0				
LZCT electricity displaced	0	0	0				

Appendix E: Pre- 1919 Terraced building Improvement 1(Emissions)



Weather: SAP

House type: Terraced

Year of build: pre 1919

Floor area, m² 90

☑ Insulation ☑ Air leakage ☑ Capacity ☑ Solar Ingress ☑ Occupancy ☑ Controlled space

Heating fuel: Mains gas

☑ Heating efficiency (%)

DHW fuel: From main

☐ DHW efficiency (%)

☐ SDHW ☐ PV ☐ Wind turbine ☐ Micro CHP ☐ Micro Hydro ☐ MVHR

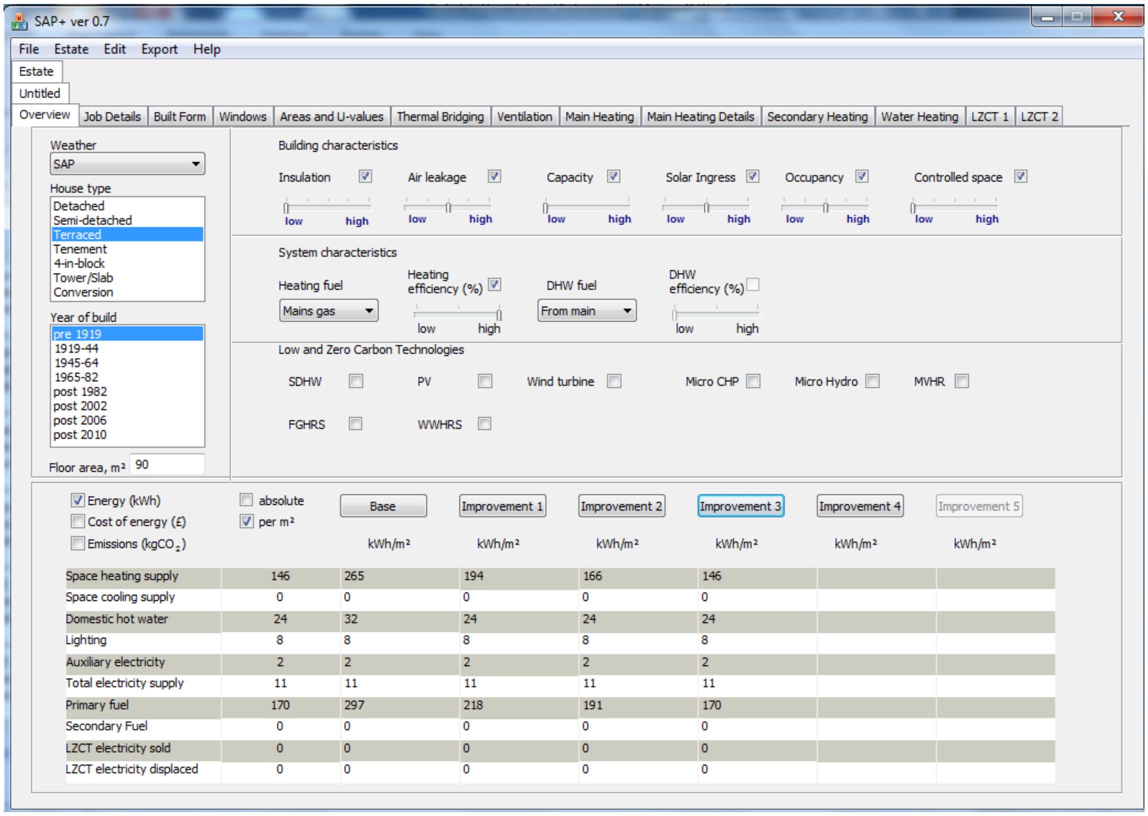
☐ FGHRS ☐ WWHRS

☐ Energy (kWh)
☐ Cost of energy (£)
☑ Emissions (kgCO$_2$)

☐ absolute
☑ per m²

	Base	Improvement 1	Improvement 2	Improvement 3	Improvement 4	Improvement 5
	kgCO2/m²	kgCO2/m²	kgCO2/m²	kgCO2/m²	kgCO2/m²	kgCO2/m²
Space heating supply	38	52	38			
Space cooling supply	0	0	0			
Domestic hot water	5	6	5			
Lighting	4	4	4			
Auxiliary electricity	1	1	1			
Total electricity supply	6	6	6			
Primary fuel	43	59	43			
Secondary Fuel	0	0	0			
LZCT electricity sold	0	0	0			
LZCT electricity displaced	0	0	0			

Appendix F: Pre- 1919 Terraced building Improvement 2 and 3



Weather: SAP

House type: Terraced

Year of build: pre 1919

Floor area, m² 90

Building characteristics

Insulation ☑ Air leakage ☑ Capacity ☑ Solar Ingress ☑ Occupancy ☑ Controlled space ☑

