Scottish Energy Centre
Institute for Sustainable Construction

CIC Start Online – Academic Feasibility Study

Scottish Energy Centre (HEI)

&

Finex Joinery Ltd

Feasibility study: The sustainability and energy efficiency of three new build dwellings in Aberdour, Fife

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EXECUTIVE SUMMARY

CIC Start Online funded by European Regional Development Fund and SEEKIT programme of Scottish Government has made it possible for this academic partnership between Finex joinery Ltd and the Scottish Energy Centre part of Edinburgh Napier University to conduct a design stage feasibility study assessing the energy demand profile and potential power generation system solutions for three dwellings to be constructed in Aberdour, Fife.

Energy modelling for the three dwellings was undertaken to established heating and power demand. These figures were used to compare against Scottish Building Standards Section 7 and Passive house design requirements. Each dwelling was virtually constructed using the plans, elevations and elemental build-up of the dwelling's envelope as provided by the architect. Based on the space heating demand dwelling A achieved aspect 2 of the Gold standard and met the Passive house space heating criteria. Dwelling C achieved Gold standard and dwelling B obtained the Silver standard.

Assessment of the site ruled out a number of technologies pertaining to hydro and wind. In terms of electricity production, solar photovoltaic panels provide the most attractive solution available. The site allows for the placement of small solar farms adjacent to each house. The report comments on the foreseeable issues relating to living in home solely dependent upon on-site electricity generation. Living in within a dwelling committed to fully off-grid power generation comes with a host of lifestyle adaptations. The overarching goal is to provide on-site power generating solutions whilst ensure a standard of electricity living that the prospective occupants can adapt to.

Complexities arise when considering the power demand during night time or times during low seasonal positioning of the sun. To achieve the off-grid aim the PV system requires additional equipment, batteries and solar regulator to enable storage of generated power to meet 24 hour demand. Snow fall presents a particular issue during the winter preventing the system to generate the simulated energy demand. It is important to be conscious that energy would be produced during the day but mainly used during the night and with a higher demand for lighting and other electronics during the darker winter period.

Therefore a secondary feasibility study was conducted investigating the potential and economic implications of connecting the site to the national electricity grid. The main difference would be the use of the grid as a back-up to electricity demand, this also provides higher feed in tariff revenue and requires less equipment investment (does not require batteries and solar regulator). The connection is quite an investment, but it reduces the price of the other equipment and provides security of supply and a more attractive economically viable solutions.

From a series of technologies investigated to generated off-grid on-site space and water heating, a wood-pellet boiler solution has been reviewed and sized which has the potential to meet the modelled design heat load and provide comfort inside houses. A biomass boiler system with a fully automated fuel feeding system is advised to ease the transition from gas grid living to off-grid fuel delivery life-style. Three solar water heaters have been sized and included in the report to provide > 50% of each dwellings hot water demand. This technology was select as it requires no fuel by which to generate the hot water, which falls in line with the Section 7 Gold aspect 3 requirements. The solar water heater will need to be on the roof of the dwellings orientated as close to South as possible. This issue will need to be raised and discussed with the local planning in a bid to generate low carbon home and satisfying any visual planning constraints. Results from final provisional SAP calculations using assumptions based on heating system and on-site electricity generation show that the three dwellings satisfy Gold aspect 1, with a DER over 42.8% lower than the TER.

The outcomes of this feasibility study are to be utilised to create a projection towards the design and implementation of micro-renewable technology in the dwellings. The results of this study will portray the feasibility of the technology in terms of its sizing and operation and its potential return on investment. The figures related to capital cost of each of the technologies have been taken as close to real market based prices in line with the buildings limitations. It is strongly recommended that the summary of results and suggestions out of this report are designed appropriately and consulted with MCS accredited installers particularly technology suppliers.

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1.0 INTRODUCTION – AIMS AND OBJECTIVES

Finex Joinery Ltd proposes to build three energy efficient homes in a rural setting near Aberdour, Fife. From design stage each dwelling is to incorporate a combination of highly insulated building envelope and power and heat generating technologies with the aspiration of autonomy from grid electricity and gas. The homes have been designed by 'Architecture Design Development +' a local architect employed by Finex. With reduced energy demand as the key design feature ADD+ adopted a strong fabric first approach to the three homes, choosing well established building techniques and high levels of insulation which enables the design to go some way towards reducing the heating requirement for the home.

This feasibility study has been conducted to better understand and economically assess an approach for reduced energy demand and reduced grid-dependency. Using the designs and details worked-up by ADD+ the three dwellings were modelled using building assessment software (CYMAP 2012). The dwelling modelling took a dual approach; a heat loss simulation was undertaken for the three dwellings assessing the individually designed envelope fabric components to provide a baseline for heating demand. Utilising a high-resolution electricity demand profile generator, the electricity demand for each of the three dwellings has been calculated to provide an approximation for each dwellings unregulated energy demand.

The main aim of the feasibility study is to assess a number of recognised low-carbon renewable power generation systems in order to ascertain the most applicable technologies to power and heat the homes in order to meet the designed comfort needs. The report comments on each of the three dwellings in terms of designed energy demand, the report continues by reviewing the design under Section 7 'Sustainability' of the Scottish Building Standards (2011). The main body of the report goes further by investigating and discussing the options and alternatives relating to off-grid and grid connected power generation solutions. Finally concluding on options to best inform the client and design team to move forward with project realisation.

