# Code for Sustainable Homes:
# An Evaluation of Low Carbon Dwellings

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# Abstract

‘Sustainable housing should ensure a better quality of life, not just for now, but also for future generations. It should combine the protection of the environment, sensible use of natural resources, economic growth and social progress, whilst conserving and enhancing the natural beauty, wildlife and cultural heritage.’ (Mrowiec, 2003).

In practice the term sustainable housing has a more specific meaning. Usually the term gives priority to the construction, building materials, design and technical functioning of the house, rather than the activities which are based on it. Housing in the UK contributes around 27% of the total $CO_2$ emissions associated with energy use, and domestic energy use is projected to rise by 6% by 2010 (Miliband, 2006). In December 2006, the Department for Communities and Local Government (DCLG) implemented tougher standards for private developers with the introduction of a new Code for Sustainable Homes (CSH) (Planning Portal, 2007), which will form the basis of future building regulation.

The intention of this project has been to evaluate the merit of the Code of Sustainable Homes. This has been done by means of a detailed carbon footprint analysis of two proposed dwellings. One of the dwellings (Harris) is semi-detached with three bedrooms and the other (Jura) is detached with four bedrooms with a built on garage. An investigation into improving energy efficiency of the services and fabric of the buildings was conducted, before a comprehensive study into implementing renewable technologies within the dwellings.

It was found that after all recommended improvements the Harris dwelling achieved a dwelling emission rate (DER) of 24.5 kg $CO_2$/(Year.$m^2$ ) using the Standard Assessment Procedure (SAP). This proved to be a 28% improvement over the building regulations and thus obtaining an energy level 3 in the CSH. The Jura dwelling proved to have a lower DER of 20.3 kg $CO_2$/(Year.$m^2$ ) after improvements however this constituted to only a 14% improvement on the building regulations.

Initially it was hoped that the carbon footprint analysis could achieve up to level 4 or 5 in terms of energy efficiency in the CSH. However this proved to be more difficult than first thought. Due to limitations with integrating renewable energy technologies into the SAP calculations the highest level achieved was 3 stars. Overall, the CSH has been found to be more of an environmental code and requires tightening to contribute to an overall sustainable code.

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# Chapter 1: Introduction

In this chapter, a brief history of sustainable housing in the UK will be outlined by giving examples of ongoing projects. Focus will be directed to the government's commitment to housing and the relationship that sustainability has with housing. Finally, an introduction to the new code for sustainable homes will be addressed.

## 1.1 Sustainable Housing in the UK

The most widely accepted definition for sustainable development is that of the Brundtland Commission, which stated that development is sustainable where it 'meets the needs of the present without compromising the ability of future generations to meet their own needs' (Bruntland, 1987).

The application of sustainability principles to development projects involves integrating and balancing economic, environmental and social criteria. Eco-houses built in accordance with the principles of sustainable development which use resources and technologies that capitalise on renewability, are a fast-development industry in the UK whether they are individual projects, or designed to accommodate and create a new community. This section looks at three examples of sustainability in housing across the UK.

The Bed ZED project, or Beddington Zero Energy Development, is the UK's largest carbon neutral eco-community in the UK. It was built in 2002 in Wallington, Surrey, within the London borough of Sutton, and comprises 82 residential homes (Lazarus, 2003). The project was developed by the Peabody Trust, a social housing initiative in London that aims to fight poverty within the capital. The intention with this project, built in partnership with both an architect and an environmental consultancy firm, was to create a housing project that incorporates new approaches to energy conservation and sustainability, and also to build a thriving community to live within it.

The houses are equipped with key features, both technological and common sense – for example, designed in south facing terraces to maximise solar heat gain that utilise renewable and conservable energy. A small-scale combined heat and power plant on site, powered by wood off-cuts, provides most of the energy to the estates. All buildings have a thick insulation jacket made from recycled materials (Sustainable Build, 2006). The project has a legally-binding green transport plan, incorporating a car pool system for residents, great public transport links and is also linked into a cycling network. For these and many more social and environmental initiatives and technologies, BedZED has won many national and international awards for sustainability, design and innovation.

A second example of a public housing eco-project is the Slateford Green Estate, in Edinburgh. The project consists of 120 homes and was developed by a housing association together with the Scottish housing agency in 2000 at a cost of £9.5million. The traditional Scottish enclosed tenement of 120 apartments is wrapped around a tear-shaped green space.

**Figure 1.1.1 BedZED & Edinburgh: Slateford Green (Wikipedia, 2007 & Wohnen, 2003)**

The Slateford Green project showcases many of the key principles of sustainable living including a low $CO_2$ energy strategy. Using waste heat from the local distillery, the district heating system borders the site and each flat is connected using stairwell ducts. This is complemented by rainwater collection, reed beds, winter gardens and passive ventilation (TCPA, 2006). Energy saving is achieved mainly by super-insulation. The structure is clad in breathing wall with 175mm of Warmcel with panel-vent sheathing. Most flats have conservatories orientated into the south facing courtyard, providing passive solar gain to living spaces. Natural ventilation is encouraged by passive stack ventilation and there is provision for retrofitting of photovoltaic panels to power lighting if and when practical cost-effective products become available (TCPA, 2006).

More recently, the Aberdonian housebuilder Stewart Milne Group completed its first near-zero carbon showcase homes situated on the BRE innovation park. The sigma house is a four storey, semi open planned terraced town house with a split level interior. The house demonstrates a whole array of environment friendly features as well as a home office and cycle storage to reduce car travel (BRE, 2007). Bath and shower water is used to flush the toilets and rainwater is collected and stored for use in the garden. Renewable energy technologies such as solar hot water tiles, photovoltaic panels and a wind turbine have been implemented to cut down on emissions and maximise energy efficiency.

**Figure 1.1.2 The Sigma House (Milne, 2007)**

The UK is committed to making substantial reductions in its carbon dioxide and other climate altering emissions; a major source of which is housing. According to the Town and Country planning association, an additional four million new dwellings will be built in the UK over the next 20 years. The building and maintaining of homes and communities in a sustainable way is crucial to meet environmental objectives including cutting greenhouse gas emissions, reductions in pollution and the conservation of resources. The problem however, is that most housing built today falls short of current best practice in relation to energy efficiency.

The relationship between sustainability and housing is two-way. Incorporating principles and refurbishment will not only make a significant contribution to achieving general sustainability objectives, but will also improve the quality, durability and cost-effectiveness of housing. A change of culture is needed so that there is a different approach to housing maintenance and development which places sustainability in the centre.

This should include developers, builders and land use planners as well as tenants and owners (SHDGS, 2007). Sustainability objectives, such as the government target for reducing carbon emissions by 60% by 2050 will only be achieved if they are taken into account at all stages, from design through to construction to long-term use, maintenance and eventual disposal of recycling. Therefore raising awareness of the parties involved is vital.

In Paul G. Tuohy's Sustainable Housing (Tuohy, 2004), standards and metrics and the impact of thermal mass, ventilation and insulation of housing provide the key areas studied. To follow on from that benchmark, the focus of this report is directed at the new Code for Sustainable Homes by contributing to the debate of the impact that it will have on houses in the UK.

### 1.2 Background to the code of sustainable homes

Design and construction standards relating to housing and affordable housing in particular, are under continual review and enhancement. The standard used over recent years for assessment of the environmental performance of grant-funded affordable housing has been EcoHomes (discussed in chapter 2). The minimum threshold for a development to be eligible for grant funding from the Housing Corporation is an EcoHomes rating of ‘Very Good’ (Drivers Jonas, 2007).

However, in April 2007 the Code for Sustainable Homes (CSH) replaced Ecohomes for the assessment of new housing in the UK. The Code is a new voluntary approach to improving the sustainability of new homes, saving water and energy, and building on the 70% improvements to the energy efficiency of new buildings that have been made since 1990. As an environmental assessment method for new homes the code is based upon BRE's

(Building Research Establishment) Ecohomes and contains mandatory performance levels in 6 key areas.

All homes built with Housing Corporation and Communities and Local Government housing growth programme funding, and all housing developed by English Partnerships will be built to Code Level 3 from April 2008. These new homes will be 25% more energy efficient than current Building Regulations, use less water than the average home and have an improved environmental performance overall. In the longer term it is expected that the Code will drive up environmental performance of new homes.

In 2004 approximately a quarter of the UK's carbon dioxide emissions were found to be a result of energy use in our homes (Sustain, 2007). Housing also creates other pressures on the environment such as water consumption and its subsequent wastage, waste disposal and pollution and wastage in the construction of the houses and the materials used. In recognition of these facts, the Code aims to protect the environment by providing guidance on the construction of high performance homes designed with sustainability in mind.

The CSH realises that as important as climate change is, housing also causes other problems on the environment around it. As such, the Code considers a number of different aspects in the design of a home and following the Code will make house building more sustainable, and ensure a better quality of housing for the future (Sustain, 2007).

The assessment of the code looks at nine categories (CSH, 2006):

1. Energy efficiency / $CO_2$ emissions
2. Water efficiency
3. Surface Water Runoff
4. Waste
5. Materials
6. Pollution
7. Health and Well-being
8. Management
9. Ecology

In each of these areas the Code looks to improve on building regulations where applicable, such as energy use, and raise the standard of house building and reduce the impact of the dwelling on the environment in other areas, such as improving waste management and using more sustainable construction materials. Each category has a number of issues to be assessed, and will be studied in chapter 3. Each of the issues has specific assessment criteria, which must be met for credits to be awarded.

In the code, each dwelling is assessed, although there are site wide credits and individual credits. For five of these assessment issues, minimum standards are set which must be achieved before the lowest level of the Code can be awarded. This applies to Materials, Surface Water Run-Off, Waste, Energy, $CO_2$ and Water. However for Energy/$CO_2$ and Water minimum standards are required at each level of the Code. Therefore to be able to achieve a specific code level, the design must incorporate the minimum standards.

There are six levels of the Code that can be achieved.

| **Code Level** | **Number of Points required (including minimum standards)** | **Energy Requirement: Percentage better than part L 2006** |
|---|---|---|
| 1 (*) | 36 | 10% |
| 2 ( * * ) | 48 | 18% |
| 3 ( * * * ) | 57 | 25% |
| 4 ( * * * * ) | 68 | 44% |
| 5 ( * * * * * ) | 84 | 100% |
| 6 ( * * * * * * ) | 90 | Zero Carbon Home |

**Table 1.2.1: Levels of the CSH (CSH, 2007).**

The main driver behind the code is the requirement of the housing corporation for all their funded projects to meet level 3 of the Code. Previous to the code, the housing corporation required their funded projects to meet EcoHomes 2006 Very Good level. At this stage, the Code is voluntary unless it is part of a contractual requirement; however, it has been suggested by several environmental organisations that the Code become a mandatory Government requirement by April 2008 for all new homes.

One aspect of the Code that is of concern is the additional cost that the Code may have on the construction of dwellings. This needs to be taken into account at the conception of a project, to ensure that the development will meet the code standards, but at a cost that is affordable to those who build and those who will subsequently own the units. As such, an understanding of the code and the different design cost aspects are essential. A recent study was carried out by Cyril Sweet on behalf of the Housing Corporation and English Partnerships which looked at the cost of meeting level 3 of the Code for Sustainable Homes. This will be discussed in chapter four.

Whilst the new Code builds on the framework already established by EcoHomes, there are a number of key changes to how the assessment operates, and the options available to achieve a particular rating. The main differences between EcoHomes and the new CSH Code are given in Table 1.2.2:

| EcoHomes 2006 | Code for Sustainable Homes | Comment |
|---|---|---|
| Overall rating built up from various elements (incl. location, ecology and amenities), to comprise total score | Rating built up from various building features (not location), each with a minimum threshold, to comprise total | **Significant changes**: (1) focus on building only – cannot 'get away' with a poor building in a great location (2) limited transfer between elements, so that poor features cannot be rescued by good performance in other areas |
| Covers new-build and refurbishment (EcoHomes XB) | Initially, will cover new-build only. Refurbishment to follow. | **Initial change** for new-build housing only |
| 4 levels of compliance – 'Pass' to 'Excellent' | 6 levels of compliance, with minimum standards for 5 key issues | **Classification change** – EcoHomes 'Very Good' to be broadly similar to CSH Level 3 |
| Overseen by BRE, with licensed assessors | Overseen by BRE, with licensed assessors | **No change**, but assessors to receive additional training, concerns over the availability of assessors. |

**Table 1.2.2 EcoHomes vs. CSH (Drivers Jonas, 2007)**

Therefore, the Code is better suited to delivering targeted reductions in carbon dioxide emissions and water use than EcoHomes, but provides less flexibility. The environmental savings expected from moving from EcoHomes 'Very Good' to Code level 3 equates to 25% reduction in carbon emissions (in comparison to the relevant Target Emissions Rate (TER) set out in Building Regulations 2006 Part L) per house and 21 litres per person per day.

The main driver behind the Code is the requirement of the Housing Corporation for all their funded projects to meet Level 3 of the Code. The Housing Corporation is the public body that funds and regulates housing associations in England. Previous to the Code, the Housing Corporation required their funded projects to meet EcoHomes 2006 Very Good level.

# Chapter 2: Alternative assessment of sustainable housing criteria

Alternative tools, instruments, standards and building legislation in reference to sustainable houses will be reviewed in this chapter.

### 2.1 UK Building Regulations

The UK building regulations are statutory instruments that seek to ensure that the policies set out in the Building Act 1984 are carried out in the construction of buildings. In terms of new housing, minimum standards are acknowledged through the building regulations. There are currently 14 sections to the building regulations and each is accompanied by an Approved Document. In 1965 Building Regulations introduced the first limits on the amount of energy that could be lost through certain elements of the fabric of new houses (Wikipedia, 2007). This was expressed as a U-value (the amount of heat lost per square metre, for each degree Celsius of temperature difference between inside and outside).

Building regulations exist to impose minimum acceptable standards, mainly in the areas of health and safety. Minimum energy performance levels are set by government to reflect a balance between benefits and costs. This balance includes the effect of carbon emissions on society through a ‘social cost of carbon’. Better performance than these minima can be good value for individual buildings, but improvement is voluntary and rarely adds market value. This may change soon, as every new building will require an “Energy Performance Certificate” (an energy label), with many dwellings covered from June 2007 and other newbuilds from 2008.

As of 6th April 2006 Part L1: Conservation of fuel power was split into Part L1A – New dwellings and Part L1B – Existing dwellings for England and Wales. The idea is that it controls the insulation values of building elements, the allowable area of windows, doors and other openings, air permeability of the dwelling, heating efficiency of boilers and the insulation and controls of heating appliances and systems together with hot water storage and lighting efficiency. The Scottish regulations were revised in 2007. In terms of sustainability the key contributors are section 3 ‘Environment’ and in section 6 ‘Energy’.

The changes include a new guidance on overall carbon dioxide emission levels for new dwellings in 6.1. The guidance to standard 6.3 (Heating System) has been expanded to cover a more complete range of heating systems, including certain low and zero carbon technologies that are localised or building-integrated.

Standards 6.5 (Artificial lighting) and 6.6 (Mechanical ventilation and air-conditioning) which also recommends minimum levels, now apply to dwellings and have been included due to the introduction of a carbon emissions standard to make it compliant with the EU Directive on the energy performance of buildings (EPBD, 2007).

Standards 6.9 (Energy performance certificates) and 6.10 (Metering) are entirely new and are required as a result of the EPBD (SBSA, 2007).

The Building Regulations also set out the requirements for SAP (Standard Assessment Procedure) calculations and carbon emissions targets for dwellings. Regulation 16 requires the advertising of the SAP rating, in all new dwellings. The SAP is the Government's recommended system for energy rating of dwellings. The Standard Assessment Procedure is used for calculating the SAP rating, on a scale from 1 to 120, based on the annual energy costs for space and water heating (BRE, 2001). In addition, the Carbon Index (CI) is also calculated on a scale of 0.0 to 10.0, based on the annual $CO_2$ emissions associated with the space and water heating. The SAP rating is used to fulfil requirements of the building regulations to notify and display an energy rating in new dwellings. The CI is used to demonstrate compliance with Approved Document L1 (England and Wales) and Technical Standards Part J (Scotland).

The energy policy of the UK through the 2003 Energy White Paper articulated directions for more energy efficient building construction. Hence, 2006 saw a significant tightening of energy efficiency requirements within the Building Regulations. The intention of the 2006 changes was to cut energy use in new housing by 20% compared to a similar building constructed to the 2002 standards. In the 2006 regulations, the U-value was replaced as the primary measure of energy efficiency by the Dwelling Carbon Dioxide Emission Rate (DER), an estimate of carbon dioxide emissions per $m^2$ of floor area.

In addition to the levels of insulation provide by the structure of the building, the DER also takes into account the airtightness of the building, the efficiency of space and water heating, the efficiency of lighting, and any savings from solar power or other energy generation technologies employed, and other factors. For the first time, it also became compulsory to upgrade the energy efficiency in existing houses when extensions or certain other works are carried out.

## 2.2 BREEAM Ecohomes

Ecohomes is an independently verified environmental assessment method and covers all standard housing developments in England, Scotland, Wales and Northern Ireland (Ecohomes, 2006):

- Private and social housing schemes

- Flats and houses
- New build and major refurbishment.

Ecohomes was first developed and used commercially in 2000, and the assessments fall under one of four versions, Pre-2002, 2003, 2005 or the 2006 version. The rating system has gone through four major revisions, the latest being Ecohomes 2006. As a consequence, it is not possible to compare homes built with one revision of the standard with homes built under another.

In particular, the 2006 version of Ecohomes increases the standards for energy efficiency, following the 2006 revisions energy efficiency requirements of the building regulations. Under the scheme, credits are first given for standards reached in the following areas:

**1. Energy (24 Credits available = 24%)**

- Ene 1 – Dwelling Emission Rate (15 credits available)
- Ene 2 – Building Fabric (2 credits available)
- Ene 3 – Drying Space (1 credits available)
- Ene 4 – Eco-labelled goods (2 credits available)
- Ene 5 – Internal lighting (2 credits available)
- Ene 6 – External lighting (2 credits available)
-

Ene 1 is the most important aspect of this section as it credit assesses the amount of carbon dioxide ($CO_2$) emitted from the dwellings as a result of space heating, hot water and lighting. $CO_2$ is selected as the measured quantity as it has a direct environmental impact and allows the type of primary fuel to be taken into consideration. The credit scale shown in figure 2.2.1, relates to the operational energy use. Credits are awarded on the basis of SAP 2005 related average $CO_2$ emissions. This is used to compare the basic performance characteristics of the dwellings against others.

| Credits | $CO_2$ emissions/DER ($kg/m^2/yr$) |
|---|---|
| 1 | ≤ 40 |
| 2 | ≤ 35 |
| 3 | ≤ 32 |
| 4 | ≤ 30 |
| 5 | ≤ 28 |
| 6 | ≤ 26 |
| 7 | ≤ 24 |
| 8 | ≤ 22 |
| 9 | ≤ 20 |

| | |
|---|---|
| 10 | ≤ 18 |
| 11 | ≤ 15 |
| 12 | ≤ 10 |
| 13 | ≤ 5 |
| 14 | ≤ 0 |
| 15 | ≤ -10 |

**Figure 2.2.1 Energy Credit Requirements (Ecohomes, 2006)**

The aim of the other five energy assessment methods include sustaining the efficiency of dwellings over their whole life, minimising the energy used to dry clothes and, encouraging the purchase of energy efficient white goods, energy efficient internal lighting and energy efficient external lighting which all reduce the $CO_2$ emissions from a dwelling.

**2. Transport (8 credits available = 8%)**

- Tra 1 – Public Transport (2 credits available)
- Tra 2 – Cycle Storage (2 credits available)
- Tra 3 – Local amenities (3 credits available)
- Tra 4 – Home office (1 credit available)

This section aims to minimise the amount of pollution by cars and encourage lifestyle change. In respect of public transport, Ecohomes provides a distinction between urban and rural locations but because the credits are location specific there is little that can be done to improve credits, unless influence can be exerted over new bus routes and the location of post boxes. Table 2.2.2 gives an example how public transport credits can be obtained in urban and rural locations.

| Credit | Urban | Rural |
|---|---|---|
| 1 | Home within 1000m of transport node with service to town centre. Frequency of:<br>7.30 – 19.00 Mon to Fri - half hourly<br>7.00 – 22.00 Mon to Sat - hourly | Home within 1000m of transport node with service to town centre.<br>Frequency of:<br>7.30 – 22.00 Mon to Sat - hourly |
| 2 | Home within 500m of transport node with service to town centre. Frequency of:<br>7.30 – 19.00 Mon to Fri – every 15 min<br>7.00 – 22.00 Mon to Sat – half hourly | Home within 500m of transport node with service to town centre.<br>Frequency of:<br>7.30 – 22.00 Mon to Sat – half hourly |

**Figure 2.2.2 Public Transport requirement for Urban and Rural locations (Ecohomes, 2006)**

The provision of cycle storage aims to encourage more cycling however the size of the shed and access to it are important. Local amenities will generally be fixed and the inclusion of home office facilities (the provision of two double plug sockets and two telephone points in a room other than the kitchen, living room, main bedroom or bathroom) is a further cost effective means to support home based working (Mactavish & Hill, 2006).

**3. Pollution (10 credits available = 10%)**

- Pol 1 – Insulant GWP (1 credits available)
- Pol 2 – NOx emissions (2 credits available)
- Pol 3 – Reduction of surface runoff (2 credits available)
- Pol 4 – Renewable and low emission energy source (3 credits)
- Pol 5 – Flood risk (2 credits available)

In terms of pollutants, the Ecohomes assessment seeks to reduce the amount associated with building materials and products. Insulation materials in particular have a key role here. Most CFCs (chlorofluorocarbons) are banned and most HCFCs (Hydrochlorofluorocarbons) have been banned in insulating products. The Green Guide to Housing Specification provides advice on materials and components. In respect of low $NO_x$ emitting boilers, the assessor will look for specification details from a supplier along with proof of payment. The same applies to insulating materials (Mactavish & Hill, 2006).

**4. Materials (14 credits available = 14%)**

- Mat 1 – Environmental impact of materials (7 credits available)
- Mat 2 – Basic building elements (3 credits available)
- Mat 3 – Finishing elements (1 credit available)
- Mat 4 – Recycling facilities (3 credits available)

The section of materials focuses on the use of natural resources during construction, building use and the whole life of the building. It considers waste materials during construction and promotes the recycling of household waste by residents. Different credits are available depending on the percentage of certified timber used. The specification of sustainable timber is essentially a supply chain issue. It is also mentioned that re-used timber or timber from pre and post-consumer waste streams can also achieve credits.

**5. Water (10 Credits available = 10%)**

- Wat 1 – Internal potable water use (8 credits available)
- Wat 2 – External potable water use (2 credits available)

Water consumption has risen by over 70% in the last 30 years. Credits are available for reducing water consumption by specifying water efficient appliances and fittings (for a Very Good rating) and introducing rainwater or grey-water systems and butts (for an Excellent rating) (Mactavish & Hill, 2006). The Ecohomes assessment looks at the calculation related to water consumption of less than 45-50m$^2$ per bed space per year.

**6. Land Use and Ecology (12 Credits available = 12%)**

- Eco 1 – Ecological value of site (2 credits available)
- Eco 2 – Ecological enhancement (1 credit available)
- Eco 3 – Protection of ecological features (1 credit available)
- Eco 4 – Change of ecological value of site (5 credits available)
- Eco 5 – Building Footprint (3 credits available)

These elements seek to reduce the negative environmental impacts on the amount and quality of land being used for development. Generally, to secure a Very Good or Excellent rating, the assessment considers an ecological study of the site by an eco-consultant. The protection of ecological features on the site, during and after construction is assessed. Eco 5 encourages the more effective use of land through building above two storeys.

**7. Health and Wellbeing (14 credits available = 14%)**

- Hea 1 – Providing adequate daylighting (5 credits available)
- Hea 2 – Sound insulation (7 credits available)
- Hea 3 – Private space (2 credits available)

These elements are designed to benefit a home into improving the quality of life for residents. Hea 1 is an early design issue to ensure the optimum credits for daylighting by reducing energy consumption and cost in use supporting passive solar gains. Sounds tests are necessary to secure credits for Hea 2 rather than reliance on robust standard details. In respect of Hea 3, access is a minimum requirement of SDS (Scheme Development Standards) and this also achieves Ecohomes credits.

**8. Management (10 points = available 10%)**

- Man 1 – Home user guide (3 credits available)
- Man 2 – Considerate constructors (2 credits available)
- Man 3 – Construction site impacts (3 credits available)
- Man 4 – Security (2 credits available)

The total number of credits available in all sections is 100. A weighting system is then used to designate the home on the basis of the total percentage of credits achieved as Pass (> 36%), Good (>48%), Very Good (>58%) or Excellent (>70%).

