Refurbishment Case Study 12

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Kincardine Castle

Installation of biomass system

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1. Introduction

This report is the twelfth in a series of Refurbishment Case Studies which describe energy efficiency upgrades in traditional Scottish buildings. While the previous case studies have focused on work to building fabric, this study describes the installation and running of a biomass system. It concerns the work carried out to install a more efficient, economical and sustainable heating system in Kincardine Castle in Aberdeenshire. Two biomass boilers were installed reusing the existing heating pipe runs and radiators, minimising intervention to fabric. The owner is using timber from the Estate to provide fuel for the boilers. The project was considered viable due to funding available under the UK Government's Renewable Heat Incentive.

2. Building Description

Fig 1: Kincardine Castle, Kincardine Estate

Kincardine Castle is a large category B-listed country house in Deeside, Aberdeenshire (Fig 1), situated in an Outstanding Conservation Area. It was designed by Niven and Wigglesworth Architects and has been a family home since its construction in 1894. It was built in a Scottish Baronial style with corbelled out turrets, pedimented dormers and large water spouts. The masonry is harled and finished with granite dressings. The current owners began to use the castle for commercial purposes, including weddings, business meetings and house parties, in 1985. Modifications to the building, such as upgrades to comply with fire regulations and the addition of fourteen extra bathrooms have already taken place. The castle sits within a 3,000 acre estate in which various activities are carried out, including farming, forestry, fishing and shooting. There are seventy houses on the estate as well as shops, workshops, a working quarry and 1,500 acres of forest.

3. Description and Performance of the Original System

Before the project started there were two heating circuits within the building. The main circuit ran on an HDG80 Multi-fuel boiler, which was installed in 1989. This provided hot water and central heating for the majority of the building. The owner had tried running the boiler on logs and then coal; however neither was satisfactory as the boiler required regular stoking and de-ashing. As the boiler could also burn oil the owner reverted to using oil as the sole fuel source. The Multi-fuel boiler heated a large water cylinder and fed heat to the heating circuit via a Weather Compensating Valve and Controller. When the heating was on, the radiators were operated for 24 hours a day, controlled on a thermostat so that the colder it got outside, the warmer the radiators became. This constant system was more efficient at heating the large building than using a time-clock.

A secondary circuit heated and provided hot water for the basement area, which was formerly a granny flat. This circuit used a simple oil boiler to provide heating and hot water via a time-clock. Between them, these boilers burnt 23,000 litres of oil per annum. It was estimated that 1 litre of oil produced 9.3kWh[1] of extracted heat so annual heat usage was presumed to be 213,000kWh. This heating system was inefficient as it was failing to heat rooms to a comfortable temperature. It was also expensive to run as fuel costs were high. The owner wished to replace the existing oil boiler with a more sustainable, energy efficient system.

4. Renewable Heat Incentive (RHI) and the Fiscal Environment

The UK Government's RHI scheme currently provides funding for non-domestic installations in the industrial, commercial and public sectors. As Kincardine Castle is used for commercial purposes, as well as being a family home, it was eligible for RHI. Funding is paid out according to the size of the boiler and how much heat energy is produced. For the biomass boiler at Kincardine Castle receipts in the region of £15,000 per year were anticipated. The availability of RHI influenced the selection of biomass boilers as, without this funding, the costs involved in installing and running this system would have been too high to make it a viable option. Costs are further detailed in Section 9.

5. Selection of Plant

Biomass boilers are run on renewable sources of energy, and so are preferable to oil or gas, which are fossil fuels or non-renewable sources of energy. Government incentives are available for biomass boiler installations in commercial properties. Biomass boilers can be fuelled by logs, wood chip or wood pellets. Wood chip and logs were chosen as the most suitable fuel sources as the large forested areas of the state make producing logs or wood chip on site a viable option.

[1] This was later discovered to be a significant over-estimate, and more in keeping with the energy produced by a highly efficient boiler. The efficiency of the old boilers is unknown.

An ETA Wood Chip Boiler and smaller Fröling Log Boiler were selected to provide the heat for the castle. The biomass boilers were to be located within a purpose-built boiler house adjacent to the castle while the existing oil boilers, which were to be retained, are located in a boiler room within the castle. The biomass heat is fed, via heat exchangers, into the existing circuits with the original oil boilers kept hot as they still remain within the system (though not normally operational). Failure of the biomass system causes the original oil boilers to operate as a back-up system. Retention of the old oil boilers as a back-up was cheaper than the cost of removing them from the system. Logs are also burnt in a number of open fires in the castle to provide supplementary heating.