System characteristics

Heating fuel: Mains gas

Heating efficiency (%) ☑

DHW fuel: From main

DHW efficiency (%) ☐

Low and Zero Carbon Technologies

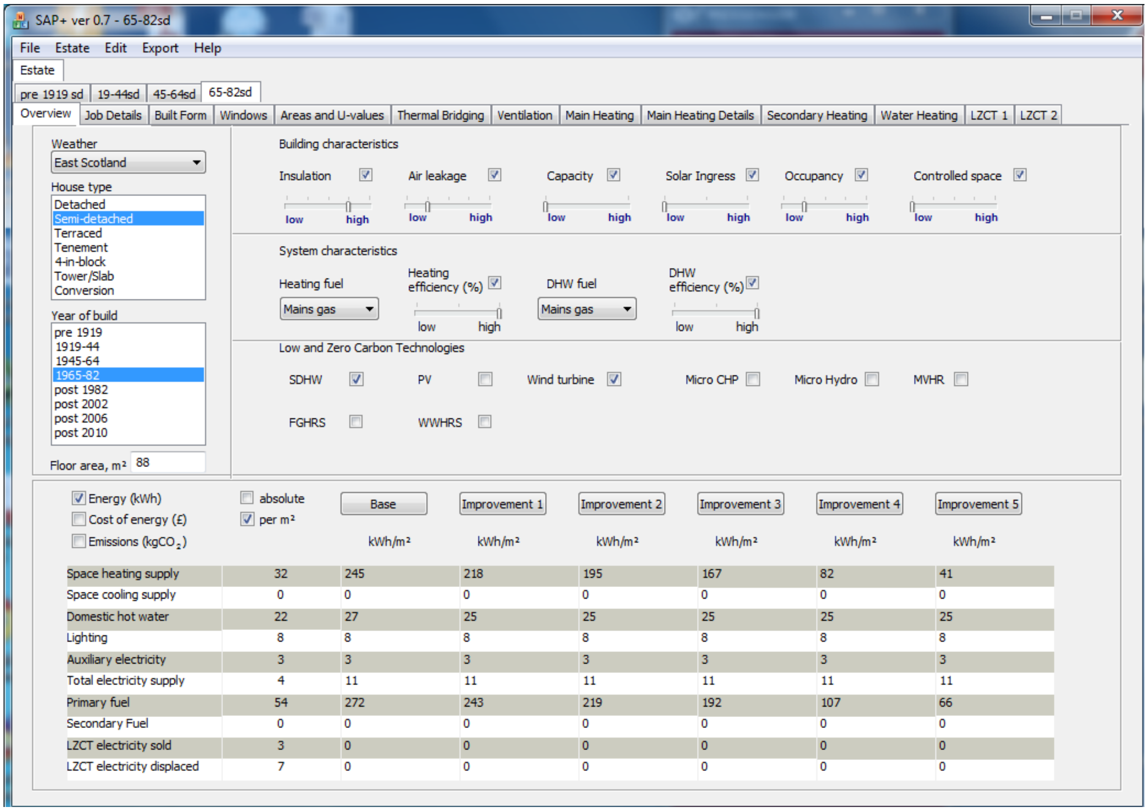
SDHW ☐ PV ☐ Wind turbine ☐ Micro CHP ☐ Micro Hydro ☐ MVHR ☐

FGHRS ☐ WWHRS ☐

☑ Energy (kWh) ☐ absolute
☐ Cost of energy (£) ☑ per m²
☐ Emissions (kgCO$_2$)

	Base	Improvement 1	Improvement 2	Improvement 3	Improvement 4	Improvement 5
	kWh/m²	kWh/m²	kWh/m²	kWh/m²	kWh/m²	kWh/m²
Space heating supply	146	265	194	166	146	
Space cooling supply	0	0	0	0	0	
Domestic hot water	24	32	24	24	24	
Lighting	8	8	8	8	8	
Auxiliary electricity	2	2	2	2	2	
Total electricity supply	11	11	11	11	11	
Primary fuel	170	297	218	191	170	
Secondary Fuel	0	0	0	0	0	
LZCT electricity sold	0	0	0	0	0	
LZCT electricity displaced	0	0	0	0	0	

Appendix G: Pre- 1919 Terraced building Improvements 1-6



Weather: East Scotland

House type:
- Detached
- Semi-detached
- Terraced
- Tenement
- 4-in-block
- Tower/Slab
- Conversion

Year of build:
- pre 1919
- 1919-44
- 1945-64
- 1965-82
- post 1982
- post 2002
- post 2006
- post 2010

Floor area, m² 88

Building characteristics

Insulation ☑ Air leakage ☑ Capacity ☑ Solar Ingress ☑ Occupancy ☑ Controlled space ☑

System characteristics

Heating fuel: Mains gas

Heating efficiency (%) ☑

DHW fuel: Mains gas

DHW efficiency (%) ☑

Low and Zero Carbon Technologies

SDHW ☑ PV ☐ Wind turbine ☑ Micro CHP ☐ Micro Hydro ☐ MVHR ☐

FGHRS ☐ WWHRS ☐

☑ Energy (kWh)
☐ Cost of energy (£)
☐ Emissions (kgCO$_2$)

☐ absolute
☑ per m²

		Base kWh/m²	Improvement 1 kWh/m²	Improvement 2 kWh/m²	Improvement 3 kWh/m²	Improvement 4 kWh/m²	Improvement 5 kWh/m²
Space heating supply	32	245	218	195	167	82	41
Space cooling supply	0	0	0	0	0	0	0
Domestic hot water	22	27	25	25	25	25	25
Lighting	8	8	8	8	8	8	8
Auxiliary electricity	3	3	3	3	3	3	3
Total electricity supply	4	11	11	11	11	11	11
Primary fuel	54	272	243	219	192	107	66
Secondary Fuel	0	0	0	0	0	0	0
LZCT electricity sold	3	0	0	0	0	0	0
LZCT electricity displaced	7	0	0	0	0	0	0