The benefits of Ecohomes include:

- Demonstrating sustainability credentials to planning authorities
- Demonstrating "green" credentials to investors helps to minimise risk investment

- Demonstrating superior environmental design to customers

There are some limitations to Ecohomes such as the ability to achieve an overall high rating without implementing energy efficient techniques. High ratings can be achieved with excellent well-being and management. This masquerades the energy performance of the household.

### 2.3 Association for Environment Conscious Buildings (AECB)

The association for Environment Conscious Builders was founded in 1989 by Keith and Sally Hall (AECB, 2007) to encourage greater environmental awareness within the UK construction industry. The members of the AECB include local authorities, housing associations, architects, designers and builders and they share a 'broad green vision' reflected in their approaches to the design of buildings and their environment.

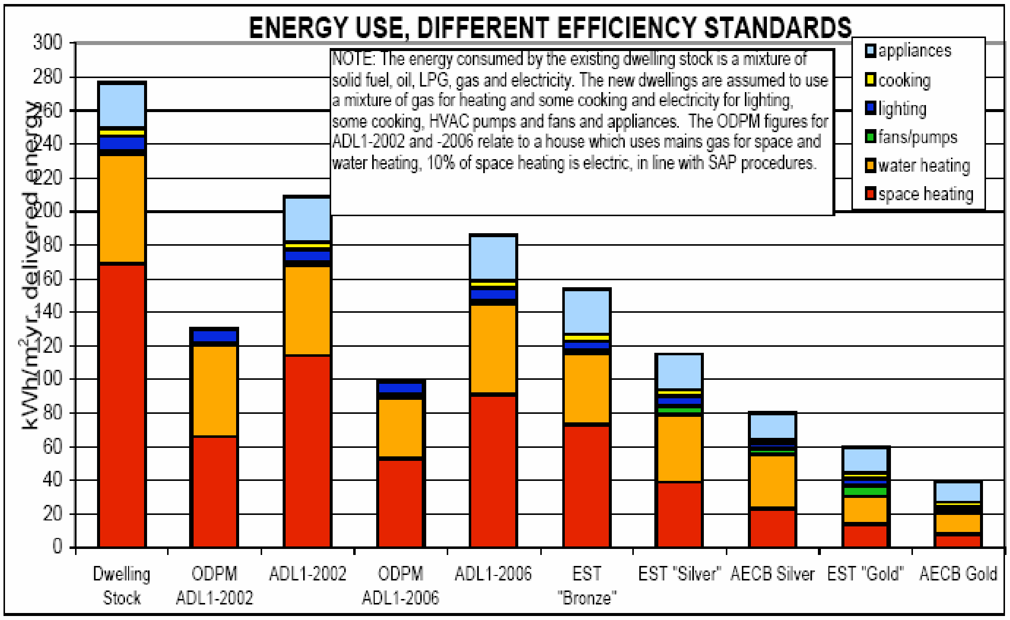
The AECB is currently focusing on trying to help reduce carbon emissions related to domestic buildings in the UK. To promote low-carbon building, the Association has developed five energy performance standards where two are advanced housing energy standards. They are:

- 2006 Building Regulations (delivered)
- **Bronze**
- **Silver**
- **Gold**
- Platinum

The five standards represent a staircase of achievable steps leading from the current building regulations ADL1-2006 to zero carbon homes (Simmonds, 2007).

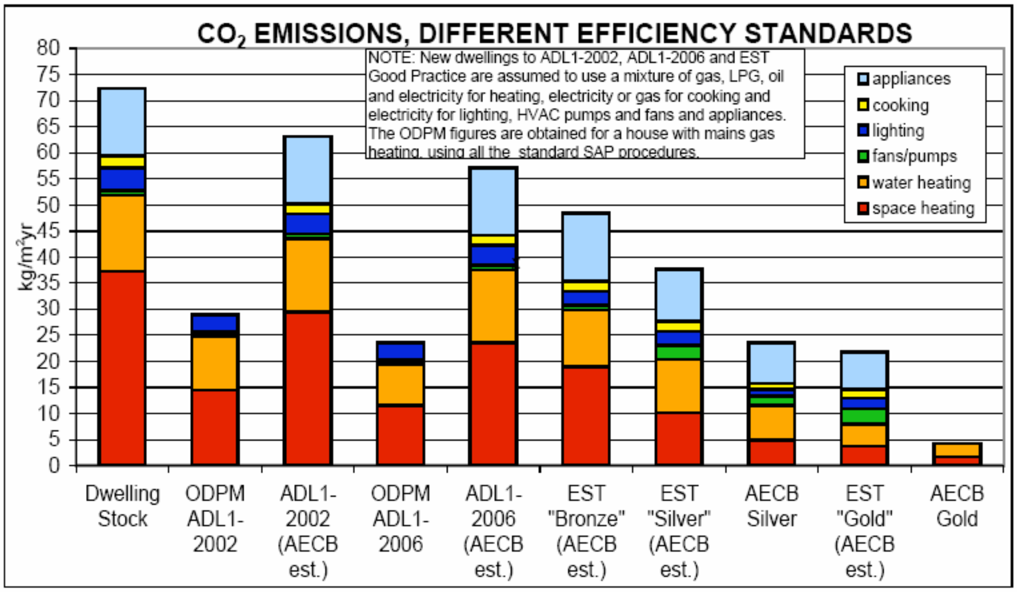
Houses constructed to the AECB silver energy standard emit around 75% less carbon dioxide than required by current Building Regulations. The standard is close to the Canadian R-2000, the German Low Energy House and the Swiss Minergie standard (AECB Standards, 2005). The AECB gold energy standard is based on the German Passivhaus standard, but requires a greater use of renewable energy sources to balance the use of electricity for lighting, appliances and ventilation in order to become close to zero energy buildings.

The gold standard corresponds to best international practice in design of building envelopes and their services and equipment. According the AECB, all the technology is in use in Europe or North America in the more leading-edge buildings. The present leader is the region comprising Germany, Austria, and part of Switzerland where 4,000 buildings met the Passiv Haus standard by spring 2004 (AECB Standards, 2005).



NOTE: The energy consumed by the existing dwelling stock is a mixture of solid fuel, oil, LPG, gas and electricity. The new dwellings are assumed to use a mixture of gas for heating and some cooking and electricity for lighting, some cooking, HVAC pumps and fans and appliances. The ODPM figures for ADL1-2002 and -2006 relate to a house which uses mains gas for space and water heating, 10% of space heating is electric, in line with SAP procedures.

**Figure 2.4.1 Comparative Energy Use, Different Energy Efficiency Standards (AECB, 2007)**



NOTE: New dwellings to ADL1-2002, ADL1-2006 and EST Good Practice are assumed to use a mixture of gas, LPG, oil and electricity for heating, electricity or gas for cooking and electricity for lighting, HVAC pumps and fans and appliances. The ODPM figures are obtained for a house with mains gas heating, using all the standard SAP procedures.

**Figure 2.4.2 Comparative CO$_2$ Use, Different Energy Efficiency Standards (AECB, 2007)**

Another important tool for sustainable housing is ‘Sustainability Works’. It is an online application developed by the Housing Corporation in co-operation with BRE, NHF (National Housing Federation), WWF (World Wildlife Federation and housing associations. It aims to bring sustainable development into the mainstream of social housing, whilst it embodies Ecohomes and incorporates the CSH.

Sustainability Works covers the full breadth of issues essential to a sustainable approach to housing by bringing together current research and best practice. Unlike the code and checklist, it does not just set overarching targets for $CO_2$ emissions for example; it provides the background information and recommendations for achieving those targets (Sustainability Works, 2006).

### 2.5 International Assessment: Haute Qualite Environmentale (HQE)

This association was founded in 1996 in Paris and works on the content of this method and the classification of the HQE principles since 1997. High Environmental Quality is a global approach designed to improve the environmental quality of buildings, in other words to control their impact on the outdoors environment and create a healthy and comfortable indoors environment. More specifically, it concerns two big units: the control of negative influences of a building on the exterior environment and the creation of a respectively satisfactory internal environment.

HQE's object is to create such conditions in order for the building to protect the natural resources, to check its influence on the exterior environment and to respond to the requirements for comfort, quality of life and health. A building that follows the HQE method must satisfy the above criteria from the first moment it is used and throughout its lifetime.

The HQE association defined 14 targets specifying the particular environmental requirements that a building whether new or rehabilitated, must satisfy. The first seven principles concern the control of the effect of a building and its management on the environment. The next seven principles concern the comfort and health of the users. The method is applicable in all phases of design and the 14 targets include:

Eco-construction

1. Relation of building with environment
2. Integrated choice of products and systems
3. Green construction site

Eco-management

4. Energy management
5. Water management
6. Activities waste
7. Maintenance

Comfort (of users)

8. Hydrothermal comfort
9. Acoustic comfort
10. Visual comfort
11. Olfactory comfort

Health

- Health conservation of building
- Air quality
- Cleanliness of indoor environment

HQE includes many parameters and is a method which has the potential to be enriched and modified in order to incorporate contemporary requirements at various scales (national, regional and local). For example, in order to attempt the development of a tool including as many parameters as possible, you could enrich the HQE method with transport, social and economic factors, as well as services, design and functionality issues.

### 2.6 Consultation, the need for a new approach?

So why is a new code needed, when there are several assessments contributing to sustainable housing already active? In the short term the only difference will be that higher levels of CSH will apply to homes developed with direct funding support from any of the DCLG's growth areas. The significance lies in the aim of seeing the voluntary application of the Code changed to a mandatory application for all new housing. The expectation is for local government to provide encouragement in this area.

In order that house builders can meet the code at minimum cost, level 1 of the code has been introduced to represent minimum standards. These minimum standards are relatively modest producing and implementing a site waste management plan to record which materials are used in the construction and to reduce water consumption by an average of 18%. However the other 3 of the 6 minimum standards are already controlled by the building regulations and the code does not raise standards in any real way above that of minimum compliance with current standards of energy efficiency, surface water disposal or household waste management.

Introducing new areas of standards, even if on a purely voluntary basis, has the effect of broadening the house building industry's awareness of environmental issues and there is an expectation that in time they will opt to implement measures to improve performance in these areas. The CSH relies on the market and developers to push for sustainable homes but there are limitations to this approach (Broome, 2006). Firstly, the housing market is controlled far more by supply, rather than demand and the suppliers, the house builders, are also notoriously resistant to change. Secondly, whilst there may be interest in solar power and other applications, it is not clear that there is substantial demand for truly sustainable building which is a complex subject involving the detailed appreciation of waste and water and the environmental impacts of materials and so on.

Introducing new standards at a relatively low level has proved successful in raising standards in the medium term. It has been used to increase the standards of energy efficiency demanded by the building regulations part L as mentioned in Section **2.1**, and by the Housing Corporation to increase standards of sustainability to Ecohomes ‘Very Good’.

The CSH has developed two main advances over its predecessor Ecohomes. The first is the number of elements that are essential for compliance whereas it is possible to obtain an Ecohomes assessment without addressing the fundamental issues of energy or water efficiency for example. The second advance of the CSH is that it is assessed after completion, unlike Ecohomes which only includes an option for a post completion assessment and which is generally awarded on a design which may or may not be amended during development and construction.

The following chapter concentrates on these minimum standards of the CSH and explains the method of scoring such standards.

# Chapter 3 – Current Standards of the Code

In this chapter, a detailed account of the current standards for the Code of Sustainable Homes will be identified. In addition, the method for scoring the current standards will be discussed.

### 3.1 Minimum Standards

The minimum standards for compliance with the Code for Sustainable Homes have been set above the current requirements in the building regulations covering the use of energy in the home and strategies to reduce carbon dioxide emissions.

The Code sets out environmental design standards that can be achieved in nine areas (as opposed to Ecohomes ratings in seven areas); energy, water, use of materials, surface water run off, waste, pollution, health and well being, management and ecology. There are minimum standards at each level of the code for the two main areas; energy and water. The energy and water elements will not be tradable, i.e. a certain score will need to be achieved in each of these areas and the total score cannot be improved by scoring higher in other areas such as ecology or health and well being. Six optional elements are also included; lifetime/adaptable homes, sound insulation, private external space, higher daylighting standards, improved security and a home user guide/log book.

For the categories of materials, surface water run off and waste, there are minimum standards at entry level (one star). For the remaining four; pollution, health and well being, management and ecology there are no minimum standards. The intention is that this offers some flexibility in achieving improvements in sustainability ratings by increasing point scores in these individual areas that improve the overall rating, while setting rigorous parameters in the two key standards, energy and water.

A key change from Ecohomes assessment is that there is no transport or location category, which posed problems for some schemes, particularly in rural areas. This chapter looks at each element of the code in detail to understand fully how the code operates.

The number of minimum points required for the non tradable elements, energy and water, at each level of the code are as follows:

| | Energy | Water | Other Points required |
|---|---|---|---|
| Code Level | No. of Points | | |
| **1**$^{*}$ | 1.2 | 1.5 | 33.3 |
| **2**$^{**}$ | 3.5 | 1.5 | 43.0 |
| **3**$^{***}$ | 5.8 | 4.5 | 46.7 |
| **4**$^{****}$ | 9.4 | 4.5 | 54.1 |
| **5**$^{*****}$ | 16.4 | 7.5 | 60.1 |
| **6**$^{******}$ | 17.6 | 7.5 | 64.9 |

**Table 3.1: The required points for each of the six star ratings (TRADA Construction Briefings, 2007).**

### 3.2 Energy / $CO_2$

Energy and $CO_2$ are based on the Target Emission Rate (TER) as used in Part L of the 2006 Building Regulations. The key measurement is the percentage improvement over the 2006 requirements. This ranges from a 10% improvement for a 1 star rating, up to the impressive zero-carbon home for a six-star rating. The table below shows the credits awarded in accordance with the criteria.

| Criteria | | |
|---|---|---|
| % improvement of DER over TER | Credits | Mandatory Levels |
| ≥ 10% | 1 | Level 1 |
| ≥ 14% | 2 | |
| ≥ 18% | 3 | Level 2 |
| ≥ 22% | 4 | |
| ≥ 25% | 5 | Level 3 |
| ≥ 31% | 6 | |
| ≥ 37% | 7 | |
| ≥ 44% | 8 | Level 4 |
| ≥ 52% | 9 | |
| ≥ 60% | 10 | |
| ≥ 69% | 11 | |
| ≥ 79% | 12 | |
| ≥ 89% | 13 | |
| ≥ 100% | 14 | Level 5 |
| 'True Zero Carbon' | 15 | Level 6 |
| | | |

**Table 3.2.1: Credits awarded in accordance with criteria (CSH, 2007, p.26)**

As well as the minimum standards, points are awarded for the level of improvement of overall energy use. This is broken down into smaller increments (15 levels).

Other points in this category are awarded for various factors, for which there are no minimum standards. The building fabric is assessed based on the heat loss parameter – a measure of how much heat is lost through walls. Points are available for heat loss values less that 1.3 W/m$^2$K and more for heat loss values less than 1.1 W/m$^2$K.

Points for dedicated energy-efficient fittings for internal lighting are awarded where the percentage of fixed fittings are greater than 40%, with extra points for more than 75%.

External lighting is covered with points for energy efficient fittings, as is security lighting of 150W of less, along with movement or daylight sensors. Points are awarded when at least 10% of the energy demand is supplied from local renewable or low carbon sources. Credits awarded for low energy technologies in dwellings are described below;

| **Criteria** | |
|---|---|
| | Credits |
| Local renewable or low carbon sources supply the energy and is funded by the Low Carbon Building Programme<br>AND<br>There is a 10% reduction in carbon emissions as a result of this supply method | 1 |
| OR | |
| There is a 15% reduction in carbon emissions as a result of this supply method. | 2 |

**Table 3.2.2: ZLC criteria and awarded credits (CSH, 2007, p.55)**

In addition, points are also awarded for drying space, energy labelled white goods, cycle storage and home office. The criteria for drying space includes secure space with posts and footings or fixings capable of holding 4m+ of drying line for 1-2 bed dwellings, and 6m+ of drying line for 3+ bed dwellings, is provided for drying clothes. Credits are also awarded for appliances which have an A+ or A rating under the EU energy efficiency labelling scheme.

Cycle Storage credits are awarded where either individual or communal cycle storage is provided that is adequate, safe, secure and weather-proof for the following number of cycles:
1 Credit awarded,

- Studio or 1 bedroom dwelling – 1 cycle for every two dwellings (only applicable to communal storage)
- 2 and 3 bedroom dwellings – storage for 1 cycle
- 4 bedrooms or more – storage for 2 cycles

Or

2 Credits awarded,

- Studio or 1 bedroom dwelling – 1 cycle storage
- 2 and 3 bedroom dwellings – storage for 2 cycle
- 4 bedrooms or more – storage for 4 cycles.

A category for home office has been included to reduce the need to commute to work by providing residents with the necessary space and services to work from home. Where sufficient space and services have been provided which allows the occupants to set up a home office in a suitable room (other than the kitchen, living room, master bedroom or bathroom), one credit is awarded.

The table below shows the levels of improved energy/carbon performance that the government are proposing over time. By working closely with the house building industry, local government and other stakeholders this is a realistic target to implement.

| Date | 2010 | 2013 | 2016 |
|---|---|---|---|
| Energy/carbon improvement compared to Part L (Building Regulations 2006) | 25% | 44% | Zero carbon |
| Equivalent energy/carbon standard in the Code | **Code Level 3** | **Code Level 4** | **Code Level 6** |

**Table 3.2.3: Proposed energy/carbon dioxide levels over time.**

### 3.3 Water

Water is the only other category with minimum standards applied to multiple star ratings. The minimum standards are based on the internal potable water consumption in litres per head per day. Potable water is assessed on an individual dwelling basis; however surface water runoff can be assessed either at the dwelling or site.

However there are minimum requirement which must be achieved in order to get 1 star and above. In regards to water management this is water use within the home and surface water run-off. So even if the development has obtained a maximum number of points in all areas apart from potable water within the house, it is impossible to get 6 stars. Only when the mandatory elements have also been achieved can the highest ratings be achieved.

| Water Consumption (L/person/day) | Credits | Mandatory Levels |
|---|---|---|
| | | |
| ≤ 120 l/p/d | 1 | Levels 1 & 2 |
| ≤ 110 l/p/d | 2 | |
| ≤ 105 l/p/d | 3 | Levels 3 & 4 |
| ≤ 90 l/p/d | 4 | |
| ≤ 85 l/p/d | 5 | Levels 5 & 6 |
| | | |

**Table 3.3.1: Internal Potable Water Consumption (CSH, 2007, p.69)**

Two areas are looked at when assessing the building:

- Location, details and type of appliances/fittings that use water in the dwelling including any specific water reduction equipment

- Location and details of any rainwater and greywater collection systems in the dwelling

In addition to the internal use, extra points are awarded for the recovery and storage of rainwater for external use.

External potable water consumption provides 1 credit, and is not a mandatory element of the code. The criteria includes the case where a correctly specified system to collect rainwater for external/internal irrigation use has been provided to a dwelling with a garden, patio, or communal space. If no individual or communal garden spaces are specified or if only balconies are provided, the credit can be awarded by default (Polypipe, 2007).

| Property Type | Litres Stored |
|---|---|
| | |
| Terrace & Patios | 100 litres min |
| 1-2 bed House with private garden | 150 litres min |
| 3+ bed house private garden | 200 litres min |

**Table 3.3.2: Size requirements of external potable water consumption**

### 3.4 Materials

The sustainability of construction materials is measured using the BRE's Green Guide, which ranks the environmental impact of materials using a life-cycle assessment method (BSRIA, 2007). To attain the minimum standard, at least three of the five key construction elements (roof, external walls, upper floor, internal walls and windows and doors) must meet the Green Guide rating of D or better.

Points are awarded based on responsible sourcing of materials as well as the environmental effects. To comply with the assessment methodology, the number of credits per code dwelling type is calculated using the calculation procedure. The calculation procedure at the design stage allows credits to be awarded based on the rating given in the 2007 version of the Green Guide as follows:

| Green Guide Rating | Credits |
|---|---|
| A+ | 3 |
| A | 2 |
| B | 1 |
| C | 0.5 |
| D | 0.25 |

**Table 3.4.1: Credits based on the Green guide for Materials (CSH, 2007, p.84)**

When there is more than one specification for an element (e.g. more than one type of external wall), the number of credits for that element are area weighted according to the rating of each specification. For the purpose of this credit, any doors with a large expanse of glazing, such as patio doors, should be assessed as windows. Similarly glazed areas of conservatories and rooflights should be assessed as windows. Partitions and internal walls should be assessed using the relevant ratings for each element, and credits awarded on the basis of the relative areas of each. The same process goes for ground floors and upper floors. The building elements include; frame, ground floor, upper floor, roof, external walls, internal walls, staircase and foundation. The following materials are assessed in the calculation of points; brick, composites, concrete, glass, plastics, metals, stone, timber and plasterboard. It should be noted that insulation materials, fixings, adhesives and other materials are excluded from the assessment.

### 3.5 Surface water run-off

Surface water run-off aims to reduce and delay the run-off from the hard surfaces of a housing development to public sewers and is a mandatory element carrying 2 credits. It ensures that peak run-off rates and annual volumes of run-off post development will be no greater than the previous conditions for the site. The attenuation of water run-off to either natural watercourses or surface water drainage systems provide percentage peaks as follows

- 50% in low flooding risk areas
- 75% in medium flooding risk areas
- 100% in high flooding risk areas

To meet the minimum standards for surface water run-off housing developments must not have any detrimental effect on the site run-off compared to previous conditions. This includes both the peak rates and annual volumes of run-off.

Other points are awarded for sustainable urban drainage systems, including peak time attenuation and the placing of houses in an area of low flood risk. The table below summarises the assessment for surface water run-off and how points are obtained.

| Issue | How points are collected | Max points avail. |
|---|---|---|
| Reduction in surface water run-off | By achieving stated performance levels | 1.0 |
| Flood Risk | By addressing the risks | 1.0 |
| Sub-total | | 2.0 |

**Table 3.5.1: Summary of surface water run-off assessment (TRADA, 2007).**

### 3.6 Waste

The minimum standard for waste looks at both site waste management and household waste storage. The Code requires a waste management plan on the site, the monitoring of waste and the setting of targets. Points are awarded for recycling and composting facilities. A management plan for the construction waste also gains points.

In terms of household waste storage, the space allowed for waste storage should be sized to hold the larger of two of the following:

Either

1. All external containers provided under the relevant Local Authority refuse/recycling schemes.

Or

2. The minimum capacity of waste storage as calculated from BS 5906 (Code of practice for storage and on-site treatment of solid waste from buildings (2005)).

| Issue | How points are allocated | Max Points Avail. |
|---|---|---|
| Household Recycling | Provision of good facilities | 3.6 |
| Construction Waste | Good site waste management | 1.8 |
| Composting Facilities | Provision of good facilities | 0.9 |
| Sub-total | | 6.3 |

### 3.7 Pollution

There are no minimum standards for the pollution effects of sustainable homes house, only point-scoring features. Points are gained for the use of insulating material that avoid substances that have a global warming potential (gwp) of 5 or more (referenced to $CO_2$ which has a gwp of 1). Points are also awarded for low emissions of nitrous oxide from space heating and hot water systems.

### 3.8 Health and Wellbeing

Health and wellbeing effectively means the comfort and live-ability of a new house. Factors assessed are daylight, sound insulation, private space and homes suitable for different stages of life. With daylighting, points are awarded where minimum average daylight factors are reached for specific rooms. There are at least 2 % for kitchens and at least 1.5% for living rooms, dining rooms and studies. Also, they should be designed to have a view of the sky.

To gain points for sound insulation, it must be proved that the standard of sound insulation is higher than that prescribed in part E of the Building Regulations. Points are also awarded for complying with the standards of the lifetime homes scheme, which looks at the potential of homes to cope with the lifetime requirements of the occupant, such as adaptability for increasing levels of disability.

### 3.9 Management

Management covers both construction and post construction management. On the construction side, points are awarded for membership of the Considerate Constructors Scheme and on a commitment and strategy to reduce the harmful effects of construction on the site environment. Points are gained for the provision of Home User Guides, which are relevant to the operation, and environmental performance of the home.

### 3.10 Ecology

The ecology category covers the ecological value of the site, ecological enhancement, protection of ecological features and the total building footprint. Designers and builders can win points by adopting the requirements in the BRE Ecological Value Checklist.

Points can be won by limiting the effects of house construction on the local flora and fauna, and where the designers and builders can demonstrate that anything of ecological value is protected during construction works and able to thrive after completion. Extra points can be awarded if the architect has commissioned a report from a qualified ecologist (although the Code is not explicit that the designer must act on its findings).

The ecology category uses the BRE Ecological Value Checklist, while the waste measurements criteria are based on WRAP/Envirowise guidance (BRE, 2006). Water use and sourcing of materials are covered by bespoke CSH calculator tools. Impact to the environment will be measured using a life-cycle assessment method, with the impact graded A+ to G-.