Figure 1 : Site location on map (circled) (TerraMetrics, 2012a)

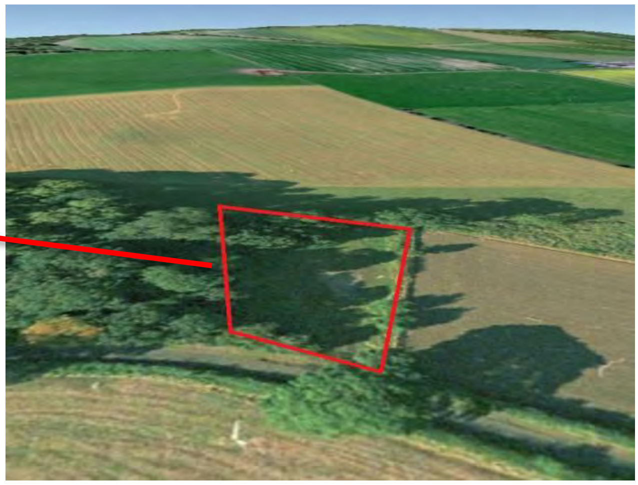

Figure 2 : 3D representation of the site (outlined) (TerraMetrics, 2012b)

Figure 3: North view of the site

Figure 4: Site plan with location of dwellings

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1.1 DWELLING DESIGN

One of the three houses; dwelling A has been designed to the passive house building methodology using timber framed blown insulation system. dwelling B is designed using structural insulated panels (SIP) with a rendered façade. dwelling C has been designed using timber frame kit with a brick façade, brief details of each dwelling is shown in Table 1.

Table 1: Summary of dwelling design parameters

	Dwelling A	Dwelling B	Dwelling C
Total floor area [m²]	255	200	249
Front elevation orientation	East	South	East
Number of rooms [excluding passages and bathrooms]	10	8	8
Number of bedrooms	4	4	3
Construction method	Timber frame passive house	Timber frame SIP's closed panel construction with cement carrier board façade	Timber framed kit construction
Glazing	Triple	Triple	Triple

Each house was modelled in Cymap and/or Ecotect computer modelling software, coupled with an energy requirement calculation based on the methods used within the SAP methodology. The following assumptions were made during the modelling and data input.

A value of 0.8W/m²K was used for the windows in dwellings A and B, a value of 0.7W/m²K was used for the windows in dwelling C as this was specified in the detailed drawings. 0.8W/m²K was chosen for dwelling A and B as this is the requirement for Passive house and without the high thermally efficient windows dwelling B would not achieve higher than Bronze under Section 7 (Scottish Government, 2011) requirements. The U-value of 1.5W/m²K has been used for the external doors in dwelling B and C whilst 0.8W/m²K has been used for the doors of dwelling A as per passive house requirements. Thermal bridging y-value of 0.01W/m²K was used for dwelling A, whilst 0.08W/m²K y-value was used for dwellings B and C as this was the generic value assigned to the Scotland's simplified approach to thermal bridging calculation of construction details. The air permeability level of 3m³/h/m² was used for dwelling B and C, this is viewed as best practice level of airtightness without taking the same stringent approach to airtightness as required in passive house design. It is important to minimise ventilation heat loss by achieving a low air permeability level to reach the higher labels within Section 7 (Scottish Government, 2011). An air permeability of 0.6 air changes per hour has been used in dwelling A as this is passive house standard. As all three properties have an air permeability level of below 5W/m²K they require mechanical ventilation, as a result and on the focus of high performance low energy housing a mechanical ventilation system has been selected with balanced heat recovery and 91% efficiency.

The passive house design standard calls for high levels of thermal efficiency across the building envelope hence the stringent levels of thermal bridging and airtightness. These are values that serve well to reduce the dwellings heat energy requirement, however, low values of air permeability will require post completion airtightness testing to be carried out. It is for this reason a level of 3m³/h/m² has been chosen for dwelling B and C, this level is viewed as achievable, however, lower levels can be selected by the design team which will reduce the dwellings space heating requirement, but this must be achieved by post completion air tightness testing. This is similar for the thermal bridging values, although no post completion confirmation is required.

REQUIREMENT FOR PASSIVE HOUSE

The house characterised as dwelling A is to be built and has been designed using building standard and methodology established by Dr Wolfgang Feist in Germany 1991 and now governed by the Passivhaus Institute, referred to as Passive House in the UK. This building standard boasts higher fabric and ventilation energy efficiency levels whilst providing all year comfort and quality maintaining indoor climate by utilising passive building design techniques.

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This is a standard unto itself; the building must still comply with relevant Scottish Building Standards. In this instance the Passive House standard relates to the energy demand of the building. The buildings compliance will be verified by using the Passivhaus Planning Package (PHPP), this is not covered in this feasibility report.

The Scottish Passive House Centre (SPHC) is a consultancy and certifier for Passive House/Passivhaus in the UK. SPHC provides advice on Passive House design and certified materials, systems and technologies. Table 2 lists a brief overview of the Passive House design criteria which must be adhered to for SPHC to accredit the design.

Table 2: The SPHC published criteria for achieving Passive (energy) house standard

	Maximum values
Space heating demand	15 kWh/m²/year
Primary energy use	120 kWh/m²/year
Air tightness	0.6 a.c.h @ 50pa
U-value	
External envelope excluding windows and doors	0.15 W/m²K
Doors, glazing units including frame	0.80 W/m²K

Finex joinery acquired SPHC approved detail drawings for use in the design and construction of dwelling A. SPHC details have been used for the modelling and heat loss simulations for dwelling A.

REQUIREMENTS FOR SCOTTISH BUILDING STANDARDS UNDER SECTION 7 (Domestic)

Section 7 'Sustainability' was introduced to the Scottish Building Standards in 2011. Section 7 introduced a labelling system based on Bronze, Silver, Gold and Platinum as indications of the dwellings performance above the 2010 building standards. Provided the building complies with the mandatory section of the Scottish building Standards Section 1-6 the dwelling will be awarded a Bronze label of 'sustainability', the addition of Section 7 provides an optional prescriptive step-change in the dwellings performance and design aspects.

Section 7 contains a total of eight aspects which extends to areas of the dwellings design and performance. Areas include additional rooms for storage and access to the external environment. Other aspects focus on increased acoustic performance and for the first time the optional standard has introduced guidance on the level of information to be available in homes for the occupant to maximise the dwellings performance. The standard highlights areas to encourage in-home recycling and recycling on a national level with the introduced 'design for de-construction' aspect.