6. Site Work

6.1 Construction of Boiler House

The location of the boiler house had to be carefully considered as the new boilers are connected to the original pipework in the castle. As the boilers are located outside of the main building there is a risk of transmission losses and so the boiler house had to be located as close to the castle as possible, particularly to the existing boiler room. The two new biomass boilers are housed within the new boiler house and the heat produced is transmitted 50 m to the main building through underground insulated pipes. It was important for the boiler house to be of high quality to suit its location adjacent to a major listed building and within an Outstanding Conservation Area. It is a simple, block built untreated larch-clad building; well hidden by trees so it is barely noticeable beside the house. The look of the building will soften as the cladding and cedar shingles weather. A double dog kennel was included to the front of the boiler house giving the building a more traditional role (Fig 2).

Fig: 2 Double dog kennel and new boiler house. Photo taken from roof of castle.

6.2 Installation of Biomass Boilers

Installation of the new system was fairly straight forward as it uses the existing heating circuits, although new pipework was needed for connection to the new boilers from the existing circuit in the old boiler room. The biomass boiler system will be maintained by the same firm who installed it.

7. Commissioning

Following installation of the biomass boilers and associated site work, the system was commissioned. This usually involves a separate company from the installation contractor. The company was responsible for carrying out safety checks, programming the boiler and providing training in how to use the system to the estate staff.

8. Sourcing, Production and Storage of Wood Chip

8.1 Wood Chip Source Options

Key to the success of the biomass boilers is the ready supply of biomass material. There are two options for sourcing wood chip, purchase from an external supplier or on-site production. The options are not mutually exclusive and the user can alternate between one and the other.

When the biomass boilers were first installed, the wood chip was bought in from a local supplier, located eight miles away. The wood chip was delivered by an 8-wheeler lorry, and approximately 4 - 5 tonnes of wood chip were delivered in each lorry load (depending on the moisture content). Once a storage facility was completed the owner began home production of wood chip from timber sourced off-site or on the estate.

8.2 Wood Chip Production

The key to wood chip production is efficiency of operation. A mobile contract chipping service is used at Kincardine Castle. As they charge approximately £120 per hour of operation it is crucial to put the timber through this machine swiftly. The wood chipper can process an articulated lorry load of Small Round Wood (SRW) in about 35 – 40 minutes. Processing a similar volume of brashings (small branches from fellings and thinnings) takes much longer. As a result the cost benefit expected from using inexpensive brashings is offset by the higher cost of chipping. The owner concluded that log lengths (Fig 3) rather than brashings were the best type of wood to use. Chipping at Kincardine is co-ordinated with other local work in order to minimise positioning costs for the chipper. Nevertheless the positioning fee for coming on site is approximately £145 per visit so this means a larger, rather than smaller, chip storage facility is more cost-efficient.

Fig 3: Round-wood logs for biomass – this is an exposed site and the logs air dry here before chipping.

Fig 4: Crane on lorry loading SRW logs into the wood chipper

The first batch of timber chipped in-house were from thinnings taken from the castle's driveways. These were stacked close to the proposed wood chip shed and left to dry for 18-24 months. Another batch of timber was bought from a neighbouring estate as they were selling dead (i.e. dry) trees at £30 per tonne, dry weight. The future plan is to use windblown softwood trees and SRW from Kincardine Estate, and thinnings and fellings from the estate and surrounding area, and/or timber sourced off site.

Based on the first year's usage the system is expected to use approximately 65 dry tonnes of wood chip each year. This equates to around 130 tonnes of fresh timber, which in turn, equates to the annual growth from about 12 hectares of woodland.

Coordinating the lorry of timber to arrive on site at the same time as the wood chipper means that the timber can be loaded directly from the lorry into the chipper (Fig 4). Although the chipper has its own loading crane it is quicker and easier to unload timber using the crane on the lorry. Fig 5 shows logs going through the wood chipper.

Fig 5: Logs being processed by wood chipper

It is imperative that the timber to be chipped is dried to the required moisture content of below 30% before chipping. If they're too wet then the heaped woodchips will heat up and compost, wasting valuable energy.