### 3.11 CSH Scoring Method

For the water and energy categories, the points scoring system is based on the Standard Assessment Procedure (SAP, 2005). The points are calibrated against percentage improvements over the 2006 Building Regulations, with a 10% improvement resulting in 1.2 points, and 100% resulting in 16.4 points. In order that zero carbon is achieved 17.6 points is required. A summary of the points available in each category are shown in table 3.11.1.

| Category | Number of Points |
|---|---|
| Energy | 35.6 |
| Water | 9 |
| Materials | 7.2 |
| Surface Water Runoff | 2 |
| Waste | 6.3 |
| Pollution | 2.5 |
| Health and Wellbeing | 13 |
| Management | 9.9 |
| Ecology | 10.8 |
| Total | 96.3 |

**Table 3.11.1: Points available in different categories**

The points scoring system differs each time for the other seven categories. This is because each category refers to existing best practice guidance. Architects will be familiar with the guidance used to score some categories, such as the Target Emission Rate of the Building Regulations used to score the energy items, and home security guidance provided by the Association of Chief Police Officers: Secured by Design - New Homes (BDOnline, 2007).

Complications with the scoring remain as some of the guidance is not yet available. For example, the use of materials will be measured using the BRE’s New Green Guide, which has not yet been published.

# Chapter 4: Practical examples and cost analysis for meeting the code

Practical examples of home design to meet code levels 1, 3 and 6 are illustrated in the published Code. The code level may be achieved through a variety of different combinations. In this chapter code levels 1, 3 and 6 are reproduced as an example rather than a definitive guide.

## 4.1 Level 1 (*)

A home meeting any level of the Code will have to meet certain minimum standards. This has been set so that house builders can meet the Code at minimum cost. This means for level 1 the home will have to be 10% more energy efficient than one built to the 2006 Building Regulations standards (CSH, 2006).

The minimum requirement at Code Level 1 is for at least three of the key elements (walls, floors etc.) to achieve a rating of at least D in accordance with the 2007 Green Guide to Housing. Beyond this points can be gained for constructions with a B rating and above.

The cost of achieving Code level 1 is relatively low and involves only enhanced controls to heating and hot water systems. Relatively little additional cost is incurred as this level of performance improvement can be achieved through simple measures such as enhanced building controls. The only exception is for the high rise apartment where a cost of around £2,800 per dwelling is incurred to install a communal heating system.

Example of meeting level 1:
Energy/$CO_2$ – in order to meet an improved energy efficiency of 10%, a high efficiency condensing boiler could be installed.
Water – to meet the designated allocation of no more than 12 litres of water per person per day the installation of a 6/4 dual flush WC toilet would suffice.
Surface water management – the provision of areas with porous paving would meet the minimum standard set (CSH, 2006).
Materials – according the CSH, a minimum number of materials at a ‘D’ grade in the Building Research Establishment’s Green Guide are required.
Waste Management – a site waste management plan need to be in place during the homes construction.
As well as the above recommendations in order to obtain level 1, other points must be considered such as; accessible drying space, energy efficient lights, cycle storage and the use of environmentally friendly materials.

### 4.2 Level 3 (***)

The home in question will have to be 25% more energy efficient than one built to the 2006 Building Regulations. It will also have to be designed to use no more than approximately 105 litres of water per person per day. Other minimum requirements are required for surface water management, materials and waste management and to reach level 3 an additional 46.7 points are needed (H+H Celcon, 2007).

This can be achieved by the developer by, for instance, providing drying space (so that tumble dryers need not be used), more energy efficient lighting (both internally and externally) and cycle storage. An example of achieving Code level 3 has to allow for some assumptions. Assuming a 3 bedroom, 2-storey semi-detached house with integral garage where for arguments sake the ground floor has an area of $50m^2$ and first floor is $55m^2$. In addition, an assumption on the SAP calculation has Target Emissions Rate of 25.0 $kgCO_2/ m^2$.

To achieve a code level 3 a 25% improvement is required giving a revised TER of 18.75 $kgCO_2/ m^2$. In this example the effective air change rate is 0.566 (based on 4 x fans and airtightness of $5m^3/h/m^2$). This airtightness value is achievable using Celcon Aircrete blockwork, provided that care is taken to seal around service penetrations etc.

The building fabric is made up as follows:

1. Ground floor = U-Value 0.15 $W/m^2K$
2. Walls = U-Value 0.25 $W/m^2K$ (achievable with Celcon inner skins and a cavity of 100mm or less).
3. Roof = U-Value 0.13 $W/m^2K$
4. Floor over garage = U-Value 0.15 $W/m^2K$
5. Glazing = U-Value 1.3 $W/m^2K$
6. Door = U-Value 1.3 $W/m^2K$

It is assumed that improved linear bridging details have been used, which are under development. The calculated Heat Loss Parameter is 1.3 $W/m^2K$. Additional factors include Zoned Heating Control, Combi gas boiler (SEDBUK = 90.2%), gas secondary heating and 1.5 $m^2$ solar panel. Total number of points required is 57 (H+H Celcon, 2007).

### 4.3 Level 6 (Zero Carbon Home)

The CSH states that in order to obtain a level 6 rating the home in question will have to be completely zero carbon (i.e. zero net emissions of $CO_2$ from all energy use in the home)(CSH, 2007). Steps to achieve this rating include improving the thermal efficiency of the walls, windows, and roof as far as is practically possible (by using more insulation or improved glass for example).

In addition, to achieve the maximum of 80 litres of water per person per day would mean that about 30% of the water requirement of the home would be provided from non-potable sources such as rainwater harvesting systems or grey water recycling systems. According to the CSH, to reach level 6 the builder/developer will need to complete 90% of everything in the Code including; energy efficient appliances (all A graded), use of highly environmentally friendly materials, minimising construction waste and building the home to the Lifetime Homes Standard amongst others (CSH, 2006).

The Kingspan Off-Site's Lighthouse design is the first to achieve level six of the Code for Sustainable Homes - which means the house is carbon neutral. The Lighthouse is a two-bedroom, two and a half storey house, with a floor area of about 100m$^2$. The curved roof sweeps down providing the living areas with a double height ceiling, making the occupant feel as though they are in a generous open-plan house, and concealing the rather tight and compact geometry of the house (Hamand, 2007).

In addition to achieving Code Level 6, Lighthouse is future-proofed to address predicted increase in temperature due to climate change. This is achieved through the incorporation of a wind catcher/light funnel providing passive cooling and ventilation and bringing daylight and reflected sunlight into the heart of the home and supported by window openings on the east and west elevations, shaded by balconies and shutters to restrict direct sunlight and heat gain. It should be noted that the building costs of the lighthouse design is 40% more than a standard house (Hamand, 2007).

**Fig 4.3 The Lighthouse Ecohouse (Hamand, 2007)**

### 4.4 Cost of meeting different code levels

A cost analysis of the CSH was undertaken by Cyril Sweett for English Partnerships and the Housing Corporation in June 2007. The aim of the report was to provide analysis of the cost implication of achieving code levels 1 to 6. The assessment of the potential reduction in the cost of meeting different Code levels arising from increased uptake of the key technologies was also conducted.

It is important to note that different house types will result in different costs. A traditionally built detached house will generally follow a different type of assessment to a concrete framed high rise apartment. For the purpose of this thesis a traditionally built detached house is considered.

The results from the analysis indicated that the cost of achieving Code level 1 is relatively low and involves only enhanced controls to heating and hot water systems. For Code level 2, the building U-values for external walls and windows are required to be reduced to 0.25 and 1.5 W/m$^2$K respectively along with an efficient heating system. The additional costs are approximately £1,650 (Mactavish, 2007).

According to Cyril Sweett, the most cost effective approach for code level 3 is to consider the carbon savings associated with microgeneration wind turbines. The additional cost of this is £1,700 per home (Mactavish, 2007). However, this approach may not be ideal for all locations, in which case a solar hot water system should be implemented as well. In this case the total additional costs are approximately £3,900 per home. If mechanical ventilation is used rather than a renewable option the cost of achieving level 3 is £4,500.

For Code level 4, a site wide CHP system is required to be the most cost effective means of obtaining the energy target. And for code level 5/6, it has been suggested that a biomass boiler system is necessary because they enable substantial reductions in $CO_2$ emissions as heating and hot water demand can be met as a virtually carbon neutral source (Mactavish, 2007). However this does result in significant additional cost and requires home to have sufficient fuel storage facilities.

| Level | Energy | Water |
|---|---|---|
| 1 | Negligible | Negligible |
| 2 | £1,000 – £2,000 | Negligible |
| 3 | £1,500 - £6,000 | Negligible |
| 4 | £5,000 - £16,000 | Negligible |
| 5 | £14,000 - £30,000 | £650 - £2,500 |
| 6 | Achieved through level 5 | £650 - £2,500 |

**Table 4.4.1 Costs of Energy and Water at different levels (Drivers Jonas, 2007)**

# Chapter 5: Carbon Footprint Analysis

This chapter details a full scope study into carbon emission reduction for Muir constructions Jura and Harris housing as planned for the Anstruther project. These two aforementioned house types have been modelled computationally using Integrated Engineering Software (IES), in order to determine energy loads and methods of reduction.

## 5.1 Anstruther Dwellings

Three main steps have been used to determine and reduce the carbon emissions of the dwellings. These are as follows:

1. Determine base electrical and thermal loads for both buildings
2. Reduce energy loads by analysing when and where energy is used.
3. Employ Low and Zero Carbon (LZC) heating and power equipment for the development.

Within these steps there are various smaller steps which have been encountered and tackled; this chain-linked approach has enabled the methodical appraisal of all low energy techniques whilst also allowing for valued and in depth judgement of energy efficiency and LZC technologies.

The first section looks at the existing energy loads of both the Harris and Jura dwellings. The loads have been determined from the detailed drawings and specification of equipment by Muir construction. The importance of the loads provides the focal point for the subsequent recommendations and decisions.

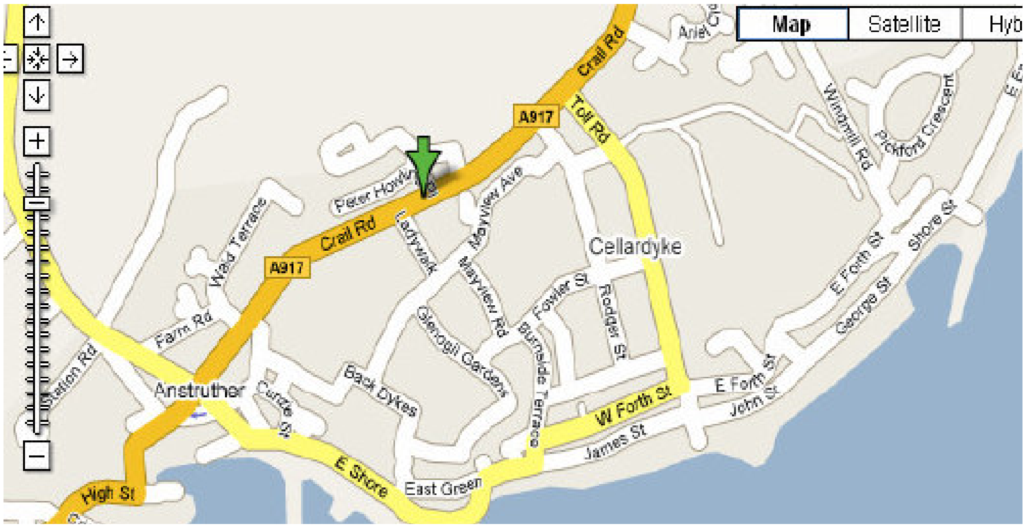


**Figure 5.1.1 – Anstruther Site Image (Google Map, 2007)**

Figure 5.1.1 illustrates the area within which the development shall take place with the arrow indicating Crail Road, one of the main roads which pass the site.

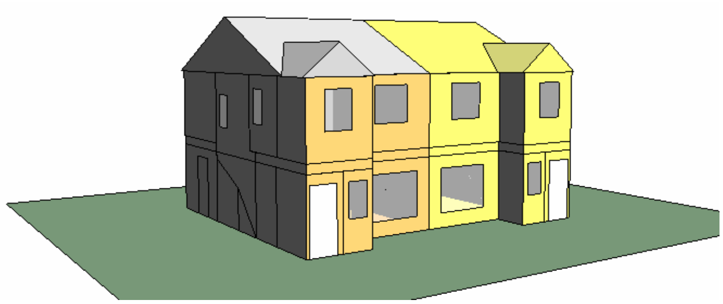


**Figure 5.1.2 Model of Harris Dwelling**

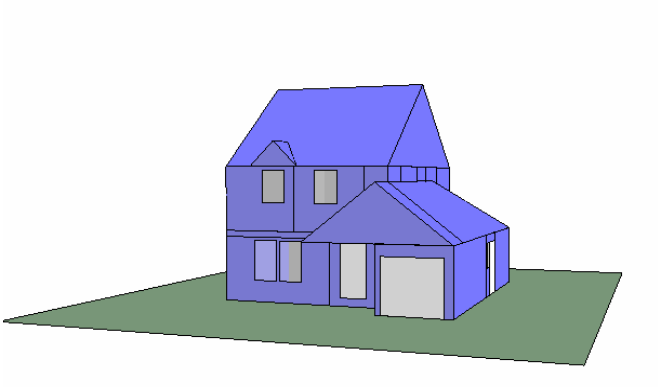


**Figure 5.1.3 Model of Jura dwelling**

Anstruther is a sea-side town located in Fife on the east of Scotland. As can be seen in 5.1.1 the town is a rather open site in terms of exposure with the North Sea adjacent. Muir construction plan to build 337 houses on the site; many of the dwellings are located in various orientations.

### 5.2 Load Profiles

In order to identify how energy is used some assumptions require to be made. Several Studies have been carried out by various researches attempting to study domestic energy consumption; these studies have indicated that the most typical load profile in the UK for weekdays is as shown in Figure 5.2.1.

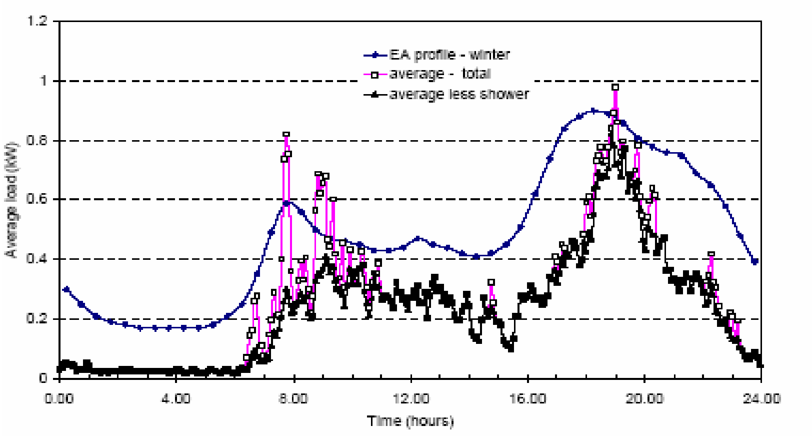


**Figure 5.2.1 – Typical Electrical Load Profile of a Dwelling Averaged over 100 Winter Days: (Abu-Sharkh et al, 2004).**

From this profile it can be seen that there are two main peaks, these being in the approximate band of *7am – 9am & 5pm – 12am* with the latter much more extreme. These two peaks would indicate a typical working day; researchers Cockcroft & Kelly (2005) generate a similar load profile (Fig 5.2.2).

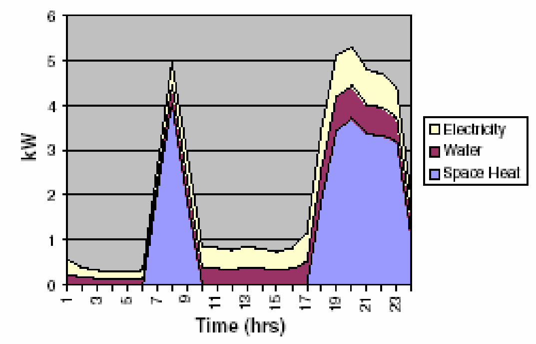


**Figure 5.2.2 – Total Demand Typical January Day for 68m² Dwelling (Cockcroft & Kelly, 2005).**

From the research carried out on load profiles it has been determined that a working week will take into account the dwellings being empty between the hours of 8am – 5pm while at the weekend the occupants, potentially, could be in at anytime of the day. Therefore it has been assumed that the dwellings will be occupied all day on Saturdays and Sundays.

### 5.3 Heating Load

The heating load has been calculated via the specified U-Values and information on the Muir construction drawings. The U-Values are shown in the table below:

| Element | U-Value (W/m$^2$K) |
|---|---|
| Wall | 0.3 |
| Roof | 0.16 |
| Floor | 0.25 |
| Window | 1.9 |

**Table 5.3.1 – Current U-Values (CIBSE, 2006)**

Heat is lost from the dwellings via two paths:

• By conduction through the building fabric (walls, floors, windows, roofs etc) i.e. flowing from the warm interior to the cold external surface, as indicated in Figure 5.3.1.

• By infiltration - cool air enters the building through cracks and gaps this air exchange is largely unwanted and unintentional.

The magnitude of conduction loss is dependent upon the thermal transmittance value, also known as the U-Value, this determines the amount of thermal energy transmitted through a particular element and is measured in W/m$^2$K; a high U-Value allows a greater amount of heat loss per unit area per unit of temperature difference between inside and outside environments. The infiltration rate used within the heat loss calculation has been determined via the SAP calculation.

The total heat loss calculated is shown in Tables 5.3.2 & 5.3.3 (please see assumptions A1 & A2):

**Harris Heat Loss**

| Room | Infiltration (m$^3$/h.m$^2$) | Ti (°C) | To (°C) | Q Floor (W) | Q Roof (W) | Q Wall (W) | Q Glazing (W) | Q Infiltration (W) | Q total (W) |
|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | | | |
| | | | | | | | | | |
| **Lounge** | 0.81 | 20.0 | -5.0 | 121 | 0 | 67 | 181 | 316 | 787 |
| **Cloakroom** | 0.81 | 18.0 | -5.0 | 12 | 0 | 7 | 28 | 32 | 91 |
| **Vestibule** | 0.81 | 18.0 | -5.0 | 12 | 0 | 26 | 92 | 31 | 185 |
| **Hall** | 0.81 | 18.0 | -5.0 | 10 | 0 | 14 | 0 | 25 | 56 |
| **Kitchen** | 0.81 | 20.0 | -5.0 | 45 | 0 | 57 | 45 | 119 | 306 |
| **Dining** | 0.81 | 20.0 | -5.0 | 47 | 0 | 22 | 361 | 123 | 635 |
| **Store** | 0.81 | 18.0 | -5.0 | 9 | 0 | 11 | 0 | 15 | 41 |
| **Upstairs Bathroom** | 0.81 | 20.0 | -5.0 | 0 | 14 | 19 | 30 | 60 | 143 |
| **En Suite** | 0.81 | 20.0 | -5.0 | 0 | 17 | 44 | 51 | 69 | 208 |
| **Bedroom 1** | 0.81 | 20.0 | -5.0 | 0 | 40 | 61 | 68 | 170 | 390 |
| **Bedroom 2** | 0.81 | 20.0 | -5.0 | 0 | 43 | 65 | 67 | 176 | 404 |
| **Bedroom 3** | 0.81 | 20.0 | -5.0 | 0 | 27 | 52 | 51 | 114 | 283 |
| **Hall Upstairs** | 0.81 | 20.0 | -5.0 | 0 | 12 | 0 | 0 | 163 | 201 |
| | | | | | | | | | |
| **Total** | | | | **256** | **153** | **446** | **973** | **1413** | **3730** |

**Table 5.3.2 – Harris Dwelling Heat Loss**

## Jura Heat Loss

| Room | Infiltration ($m^3/h.m^2$) | Ti (°C) | To (°C) | Q Floor (W) | Q Roof (W) | Q Wall (W) | Q Glazing (W) | Q Infiltration (W) | Q total (W) |
|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | | | |
| **Lounge** | 0.71 | 20.0 | -5.0 | 151 | 0 | 93 | 128 | 347 | 827 |
| **Hall** | 0.71 | 18.0 | -5.0 | 53 | 0 | 56 | 98 | 123 | 380 |
| **Toilet downstairs** | 0.71 | 18.0 | -5.0 | 9 | 0 | 5 | 0 | 20 | 39 |
| **Utility** | 0.71 | 20.0 | -5.0 | 28 | 0 | 6 | 105 | 63 | 231 |
| **Breakfast Area** | 0.71 | 20.0 | -5.0 | 50 | 0 | 62 | 51 | 115 | 320 |
| **Kitchen** | 0.71 | 20.0 | -5.0 | 61 | 0 | 28 | 45 | 140 | 316 |
| **Dining** | 0.71 | 20.0 | -5.0 | 70 | 0 | 55 | 190 | 160 | 545 |
| **Store** | 0.71 | 18.0 | -5.0 | 6 | 0 | 0 | 0 | 7 | 15 |
| **Bathroom** | 0.71 | 20.0 | -5.0 | 0 | 15 | 22 | 0 | 54 | 105 |
| **En-Suite** | 0.71 | 20.0 | -5.0 | 0 | 9 | 21 | 30 | 32 | 105 |
| **Bedroom 1** | 0.71 | 20.0 | -5.0 | 0 | 42 | 69 | 51 | 150 | 360 |
| **Bedroom 2** | 0.71 | 20.0 | -5.0 | 0 | 33 | 24 | 45 | 120 | 255 |
| **Bedroom 3** | 0.71 | 20.0 | -5.0 | 0 | 34 | 51 | 52 | 122 | 298 |
| **Bedroom 4** | 0.71 | 20.0 | -5.0 | 0 | 28 | 54 | 52 | 101 | 271 |
| **Upstairs Hall** | 0.71 | 18.0 | -5.0 | 0 | 15 | 20 | 0 | 56 | 105 |
| | | | | | | | | | |
| **Total** | | | | **428** | **177** | **565** | **848** | **1609** | **4171** |

**Table 5.3.3 – Jura Dwelling Heat Loss**

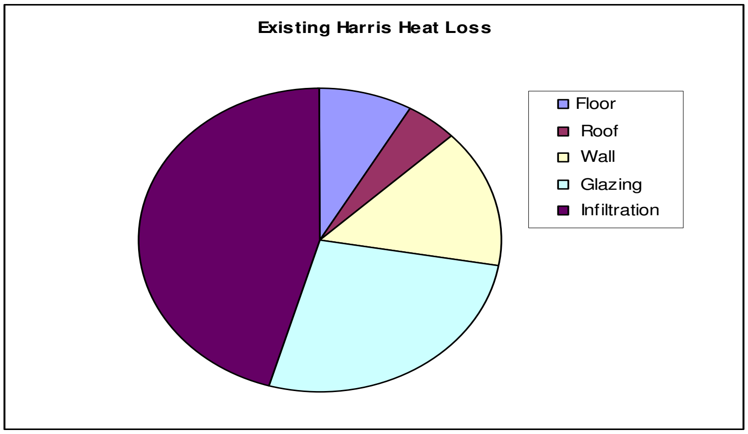


**Figure 5.3.2 – Harris Proportional Heat Loss**

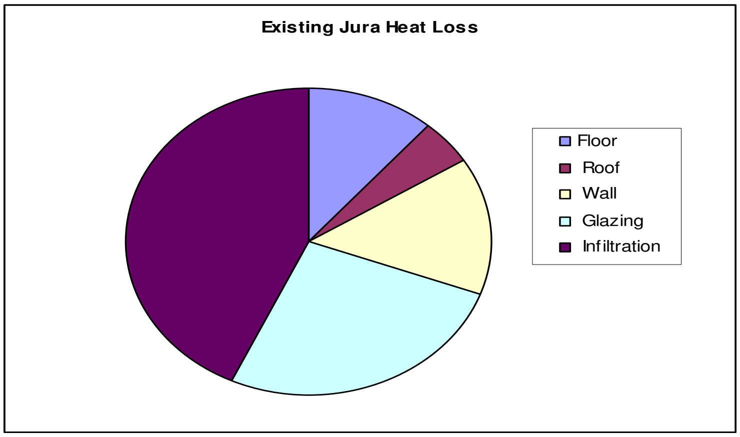


**Figure 5.3.3 – Jura Proportional Heat Loss**

### 5.4 Appliance Load

The appliances which shall be used within the dwellings have been specified by Muir construction; the table below details the manufacturer, model and annual energy consumption of each appliance:

| Appliance | Manufacturer | Model | Energy Consumption (kWh/year) | Gas Consumption | House Type | CO$_2$ Emissions (kgCO$_2$/year) |
|---|---|---|---|---|---|---|
| | | | | | | |
| Fridge-Freezer | Siemens | KI38VV00GB | 317 | N/A | Jura & Harris | 133.8 |
| Fan Oven | Siemens | HB131550B | 285 | N/A | Jura | 120.3 |
| Dishwasher | Siemens | SE65E330GB | 192 | N/A | Jura | 81.0 |
| Washer Dryer | Siemens | WDi1440GB | 850 | N/A | Jura & Harris | 358.7 |
| Hood | Siemens | LC45650GB | 33 | N/A | Jura | 13.9 |
| Hood | Siemens | LE62031GB | 24 | N/A | Harris | 10.1 |
| Fan Oven | Siemens | HB131250 | 365 | N/A | Harris | 154.0 |
| Gas Hob | Siemens | ER124123EU | 858 | 802m$^3$s-$^1$ | Jura | 162.2 |
| Gas Hob | Siemens | ER141123EU | 858 | 802m$^3$s-$^1$ | Harris | 162.2 |
| | | | | | | |

**Table 5.4.1 – Appliance Energy Use**

The above table quantifies the energy consumption due to the appliances; it should be noted that in order to get to these figures, assumptions have been made; these are detailed in the appendix under A3 – A8. Manufacturer's literature has been used in accordance with the Muir Construction specification.