Section 7 remains an optional standard to achieving enhanced 'sustainability' label nationally recognised for the dwelling. In order to achieve 'Section 7 Gold label' all eight aspects must be adhered to. For the purposes of this feasibility study, the first three aspects of 'Section 7 Gold' (see Table 3) have been referred to when assessing the three ADD+ designed dwellings. Carbon dioxide emissions and energy for space and water heating are a key part of the building performance evaluation. The targets set by Gold aspects 1, 2 and 3 will be used as a benchmark by which each of the three dwellings will be compared. Whereas other areas such as flexibility and adaptability and well-being and security etc. are left to the design desecration of the architect. A side-by-side compressed guide to Section 7 'Silver' and 'Gold' has been included in Table 3.

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Table 3: First three aspects as detailed in Section 7 sustainability (Scottish Government, 2011)

Silver			**Gold**	
aspect 1	**Carbon dioxide emissions**		**aspect 1**	**Carbon dioxide emissions**
a	DER 21.4% lower than the TER set by 2010 standards		a	DER 42.8% lower than the TER set by 2010 standards
aspect 2	**Energy for space heating**		aspect 2	**Energy for space heating**
a	40kWh/m² maximum annual demand – houses		a	30kWh/m² maximum annual demand – houses
aspect 3	**Energy for water heating**		**aspect 3**	**Energy for water heating**
a	5% of the dwellings energy demand for water heating is generated from heat recovery or renewable sources		a	50% of the dwellings energy demand for water heating is generated from heat recovery or renewable sources
			b	a monitor displaying the energy generation from the primary renewable source, easily accessible

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2.0 MODELLING BUILDING ENERGY DEMAND

Modelling the energy requirement of the three proposed dwellings was the first step towards identifying the energy demand profile by which to attribute various renewable energy solutions. Autodesk Ecotect and Cadline Cymap software packages have been used to model the designs and simulate the energy profiles. Models include thermal analysis and fabric behaviour simulation taking in account the weather data for the area. Part of the modelling process includes creating layers and assigning materials to each element in the structures envelope. This was achieved by virtually constructing the design details as provided by ADD+. According to the thermal performance of each material the U-value and fabric heat loss was determined. Running the simulation it assessed the thermal efficiency of the building, providing an output showing the capacity of the fabric to hold the heat inside the house. A second set of thermal assessments were conducted used the calculation method set up in the industry and government recognised and accepted Standard Assessment Procedure (SAP).

2.1 ENERGY DEMAND FOR SPACE HEATING

Two methods were used to calculate the heating demand requirements for the three properties. The simulations results from Cymap generated a yearly heating load of circa 5600 kWh for dwelling A, the output for heating requirement from SAP is much lower at 2590 kWh/annum. Monthly results are detailed in Figure 5.

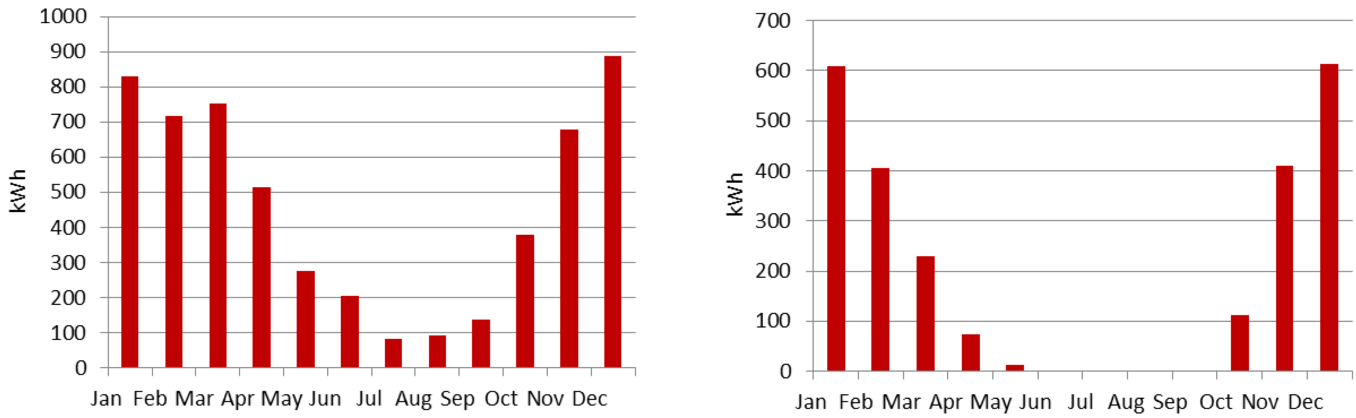

Figure 5: Heating loads over the year, dwelling A output from Cymap modelling [left] and output from SAP calculation method [right]

The bar chart shows the monthly heat demand for dwelling A and provides an annual heating demand in kWh which is used to size the technologies in Section 3.0 and 4.0. The data displayed in Figure 5 show a heating load profile as expected for this dwelling, with the largest demand in December and January. The proportion of monthly heating profile is a similar for dwellings B and C with the highest demand in December and January. Table 4 shows the modelled and calculated annual heating demand for the three dwellings along with comparative figures from 2011 DECC sub-national gas sales for Fife area and the 2011 OFGEM published median UK gas consumption figure.