8.3 Storage

Proper storage facilities are a crucial part of a biomass project. An old covered silage shed was renovated for use as a wood chip store at a cost of £4,000 (Fig 6). This shed is situated about ½ mile by road from the castle. This is a temporary measure while the owners learn about drying timber for chipping, storage and handling. As it is essential that there is clearance for the chipper, the roof trusses were raised and a movable flap was fitted to create more clearance above the doorway. The walls of the shed were lined with mesh to allow airflow so that any surface moisture on the chips or in the building, i.e. from condensation, would dry naturally. (Fig 7).

Fig 6: Wood chip propelled to the rear of the wood chip store

Fig 7: Wood chip store in a renovated silage pit, note the mesh walls for ventilation

This temporary store will be replaced with a bespoke wood chip store in a location about 1 mile from the castle. While this will entail a longer round trip between storage shed and castle for re-fuelling, (Fig 8) the new shed's location beside a public road will reduce wear and tear on the estate's drive caused by heavy lorries. The new shed will also be more conveniently located for supplying other biomass plants on the estate. Ideally there should be space to stack some timber close to the store, so that it can be easily moved and cut by the chipper. This would mean that when the lorry is away re-loading elsewhere on site, the chipper's crane could continue operations albeit at a slower pace.

Fig 8: Wood chip (approx 20-22 cu.m.) brought from storage facility to the new boiler house. Photo taken before roof structure completed.

A larger shed would allow more wood chip to be produced at one time and so reduce the cost of chipping. It would be best to have a chip store with two sections. The empty section can be re-filled at any time convenient to the chipping contractor's periodic visits while the second section is used. Thus the 'bins' would be used alternately. This store would supply wood chip for the castle and other estate properties. A Combined Heat and Power (CHP) plant could be built in conjunction with new development. This would provide more economical and sustainable heating for tenants on the estate and for other households.

9. Wood Chip Costs

It costs £145 to bring the wood chipper on site plus an additional £120 for each hour on site. Fuel costs are also charged. A delivery lorry with a crane was also needed to move the timber to the chipper and, as mentioned earlier, it is quicker to use the lorry's crane rather than the chipper's smaller crane, to load the chipper. While the spot-rate of chipping is about 1.5 loads/hour, by the time the lorry has re-loaded the actual rate is closer to 1 lorry load per hour. This is equivalent to approx. 25 tonnes of fresh timber. After drying in the stack the weight of the wood chip is reduced by about 50% so around 12 tonnes of wood chip are produced in approximately one hour. Table 1 compares the assumed costs of chipping for one hour or two hours.

Time	Cost of Timber[1]	Cost of Chipper[2]	Cost of Lorry	Cost of fuel	Total cost	Tonnes of Wood Chip Produced[3]	Cost of Wood Chip per Tonne	Cost of Wood Chip per kWh[4]
1 hr	£700	£265	£100	£40	£1,105	12	£92.08	£0.0288
2 hrs	£1,400	£438	£180	£80	£2,008	24	£83.66	£0.0261

Table 1 Wood Chip Costs

[1] *Fresh timber at £28/tonne. 25 tonnes produces 12 tonnes of dry chips*
[2] *Positioning fee £145 + £120/hour*
[3] *Dry weight*
[4] *Assuming 3,200 kWh/tonne of dry chips*

It is therefore less costly and more efficient to chip larger quantities of timber at one time.

9.1 Purchasing Raw Material - Timber

In 2013 Kincardine Estate was able to buy 100 tonnes of dead timber that had dried standing at £30/tonne (dry weight). The down-side of this has been that the timber is so dry and light that the chipper doesn't blow the chips to the rear of the store and a JCB has to be used to push the chips to the rear of the shed. This slowed down the pace of processing to 1 lorry load per hour. Nevertheless it is estimated that this lower timber cost has brought the cost of biomass below £0.02p/kWh (£58.04/tonne) with the drier woodchips having a higher calorific value per unit of weight or volume. Having the ability to process biomass has thus produced considerable savings over bought-in wood chips (£99/dry tonne delivered). This provides a saving of £40/tonne or £2,560/annum when both are compared.

9.2 Using on-site 'free' Timber

Bringing large forestry machinery onto a forest site is costly, so frequently small-scale or well-scattered 'wind-throw' in plantations is left un-harvested. For example, it is not worth paying the £500 positioning fee for harvester and forwarder to tackle say 30 trees in a plantation. Whilst this, currently un-salvaged timber may appear to have little value to the owner it may be that smaller equipment, which can be brought on site more cheaply (i.e. behind a 4WD vehicle), can be used for small scale extraction and this un-used biomass resource exploited. Kincardine Estate is currently investigating such possibilities.