All appliances which are specified by Muir Construction are A rated goods therefore further improvements on these goods is difficult; therefore, no attempt has been made to change appliances used; the energy consumption of these goods will be used when determining electrical loads for renewable energies.

### 5.5 Hot Water Load

The Harris dwelling is to be fitted out with a 9.5kW rated shower. Based on this and the assumptions outlined in A9, it has been determined that the energy consumption due to showering in the dwelling will be 874kWh/year giving an annual CO$_2$ emission of 369kgCO$_2$. It is important to note that the conversions for emissions are also shown in SAP. Bathing requirements have been determined in a similar fashion (please see assumption A10) with the energy consumption and annual CO$_2$ emissions being 707kWh/year and 137.2kgCO$_2$/year respectively. The energy consumptions and emissions due to hot water for washing dishes etc (please see assumption A11) are 106kWh/year and 21kgCO$_2$/year respectively.

The hot water consumption for the Jura dwelling has been determined in a slightly different fashion; there is to be a *Heatrae Sadia Megaflo Cylinder* installed within this development with a capacity of 210 litres. The cylinder will heat this 210 litres of water per day no matter how it is consumed (please see A12).

| Dwelling | Shower $CO_2$ Emissions (kg/year) | Bath & Sink $CO_2$ Emission (kg/year) | Net $CO_2$ Emissions (kg/year) |
|---|---|---|---|
| | | | |
| Jura | N/A | N/A | 865 |
| Harris | 369 | 158 | 527 |

**Table 5.5.1 – $CO_2$ Emission for Water Heating**

### 5.6 Lighting Loads

In order to quantify lighting loads, several assumptions have been made (please see assumptions A13 & A14). The tables below illustrate the hypothetical resultant carbon emissions from lighting use.

**Light emission for Harris**

| Room | Light Fitting Power (W) | Time Running (hours) | Energy Use (kWh) | Carbon Reduction ($kgCO_2$) |
|---|---|---|---|---|
| | | | | |
| | | | | |
| **Lounge** | 100 | 2521 | 252 | 106.4 |
| **Cloakroom** | N/A | N/A | N/A | N/A |
| **Vestibule** | N/A | N/A | N/A | N/A |
| **Hall** | 60 | 365 | 22 | 9.2 |
| **Kitchen** | 60 | 365 | 22 | 9.2 |
| **Dining** | 100 | 365 | 37 | 15.4 |
| **Store** | N/A | N/A | N/A | N/A |
| **Upstairs Bathroom** | 60 | 183 | 11 | 4.6 |
| **En Suite** | 60 | 183 | 11 | 4.6 |
| **Bedroom 1** | 60 | 365 | 22 | 9.2 |
| **Bedroom 2** | 60 | 365 | 22 | 9.2 |
| **Bedroom 3** | 60 | 365 | 22 | 9.2 |
| **Hall Upstairs** | 60 | 365 | 22 | 9.2 |
| **Total** | | | | **186.5** |

**Table 5.6.1 – Lighting Emissions (Harris)**

**Light Emissions for Jura**

| Room | Light Fitting Power (W) | Time Running (hours) | Energy Use (kWh) | Carbon Reduction ($kgCO_2$) |
|---|---|---|---|---|
| | | | | |
| | | | | |
| **Lounge** | 100 | 2521 | 252 | 106.4 |
| **Hall** | 60 | 365 | 22 | 9.2 |
| **Toilet downstairs** | 60 | 183 | 11 | 4.6 |
| **Utility** | N/A | N/A | N/A | N/A |
| **Breakfast Area** | 60 | 365 | 22 | 9.2 |
| **Kitchen** | 60 | 365 | 22 | 9.2 |
| **Dining** | 100 | 365 | 37 | 15.4 |
| **Store** | N/A | N/A | N/A | N/A |

| | | | | |
|---|---|---|---|---|
| **Bathroom** | 60 | 183 | 11 | 4.6 |
| **En-Suite** | 60 | 183 | 11 | 4.6 |
| **Bedroom 1** | 60 | 365 | 22 | 9.2 |
| **Bedroom 2** | 60 | 365 | 22 | 9.2 |
| **Bedroom 3** | 60 | 365 | 22 | 9.2 |
| **Bedroom 4** | 60 | 365 | 22 | 9.2 |
| **Upstairs Hall** | 60 | 365 | 22 | 9.2 |
| | | | | |
| **Total** | | | | **209.6** |

**Table 5.6.2 – Lighting Emissions (Jura)**

## 5.7 Total Existing Carbon Emissions

Having quantified all the appliances and services which will emit carbon a total carbon emissions value can be determined for both the Harris and Jura dwellings:

| Dwelling | Space Heating ($kgCO_2$) | Lighting ($kgCO_2$) | Hot Water ($kgCO_2$) | Cooking ($kgCO_2$) | Appliances ($kgCO_2$) | Net ($kgCO_2$) |
|---|---|---|---|---|---|---|
| | | | | | | |
| **Harris** | 1575 | 186.5 | 527 | 326.3 | 493 | **3107.8** |
| **Jura** | 1741 | 209.6 | 865 | 296 | 574 | **3685.6** |

**Table 5.7.1 – Total $CO_2$ Output**

As can be seen, the Jura, as expected, gives a greater carbon output. This is mainly due to its larger size. A SAP calculation has also been carried out in order to determine the Dwelling Emission Rates (DER) and Target Emissions Rating (TER) emission rates: the net carbon emission values for the Harris and Jura dwellings within the SAP calculation are 2041$kgCO_2$/year and 2828$kgCO_2$/year respectively. The SAP calculation does not take into account energy used for appliances while the energy used for water heating in the SAP calculation is much more conservative and less accurate. The hand calculations are much more specific to the Anstruther project as they include equipment being used within the dwelling.

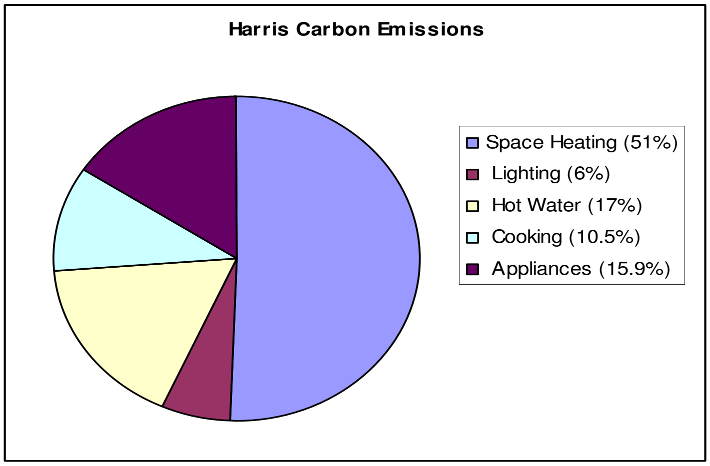


**Figure 5.7.1 – Harris Carbon Output**

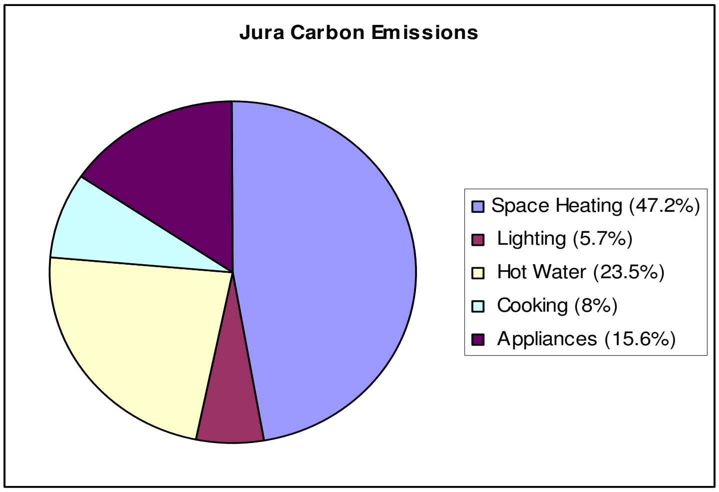


**Figure 5.7.2 – Jura Carbon Emissions**

The two pie-charts indicate where and why carbon is being emitted; it is clearly visible that the proportion of hot water usage is much greater in the Jura dwelling than in the Harris dwelling. Although space heating is lower in Jura, it should be noted that pie-charts are proportional and do not illustrate the specific magnitude but instead indicate the proportional values.

Both charts correlate very well with the Government value on carbon emissions for dwellings in figures 5.3.2 – 5.3.3. The total energy usage values for gas and electricity for both dwellings are shown in the table 5.7.3 for reference.

| Dwelling | Space Heating (kWh) | Lighting (kWh) | Hot Water (kWh) | Electric Appliances (kWh) | Gas Appliances (kWh) |
|---|---|---|---|---|---|
| | | | | | |
| **Harris** | 8121 | 442 | 1687 | 1556 | 858 |
| **Jura** | 8975 | 497 | 4461 | 1677 | 858 |
| | | | | | |

**Table 5.7.3 – Energy Consumption Values**

# Chapter 6: Investigation for reducing the Carbon Footprint

This chapter looks at improving the energy efficiency of the services and fabric of the buildings where possible.

## 6.1 Infiltration

The proportional heat losses illustrate where improvements can be made. It is evident that infiltration is the biggest cause of heat loss. Infiltration is quite simply unwanted external air leaking into the building (depicted in Figure 6.1.1). Infiltration losses can be tackled by a higher standard of building tightness. For this study the infiltration values calculated in the SAP have been used for consistency and compliance with the new domestic building regulations. They state the following:

> **"…if the dwellings designed and built following the guidance in 'Accredited Construction Details (Scotland)' the input data to the methodology (see clause 6.1.3) should be taken as air permeability 10m$^3$/m$^2$h at 50Pa and air-tightness testing is considered unnecessary" (Technical Handbook, Domestic, 2007).**

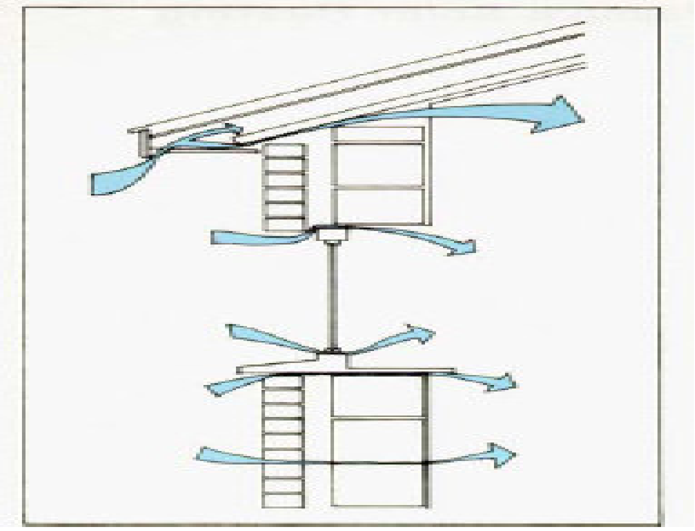


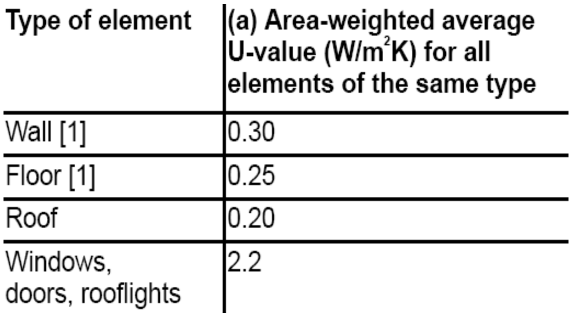
**Figure 6.1.1 – Infiltration (Yannas, 1994)**

The above statement essentially states that when calculating the DER the input infiltration value should be 10m$^3$/m$^2$h as this is the expected air infiltration rate for new dwellings. The infiltration rate value is essentially the 10m$^3$/m$^2$h air permeability value with additional infiltration caused by intermittent fans and open flues this keeps the heat loss calculations in-line with the SAP calculations (see assumption A2).

It should be noted that air-permeability testing on the Hockerton Low Energy housing Scheme developed in 1998 has been carried out and results in the region of 0.95 and 1.23m$^3$/h/m$^2$ were found (IESD, 2007). Therefore this evidence indicates that very low infiltration rates are achievable, although this is an area which is difficult to demonstrate compliance.

## 6.2 U-Values

Thermal transmittance, otherwise know as the U-Value; of an element is a measure of its thermal conductivity and is measured in W/m$^2$K as mentioned in section 5.3. The Technical Standards indicate specific U-Values for dwellings; this is illustrated below:



| Type of element | (a) Area-weighted average U-value (W/m$^2$K) for all elements of the same type |
|---|---|
| Wall [1] | 0.30 |
| Floor [1] | 0.25 |
| Roof | 0.20 |
| Windows, doors, rooflights | 2.2 |

**Figure 6.2.1 – Maximum U-Values for Building Elements. (SBSA, 2007)**

As can be seen from the heat loss tables in section 5.3, windows, behind infiltration, are the second biggest contributor to heat loss within the dwellings.

Muir Construction has indicated a window make up of 4mm double glazing (clear float) with a 12mm argon filled gap between both sheets of glass. This glass build up has a U-Value of 1.9W/m$^2$K (CIBSE, 2006). The glazing specification which Muir Construction has identified is better than the figure set out in the Technical Standards. However, it is still possible to improve the U-Value further in order to reduce heat loss.

The key parameters for heat loss reduction through the windows are the emissivity, cavity spacing and the properties of the gas trapped in between window panes. Increasing the thickness of the glass is not an effective way in reducing the U-Value due to the high conductance value of glass. The coating on the glass is already a low-e coating therefore improvement of the coating is difficult, the only option remaining would be to increase the thickness of the cavity. A triple glazed (4mm panes), argon filled, low-e ($\varepsilon = 0.1$) window system would provide a U-Value of 1.4W/m$^2$K (CIBSE, 2006).

| Heat Loss Through Window (W) | | |
|---|---|---|
| Notional Home (U-Value) | 1.9 | 1.4 |
| | | |
| Harris Heat loss | 973 | 712 |
| Jura Heat loss | 848 | 625 |
| Reduction Harris | | 261 |
| Reduction Jura | | 223 |

**Table 6.2.1 – Triple Glazing Reduction**

Table 6.2.1 indicates the savings made via upgrading the window to a triple glazed system, percentage reduction in the overall dwelling heat loss is fairly small and in the region of 7% and 5% of the total heat loss for Harris and Jura respectively. The external wall is the greatest element in terms of exposed area - it is another area of potential improvement. Muir Constructions have developed two alternative external wall build ups; both are shown below:

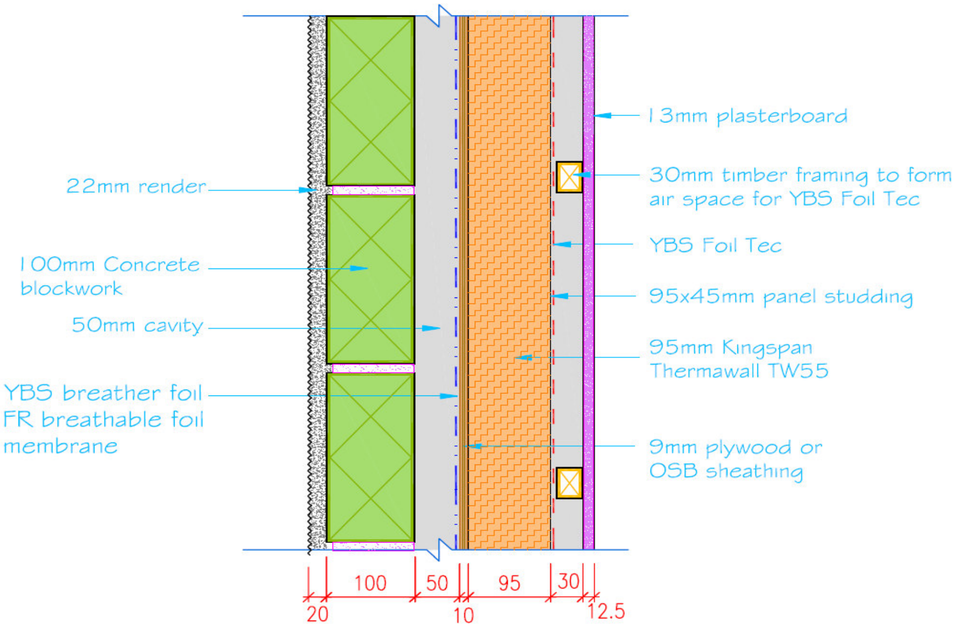


**Figure 6.2.2 – Alternative External Wall 1 (U-Value = 0.21 W/m$^2$K)**

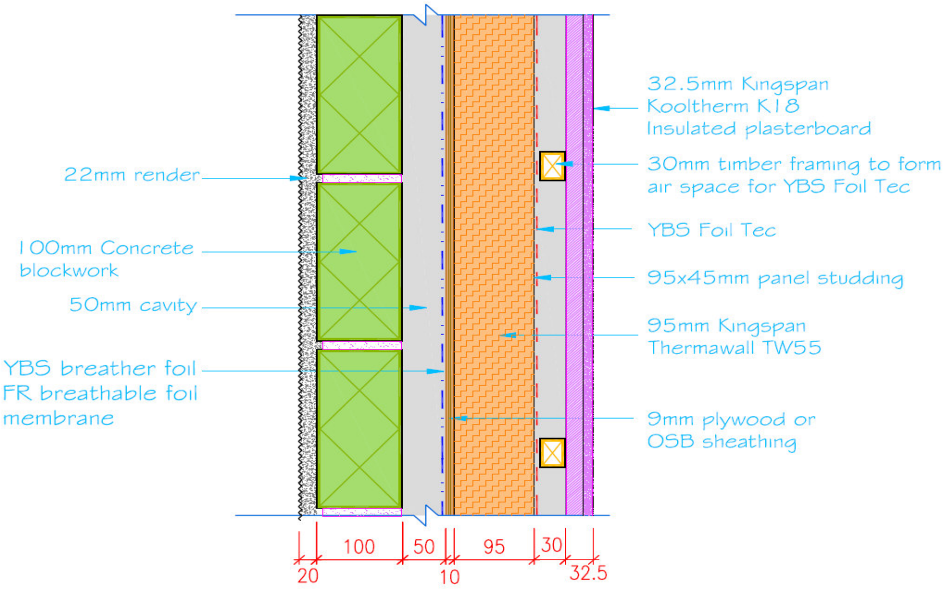


**Figure 6.2.3- Alternative External Wall 2 (U-Value = 0.18 W/m$^2$K)**

Thickness levels for both constructions range from 318mm (alternative 1) to 338mm (alternative 2). From a heat loss perspective, alternative 2 would perform better. Both scenarios have been calculated for heat loss and the results are shown below:

| Home | $0.3W/m^2K$ | $0.21 W/m^2K$ | $0.18 W/m^2K$ |
|---|---|---|---|
| | | | |
| **Harris** | 446 W | 312 W | 268 W |
| **Jura** | 565 W | 396 W | 339 W |
| | | | |
| **Reduction Harris** | | **134 W** | **178 W** |
| **Reduction Jura** | | **169 W** | **226 W** |

**Table 6.2.2 – Wall Heat Loss Comparison**

The actual reduction in heat loss via upgrading the wall is fairly small in proportion to the overall dwelling and is in the region of 5% of the total heat loss for both dwellings. If both improvements were to be made within the dwelling a combined heat loss reduction of ~ 11% would be achieved.

### 6.3 Lighting

Energy used to light a dwelling is often fuelled by grid supplied electricity. Grid supplied electricity has a fairly high carbon emissions factor applied to it. A possible reason for this higher carbon emissions factor is said to be due to the low energy conversion efficiency of power plants.

Most plants providing electricity in the UK are either gas or coal fired. Most were coal fired until the rush for gas in the late 80's and early 90's. This generated a large switch from coal to Combined Cycle Gas Turbines (CCGT) which are more efficient - up to 60% overall compared to 35% for the best conventional coal plant. Although CCGT plants are more efficient than coal, they are still relatively inefficient and this is said to be the main reason for high carbon emissions factors for grid supplied electricity.

It is fundamental that electricity use is kept to a minimum; the carbon emissions factor for electricity is $0.422kgCO_2/kWh$ while that for gas is $0.192kgCO_2/kWh$ (Part L, 2006), therefore a saving on electricity use is over two times more advantageous than that of gas. The new Technical Standards also identify lighting as an area requiring improvement;

> ***"A minimum of 50% of the fixed light fittings and lamps installed in a dwelling should be low energy type"*** **(Technical Handbook, Domestic, 2007).**

Working with Whitbybird it was assumed that each room will be installed with a fixed fitting (unless stated otherwise with a N/A note); Table 6.3.1 indicates what each room potentially could have currently and in the future:

**HARRIS**

| Room | ~ Area ($m^2$) | Light Fitting Power (W) | Fitting Type (Phillips) | Energy Flux ($W/m^2$) | New Light Fitting Power (W) | New Energy Flux ($W/m^2$) | Fitting Type (Phillips) |
|---|---|---|---|---|---|---|---|
| **Lounge** | 19.3 | 100 | Softone Standard | 5 | 18 | 1 | Master PL-T |
| **Cloakroom** | 2.1 | N/A | N/A | N/A | N/A | N/A | N/A |
| **Vestibule** | 2.1 | N/A | N/A | N/A | N/A | N/A | N/A |
| **Hall** | 1.7 | 60 | Softone Candle | 36 | 10 | 6 | Master PL-C |
| **Kitchen** | 7.3 | 60 | | 8 | 11 | 2 | Ecotone Econ |
| **Dining** | 7.5 | 100 | | 13 | 18 | 2 | Master PL-T |
| **Store** | 1.6 | N/A | N/A | N/A | N/A | N/A | N/A |
| **Upstairs Bathroom** | 3.6 | 60 | Softone Standard | 17 | 11 | 3 | Ecotone Econ |
| **En Suite** | 4.2 | 60 | Softone Standard | 14 | 11 | 3 | Ecotone Econ |
| **Bedroom 1** | 10.0 | 60 | Softone Standard | 6 | 11 | 1 | Ecotone Econ |
| **Bedroom 2** | 10.8 | 60 | Softone Standard | 6 | 11 | 1 | Ecotone Econ |
| **Bedroom 3** | 6.8 | 60 | Softone Standard | 9 | 11 | 2 | Ecotone Econ |
| **Hall Upstairs** | 2.9 | 60 | Softone Candle | 21 | 10 | 3 | Master PL-C |

**Table 6.3.1 – Light Fittings Harris**

**JURA**

| Room | ~ Area ($m^2$) | Light Fitting Power (W) | Fitting Type (Phillips) | Energy Flux ($W/m^2$) | New Light Fitting Power (W) | New Energy Flux ($W/m^2$) | Fitting Type (Phillips) |
|---|---|---|---|---|---|---|---|
| **Lounge** | 24.2 | 100 | Softone Standard | 4 | 18 | 1 | Master PL-T |
| **Hall** | 9.3 | 60 | Softone Candle | 6 | 10 | 1 | Master PL-C |
| **Toilet downstairs** | 1.5 | 60 | | 40 | 11 | 7 | Ecotone Econ |
| **Utility** | 4.4 | N/A | N/A | N/A | N/A | N/A | N/A |
| **Breakfast Area** | 8.0 | 60 | N/A | 7 | 11 | 1 | Ecotone Econ |
| **Kitchen** | 9.8 | 60 | N/A | 6 | 11 | 1 | Ecotone Econ |
| **Dining** | 11.2 | 100 | N/A | 9 | 18 | 2 | Master PL-T |
| **Store** | 1.0 | N/A | N/A | N/A | N/A | N/A | N/A |
| **Bathroom** | 3.8 | 60 | Softone Standard | 16 | 11 | 3 | Ecotone Econ |
| **En-Suite** | 2.2 | 60 | Softone Standard | 27 | 11 | 5 | Ecotone Econ |
| **Bedroom 1** | 10.5 | 60 | Softone Standard | 6 | 11 | 1 | Ecotone Econ |

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| **Bedroom 2** | 8.4 | 60 | Softone Standard | 7 | 11 | 1 | Ecotone Econ |
| **Bedroom 3** | 8.5 | 60 | Softone Standard | 7 | 11 | 1 | Ecotone Econ |
| **Bedroom 4** | 7.1 | 60 | Softone Standard | 9 | 11 | 2 | Ecotone Econ |
| **Upstairs Hall** | 4.2 | 60 | Softone Candle | 14 | 10 | 2 | Master PL-C |

**Table 6.3.2 – Light Fittings Jura**

As can be seen from tables 6.3.1 and 6.3.2 all fittings have been changed to low energy fittings. This method allows compliance with Part 5.4.1. It also goes further and totally minimises energy consumption from the lighting. It is very difficult to quantify when people will switch lights on and when they will be left off. However, in order to provide an energy consumption a lighting usage pattern is given (please see A14). This is detailed below:

- Bedroom Lighting on for 1 hour/day all year.
- Bathroom lighting on for 0.5 hours/day all year.
- Lounge lighting on for:

| | |
|---|---|
| Summer | Lights on from 9pm – 12.30am all year |
| Winter | Lights on from 7am – 8am, 5pm – 12.30am all year |
| Autumn | Lights on from 6pm – 12.30am all year |
| Spring | Lights on from 7am – 8am, 5pm – 12.30am all year |

Summer months – July to September
Winter months – December to February
Autumn months – October to November
Spring months – March to June

- Dining/Kitchen shall be on for 1 hour all year.
- Hall lighting shall be on for 1 hour all year.