Table 4: Calculated annual heating demand for the three dwellings, showing OFGEM and DECC published figures

	Dwelling A		Dwelling B		Dwelling C		Ofgem (2011) Median UK gas consumption	DECC (2011) Average domestic gas consumption Fife area
	Cymap	SAP	Cymap	SAP	Cymap	SAP		
Heating demand [kWh/annual]	5300	2590	9200	7319	9000	6955	16500	16300
Heating demand [kWh/annual/m²]	21	10	46	37	36	27		

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The Cymap modelling and simulations show a higher space heating energy demand than that calculated with the SAP calculation methodology. However, cross referencing the SAP results in Table 4 with requirements set out in Tables 2 and 3, dwelling A does meet the Passive house maximum heating criteria. With reference to aspect 2 of section 7 dwelling A and C meets gold and dwelling B meets silver (See Table 5)

Table 5: Dwelling demand for space heating and satisfying of design standards

Dwelling	Section 7 aspect 2	Passive house space heating criteria
A	Gold	Yes*
B	Silver	N/A
C	Gold	N/A

Building information modelling through Cymap has been conducted to show comparison to the Government Standard Assessment procedure (SAP). In this respect the SAP values are ones chosen to compare to Section 7 (Scottish Government, 2011), however, it is prudent to size heating technology based on modelled Cymap values.

*Certification of passive house label is obtained through successful completion of the passive house approved design software PHPP, which has not been covered in this report.

2.2 UNREGULATED ENERGY DEMAND

Utilising a combination of established domestic electricity demand profiling software developed by Loughborough University (Richardson 2010) and Autodesk (2011) the electricity demand for the dwellings was calculated based on a number of parameters:

- Active occupancy,
- Number of occupants,
- Dwelling usage profile based on occupancy pattern,
- Number of appliances, electronic equipment and lighting,

The use of domestic appliances, equipment and light within each dwelling was simulated over multiple 24-hour periods at one-minute time resolution. Several scenarios were modelled based upon weekdays and weekends, public holidays and expected occupancy patterns based on working and school timetables. Monthly and yearly occupancy behaviour and patterns were modelled to incorporate two main themes of electricity use, high electricity use and low electricity use. Electricity consumption is highly depends on the tenants' behaviour but for the purpose of the study some assumptions were made to simulate two behaviour styles. Assumptions were made based on hours of use for household appliances and number of entertainment devices in the dwellings. Table 6 displays each dwellings annual and peak electricity demand based on the higher and lower electricity usage. The UK national and sub-national electricity consumption figures have been added as published by OFGEM (2011) and DECC (2011).

Table 6: Calculated annual electricity demand for the three dwellings, showing OFGEM and DECC published figures

<table>
<tr><th></th><th>Calculated Electricity demand</th><th>Dwelling A</th><th>Dwelling B</th><th>Dwelling C</th><th>Ofgem (2011) Median UK consumption [kWh/annual]</th><th>DECC (2011) Average domestic consumption Fife area [kWh/annual]</th></tr>
<tr><td rowspan="2">Higher modelled</td><td>kWh/annual</td><td>5500</td><td>5500</td><td>4400</td><td rowspan="2">5100</td><td rowspan="4">4300</td></tr>
<tr><td>kWh/peak</td><td>8</td><td>8</td><td>6</td></tr>
<tr><td rowspan="2">Lower modelled</td><td>kWh/annual</td><td>3300</td><td>3300</td><td>2600</td><td rowspan="2">2100</td></tr>
<tr><td>kWh/peak</td><td>5</td><td>5</td><td>4</td></tr>
</table>

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Modelling multiple occupancy behaviour scenarios highlighted key concerns with the level of electricity that would need to be maintained during the winter period. Increased demand for lighting and assumed increased in electronic entertainment equipment usage during winter months suggests that the lower annual modelled electricity profile would be difficult to maintain. With the understanding the occupants for the homes will possess a level of energy frugality based on the vested interest with the project; it remains prudent to size the on-site electricity generating technology to the upper modelled demand profile. This is done in the interest of family growth and allowing the inhabitants to maintain a level of electricity use they would be accustomed to whilst allowing energy conservation and reducing energy demand to be worked into the occupants lifestyle without concern of black-out or power shortages.

2.3 MICROGENERATION

The selection and application of appropriate on-site power and heat generating technologies relies upon a number of factors. The technology needs to be sized according to the calculated heating and power usage profile of the dwellings as discussed in Section 2.1 and 2.2. The size and orientation of the site as well as the design dwellings along with the surrounding natural landscape i.e. valley formation, well established tree line/groups of tree and local water channel etc.

A site visit and aerial photographic survey identified that the site occupies the area between two hills, facing the east; the area is sheltered by trees on the west side. With this information some of the technological solutions available are not suitable for this project linked to feasible reasons, profitability, or physical and technical constraints. It doesn't mean that it can't be used, simply that for payback and efficiency optimisation reasons these should be avoided in this specific case.

Here are presented some of the potential technological solutions which could apply to this project with a description as to the reason they were ruled out of further investigation (non-exhaustive list).

Hydro technologies – It is understood that there is no meaningful water stream in the surroundings which could be used for power supply purposes.

Wind turbines – Could have been effective on this project but considering the site location and advice from a wind turbine design-and-install team, it was decided that the site would not be applicable for a wind turbine based on the sites low sitting and high surrounding hillside.

Solar PV – Considered for its potential to provide complete electricity generation, photovoltaic (PV) panels have the potential to provide all or part of the demand. The level of open area in the field adjacent to the dwellings provides good siting location for free standing solar farm. With no nearby or forecasted shading from foliage or neighbouring buildings to the area East of the site provides good reason to investigate PV's as part of the economic analysis.

Off-grid systems have been studied (Section 3.0), which involves additional equipment in comparison with the roof-mounted installations. Therefore systems such as charge controller also called solar regulator, including an MPPT device (Maximum Power Point Tracking) should be implemented to the PV array. It also includes tracking systems to maximize the PVs efficiency, and a battery bank to store the energy produced. This would allow for the 'unused' generated electricity to be stored during the day to all for night time energy demand. Indeed, during night time, as it is an off-grid construction, no electricity would be delivered to the house, and the solar panels won't generate energy during this period of time. Therefore grid-connected PV system has also been economically assessed in Section 4.0.