**Harris**

| Room | Light Fitting Power (W) | Time Running (hours) | Energy Use (kWh) | New Light Fitting Power (W) | Energy Use (kWh) | Carbon Reduction (kg$CO_2$) |
|---|---|---|---|---|---|---|
| **Lounge** | 100 | 2521 | 252 | 18 | 45 | 87 |
| **Cloakroom** | N/A | N/A | N/A | N/A | N/A | N/A |
| **Vestibule** | N/A | N/A | N/A | N/A | N/A | N/A |
| **Hall** | 60 | 365 | 22 | 10 | 4 | 8 |
| **Kitchen** | 60 | 365 | 22 | 11 | 4 | 8 |
| **Dining** | 100 | 365 | 37 | 18 | 7 | 13 |
| **Store** | N/A | N/A | N/A | N/A | N/A | N/A |
| **Upstairs Bathroom** | 60 | 183 | 11 | 11 | 2 | 4 |
| **En Suite** | 60 | 183 | 11 | 11 | 2 | 4 |
| **Bedroom 1** | 60 | 365 | 22 | 11 | 4 | 8 |
| **Bedroom 2** | 60 | 365 | 22 | 11 | 4 | 8 |
| **Bedroom 3** | 60 | 365 | 22 | 11 | 4 | 8 |
| **Hall Upstairs** | 60 | 365 | 22 | 10 | 4 | 8 |
| **Total** | | | | | | **153** |

**Table 6.3.3 – Lighting Carbon Reductions**

**JURA**

| Room | Light Fitting Power (W) | Time Running (hours) | Energy Use (kWh) | New Light Fitting Power (W) | Energy Use (kWh) | Carbon Reduction (kg$CO_2$) |
|---|---|---|---|---|---|---|
| **Lounge** | 100 | 2521 | 252 | 18 | 45 | 87 |
| **Hall** | 60 | 365 | 22 | 10 | 4 | 8 |
| **Toilet downstairs** | 60 | 183 | 11 | 11 | 2 | 4 |
| **Utility** | N/A | N/A | N/A | N/A | N/A | N/A |
| **Breakfast Area** | 60 | 365 | 22 | 11 | 4 | 8 |
| **Kitchen** | 60 | 365 | 22 | 11 | 4 | 8 |
| **Dining** | 100 | 365 | 37 | 18 | 7 | 13 |
| **Store** | N/A | N/A | N/A | N/A | N/A | N/A |
| **Bathroom** | 60 | 183 | 11 | 11 | 2 | 4 |
| **En-Suite** | 60 | 183 | 11 | 11 | 2 | 4 |
| **Bedroom 1** | 60 | 365 | 22 | 11 | 4 | 8 |
| **Bedroom 2** | 60 | 365 | 22 | 11 | 4 | 8 |
| **Bedroom 3** | 60 | 365 | 22 | 11 | 4 | 8 |
| **Bedroom 4** | 60 | 365 | 22 | 11 | 4 | 8 |
| **Upstairs Hall** | 60 | 365 | 22 | 10 | 4 | 8 |
| **Total** | | | | | | **172** |

**Table 6.3.4 – Lighting Carbon Reductions**

Table 6.3.4 indicates the reduction in carbon dioxide emissions when low energy lighting is applied to the dwellings.

## 6.4 Hot Water Carbon Emissions

As mentioned previously, the hot water carbon emissions related with both the dwellings are different. The main reason for this difference is the fact that the Jura dwelling has a hot water storage tank while the Harris dwelling has an electric shower and a combi-boiler being used for all other hot water uses. Since the Harris dwelling does not have a storage tank, it only uses the hot water which is required; it's maybe the case that the Jura dwelling heats up 210 litres of water but does not use all of this volume therefore heating excess water; this is the main reason the difference occurs.

The Jura dwelling would generate too great a demand for a combi-boiler to cope with; it could be possible that an electric shower is fitted in the En-Suite and a combi-boiler is used throughout similar to the Harris dwelling. However, this would mean that the tank has to be taken out – a step which would be detrimental if installation of a solar hot water system is to be used.

### 6.5 Carbon Emissions after Improvements

| Dwelling | Space Heating (kg$CO_2$) | Lighting (kg$CO_2$) | Hot Water (kg$CO_2$) | Cooking (kg$CO_2$) | Appliances (kgCO2) | Net (kg$CO_2$) |
|---|---|---|---|---|---|---|
| | | | | | | |
| **Harris** | 1339.0 | 33.5 | 527 | 326.3 | 493 | 2718.8 |
| **Jura** | 1534.0 | 37.7 | 865 | 296 | 574 | 3306.7 |

**Table 6.5.1 – New Carbon Emissions from Efficiency Improvements**

Table 6.5.1 illustrates the new carbon emissions levels as determined via calculations. The new carbon emissions are based on the improvements detailed in this section these are:

- Upgrade windows U-Value to 1.4W/m$^2$K by installing triple glazing, argon filled cavity low-e window system.
- Upgrade wall U-Value to 0.18W/m$^2$K by changing wall make up as detailed in figure 4.1.3.
- Install low energy lighting throughout the dwelling.

There is a slight reduction in space heating requirements while lighting emissions have significantly reduced due to the new low energy light bulbs fitted throughout the dwellings. The hot water and appliance emissions remain the same due to reasons mentioned earlier within the study.

| Dwelling | Space Heating (kWh) | Lighting (kWh) | Hot Water (kWh) | Electric Appliances (kWh) | Gas Appliances (kWh) |
|---|---|---|---|---|---|
| | | | | | |
| **Harris** | 6903 | 79 | 1687 | 1556 | 858 |
| **Jura** | 7907 | 89 | 4461 | 1677 | 858 |

**Table 6.5.2 – Energy Consumption from Efficiency Improvements**

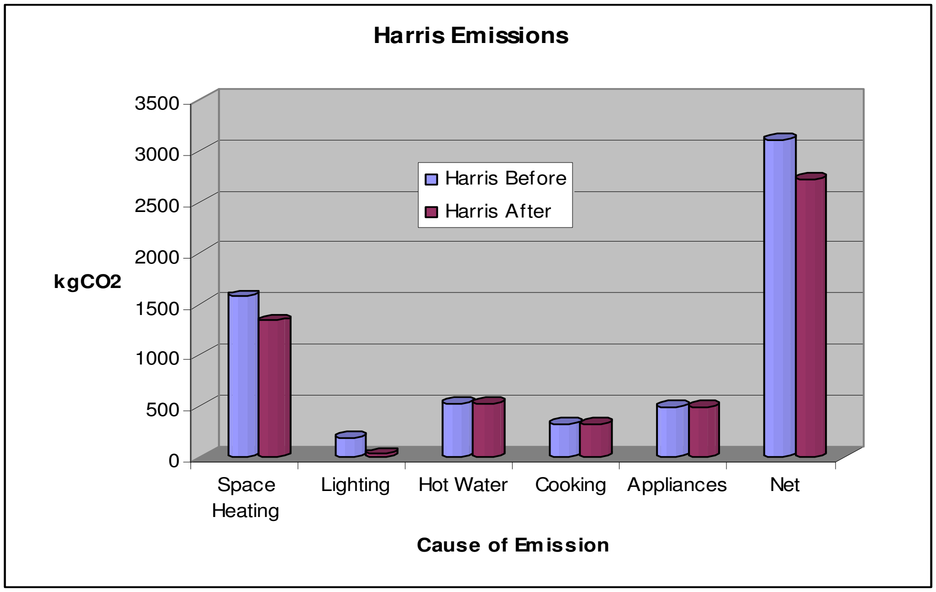


Figure 6.5.1 – Carbon Emissions Comparison (Harris)

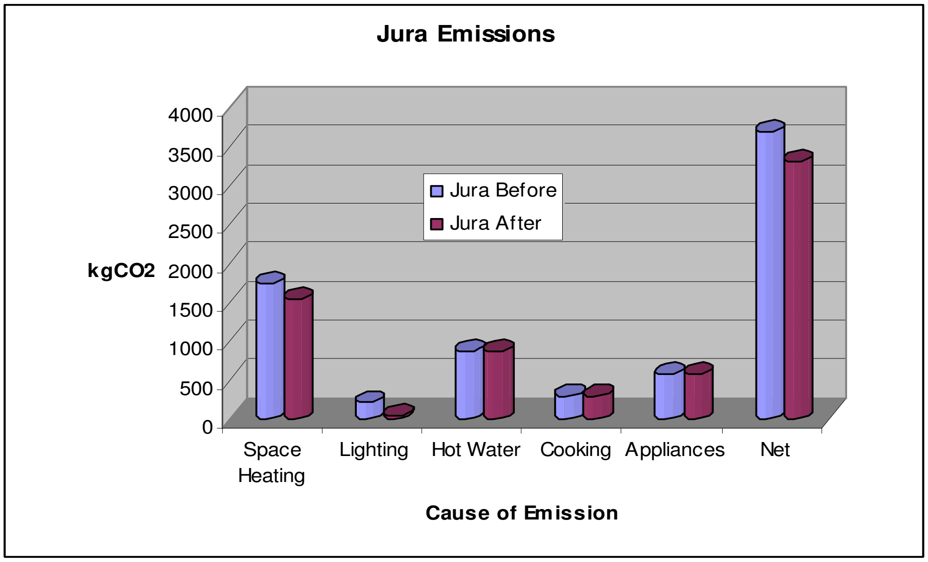


Figure 6.5.2 - Carbon Emissions Comparison (Jura)

From the energy efficiency steps outlined in this section; the carbon emission reduction from the Harris and Jura dwellings respectively are 12.5% and 10.3% with overall emissions being 2.7tonnes $CO_2$ and 3.3 tonnes $CO_2$ respectively.

# Chapter 7: Feasibility of renewable energy systems (Micro-generation)

A comprehensive study into which Micro-generation systems are suitable for the Harris and Jura dwellings is carried out in this chapter. During all analyses of the renewable technologies it has been assumed that all the energy efficiency improvements have been carried out; these include reduced wall and window U-Values and low energy lighting fitted throughout.

## 7.1 Biomass

### 7.1.1 Operation

Biomass heating has been identified as a potential heating system and LZC technology. Its use and viability within individual homes has been investigated as a potential replacement of the existing gas fired boilers as well its use as a community heating system.

Although burning biomass will still produce carbon, this can be offset against the carbon it absorbs during its life span. Biomass can come from waste products from sawmills etc and can also be grown as crop which in essence makes it renewable. However, it should be noted that the resource would have to be carefully monitored to avoid the demand outgrowing the ability to supply (Biomass Feasibility, 2007).

### 7.1.2 Individual Systems

In considering individual biomass systems the main concern has centred on spatial requirements; the system not only requires space for the boiler but also the storage of fuel. It is difficult to see where a biomass system can be located within the Harris dwelling. However; quantifying the requirements has been carried out nevertheless.

The Jura dwelling has a 15.4m$^2$ garage which would provide ideal space for a floor standing boiler and a certain degree of fuel storage. There are a number of different biomass fuels that could be used and they are shown in Table 7.1.1 along with their energy content compared with volume and weight.

| Fuel Type | MWh/m$^3$ | MWh/tonne |
|---|---|---|
| | | |
| Pellets | 3.5 | 5 |
| Chips, MC 25% | 0.9 | 4 |
| Chips, MC 35% | 0.85 | 3.5 |
| Chips, MC 50% | 0.8 | 2.5 |
| Hardwood logs, seasoned, stacked | 1.75 | 4 |

| | | |
|---|---|---|
| Hardwood logs, green, stacked | 1.7 | 2.5 |
| Softwood logs, seasoned, stacked | 1.3 | 4 |
| Softwood logs, green, stacked | 1.2 | 2.5 |

**Table 7.1.1 – Fuel Types (Okofen, 2006)**

As can be seen from table 7.1.1, pellets offer the greatest amount of energy as per weight and volume due to its high density making them ideal for situations with limited space and making them more efficient than any other.

In order to assess the viability of installing a biomass system a boiler has been sized to cope with the dwelling heat losses and quantities of fuel required for a worst case fortnight in a U.K heating season. The equipment and fuel information comes from 2 companies, Okofen, the boiler manufacturers and Perthshire Biofuels the wood pellet distributors. Perthshire Biofuels are the closest supplier of wood pellets at 40 miles from the development site and have the infrastructure to deliver to Anstruther. The following table outlines the details surrounding the pellets.

| Parameter | Value |
|---|---|
| Density (kgm$^{-3}$) | 650 |
| Energy Content (kWh/kg) | 4.9 |
| Cost (£/tonne) | 175 |
| Travel (£/tonne) | 25 |

**Table 7.1.2 – Pellet Details**

A single delivery from Perthshire Biofuels would be a minimum of 1 tonne to make it financially viable and using the density of the pellets this gives a required storage volume of 1.54$m^3$, and taking a stacking height of ~ 2m this gives a floor area of 0.77$m^2$.

If biomass is considered to be carbon neutral then the total amount created through space heating using gas can be considered as the saving, this saving will be 0.194 kg $CO_2$ per kWh of space heating. It is essential that the fuel supplier is local as extensive travelling distance will mean that the fuel loses its carbon neutral status. There are no set laws on distance-carbon neutral relationship as of yet however it is a common sense issue. The boiler selected is an Okofen PE08: this boiler is capable of producing 8kW of heat and runs on a partial load of 2.4kW; this being its lowest heat output.

Both dwellings have heat losses at peaks of 3.7kW to 4.1kW. Therefore the boiler will always run below peak rated output. This mismatch in output and requirement causes a slight problem for a biomass system, the heat requirement will most often than not be under the minimum load of the boiler therefore excess heat shall be generated. In order to get around this complication a thermal store can be created by discharging the heat into a cylinder which holds this thermal energy until required; this system could potentially link up with the DHW system.

The dimensions of the Okofen boiler are 1013mm (B) x 691mm (T) x 1066mm (D) with a flue of 4500mm; this dimension does not include storage, the boiler can come complete with a storage vessel. An Okofen boiler is shown figure 7.1.1:

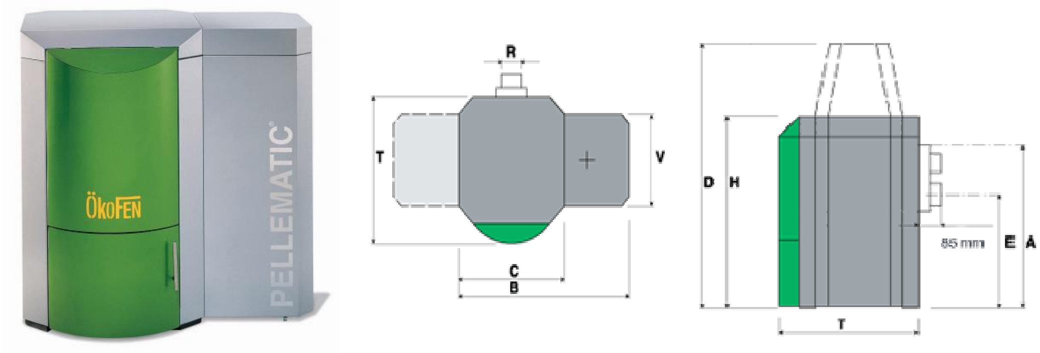


**Figure 7.1.1 – Okofen Boiler (Okofen, 2007)**

The Okofen storage system for this boiler would be in the region of 1100mm in length 1100mm in width and 1350mm in height. An image of this is shown in Figure 7.1.2:

**Figure 7.1.2 – Storage System. Courtesy of Okofen**

The Okofen S110 flexi storage system will hold approximately 450kg of wood pellets.

### 7.1.3 District/Community System

In looking into the viability of a community or district heating system a total heating load across all 337 homes in the development was approximated (please see assumption A15), by assuming that 50% of the houses would be represented by the average winter Harris heat load (3.7kW) and 50% would be represented by the Jura heat load (4.1kW). This gave an overall load of ~ 1.17MW. Hoval STU 600 boilers have been used as an example to provide the heat load and the associated information regarding duty, cost and space requirement. Three of the STU 600 boilers would be required to meet the heating load with a combined cost of nearly £140,000.

The community system would use approximately 510.3tonnes of wood pellets per year; this would come at a fuel cost of approximately £89,250. To determine a spatial requirement it has been assumed that a delivery rate of 72 tonnes per month is met. This would be during the winter heating season. At 80 tonnes per month, a steady supply of heat is ensured at a consumption rate of 1.17MW per day for 10 hours everyday all month; this supply would obviously dwindle and lower as the heating season finishes.

Spatially, 80 tonnes is 124m$^3$ and with a 2 metre high stacking height this requires a floor space of 62m$^2$; it would require approximately 5 Lorries to deliver this load. This could be reduced by increasing the frequency of delivery to one 25 tonne lorry load per week and each boiler could come with a 20m$^3$ hopper that can hold 13 tonnes. The site would require this level of infrastructure in order to deal with a community system; the installed pipework routes would also add a significant cost due to underground fitting of heavy pipework as well as large pumps.

| | **Energy Consumption (kWh/year)** | **Quantity of Pellets (tonnes/year)** | **Fuel Cost (£)** | **$CO_2$ Reduction ($kgCO_2$)** |
|---|---|---|---|---|
| Harris Energy Required | 6903 | 1.41 | 247 | 1339 |
| Jura Energy Required | 7907 | 1.61 | 282 | 1534 |
| Community Energy required | 25003000 | 510.3 | 89, 250 | 485537 |

**Table 7.1.3 – Carbon Reductions from Biomass**

## 7.2 Solar Hot Water (SHW)

### 7.2.1 Operation

SHW systems produce hot water by capturing heat from the sun. For domestic hot water there are three main components to the system;

1. Solar Collector - is fitted to the roof of the house and collects heat from the sun's radiation.
    - Flat plate system consists of an absorber plate with a transparent cover (£2,000 - £3,000)
    - Evacuated system comprised of a row of glass tubes each containing an absorber plate feeding in to a manifold transporting the heated fluid (£3,500 - £4,500).
2. Heat exchanger - uses the collected heat to heat water.
3. Hot Water Cylinder – stores the hot water that is heated during the day and supplies is for use later. (Energy Saving Trust, 2007)

SHW depends on radiation not sunlight; it absorbs heat on overcast days but works better on bright cloudless days thus in winter, although a panel can be helpful in pre-heating the water, a top up system such as gas boiler is still required. An important point to note is that a SHW system is not designed to work in conjunction with the central heating radiators – the can heat water for DWH and also be used for space heating.

The collector should face south or close to south and lie on a pitched roof that will provide the natural angle to face the sun. A conventional central heating pump forces water through a coiled pipe in the solar panel where it is heated by the sun. The heated water then flows down and through a second (lower) coil in the hot water cylinder, referred to as a solar cylinder. The hot water passing through this coil heats the water in the cylinder.

The slightly cooled water is then returned back to the solar panel via the pump. A controller box should be used which continuously compares the temperature in the panel against that in the hot water cylinder. It switches the pump on when the water temperature in the panel is hotter than that in the cylinder and switches it off when the reverse conditions apply. The boiler heating coil, show at the top of the cylinder will come on if the SHW cannot meet the required DHW temperature.

The water flowing around the SHW system is used to heat the water in the cylinder indirectly. This means that no water in the SWH system will come into contact with water in the hot water cylinder. The heat is transferred, not the water.

### 7.2.2 Hot Water Energy Consumption

The annual hot water energy consumption for the dwellings has been calculated previously and is 1687kWh and 4461kWh for the Harris and Jura respectively. The Harris dwelling has an electric shower and combi-boiler. This appears to be due to lack of space for a hot water tank. A SHW system requires a hot water tank, and the savings made by a SHW system in the Harris have been illustrated regardless.

For this analysis the electric shower in the Harris dwelling was be removed and a hot water tank is assumed to have been installed while the boiler has also been changed to a regular condensing gas fired high efficiency boiler with a set up similar to the boiler at Jura. The boilers shall serve as a top-up to the SHW system; this effectively means that Harris has been fitted out with a 210 litre hot water cylinder.

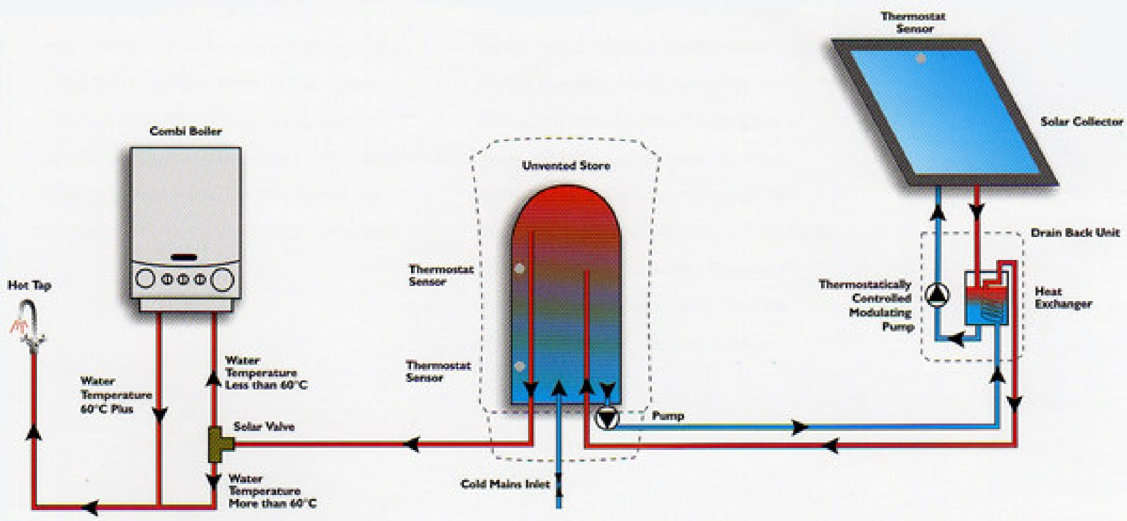


**Figure 7.2.1 – SHW/Boiler Hot Water System (UKHeat, 2007)**

It is generally stated that the UK and Northern Europe receive on average 1000kWhm$^{-2}$y$^{-1}$ to 1 500kWhm$^{-2}$y$^{-1}$ (Boyle, 2004). These are integrated energy figure for a year and large variations are seen from summer to winter; it most likely that the majority of solar irradiation is absorbed by the plate during summer with the SHW system having a small contribution in winter. As can be seen from Figure 7.2.1 the average solar irradiance over Scotland is approximately 950 kWhm$^{-2}$y$^{-1}$.

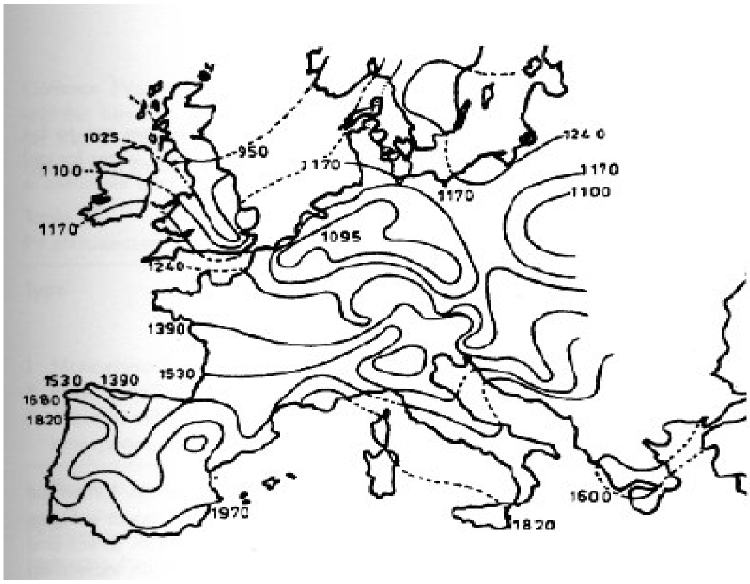


**Figure 7.2.2 – Solar Irradiation over Europe (kWhm$^{-2}$y$^{-1}$) (IESD, 2006).**

| Direct Solar (kW/m$^2$) | Diffuse Solar (kW/m$^2$) | Total Solar on Surface (kW/m$^2$) | Heat Recovered (kW) |
|---|---|---|---|
| 600 | 545 | 1146 | 3123 |

**Table 7.2.1 - Solar collector power output data, Oban Climate data.**

**Collector data:**

***Area = 4m$^2$ Transmission Coefficient = 0.87 Absorption Coefficient = 0.95 U-value = 1.1***

It should be noted that the solar collector was facing south at a tilt angle of 45°. Table 7.2.1 indicates that with a typical 4m$^2$ SHW collector, a large proportion of the hot water demand can be met; it should be noted that a large degree of this heating will be concentrated into the summer months and it is possible that in winter the contribution from the SHW system could be minimal.