Ground source heat pump – A ground source heat pump extracts the heat from the ground. There are 3 types of systems which differ by their size and the ground surface they require to be implemented: Horizontal which the easiest to install but takes a lot of surface, vertical which requires bore holes of about 100m deep and requires soil analysis rising issues such as soil decontamination, and finally the slinky configuration, horizontal system improved in order to take less space. A heat pump could cost around £14,000 not including soil analysis and ground works.

A biomass boiler - can be considered in terms of heating systems. It is recommended to have a fully automated system to reduce the frequency of maintenance, and to have a dry space to store the pellets. A large store is advised to reduce the

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frequency of fuel delivery. Different kinds of storage exist depending on the space attributed to it. It could be a pellet storage room, a sheet steel tank, a fabric tank or an earth tank. A built store room has been recommended to save cost on ground work, and allow for easier access for upgrade, extension or maintenance. Packages exist on the market including a hot water tank, a boiler, a MES (Modular Energy System) and a system distributor.

Air source heat pumps - have been compared to a biomass boiler and a ground source heat pump. The main concern is the efficiency ratio drop down during the cold weather. Therefore reducing its attractiveness as a heating solution for the three dwellings. A concern with living off-grid is the new transition from pervious on-grid instantaneous energy supply. Without a gas grid connection as back-up to the heat pumps it may be difficult to secure affordable heating during the heating season when the external environment is much colder and the heat pump requires more electricity to maintain a comfortable internal environment.

A micro-CHP (Combined Heat and Power) - could have been a means of production to complete the PV array production. It raises some issues of profitability because the greener solution would be to power it with biomass which seems to be possible only in the case of district CHP, much more expensive. Micro-CHP units working using gas as a raw material. The site is off the gas grid network, for that reason micro CHP has not been discussed at detail within this document.

Solar thermal - Solar thermal technology utilised for its functionality to heat water using solar heat. The application of this system fulfils the Scottish Building Standards Silver aspect 3 which requires the addition of a renewable energy system which generates or recovers heat to contribute towards the building's annual energy demand for water heating. To satisfy the requirements to meet Gold aspect 3, the heat output from the system must raise to above 50% of the dwellings demand. Solar water heater (SWH) system fits within applicable water heating renewable source, as it requires little or no associated fuel costs that are allocated for water heating.

It should be noted that the main system to generate space heating will be working to complicate the solar thermal technology. SWH system is dependent upon the solar heat gain, although the unused heated water can and should be stored in an well insulted water tank as a thermal store. An additional factor to consider specifically on this design is the desire to keep the roof area clear of panels. Because of heat losses considerations along hot water pipes (even insulated), it would not be prudent to install the system on the ground. The main solution would be to install the SWH onto the roof area of the dwellings, alternatively the panels may be installed on top of the biomass boiler housing. The SWH would be adequately designed by MCS approved installer, as it is a modular system it may be integrated in to the main heating system for water heating.

3.0 THE OFF-GRID CONFIGURATION: PROS AND CONS

3.1 ELECTRICITY GENERATION

Utilising the abundant area of land adjacent to the site and preserving dwelling roof area for the solar water heater system it is then recommended to use tracking systems set on the ground. Several simulations were run and a medium size system was elected. With a power peak of 13.2kWp and considering the assumption of 9kWh/day consumption, it would produce 8,937kWh/year(degrading each year with panel efficiency). This size of system will require 54 panels of 245W each, and should be linked to a battery bank of 16 batteries of 6V. These batteries should be sheltered to avoid drops into the efficiency during the colder seasons (below 5°C). Running in this modelled usage profile scenario the batteries should have a life expectancy of about 12 years. The autonomy is approximately 5 to 6 24hour periods. A dump-load system to reuse the energy losses should be considered such as a water heater or as a heating system for the batteries, which will be factored in by the elected design team.

To calculate the economical assessment the government repayment tariff scheme has been factored in. The FiT or Feed-in-Tariff repays the owner of the building based upon the technology and usage. The feed-in-tariff rates for this assessment are 7.1p/kWh for stand-alone off-grid PV installation, no export tariff, factoring in the savings made by not paying a utility company for grid electricity and a calculated capital cost of £73,600 including VAT and labour for installation. The return on investment would not occur within the 20 year lifespan of the scheme. At the end of this period, panels may need replacing, and batteries at least twice adding to the costs. Moreover the price of the tracking systems should be added to the capital investment. Without these replacements, Figures 6 and 7 show the cash flow and the payback expectancy for the considered system, showing that the system does not make profit during the FiT lifespan

Figure 6: Payback for 10kW stand-alone PVs

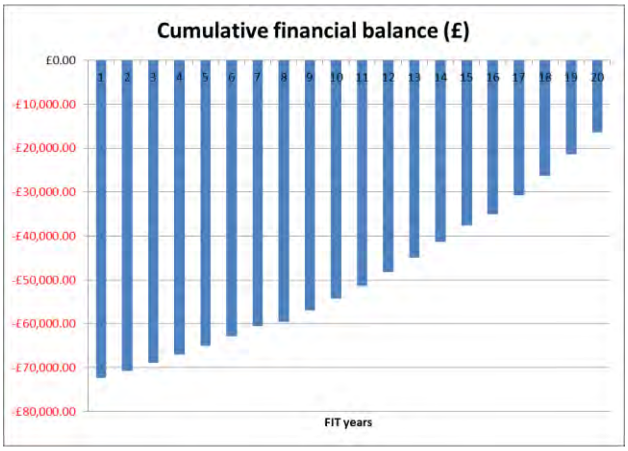

Figure 7: Cashflow over the years

From an electrical point of view the generation will struggle to meet the demand especially during time of less sunlight when demand is most likely to increase. It appears to be not viable from an economic point of view as the capital investment will not be recovered within the 20year lifespan of the FIT scheme. Furthermore, the payback period is closely affected by the periodical replacement of various aspects of minor equipment as shown in Figure 6 and 7. This is further affected by the decrease in panel efficiency and subsequent panel replacement estimated 25 years after install.

BATTERIES

For this kind of power storage and use, i.e. charging and discharging, batteries with longer life span referred to as deep-cycle batteries are recommended. The efficiency of the batteries are influenced by the external temperature, but also the energy stored should always stays above the depth of discharge of the battery (DOD) which could be up to 50% of the battery charge. For the battery bank sizing step, it is important to consider the voltage of the batteries and the entire system. For example a system of 48V will need to have 2 batteries of 24V in each strings (whatever their number) or 8 batteries of 6V.

Table 7: PV design options and equipment list based on higher and lower modelled peak demand

Dwelling	A and B		C	
Demand figure	9 kWh/day	15 kWh/day	7 kWh/day	12 kWh/day
Annual (kWh/year)	3,265	5,475	2,555	4,380
Simulated Peak (kW)	5	8	4	6
System Size (kWp)	13.2	19.1	9.6	16.9
No. Panels	54	78	39	69
No. Batteries / Voltage	16/6	40/6	16/6	32/6
No. Strings	2	5	2	4
Generation (kWh/year)	8,937	12,727	6,390	11,305
Area	90 m^2	130 m^2	65 m^2	114 m^2

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Such system sizes are required to cover not only the year demand but also the peak of demand which have been estimated to be half the value of the demand per day. The systems designed and presented in Table 7 are calculated examples that have been designed to cover the demand during peak times under two scenarios, and produce more than required electricity during summer with the intension of soothing the transition to off-grid living and reducing the likelihood of loss of power during times of continuous power demand.

3.2 SPACE HEATING

A fully automated vacuum feed wood pellet biomass boiler of 9-12kW with weather compensator is the designed off-grid heating solution analysed and described for each of the three dwellings. It requires once a year a maintenance operation, and there is no need to feed it manually. It is recommended to put the pellet storage be above ground mounted and constructed close to the house and the boiler to fulfil the fire-safety requirements, to save space and to avoid spoiling the landscape. This storage should have a capacity of approximately 6.3m^3 to store enough pellets for most of the year.

The system has been costed by a local MCS approved installer at provisionally £16,000 plus installation. The system has been sized above the annual predicted heating demand for the dwellings plus addition generation for shortfall in hot water supply from the solar water heater and the additional 50% hot water demand. The pellet boiler will require a 13amp supply to power the feeder. This system can be connected to the main house supply either from the battery/PV system. Government funding mechanisms to incentivise and reward the use of on-site heat generation is available referred to as renewable heat incentive (RHI) and renewable heat premium payment (RHPP).

RHPP

The RHPP household vouchers scheme was launched in August 2011 and is available until March 2013. The RHPP takes the form of a grant to contribute to the cost of installing renewable heating systems. At the time of launch it was made clear that anyone receiving the RHPP would be eligible for the domestic RHI when it came in subject to meeting the requirements of the scheme. For a biomass boiler up to 45kW system £950 is available per installation to households off gas grid. This grant can must be applied for before the end of the scheme in March 2013 with the provision that the system is installed 6 months after receipt of the voucher.

RHI

The installation of a biomass boiler is considered an eligible renewable heat system which will allow for the renewable heat incentive (RHI) tariff to be claimed for the first 20 years after the installation of the system. Similar to the concept of repayment tariff used for the feed-in-tariff, this funding mechanism provides the building owner with a quarterly income based on a tariff selective to the biomass boiler. In a recent DECC (2012) consultation document, it is proposed that a single tariff for biomass under the domestic scheme.

The proposed scheme applies to MCS accredited installations of biomass up to 45kW, and should lead to full payback for renewable heating systems within 7 years and fuel savings continuing after that. Specific details on domestic tariff are due for release in summer 2013, and systems installed since 2009 are eligible for the RHI. The payments will be based on heat usage over 20 years (total expected kWh over 20 years multiplied by tariff). The payments condensed to 7 years, paid quarterly, however for biomass a small amount of income may be held back and paid in years 7 to 20, to assist with on-going fuel bills. Table 8 and 9 have been generated based on a selected biomass boiler sized to service each dwelling. Assumptions have been made on the tariff information proposed by recent DECC (2012) RHI consultations. The tables list cost of system, payback period savings compared to an alternative fuel source and the income from the assumed RHI.

Table 8: Renewable Heat Incentive (RHI) biomass system calculator – per dwelling

Boiler Size kWh			9-12		kW
Calculated upper heat output from system			11,800		kWh/year
RHI Rate (p /kWh) -Tier 1 [estimated from RHI consultation]			8.7		kWh
Biomass Fuel	Fuel		Pence/kWh		
	Wood Pellet		3.7		
Cost of Project (£)	16,000				
Compared with likely alternative heating fuel	Type	p/kWh	**CO_2 saving per kWh (Kg)**		
	Electric	13.3	0.509		
Summary of Results	Payback Period (yrs)	7		Net Project Cashflow	51,900

Table 9: Cashflow calculations for 20years of estimates RHI scheme – per dwelling

Income from RHI	Alternative Fossil Fuel Cost	Biomass Fuel Cost	Net Fuel Saving	Total Gain over 20 years
£	£	£	£	£
27,000	**52,000**	**11,600**	**40,300**	**67,900**

3.3 HOT WATER

The hot water demands for the three dwellings have been calculated using a domestic modelling calculator. The calculator factored in common domestic wet appliances and number of water outlets in the homes. A combination of manufacturers data, modelled human hot water usage behaviour and usage scenarios were used to calculate the water demand profile. The hot water demand in terms of energy demand (kWh) has been calculated at 4000kWh/year. The solar water heater detailed in table 10 has been sized to generated 50% of the each household's annual demand for hot water. This technology has been designed to satisfy the requirements for Scottish building standard Section 7 aspect 3 Gold label for each dwelling.