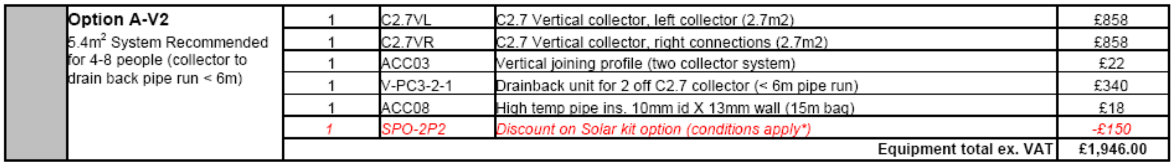
It would require approximately 5.2m$^2$ of collector area to recover all the heat required for the Jura dwelling. Care should be taken when considering these figures since, as mentioned above, a large proportion of the energy from the sun will occur during the summer. Most manufacturers state that the SHW system will cover 50 – 60% of the heating demand for a domestic property in the UK. Therefore it is assumed that, if the above collector areas are installed, the Jura and Harris will both generate a carbon emission reduction output of 50% on hot water production.

The 50% reduction in hot water energy consumption would mean that the Harris and Jura, after both have a 210 litre storage tank installed, would consume approximately 2231kWh. If this was to be supplied by a gas fired heating system then the carbon emissions for hot water would be approximately 433kg$CO_2$/year.

### 7.2.3 Sizes and Costs

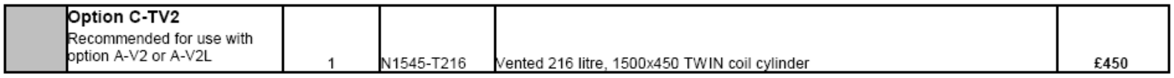
Figures 7.2.5 and 7.2.6 are taken from a SHW vendor; the system shown in Figure 7.2.5 is a little larger than the typical 4$m^2$ panels used within the UK. However it gives a good indication of cost breakdowns. A 4$m^2$ panel system would cost in the region of £1400 for the collector and approximately £450 for the 210 litre storage tank.

The information below is for illustration only:



| | | | | |
|---|---|---|---|---|
| **Option A-V2**<br>5.4$m^2$ System Recommended for 4-8 people (collector to drain back pipe run < 6m) | 1 | C2.7VL | C2.7 Vertical collector, left collector (2.7m2) | £858 |
| | 1 | C2.7VR | C2.7 Vertical collector, right connections (2.7m2) | £858 |
| | 1 | ACC03 | Vertical joining profile (two collector system) | £22 |
| | 1 | V-PC3-2-1 | Drainback unit for 2 off C2.7 collector (< 6m pipe run) | £340 |
| | 1 | ACC08 | High temp pipe ins. 10mm id X 13mm wall (15m bag) | £18 |
| | *1* | *SPO-2P2* | *Discount on Solar kit option (conditions apply*)* | *-£150* |
| | | | **Equipment total ex. VAT** | **£1,946.00** |

**Figure 7.2.5 – SHW Cost Breakdowns (Imagination Solar Limited, 2007)**



| | | | | |
|---|---|---|---|---|
| **Option C-TV2**<br>Recommended for use with option A-V2 or A-V2L | 1 | N1545-T216 | Vented 216 litre, 1500x450 TWIN coil cylinder | **£450** |

**Figure 7.2.6 – Storage Tank Cost (Imagination Solar Limited, 2007)**

The carbon savings from 5.4$m^2$ collector would be greater than the 4$m^2$ system. However, the 4$m^2$ system is the typical collector size for the UK and increasing the collector area in a 4 -5 person house above may not prove significantly useful. The cost of professional installation needs to be added to the above costs in Tables 7.2.5 and 7.2.6. However for installed (as opposed to DIY systems), VAT is only 5%.

## 7.3 Photovoltaic Cells (PV Cells)

### 7.3.1 Operation

PV Cells consist, in essence, of a junction between two thin layers of dissimilar semi-conducting materials, know respectively as p (positive) type semiconductors and n (negative) type semiconductors both normally made from silicon. Light consists of tiny particles of energy called photons. When photons of light from a suitable wavelength fall within the p-n junction, the transfer energy to some electrons, exciting them and generating an electric charge in the process.

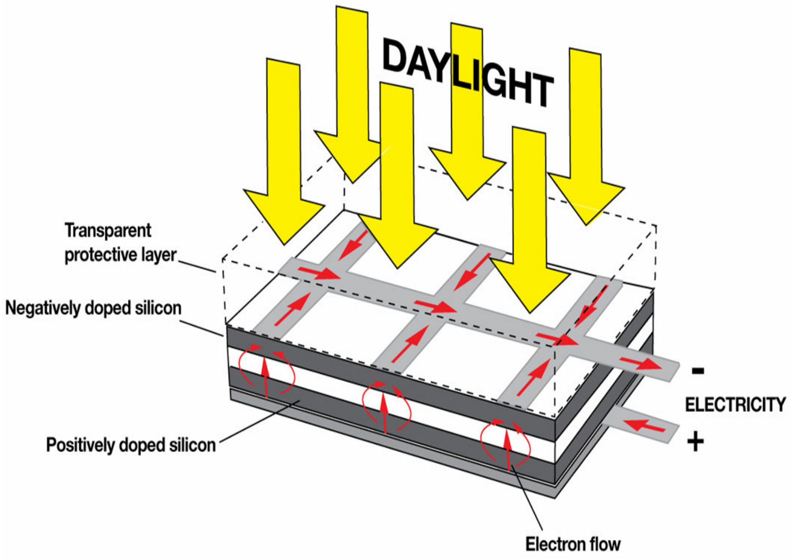


**Figure 7.3.1 – PV Cell Mechanics (Solar Century, 2007)**

### 7.3.2 Solar Irradiance Analysis & Potential Output

The solar irradiance values for the closest weather file (Dundee EWY) were analysed in order to quantify the level of potential power produced (please see assumptions A15).

**Eastern Orientated Monocrystalline Cell**

| Panel | Total (Weekday) kWh | Total (Weekend) kWh |
|---|---|---|
| Energy From 1m$^2$ PV Cell (kWh) | 354.8 | 194.5 |
| Energy From 2m$^2$ PV Cell (kWh) | 709.6 | 389.0 |
| Energy From 3m$^2$ PV Cell (kWh) | 1064.4 | 583.5 |
| Energy From 4m$^2$ PV Cell (kWh) | 1419.3 | 777.9 |
| Energy From 5m$^2$ PV Cell (kWh) | 1774.1 | 972.4 |
| Energy From 6m$^2$ PV Cell (kWh) | 2128.9 | 1166.9 |
| Energy From 7m$^2$ PV Cell (kWh) | 2483.7 | 1361.4 |
| Energy From 8m$^2$ PV Cell (kWh) | 2838.5 | 1555.9 |

**Table 7.3.1 - Energy from Eastern Orientated PV Cell**

**Western Orientated Monocrystalline Cell**

| Panel | Total (Weekday) kWh | Total (Weekend) kWh |
|---|---|---|
| Energy From 1m$^2$ PV Cell (kWh) | 200.4 | 209.9 |
| Energy From 2m$^2$ PV Cell (kWh) | 400.8 | 419.8 |
| Energy From 3m$^2$ PV Cell (kWh) | 601.2 | 629.6 |
| Energy From 4m$^2$ PV Cell (kWh) | 801.5 | 839.5 |
| Energy From 5m$^2$ PV Cell (kWh) | 1001.9 | 1049.4 |
| Energy From 6m$^2$ PV Cell (kWh) | 1202.3 | 1259.3 |
| Energy From 7m$^2$ PV Cell (kWh) | 1402.7 | 1469.2 |
| Energy From 8m$^2$ PV Cell (kWh) | 1603.1 | 1679.1 |

**Table 7.3.2 Energy from Western Orientated PV Cell**

**Southern Orientated Monocrystalline Cell**

| Panel | Total (Weekday) kWh | Total (Weekend) kWh |
|---|---|---|
| Energy From 1m$^2$ PV Cell (kWh) | 103.1 | 356.6 |
| Energy From 2m$^2$ PV Cell (kWh) | 206.3 | 713.2 |
| Energy From 3m$^2$ PV Cell (kWh) | 309.4 | 1069.9 |
| Energy From 4m$^2$ PV Cell (kWh) | 412.5 | 1426.5 |
| Energy From 5m$^2$ PV Cell (kWh) | 515.7 | 1783.1 |
| Energy From 6m$^2$ PV Cell (kWh) | 618.8 | 2139.7 |
| Energy From 7m$^2$ PV Cell (kWh) | 721.9 | 2496.4 |
| Energy From 8m$^2$ PV Cell (kWh) | 825.1 | 2853.0 |

**Table 7.3.3 – Energy from Southern Orientated PV Cell**

Three different cell outputs have been calculated. This data manipulation is essential and the potential energy consumed on three different facades for two different time bands has been quantified. The time bands are exceptionally important as they give and illustrate the potential use when the dwellings are occupied during the week and when they are occupied during the weekend.

The weather file data reveals that a southerly orientated PV Cell produces the most potentially exported electricity; a cell orientated to the east would provide most power in-line with the dwelling being occupied however it is likely that the dwelling will only use a small proportion of the electricity of an easterly orientated cell as the occupants are likely to wake and leave the house early in the morning therefore leaving a large proportion of power being exported. Ultimately a southern mounted PV Cell produces most power however this includes exported power.

Exporting power to the grid from PV cells would require synchronous inverters which transform the DC power from the PV arrays into AC power at a voltage and frequency that can be accepted by the grid. This would require debit and credit meters in order for the customer/generator to know how much they need to pay/get paid. Taking appliances such as a fridge freezer off a PV cell system could generate problems with the operation of the fridge freezer. Therefore care should be made when considering how systems are potentially linked into appliances.

### 7.3.3 Cost of PV Cells

PV modules are one of the most expensive forms of renewable energy at present; the costs for 1m$^2$ of installed PV module is said to be in the region of £500 (CIBSE, 2000). This is a significant cost when the output of a 1m$^2$ system is considered. The energy consumption of grid supplied electricity for both the Jura and Harris would suggest a PV cell array of approximately 5m$^2$ is required, this could potentially cover the electricity consumption and offset into the grid; it should be noted that this is after energy efficiency improvements and with optimum mounting conditions.

## 7.4 Wind Resource

### 7.4.1 Operation

A wind turbine taps into the kinetic energy of the wind and transforms this into electricity via a generator. Wind and power have a cubic relationship; which means if you increase the wind by a factor of two the energy output would change by a factor of eight. Economics play a major role in wind development projects and therefore, each site is evaluated on a case-by-case basis.

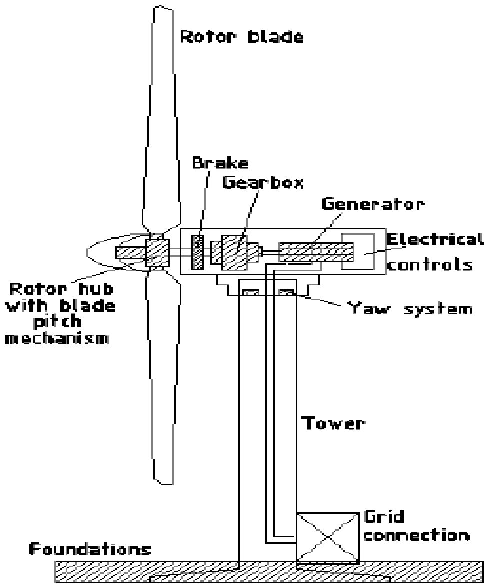


**Figure 7.4.1 – Components of a Wind Turbine (IESD, 2007).**

### 7.4.2 Weather Analysis & Wind Resource

The key to wind turbine energy production is the wind speed; the Beaufort wind scale depicts the wind speeds in which a turbine is most efficient. Studies have shown that approximately 14ms$^{-1}$ – 17ms$^{-1}$ is required in order for a wind turbine to provide power at its rated output. Research work published in the Energy & Buildings Journal (Vol 39, pp 154 – 165) indicates that at 17ms$^{-1}$, the wind turbine will produce power at the rated output; this is shown in Figure 7.4.2, a performance chart for various wind turbines, each with a different rating:

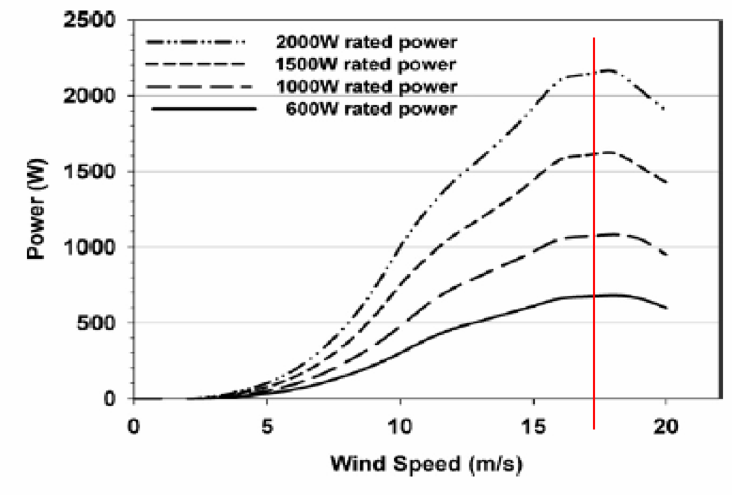


**Figure 7.4.2 – Turbine Output**

By consulting with the MET Office historical wind records for the area were made available in order to further investigate wind resource; a chart depicting the results is shown below, this indicates that at no point does the wind speed exceed 17ms$^{-1}$.

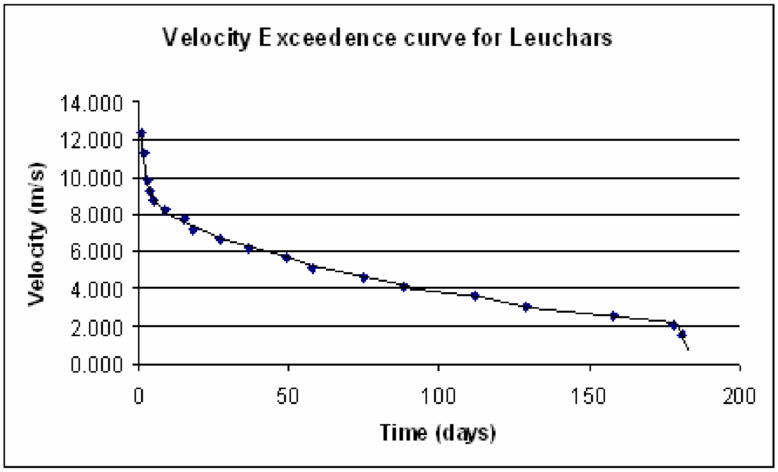


**Figure 7.4.3 – MET Office Wind Data for Leuchars**

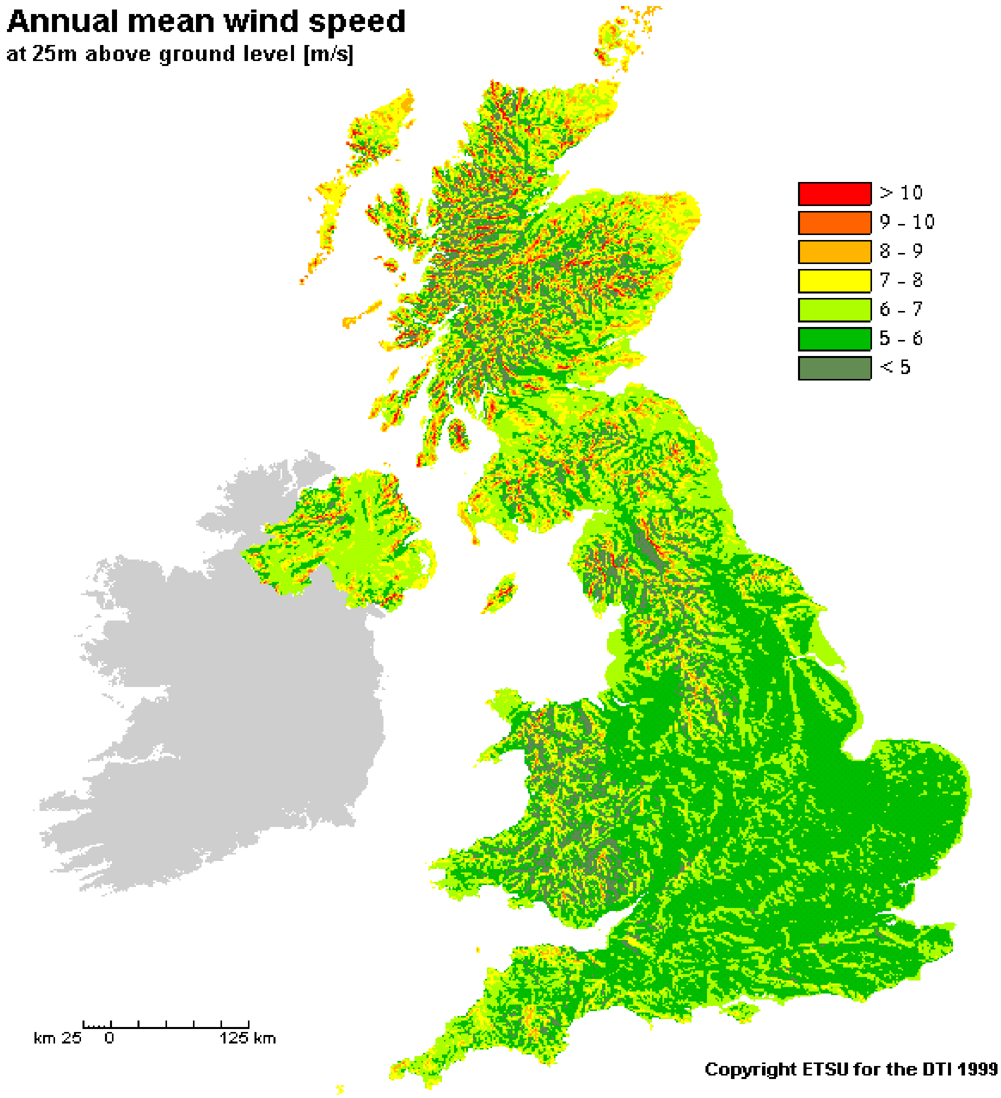


**Figure 7.4.4 – Annual Mean Wind Speed (BWEA, 2005)**

The annual wind speed map for the UK indicates that an average wind speed of approximately $7ms^{-1}$.

| Town | Average Winter Season Wind Speed ($ms^{-1}$) |
|---|---|
| | |
| Anstruther | 5.0 |
| Crail | 4.6 |
| Leuchars | 5.3 |
| Dundee | 6.3 |

**Table 7.4.1 – Calculated Average Wind Speeds**

In order to exhaust wind speed examination, the DTI were consulted and the information recorded by them was used to generate an average wind speed at a height of approximately 5m. Table 7.4.1 indicates the average values in varying local towns. It is clearly visible that wind speeds often fall short of manufacturers rated output datum values. Turbulence due to surrounding buildings will also have an effect on the performance of any small scale wind turbine. There are two possibilities for wind turbines at Anstruther i) small-scale roof mounted systems ii) large scale community system.

### 7.4.3 Wind Turbine Output

Wind turbines produce electricity directly to the household. Therefore this system could potentially be used to power electrical equipment within the dwelling such as appliances and lighting. Several wind turbines have been investigated, these are discussed below:

#### 7.4.3.1 Windsave WS1000

This turbine is a small-scale tower mounted unit produced by Scottish renewable energy company Windsave.

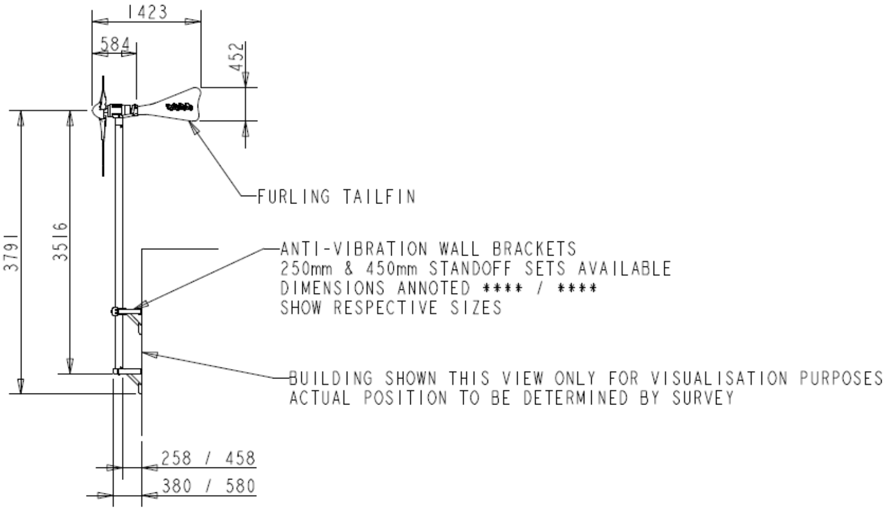


**Figure 7.4.5 – Windsave WS1000 (Windsave, 2007).**

The main components, rotors, brake, gearbox, generator and furling fan are mounted on top of a 3.7m high tower which connects to the side wall of the dwelling (as indicated in the figure 7.4.5), while the blades are 1.7m in diameter. This wind turbine is said to produce 1kW at 12.5ms$^{-1}$, the cut out wind speed of this unit is 14ms$^{-1}$ i.e. the unit will stop and shut down at this speed while the cut in speed is approximately 4ms$^{-1}$ i.e. the unit start up only when the wind speed exceeds this level.

The Windsave turbine regulates its energy input to the dwelling based on wind speed and demand; it feeds into the mains supply to the dwelling and only supplies when it can invert and supply conditioned (230VAC, 50Hertz) electricity to the main supply. As a micro wind turbine, the chances of the Windsave WS1000 exporting to the Grid are minimal. Properties typically have a base-load that is an ongoing consumption of electricity; this will often use the wind power if capacity is available. At 12m/s the turbine will run towards a 1kW output. The wind would have to blow a full hour to give 1kWh output. This is equal to a 'unit' of electricity (It may cost as much as 12p but typical figures for your supplier buying back kWh are 2.5p and buyback tariffs cost as much as £150 to setup (Windsave Ltd (2006))). There are very few places in the UK that would ever viably export to the grid from just one micro turbine. On this basis the opportunities from exported electricity from the Windsave WS1000 are minimal.

From the analysed wind speeds of tables 7.4.2 and 7.4.3 it can be seen that very rarely will the wind speed reach the 12.5ms$^{-1}$ for rated output.

| Wind Speed (ms$^{-1}$) | Power (W) | Energy (kWh) |
|---|---|---|
| | | |
| 4 | 32.3 | 57.9 |
| 5 | 63.0 | 87.4 |
| 6 | 108.9 | 112.3 |
| 7 | 172.9 | 148.8 |
| 8 | 258.0 | 149.2 |
| 9 | 367.4 | 144.8 |
| 10 | 504.0 | 136.6 |
| 11 | 670.8 | 107.3 |
| 12 | 870.9 | 79.3 |
| | | |
| Total | | **1023.6** |

**Table 7.4.2 – Calculated Output Windsave (Weekdays)**

| Wind Speed (ms$^{-1}$) | Power (W) | Energy (kWh) |
|---|---|---|
| | | |
| 4 | 32.3 | 44.2 |
| 5 | 63.0 | 67.9 |
| 6 | 108.9 | 87.6 |
| 7 | 172.9 | 113.7 |
| 8 | 258.0 | 110.2 |
| 9 | 367.4 | 102.5 |
| 10 | 504.0 | 90.7 |
| 11 | 670.8 | 79.2 |
| 12 | 870.9 | 60.1 |
| | | |
| Total | | **756.2** |

**Table 7.4.3 – Calculated Output Windsave (Weekends)**

Tables 7.4.2 and 7.4.3 indicate energy production during the week when the occupants are within their dwellings. Several assumptions have been made within the working out of this these are required to be made in order to generate a load production performance at varying wind speeds (please see A15).

| Dwelling | Appliance Load (kWh) | Lighting Load (kWh) | GSHP Load (kWh) |
|---|---|---|---|
| Harris | 2414 | 79 | 1818 |

| | | | |
|---|---|---|---|
| Jura | 2535 | 89 | 2111 |
| **% Load Covered by WS1000** | | | |
| Harris | 73.7 | 100 + | 97.9 |
| Jura | 70.2 | 100 + | 84.3 |
| **Number of Homes Powered** | | | |
| Harris | 0.7 | 23 | 1 |
| Jura | 0.7 | 20 | 0.8 |

**Table 7.4.4 – Potential Reduction due to WS1000**

The above table indicates the potential % load which could be covered if this wind turbine was installed at the Harris and Jura dwellings (please see A17).

### 7.4.3.2 Proven WT2500

This turbine comes as a 6.5m or 11m tower height and provides 2.5kW of power at peak conditions; the WT2500 is significantly bigger than the WS1000.

**Figure 7.4.6 – Proven WT2500 (Proven, 2007)**

This wind turbine is said to produce 2.5kW at 12ms$^{-1}$, the manufacturer states that this turbine does not have a cut out speed while the cut in speed is stated as 2.5ms$^{-1}$ i.e. the unit start up only when the wind speed exceeds this level.

| Wind Speed (ms$^{-1}$) | Power (W) | Energy (kWh) |
|---|---|---|
| 4 | 92.2 | 165.5 |
| 5 | 180.0 | 249.8 |
| 6 | 311.0 | 321.0 |
| 7 | 493.9 | 425.3 |
| 8 | 737.3 | 426.1 |
| 9 | 1049.8 | 413.6 |
| 10 | 1440.0 | 390.2 |
| 11 | 1916.6 | 306.7 |
| 12 | 2488.3 | 226.4 |
| | | |
| Total | | **2924.7** |

**Table 7.4.6 - Calculated Output Proven (Weekdays)**

| Wind Speed ($ms^{-1}$) | Power (W) | Energy (kWh) |
|---|---|---|
| 4 | 92.2 | 126.3 |
| 5 | 92.2 | 99.3 |
| 6 | 92.2 | 74.2 |
| 7 | 92.2 | 60.6 |
| 8 | 92.2 | 39.4 |
| 9 | 92.2 | 25.7 |
| 10 | 92.2 | 16.6 |
| 11 | 92.2 | 10.9 |
| 12 | 92.2 | 6.4 |
| | | |
| Total | | **459.3** |

**Table 7.4.7 - Calculated Output Proven (Weekends)**

| Dwelling | Appliance Load (kWh) | Lighting Load (kWh) | GSHP Load (kWh) |
|---|---|---|---|
| Harris | 2414 | 79 | 1818 |
| Jura | 2535 | 89 | 2111 |
| **% Load Covered by WT2500** | | | |
| Harris | 140.2 | 100 + | 186.1 |
| Jura | 133.5 | 100 + | 160.3 |
| **Number of Homes Powered** | | | |
| Harris | 1.4 | 42 | 1.8 |
| Jura | 1.3 | 38 | 1.6 |

**Table 7.4.8 - Potential Reduction due to WT2500**

The Proven WT2500 covers the usage of all aspects, but only individually, i.e. if we sum the electrical loads for the heat pumps and appliances, the WT2500 would cover only 80% and 73% of the Harris and Jura loads respectively. This turbine, obviously due to its size, is more advantageous than the WS1000 however its size could also be a potential drawback with regards to planning. Exporting to the grid with the Proven WT2500 would also be fairly uneconomical and potentially difficult. The low power rating and probable low power production would not add to the grid significantly.

### 7.4.3.3. Proven WT15000

The Proven WT15000 is a fairly large turbine, and most likely the largest type to be critically appraised. This system provides 15kW at peak power. It is similar to the WT2500 however, and the tower is much larger and can range from 15m to 25m:

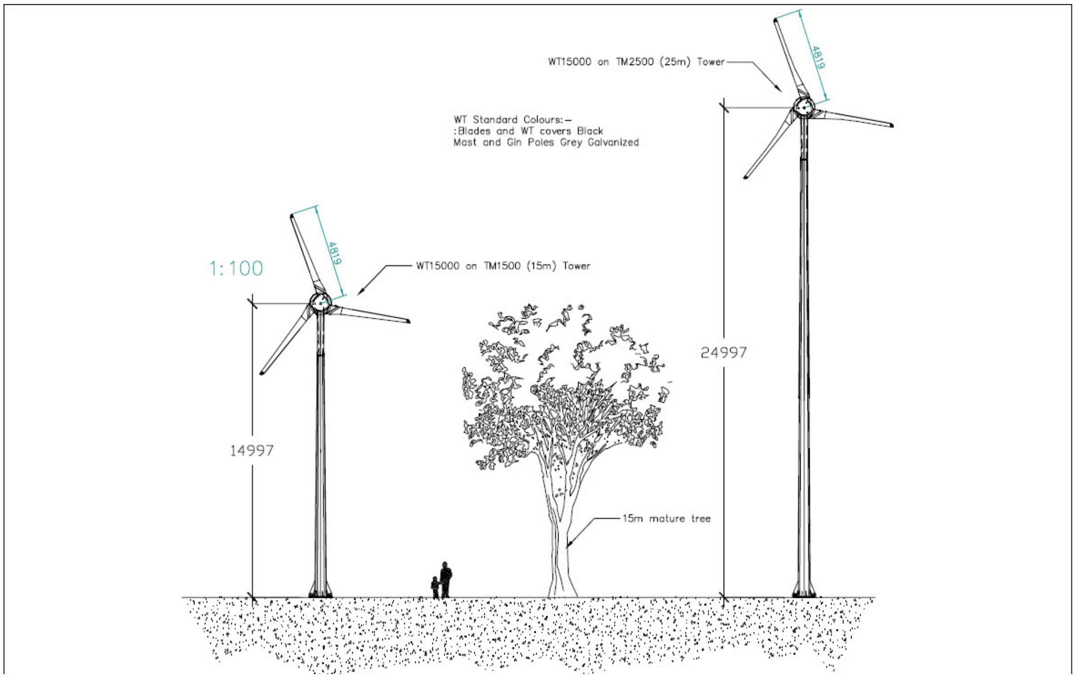


**Figure 7.4.7 – WT15000 Illustration (Proven, 2007)**

This wind turbine is said to produce 15kW at 12ms$^{-1}$. The manufacturer states that this turbine does not have a cut out speed while the cut in speed is stated as 2.5ms$^{-1}$ i.e. the unit starts up only when the wind speed exceeds this level. This cut in speed, similarly to the WT2500, is fairly low and would be sensible to assess this turbine as though it had a cut in speed of 4ms$^{-1}$. The size of this turbine means that it may create serious objections because in a small community it may not be aesthetically pleasing with a wind turbine towering over.

| Wind Speed (ms$^{-1}$) | Power (W) | Energy (kWh) |
|---|---|---|
| | | |
| 4 | 554.4 | 995.7 |
| 5 | 1082.8 | 1502.9 |
| 6 | 1871.1 | 1930.9 |
| 7 | 2971.2 | 2558.2 |
| 8 | 4435.1 | 2563.5 |
| 9 | 6314.8 | 2488.0 |
| 10 | 8662.3 | 2347.5 |
| 11 | 11529.5 | 1844.7 |
| 12 | 14968.5 | 1362.1 |
| **Total** | | **17.6MW** |

**Table 7.4.9 - Calculated Output Proven WT15000 (Weekdays)**

| Wind Speed (ms$^{-1}$) | Power (W) | Energy (kWh) |
|---|---|---|
| | | |
| 4 | 554.4 | 759.5 |
| 5 | 1082.8 | 1167.2 |
| 6 | 1871.1 | 1506.2 |
| 7 | 2971.2 | 1955.0 |

| | | |
|---|---|---|
| 8 | 4435.1 | 1893.8 |
| 9 | 6314.8 | 1761.8 |
| 10 | 8662.3 | 1559.2 |
| 11 | 11529.5 | 1360.5 |
| 12 | 14968.5 | 1032.8 |
| **Total** | | **13.0MW** |

**Table 7.4.10 - Calculated Output Proven WT15000 (Weekends)**

| Dwelling | Appliance & Cooking Load (kWh) | Lighting Load (kWh) | GSHP Load (kWh) |
|---|---|---|---|
| Harris | 2414 | 79 | 1818 |
| Jura | 2535 | 89 | 2111 |
| **% Load Covered by WT15000** | | | |
| Harris | 1267.6 | 100 + | 1683.2 |
| Jura | 1207.1 | 100 + | 14496.0 |
| **Number of Homes Powered** | | | |
| Harris | 12.6 | 387 | 16 |
| Jura | 12 | 343 | 14 |

**Table 7.4.11 – Load Met (WT15000)**

From the tables above it can be seen that the Proven WT15000 can cover the lighting for either 387 Harris homes or 343 Jura homes. If the site was split 50-50 between Jura and Harris, the lighting load would be met by the WT15000 with 2208kWh potential remaining. The WT15000 doesn't cover many dwellings with regards to GSHP and appliance loads; however, it will offset a certain amount of the site's carbon and would easily offset single dwellings' carbon emissions.

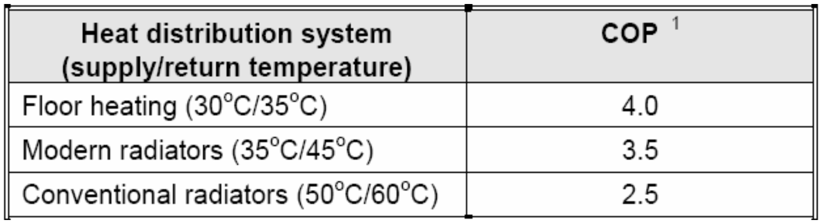
It should be noted that the analysis of wind turbines on paper is totally hypothetical. In reality modern turbines extract around 30-40% of the power in the wind – this has been built into the calculations. The most dominant and simple fact within the energy supply of the wind turbine is that it can't provide power when the wind isn't blowing. The historical wind data has been used in order to best quantify the wind resource in Anstruther. As mentioned earlier, the weather file investigation has given the best indication of wind velocities and this is the data which has been used within the calculations.

## 7.5 GSHP

### 7.5.1 Operation

Ground Source Heat Pumps (GSHP) are attractive alternatives for conventional heating systems; they are essential systems which take heat and increase it to a higher temperature. The main component of a heat pump is the heat exchangers through which energy is extracted and emitted and a means of pumping heat between these exchangers.

The GSHP transfer heat from the ground into a building to provide space heating and, in some cases, to preheat domestic hot water (Energy Efficiency Best Practice, 2000). The key to energy reduction through a GSHP system is the Coefficient of Performance (COP) which is a measure (expressed as a ratio) of the energy output to the energy input of the system. A typical COP for a radiator system (such as that at Anstruther) is in the region of 3.5 however this has implications on radiator sizes due to the lower flow and return mean temperature; the flow and return temperature within the study has been taken as 45℃ flow and 35℃ return (BSRIA, 1999).



| Heat distribution system (supply/return temperature) | COP [1] |
|---|---|
| Floor heating (30°C/35°C) | 4.0 |
| Modern radiators (35°C/45°C) | 3.5 |
| Conventional radiators (50°C/60°C) | 2.5 |

**Figure 7.5.1 – COP and F&R Temperatures (GSHP- A Technology Overview, 2005)**

Since the carbon emissions factor for grid supplied electricity (the fuel used by a heat pump) is 0.422kg$CO_2$/kWh and the same value for the gas boiler is 0.194kg$CO_2$/kWh the heat pump would only break even from a gas boiler system with a minimum COP of 2.2. The COP of the system is therefore fundamental in the carbon emissions calculation.

Underfloor heating in a dwelling could be fairy ineffective and inefficient due to the extent of obstructions over the floor e.g. the bedroom would have cupboards and beds taking up a large degree of the floor area therefore restricting certain exposure area of the underfloor heating system. However, there are many successful installations of underfloor heating in the UK (Nu-Heat, 2006). More research may be required to meet the specifications of the Anstruther dwellings.

The *Viessmann Vitocal 300 B/W* is identified as a potential heat pump; this unit generates a footprint of approximately 600mm wide x 650 deep with a height of 1200mm; an image of this is given in Figure 7.5.4.

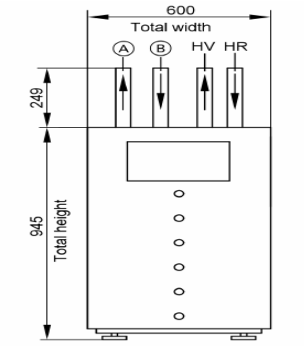


**Figure 7.5.2 – Elevation of GSHP**

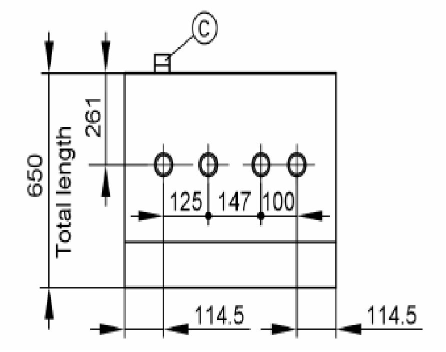
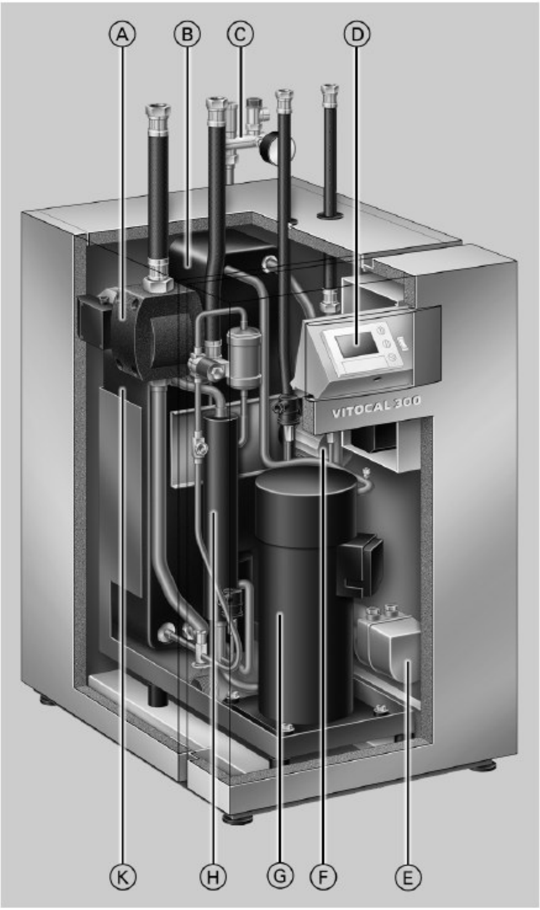


**Figure 7.5.3 – Footprint of GSHP**

Figure 7.5.4 – Image of GSHP



Ⓐ Brine circulation pump
Ⓑ Condenser (thermally insulated)
Ⓒ Safety assembly
Ⓓ Weather-compensated, digital heat pump control unit CD 70
Ⓔ Electric booster heater
Ⓕ Heating circuit pump
Ⓖ Hermetically sealed Compliant scroll compressor
Ⓗ Additional heat exchanger
Ⓚ Evaporator (thermally insulated)

Figure 7.5.5 – Section through GSHP Unit

***N.B Above three GSHP images taken from Viessmann specification catalogue***

### 7.5.2 Output

The GSHP is based on the 4.8kW *Viessmann Vitocal 300*. The COP from this heat pump is approximately 4.1 (as determined by the manufacturer). The water flow and return temperatures to the emitters when this system is used would be 35℃ and 30℃ respectively; this would require the current emitters to increase in size by approximately 570%. The type of emitters could be changed in order to deal with this increase in surface area requirement. However, it is likely that the emitters will still be exceptionally large and impractical.

It is possible to increase flow and return temperatures and accept a lower COP in order lower the size of emitters required however, this deviates from the point in the heat pump system and any COP below 2.2 would actually be worse for carbon emissions than a gas fired boiler. With flow and return temperatures of approximately 45℃ and 35℃ respectively; the COP would be around 3.5 (BSRIA, 1999). This level of COP is acceptable from an energy consumption perspective but the current emitters would have to be 3.5 times larger than they currently are or higher performance emitters would be required; higher performance emitters would still be very large and possibly impractical.

In the absence of the full range of site specific data such as the soil conductivity, ground diffusivity and recharge rate, which are normally obtained by geotechnical analysis; rule of thumb estimates can be used as an alternative in order to determine external values. The main type of coil for a domestic system is a spiral (also known as a Slinky) coil; this is effectively a long piece of piping wound into hoops like a coil an image of which is shown in Figure 7.5.6:

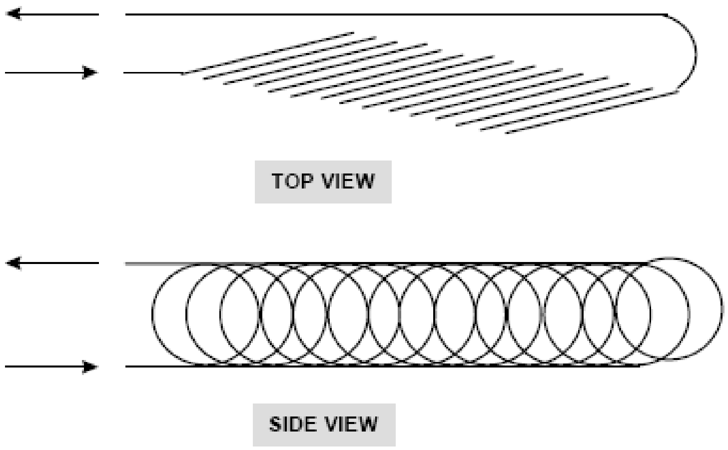
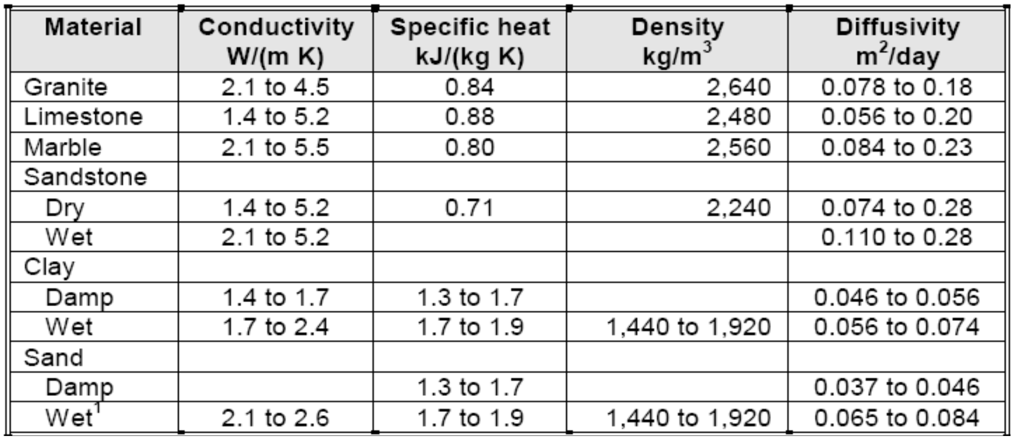


**Figure 7.5.6 – Spiral Ground Coil (LCBP, 2004)**

**Figure 7.5.7 – Installing Spiral Coil (LCBP, 2004)**

It should be noted that installation of the ground loop should not be made underneath tarmac or overlain concrete areas as these affect the performance of a GSHP significantly. It is better for the heat exchanger section of the GSHP system to be in contact with wet materials due to the high thermal conductivity of water; Table 7.5.8 illustrates this:



| Material | Conductivity W/(m K) | Specific heat kJ/(kg K) | Density kg/m$^3$ | Diffusivity m$^2$/day |
|---|---|---|---|---|
| Granite | 2.1 to 4.5 | 0.84 | 2,640 | 0.078 to 0.18 |
| Limestone | 1.4 to 5.2 | 0.88 | 2,480 | 0.056 to 0.20 |
| Marble | 2.1 to 5.5 | 0.80 | 2,560 | 0.084 to 0.23 |
| Sandstone | | | | |
| Dry | 1.4 to 5.2 | 0.71 | 2,240 | 0.074 to 0.28 |
| Wet | 2.1 to 5.2 | | | 0.110 to 0.28 |
| Clay | | | | |
| Damp | 1.4 to 1.7 | 1.3 to 1.7 | | 0.046 to 0.056 |
| Wet | 1.7 to 2.4 | 1.7 to 1.9 | 1,440 to 1,920 | 0.056 to 0.074 |
| Sand | | | | |
| Damp | | 1.3 to 1.7 | | 0.037 to 0.046 |
| Wet[1] | 2.1 to 2.6 | 1.7 to 1.9 | 1,440 to 1,920 | 0.065 to 0.084 |

**Figure 7.5.8 – Thermal Properties of Certain Materials (GSHP Technology Overview, 2007)**

To critically appraise boreholes is much more difficult as these require very deep holes; a full geotechnical survey would be required to technically appraise such a system. For a system of this scale, spiral coils would generally be more economical and practical.

The table below gives a range of estimates of ground heat exchanger lengths per kW load. In order to match the heat pump unit load a spiral coil of at least 192m in length would be required while at the large end of the coil size spectrum, a coil of 432m would be needed. The Spiral system usually sits in a trench which is approximately 400mm wide and 1800mm deep; the Ground Source Heat Pump Association state that in typical domestic installations a few 50m length trenches are required for a domestic situation therefore the lower figure for the spiral coil length (192m) is required based on this information.

| **Exchanger lengths** | |
|---|---|
| Spiral | 40 – 90 m/kW |
| Horizontal | 5 – 35 m/kW |
| Vertical | 20 – 50 m/kW |
| **Estimates of GSHP cost** | |
| Heat Pump unit | £200 – 300 per kW |
| Bore-holes (open loop) | £1500 – 2000 (single well) |
| | £2000 – 3000 (pair) |
| Bore-holes (closed loop) | £140 per kW |
| O&M costs | Approx. 30% less than conventional heating systems |
| Payback period | 2-6 years (based on the difference in installation costs between a high efficiency gas boiler and a GSHP system) |
| **Estimates of GSHP cost/emission** | |
| $CO_2$ emissions | Approx. 40% reduction to that of conventional heating/cooling systems |

**Table 7.5.1 - Rule of Thumb Data (GSHP Eco-House, Doherty et al, 2003)**

The calculation methodology detailed by the ODPM (please see assumption A18) on carbon emission indicates reductions for Harris and Jura as 51.3% and 51.2% respectively; Table 7.5.2 details the figures.

| Dwelling | Existing ($kgCO_2$) | GSHP ($kgCO_2$) | Reduction ($kgCO_2$) | % Reduction |
|---|---|---|---|---|
| **Harris** | 1575 | 767 | 808 | 51.3 |
| **Jura** | 1741 | 891 | 850 | 51.2 |

**Table 7.5.2 – Carbon Reduction of GSHP**

### 7.5.3 Costs

A GSHP system is significantly more expensive than a traditional gas fired boiler system; Table 7.5.2 indicates the costs of the ground coils as well as typical GSHP unit costs; the EST (2003) state that an installed cost of £800 - £1200 per kW would be likely. Thus totals for the Jura and Harris are in the region of £2640 - £4000 and £2960 - £4440.

## 7.6 Combined Heat & Power (CHP)

### 7.6.1 Operation

CHP systems are essentially small power plants located within the site on which the energy output shall be consumed. The CHP plant essentially generates electricity; a by-product of electricity generation is heat. Most power plants lose this heat as waste however, since CHP is intended to be used within close proximity to the site, this waste heat can be used to heat water and thus provide space heating. CHP systems can be fuelled by various methods such as gas, diesel, oil, biomass and biogas. It's exceptionally important to understand the heat-power ratio when sizing such a system.

### 7.6.2 Output & Performance

For this study, small scale i.e. individual dwelling CHP has been disregarded outright due to the low loads as well as the extreme fluctuations of electricity and heat consumption of single dwellings.

A community CHP system has been sized in order to cope with the calculated loads based on the site incorporating 50% Harris and 50% Jura dwellings. The maximum demand generated by dwellings is very difficult to measure and would most likely require on-site measuring in order to be completely accurate. However, 2kW is the figure which utility companies use in order to size domestic systems. By using this figure, a reasonable estimate can be made.