Table 10: SWH system sizing details per dwelling.

Technology	System size	Hot water generation	No. Panels	Additional equipment	System cost
Solar Thermal	3kWp	2,163 kWh/yr.	4 panels	1x 300L cylinder	£4100

The addition of the SWH will also be eligible to claim the RHI. Which criteria still undefined by DECC sources it is proposed that the tariff may be similar to that of the pervious renewable heat incentive domestic tariff. For a system upto 20kW, the tariff is 18p/kWh lasting for the first 20years, with the provision under the evolving proposed guidelines for the summer 2013 tariff that the RHI will payback the system in 7 years.

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4.0 THE ELECTRICITY ON-GRID CONFIGURATION: AN ALTERNATIVE

From the outset of the investigation, the drive has been to hone a range of viable solutions for the implementation of three properties to reliable solely upon power and heat generated on-site. This altruistic desire was reinforced by the fact that proposed site does not have a mains gas or electricity supply. However, after completing the exploratory investigation into viable options and proposed solution, a concern arose with regard to secure and continuous supply of year round electricity, this coupled with assisting the transition from grid to off-grid living. Therefore, an additional option has been explored which involved the site procuring an electricity supply by which to act as a secure back-up to the householders unregulated electricity needs, negating the requirement for batteries, their storage etc, proving the dwellings with secure electricity during period of no or little sun.

To facilitate the options to include the grid connected an estimation has been generated using a third party charging methodology from an energy provider that supplies the area local to the site in question. The grid connection configuration has between calculated to between £60,700 and £77,500 (See Table 11).

Table 11: Grid Connection estimation

1-4 Premises, single phase LV, extension to the LV network required			
		Min.	**Max.**
C - Assessment and Design for all relevant work		-	-
D - CIC Assessment and Design of the Non-Contestable Work		-	-
E - CIC Design Approval of the Contestable Work		£ 263.00	
F - Construction		£29,360.00	£40,441.00
F3 - Other LV services not covered by the QAS		-	-
F5 - Main Cables		£31,000.00	£37,000.00
Assumption : 1km distance from connection point (same side grass)	TOTAL	£60,623.00	£77,441.00

4.1 ELECTRICITY

The nature of the connection is assuming a simple phase cable running from a transformer at 1km from the house, including everything except for the site ground works. There are several advantages for this connection. First, batteries are not required neither the solar regulator. The higher on-grid Feed-in-Tariff of 13.99p/kWh of systems between 4 and 10kWp plus the export tariff rates of 4.5p/kWh would apply for such configuration, and the size of the PV array could be reduced to get a better payback. A simulation has been run of the same size PV array grid-tied (10kWp).

Results show a payback after 12 years and after 20 years the cumulative profit would reach almost £25,054 for an original capital cost of £23,990. Figures 8 and 9 are showing the payback period and the cumulative balance. This system would provide 6089kWh/year (degrading 0.5% each year in line with panel efficiency), and contains 42 panels of 245W each and an inverter replacement every 8 years. A comparison has been made between a system with and without a tracking system working on two axes (tilt from 10° to 80° and azimuth on 180°). Results shown in Figure 10 and 11 show that investment into a tracker system is perhaps a less attractive option. The output would be better (7454kWh/year) but as the investment is higher (£54,230), the payback time is delayed until the 19th year. Moreover at the end of the 20 year period the cumulative profit would be only of £9,804.

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Figure 8: Payback of 10kWp system grid-connected

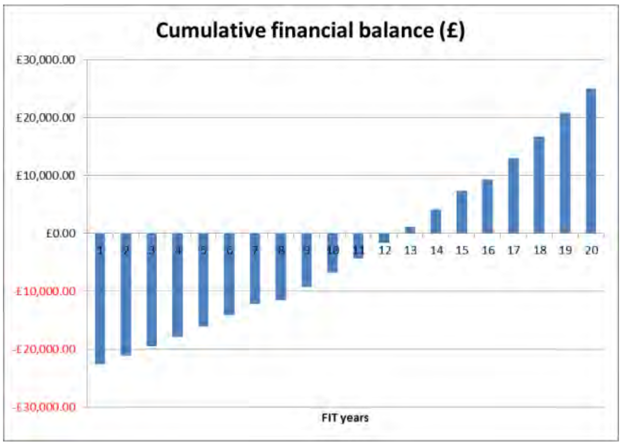

Figure 9: Cash flow 10kWp system grid-connected

Figure 10: Payback for a 10kWp grid-tied system with a tracking option

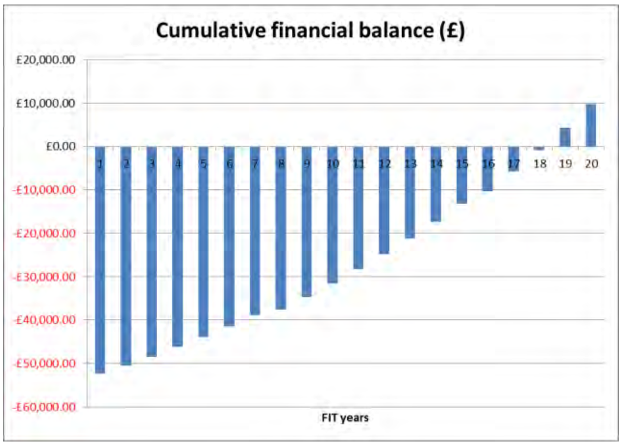

Figure 11: Cash flow for a 10kWp grid-tied system with a tracking option

Comparison between the two options would suggest that the money saved through not investing in a tracker system could be used as an investment into the replacement of the panels. With the added power security of the grid connection there is no important need of a tracking system to maximise generation. The capital costs in these calculations do not include the £60,700 to £77,500 required to connect the side to the grid.