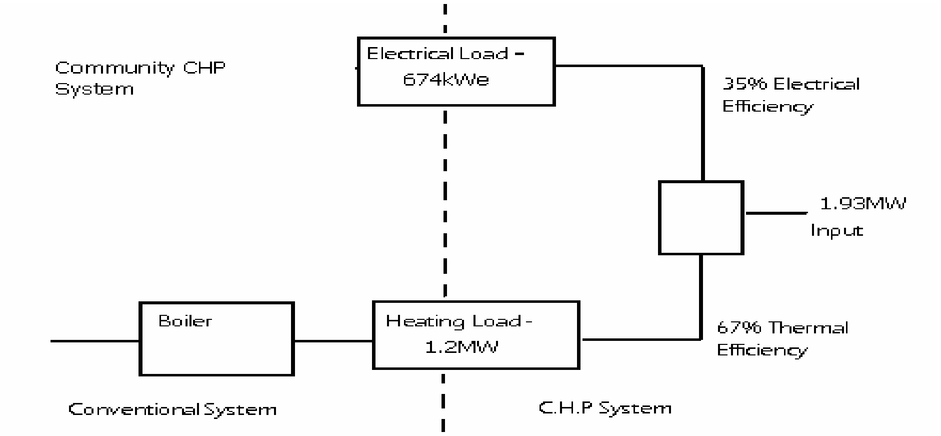


**Figure 7.6.1 – CHP Ratio Illustration (EA, 2000)**

Figure 7.6.1 indicates the base heating and power loads; it has been assumed that the CHP system has a 35% electrical efficiency and 67% thermal efficiency; these are typical values. The boiler system on the heating side is for top-up and back up, it maybe the case that it is never required for top-up.

The heat to power ratio is 1.78:1, with this ratio, the CHP system (based on the above efficiencies). It should be noted that Figure 7.6.1 is an illustration intended to highlight the importance and reliance of heat to power ratios. It can be seen that heat and electricity are reciprocal by-products in this system i.e. if heat only is required electricity will be wasted and if only electricity is required heat will be wasted therefore a CHP system is generally only useful when heating is required which will only be in the winter months. Therefore it may be the case that electricity generation during summer will be via another source.

Energ are a company with the capability of supplying CHP units at the scale of a community system. The unit which they could supply covering the base electrical load is the ENERG 770; this provides 770kW electrical power and a thermal output of 912kW generating a heat to power ratio in the region of 1.18:1 with a fuel input of 2.3MW.

### 7.7 Analysis of SAP calculations

In order to provide reductions in line with the Code for Sustainable Homes, an improvement on Part L (the English equivalent of Part 6) is required. Therefore a percentage improvement required to take the carbon emission level down to the value calculated via SAP has been added onto the stepped emission bands of 10%, 18%, 25%, 40% and 100% reduction over the SAP value. Table 8.1.1 shows a summary of the SAP calculations for different scenarios.

| Scenario | Harris | | Jura | |
|---|---|---|---|---|
| | Total $kgCO_2$/Year | Dwelling $CO_2$ Emission Rate ($kgCO_2/Year/m^2$) | Total $kgCO_2$/Year | Dwelling $CO_2$ Emission Rate ($kgCO_2/Year/m^2$) |
| Notional as Existing | 2730.2 | **34.2** | 3106.1 | **23.8** |
| Actual as Existing | 2431.3 | **30.4** | 3425.1 | **26.3** |
| Actual – wall U-value 0.18 | 2280.1 | **28.5** | 3180.9 | **24.4** |
| Actual – wall U-value 0.21 | 2317.3 | **29.0** | 3234.6 | **24.8** |
| Actual – window U-value 1.4 | 2342.1 | **29.3** | 3342.0 | **25.6** |
| Actual – 100% Low Energy Lighting | 2383.5 | **29.8** | 3336.8 | **25.6** |
| Actual – $4m^2$ SHW panel (50% of hot water load) | 2261.4 | **28.0** | 3063.2 | **23.5** |
| Actual – All improvements above | 1977.6 | **24.5** | 2652.6 | **20.3** |

**7.7.1 SAP Calculations Summary**

The notional scenario complies with the CIBSE Building Regulation Part L 2006. With that in mind it is important to note that after all improvements are applied, the Harris dwelling gives a DER of 24.5 $kgCO_2/Year/m^2$, which is 28.36% of an improvement on the existing building regulations. The Jura dwelling on the other hand only has a 14.7% improvement on the building regulation with all improvements implemented.

### 7.8 Conclusion of renewable energy technologies

This section has looked at which renewable technologies are available to provide suitable energy requirements of the Jura and Harris dwellings. From the analysis it was found that most micro-renewable technologies have the potential to be integrated into new developments at the design stage. It is vital for the installation of micro-renewables to be considered early on in the design process to minimise costs and take the greatest advantage of the resources available. This will also allow developers to factor any added costs into their calculations. In general, more effort is required to add a micro-renewable system to an existing building than for a new build where it can be included at the development stage.

The integration of renewable energy sources into a project like Anstruther requires an analysis of all energy using and energy generating equipment to assess the impact they have on the prospective annual energy balance. Installing some photovoltaic panels to a conventional design does not make a building sustainable.

A combination of micro-generation technologies such as wind and solar is a good idea in order to take advantage of all weather conditions to provide energy needs. An advantage of combining solar and wind power is that they have a power generation profile that relates well with domestic demand (i.e. steady moderate power generation with peaks of output for planned uses.

In terms of combining GSHP and CHP with solar or wind, it would be more effective to integrate the combination within a community rather than individual dwellings. The analysis of the two residential dwellings indicates that when assessing the renewable energy options there are certain steps that need to be followed. The steps are as follows;

1. Understand the energy requirements:  consider energy efficiency measures which will enable to meet a proportion of these requirements using a renewable technology.
2. Understand the dwelling: compare possible technologies against the characteristics of the dwelling, such as space, materials and structure.
3. Specialist advice: After identifying a renewable energy technology a feasibility study should be taken.

4. Identify a supplier: Reliable supplier will be required after the feasibility study
5. Planning: Legal issues regarding planning permission will need to be resolved
6. Implementation: Installation of chosen technology should be carried out.
7. Maintenance: Monitoring of system so that it continues to operate at maximum efficiency.

# Chapter 8: Discussion and Conclusion

## 8.1 Categorisation of Anstruther dwellings

The investigation into the carbon footprint of the two dwellings indicates the performance of the Energy and Water minimum standards applied to the Code for Sustainable Homes.

The target emission values for compliance with Part 6 are 2730.2kg$CO_2$/year and 3106.1kg$CO_2$/year for the Harris and Jura dwellings respectively; these have been determined via a SAP calculation for both dwellings.

The results in table 7.7.1 show that the Harris dwelling can achieve level 3 rating in energy and water after recommended improvements have been applied. From Table 1.2.1, it states that 57 points are required to achieve a level 3 (***) rating.

Therefore, 46.7 points are still required to reach the acquired level. As well as meeting the minimum requirements for the remaining standards other things must be done obtain the points. These could include, cycle storage, provision of a home office set up, reducing the amount of water that runs off the site and the use of highly sustainable materials.

The Jura dwelling currently emits 3360kg$CO_2$/year. This exceeds the notional TER by 8.2%. Improvements are required in order for the dwelling to pass regulations. By reducing the wall U-Value to 0.21 W/m$^2$K in line with the upgraded wall U-Value detailed by Muir Construction, the SAP calculation reveals a $CO_2$ emission of 2730kg$CO_2$/year. This complies with Part 6 of the building regulations.

However, even by implementing a lower wall U-value of 0.18, 100% low energy lighting and a 4m$^2$ SWH panel results in an improvement over Part 6 of only 14.7% which is slightly greater than the minimum level 1 standard.

In summary, from the carbon analysis of the two dwellings it was found that the three bedroom semi-detached Harris dwelling met level 3 of the CSH in terms of Energy/$CO_2$. The larger dwelling Jura on the other hand only achieved level 1 in terms of Energy/$CO_2$.

### 8.2 Discussion

The aim of this work has been to provide an evaluation of low carbon dwellings relative to the Code for Sustainable Housing. This was carried out by identifying energy efficiency improvements for new UK house builds using Muir Construction's Anstruther dwellings as a case study. The intention was to provide knowledge of principles and techniques of sustainable housing in the UK and apply them to reduce energy consumption in new homes.

The recommended approach outlined is holistic and carried through from the carbon footprint analysis to renewable energy technology selection. This has been detailed and presented in chapters five to seven. The analysis is to show how base loads of a house are determined and reducing the energy loads by analysing when and where energy is used and, by employing low and zero carbon heating and power equipment for the development of new homes.

The analysis undertaken in this study suggests that the recently revised Part L of the Building Regulations leads to a significant reduction in carbon emissions from dwellings. Harris and, in particular Jura demonstrate that the levels of carbon dioxide produced at a notional standard are in fact relatively low with Jura only emitting 23.8 $kgCO_2/Year/m^2$.

Due to the limited data on the specifications of the dwellings proposed at Anstruther the analysis has been based on a number of assumptions including the quantity of hot water consumed per person, use of white goods per day and periods with which the dwelling is occupied. Where assumptions have been made, calculated figures have been compared with published data and data supplied by Muir construction. Although limited in range the calculated energy consumption and emissions figure compare well with published data.

It was found that there was in depth literature available both practical and theoretical on sustainable housing but only limited resources available with respect to established examples of the CSH. Currently the CSH is only applicable to England & Wales. However, with the English Performance of Buildings Directive enforcing that all new homes will require an Energy Performance Certificate it is likely that new homes in Scotland will follow suit. This is why this study used the energy and $CO_2$ benchmarks in the CSH.

Although the CSH acts as a comprehensive environmental assessment a significant problem arose during this evaluation. The problem is the method in which the CSH determines an improvement over the target emission rates. Although the Harris dwelling calculated to have a 28.4% improvement over the notional value compared to Jura's improvement of 14.7%, the Jura dwelling in actual fact produced less carbon emissions.

| Scenario | Harris ($kgCO_2$/Year/$m^2$) | Jura ($kgCO_2$/Year/$m^2$) |
|---|---|---|
| Notional | 34.2 | 23.8 |
| All improvements | 24.5 | 20.3 |

**Table 8.2.1: Key SAP calculations of the two dwellings**

Table 8.2.1 shows the Harris dwelling performs quite poorly after the improvements are included to reduce the carbon emissions. The SAP results for the Harris dwelling is only 0.7 $kgCO_2$/Year/$m^2$ greater than the notional value (i.e.no improvements added) of the Jura dwelling. This may be due to the SAP calculation unable to calculate for specific renewable energy technologies such as CHP. As renewable energy technologies become more common in housing this area will need to be addressed. It seems that at present the current set up of calculating carbon emissions of a home.

The standard for water efficiency in cubic metres per bed space per year does appear to be an improvement over the current situation. However, it is apparent that the actual usage is dependent upon the habits of the occupants. It is difficult to see how it can be realistically measured at the design stage. Moreover, there is no clear indication about whether the figure of water consumed relates to just mains water or all water use.

It is important to note that not all the categories of the CSH carry the same importance. For example, minimum standards for energy and water efficiency have been set at each of the Code's six levels. This is why each category should be individually scored and very high minimum standards set for the most significant, such as insulation and recycling. This would be a step in the right direction for a simpler and more accessible system for both industry and the public.

### 8.3 Conclusion

Housing in the UK contributes to around 27% of the total $CO_2$ associated with energy use. The research of this project has contributed to evaluating low carbon housing with respect to the standards issued in the Code for Sustainable Housing. Results show that carbon emissions can be reduced using lower U-values in walls and windows, increased energy efficient lighting and also the use of some renewable energy technologies to achieve level 3 in terms of energy and $CO_2$ of the CSH.

There is evidence that there has been increasing investment in Sustainable Housing in the U.K. with more and more construction companies wising up to the new regulations. Companies such as Stewart Milne house builder have proved that level 6 of the CSH can be obtained with the development of the Sigma House.

The barriers which face low carbon housing vary and include the following; design practices such as the quantity of inaccurate assumptions and rules of thumb (which is evident in the appendices below), the perception that the building industry has a reluctance to build to a higher standard than the minimum required and to people investing in home renewable technologies due to a lack of awareness.

The Code of Sustainable Homes is said to be the sustainable assessment of new homes in the UK. However, in the code the only area of sustainability that is assessed is the environment. Leaving the other two pillars of sustainability (social and economic) ignored. In order that new housing the UK is comprehensively sustainable, both the social and economic aspects must be considered. This may include effects on transport energy consumption because this would reflect the relative locations of houses, shops and workplaces as well as household income levels.

While the CSH relates to new homes, it is possible to see a time when a similar standard could be developed for non-dwellings and non-residential buildings. It is important that the voluntary status is changed to mandatory as soon as possible. On a final note, as temperatures rise as a result of global warming, homes will have to increasingly rely on air conditioning to remain comfortable. This will increase energy usage and carbon emissions. Therefore the CSH must try and address the issue of overheating as this will prove to be a problem with homes during the next fifteen years.

### 8.4 Recommendations of Further work

Social and economic aspects of sustainable homes are good research topics. All new developments will add stress on to the environment. Therefore making a house as sustainable as possible including environmental, social and economic aspects is important to reducing the added stress.

During this project the main focus was on the energy/$CO_2$ and water aspects of the CSH. More insight into environmentally friendly materials, site and household waste and surface water run-off may be considered in terms of feasibility and costs.

Furthermore, if those involved in the design, approval and construction of new housing are to make a positive contribution to the raising of environmental standards it is important that key areas where education and training are needed are identified. Finally, a closer study into how different types of renewable energy technologies combined compliment each other should be examined.

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# Appendix

Appendix: Calculations

**C1. Heat Loss Calculations (Existing)**

All heat loss calculations have been determined by using the conductance and infiltration formula shown below:

$Q_{con}$ = U x A x ΔT

$Q_{inf}$ = 1/3 x N x V x ΔT

**C2. Appliance Calculations (Existing)**

Energy Consumption of Fridge Freezer = 317kWh/year (value taken direct from manufacturer)

Energy Consumption Fan Oven = Rating x Time x Days
= 0.78 x 1 x 365
= 285kWh/year

Energy Consumption Dishwasher = Rating x Time x Days
= 1.05 x 365
= 192kWh/year

Energy Consumption Washer/Dryer = 850kWh/year (value taken direct from manufacturer)

Energy Consumption Canopy Hood = Rating x Time x Days
= 0.18 x 0.5 x 365
= 33kWh/year

Energy Consumption Canopy Hood = Rating x Time x Days
= 0.13 x 0.5 x 365
= 24kWh/year

Energy Consumption Fan Oven = Rating x Time x Days
= 1 x 1 x 365
= 365kWh/year

Gas Consumption Hob = P / GCV
= 4.7 / 38.7
= $0.000122 m^3 s^{-1}$

**C3. Shower Hot Water Consumption (Existing Harris)**

4 people at 5 minutes per shower for 75% of the year

= 20 minutes
= 0.333 hours x 365 x 0.75
= 92 hours

Energy Consumption = Rating x Time
= 9.5 x 92
= **874kWh/year**

**C4. Bath Hot Water Consumption (Existing Harris)**

E = v x Cp x ΔT
= 133.3 x 4.186 x (60 – 10)
= 27900kJ
= 27.9MJ/day
= 10184MJ/year

Since the bath is only being used for 25% of the year, this value reduces:

= 10148 x 0.25
= 2546MJ/year

1kWh = 3.6MJ

Energy Consumption = E / 3.6
= 2546 / 3.6
= **707kWh/year**

**C5. Cleaning Hot Water (Existing Harris)**

E = v x Cp x ΔT
= 2.5 x 4.186 x (60 – 10)
= 523.3kJ
= 0.523MJ/day

If there are two sink full's of hot water used to wash dishes etc per day this changes to 1.05MJ/day

With an annual value being 382MJ

1kWh = 3.6MJ

Energy Consumption = E / 3.6
= 382 / 3.6
= **106kWh/year**

**C5. Cylinder Hot Water Consumption (Existing Jura)**

There is a 210litre cylinder specified for Jura therefore:

E = v x Cp x ΔT
= 210 x 4.186 x (60 – 10)
= 43953kJ
= 44MJ/day
= 16060MJ/year

1kWh = 3.6MJ

Energy Consumption = E / 3.6
= 16060 / 3.6
= **4461kWh/year**

**C6. Hot Water Carbon Emissions (Existing Harris - Shower)**

Carbon Output = Energy Consumption x Carbon Factor
= 874 x 0.422
= **369kg$CO_2$/year**

**C7. Hot Water Carbon Emissions (Existing Harris - Bath)**

Carbon Output = Energy Consumption x Carbon Factor

= 707 x 0.194
= **137.2kgCO$_2$/year**

**C9. Hot Water Carbon Emissions (Existing Jura - Bath)**

Carbon Output = Energy Consumption x Carbon Factor
= 4461 x 0.194
= **865kgCO$_2$/year**

**C10. Plant Operation Length**

Base Temperature = 21 – 5
= 16°C

Ratio = 1.06

Equivalent Full Load Operation

= 24 x 2496 x 1.06 / (21 - -5)
= 41932.8 / 26
= 2442.24 hours

Corrected Full Load Operation

= 2442.24 x 1 x 0.7 x 1.25
= **2137 hours**

**C11. Glazing U-Value (Existing)**

The U-Value for the existing window has been taken as 1.9W/m$^2$K in accordance with the window makeup details as per drawing no 866-50. This is in line with the CIBSE Guide A rating for this type of glass.

**C12. Glazing U-Value (Improved)**

The improved window U-Value has been taken as 1.4W/m$^2$K in accordance with the triple glazed, argon filled, low-e construction detailed by CIBSE (2006).

**C13. Infiltration Rate (Existing)**

The SAP calculation summates air exchange losses for chimneys, flues, fans and passive vents; it also considers the infiltration loss due to air-permeability of the façade of the dwelling.
It has been assumed that the dwelling has undergone and is built in compliance with the Accredited Standards and thus an air-permeability of 10m$^3$/m$^2$h has been taken.

Infiltration = $V_{50}$ / k
= 10 / 20
= **0.5ACH$^{-1}$**

**C14. Space Heating Carbon Emissions (Existing – Harris)**

Carbon Output = Heat Load x Operation Time x Carbon Factor
= 3.8 x 2137 x 0.194
= **1575kgCO$_2$/year**

**C15. Space Heating Carbon Emissions (Existing – Jura)**

Carbon Output = Heat Load x Operation Time x Carbon Factor
= 4.2 x 2137 x 0.194

= **1741kg$CO_2$/year**

### C16. External Illuminance Values

DF = $E_i / E_o$ - Lounge
0.015 = 150 / Eo
$E_o$ = 150 / 0.015
= **10,000lux**

DF = $E_i / E_o$ - Bedroom
0.015 = 100 / Eo
$E_o$ = 100 / 0.01
= **10,000lux**

### C14. Space Heating Carbon Emissions (Improved – Harris)

Carbon Output = Heat Load x Operation Time x Carbon Factor
= 3.23 x 2137 x 0.194
= **1339kg$CO_2$/year**

### C15. Space Heating Carbon Emissions (Improved – Jura)

Carbon Output = Heat Load x Operation Time x Carbon Factor
= 3.7 x 2137 x 0.194
= **1534kg$CO_2$/year**

### C17. Carbon Emission Reduction (Energy Efficiency)

Carbon Reduction $_{(Harris)}$ = (1 – (Emissions After / Emissions Before)) x100%
= (1 – (2697.5 / 3086.5)) x 100%
= **12.6%**

Carbon Reduction $_{(Jura)}$ = (1 – (Emissions After / Emissions Before)) x100%
= (1 – (3306.6 / 3685.5)) x 100%
= **10.2%**

### C17. Carbon Emission Reduction (GSHP - Harris)

$Q_{gshp}$ = 3.23kW

$Q_h$ = ($Q_{gshp}$ / $COP_{gshp}$) x Operation Time
= (3.23 / 4.1) x 2137
= 1688kWh

$C_{fh}$ = 0.422kg$CO_2$/kWh

$C_{gshp}$ = ($Q_h$ + $Q_h$) x $C_{fh}$
= (1688 + 130) x 0.422
= **767kg$CO_2$/kWh**

### C18. Carbon Emission Reduction (GSHP - Jura)

$Q_{gshp}$ = 3.8kW

$Q_p$ = 130kWh

$Q_h$ = ($Q_{gshp}$ + $Q_p$ / $COP_{gshp}$) x Operation Time
= (3.8 / 4.1) x 2137
= 1981kWh

$C_{fh}$ = $0.422kgCO_2/kWh$

$C_{gshp}$ = $(Q_h + Q_h) \times C_{fh}$
= 1981 + 130 x 0.422
= **<u>$891kgCO_2/kWh$</u>**

### C18. Wind Turbine Correction Factor (Winsave WS1000)

P = $0.5 \times \rho \times AV^3$
= $0.5 \times 1.2 \times (2.4 \times 12.5^3)$
= <u>2812.5W</u>

Manufacturer's information states that power output at this speed is 1000W therefore a correction factor has been applied to the formula in order to align with manufacturer's data:

Correction Factor = 1000 / 2812.5
= <u>0.356</u>

### C19. Total Electrical Requirements

Total electrical eoad for all 337 dwellings with 50% being Harris and 50% Jura is as follows:

Community without GSHP

C20. Biomass Community System

$Q_{bio}$ = 1.17MW

$Q_{consumption}$ = $Q_{bio}$ x Operation Time
= 1.17 x 2137
= <u>25003MWh</u>

Fuel Consumption = $Q_{consumption}$ / Energy Content
= 25003 / 0.0049
= 510263.1kg
= <u>510.3 tonnes</u>

Appendix: Assumptions

- **A1)** In the heat loss calculation a 15% margin has been added to the heat loss in order to account for issues such as heat loss from pipes.
- **A2)** Within the calculations it has been assumed that Muir Construction follow the Accredited Construction Details (Scotland) and build to an air-permeability of $10m^3/m^2h$
- **A3)** It has been assumed that Harris will have the same fridge freezer as the Jura dwelling.
- **A4)** The fan oven shall be in operation 1 hour per day for both the Harris and Jura dwelling types.
- **A5)** It has been assumed that the dishwasher at Jura shall be in operation once every two days.
- **A6)** It has been assumed that both the Harris & Jura shall have the same washer/dryer and that this appliance shall be in operation with one full load per day.
- **A7)** The canopy hood shall be in operation during the whole time which the hob is in use; this has been taken as 30 minutes per day.
- **A8)** Two rings on each hob shall be in use for 30 minute's per day.
- **A9)** It has been assumed that the Harris dwelling shall have 4 occupants each having a shower for 5 minutes per. The shower shall be used 75% of the year.
- **A10)** Bath Volume has been taken as 22 gallons which is equivalent to $0.1m^3$ 1/3 of this volume shall be hot water thus hot water volume ~ $0.0333m^3$.
  The bath shall be used when the shower is not i.e. 25% of the year.
- **A11)** It has been assumed that a 5 litre sink is filled with 50% hot water twice a day in order to determined and quantify hot water load for domesticated use such as dishwashing
- **A12)** Within the calculation for the hot water cylinder it has been assumed that the water in the tank shall start off at a temperature of 10℃ everyday. This may not be the case in real life as water draw off may never reach 210 litres therefore a level of heated water will be carried over to the next day; this is just one of many possibilities however, in order to quantify the energy consumption a line has been drawn and the assumption has been made that 10℃ shall be the starting temperature of the tank each day. Based on the control of the boiler and water tank, it has been assumed that the boiler shall always heat the hot water, even in summer time; the 3-port control valve indicated on Muir drawing 866-62 makes this possible. It has been assumed that no more than 210 litres shall be used per day and that the electrical element heater does not start up.
- **A13)** Several light fittings have been assumed in order to determine a lighting load; this is shown in the lighting table.

- **A14)** BS8206-2:1992 states a minimum daylight factor for living areas as 1.5% and 1% for bedrooms.
  CIBSE Lighting Guide 9 (LG9, 1997) states illuminance levels for living spaces and bedrooms as 150 and 100 lux respectively therefore the external illuminance can be found which generally turns out to be 10,000lux (please see calculation C16) from here lighting usage has been assumed and the pattern is shown in the main text. These values have helped determine the lighting usage pattern.
- **A15)** It has been assumed that the development shall incorporate 50% Jura and 50% Harris housing, this is not the case on the site layout however, Muir Construction have informed this method of analysis.
- **A16)** The periods within which the dwellings are occupied have been assumed, the theory for this assumption is outlined in section 2.3.1 of this report. The time bands are 8am to 5pm, the occupants are out at work (this is from Monday – Friday only). It has been assumed that the dwellings could potentially be occupied at anytime during the weekends.
- **A17)** The output for varying wind speed has been determined based on the cubic power-wind relationship. In order to do this a correction factor of 0.35 has been applied to the formula, this essentially accounts for the Betz limit. The calculations are estimates as monitoring of the turbine would be required.
- **A18)** It has been assumed that there is a mistake in the Governments published calculation methodology, the mistake can be found on page 19 of the document titled *Low or Zero Carbon Energy (Strategic Guide, 2007)*.
- **A19)** These times have been selected as this is when the occupants shall be in the dwelling therefore this is when demand will be present.
- **A20)** It has been assumed that a 5 litre sink is filled with 50% hot water twice a day in order to determined and quantify hot water load for domesticated use such as dishwashing