4.2 SPACE HEATING

BIOMASS BOILER

No difference is made to the size or funding available to the biomass installation if the dwelling is connected to the electricity network.

GROUND SOURCE HEAT PUMP-[IS THIS ONLY VIABLE IN THE ON-GRID OPTION]

The grid-connection option allows alternatives to the biomass boiler as a source of space and backup hot water generation. A ground source heat pump could be installed to provide heating to the house. A 10kWp system would cover the demand and include a hot water system. The average cost for such system is £8000, for equipment only. Including the labour, the price reaches £11,200 but a cost for groundwork's needs to be more accurately assessed. As horizontal system, it would require an area of 588m^2 which is equivalent to a square of 24.25m a side. It is only for on-grid option because the system requires an electricity supply. The heat pump works on the coefficient of performance (COP), this value varies between model and brand but is typically in the region of 1:3 to 1:4, which refers to the units of heat energy extracted from the ground with the equivalent electricity unit to power the system. The concern during the colder periods when the COP can drop to 1:2 or 1:1 which results in the system increasing the dwellings electricity demand for the required heating thereby increasing cost and creating a possible issue with affordable warmth.

COMBINED HEAT AND POWER

An alternative to the described biomass is a micro combined heat and power system (mCHP). This system required a connection to the gas grid as the primary source of fuel. The system generates electricity whilst recovering heat lost during the process to supply the property with space and water heating. If a connection to the gas grid is investigated and required as an alternative to a biomass boiler then the mCHP is an option to discuss further with mCHP design and install team which SEC can advise upon.

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5.0 CONCLUSIONS

The start of the report focuses on the performance evaluation of three distinctive systems for the construction of three new build houses in Aberdour, Fife. The three designs and dwellings have been dynamically modelled to establish the heat and power demand and a value for heat energy requirement has been predicted through SAP calculation methodology. The three dwellings have been rated based upon their standing within the Section 7 labelling system. Therein the three properties received different labels which have only been reviewed to aspect 2 of Section 7, space heating requirement. Based upon the SAP calculations from the architectural drawings and details dwelling A meets the space heating criteria for the targeted Passive House design standard and gold label under Section 7 aspect 2. Dwelling B and C were not subjected to the Passive House design standard and satisfied Silver and Gold aspect 2 respectively. Assumptions were made during the design calculation to predict the heat requirement, it is possible for dwelling B to achieve a Gold label under aspect 2 if the architect was to improve the y-value for thermal bridging calculations and reduce the level of air permeability.

From the initial investigation on regulated and unregulated energy demand for the three designs, the feasibility study focused on evaluating a range on-site micro-renewable power and heat generating system with the aim of providing energy solutions and maintaining dependency from grid electricity and gas. This extended to a site and desktop study which was used to analysis the surrounding area for the application of well-established and government supported power and heat technology. The survey identified that the site was not applicable for wind or hydro based systems for electricity generation. Therefore, in terms of electricity production, solar photovoltaic panels are the most practical and financially attractive option for off-grid supply. To maintain available roof area for the application of solar thermal panels, an area adjacent and in close proximity to the dwellings has been identified as the most appropriate for the installation of three solar PV farms.

The outcomes from the first economic and technical analysis of the renewable solutions highlighted less favourable conditions when considering the capital and maintenance cost associated to generating sufficient levels of peak and yearly on-site electricity. This urged a further investigation to consider the financial implications of connecting the site to the mains electricity grid. Grid connected option excludes the need for batteries, solar tracking systems and other associated technology/equipment. Therefore reducing the cost of the system and increasing income from the higher 'grid-connected' feed in tariff funding mechanism. This option has been laid out as an alternative to off-grid electricity generation dependency, providing less cost associated to life-time running cost of the PV system and adding a layer of security to the electricity supply.

Under aspect 3 of Section 7 (Scottish Government 2011) a solar thermal system has been evaluated as means to contribute over 50% energy required to the dwelling's hot water requirement. 50% contribution is an element within the gold aspect 3 of the Section 7, in the instance where a design decision was to focus upon designing and delivering dwelling B as a silver label then a smaller and potentially less expensive solar water heater system may be selected to satisfy the requirements under the silver aspect 3, requiring a smaller portion of the dwellings hot water demand from low or no fuel renewable technology (5%).

The high thermal performance of the dwellings reflected in the lower than national average demand for heat energy. Therefore, the off-grid options to provide sufficient space heating fell into two categories, heat pumps and solid fuel. Heat pumps were removed from the deeper economic analysis section of the report due to concerns with electricity demand of the heat pump system during colder weather placing considerable extra demand on electricity generation and stored electricity during times of potentially peak domestic electricity demand. Therefore, a solid fuel option in the form of a biomass boiler system was investigated which works well with the dwellings rural setting and continuous supply of heat along with the automatic feeder option which will facilitate the transition to off-gas grid living.

A connection to the grid brings in the possibility to use heat pump technology, which is powered by electricity. However, with the advantages and cost associated to biomass heating system supplying each dwelling heating requirement it was important to reduce each households electricity demand, whether it be grid or battery supplied with the focus on affordable heating. This feasibility study focused on off-grid solutions, off-grid heating option was as the biomass system is not dependent upon weather conditions and a storage requirement. Therefore, technology such as micro-CHP, which requires a gas grid-connection, has not been explored within this document.

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Aspect 1 of Section 7 (Scottish Government, 2011) relates to the carbon dioxide emissions produced by the dwelling. Table 3 lists the difference between silver and gold label. It is not until a complete dwelling design is confirmed that this aspect can be checked. After completion of the SAP calculation method for the three dwellings with the biomass heating system and either one of the three PV options, the resultant output for predicted dwelling emission rate (DER) with reference to target emission rate (TER) was as follows:

The DER for dwelling A, B and C was over 42.8% lower than the respective TER therefore the results from the calculation method indicates that each dwelling will satisfy gold Aspect 1.

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