10. Performance Assessment

10.1 Problems in the First Year

The heating system is constructed in such a way that, should the biomass system fail, the old oil boilers can operate as a back-up heating system. During the first year the oil boilers were triggered into use due to a number of relatively minor issues; de-pressurisation of the system (air bubbles moving around the circuit and being vented at air-valves), running out of wood chip, failing to empty ash container in time, failure of the igniter and failure of the flue-gas temperature sensor. Future oil consumption is expected to be lower as the de-pressurisation issue has now been resolved and operational errors should reduce as knowledge increases and staff become more familiar and confident with the system.

10.2 Fuel Costs and Savings

Three heat-meters record the performance of the system. A meter on each biomass boiler records the output from the boilers while a third meter records the heat imported to the castle. The transmission losses can be calculated by deducting the imported heat from the combined boiler outputs. The biomass boilers (Fig 9) produced 238,149kWh during the first year, of which 202,230kWh were imported into the main house. This means 35,919kWh were lost between the boiler house and the main house. From March to November 2012 wood chip was procured off-site (after this time it was produced on-site). At a delivered-in cost of £90-£100 per tonne and with the yield from the wood chip boiler at 3,200kWh/tonne this equates to a cost of £0.0280p-£0.0312p per kWh. 12,000kWh was produced from the log boiler where the fuel is effectively free, discounting labour.

Fig 9: Looking across the large ETA Boiler toward the twin buffer tanks. To the right at the rear is the 20kW Fröling Log boiler. Photo taken before pipework insulated.

During this year the average heating oil price was £0.65p/litre. This equates to a cost of heat generated from oil at £0.07p[2] per kWh with a modern high efficiency boiler. It should be noted that the efficiency of the old oil boilers in the castle is unknown. For comparison purposes the biomass system is being compared to a high efficiency oil boiler system (a typical installation by today's standards).

The savings generated by switching from an oil-supplied system is therefore £0.04p/kWh (£0.07p minus £0.03p). With heat usage at 202,230kWh this equates to assumed fuel savings of £8,089 per annum (202,230KWh x £0.04p/kWh). Table 2 below shows that the availability of biomass heat and the installation of several new radiators has also reduced or eliminated electricity consumption in several rooms. These rooms were previously heated using electric heaters.

[2] This number was generated as follows: Kerosene has an energy value of 10.4kWh per litre. With an assumed 89.5% efficiency for a new oil boiler this equates to 9.3kWh. 65p per litre divided by 9.3kWh = 6.99p or £0.07p.

Room	**a) Power**	**b) Number of days used**	**c) Hours in use per day**	**d) Percentage of the time in use due to outside temperature**	**Previous electricity usage for heating per year (a x b x c x d)**	**Current Electricity Usage**
Office	3kW	120 days	11.5hrs	50%	2,070kWh	Very occasional use.
Morning Room	3kW	120 days	24hrs	50%	4,320kWh	Very occasional use.
Gents	0.75kW	150 days	24hrs	30%	810kWh	None
Back Passage	1.2kW	90 days	12hrs	50%	648kWh	None
Kitchen	3kW	30 days	24hrs	50%	1,080kWh	Very occasional use
Butler's Staircase	2kW	20 days	24hrs	50%	480kWh	None
Gas Stove in Entrance Hall	5kW	150 hours				Very occasional use
Total					6,408kWh x £0.13p = £833 per annum	

Table 2 Rooms with new radiators fed from Biomass Boiler

However the Biomass Plant does use significant amounts of electricity to run the pumps, the stoker and the igniter. The total cost of electricity to run the Biomass Plant is estimated at £2,000 per annum as Table 3 below shows.

	a) Power	**b) Days in use**	**c) Hours in use per day**	**d) Percentage of time actually in use**	**Electricity usage for heating per year (a x b x c x d)**
Pumps	1,580w	365	24	100%	13,840kWh
Stoker	3kW	365	24	3.8%	998kWh
Igniter	3kW	365	0.5 (30mins)		548kWh
Total					15,386kWh x £0.13 = £2,000 per annum

Table 3 Cost to run Biomass Plant

Taking into account the savings generated from reduced oil (Section 10.2) and electricity consumption (table 2), and factoring in the results from Table 3, the net fuel savings can be calculated as shown in Table 4.

Net Fuel Savings:	
Savings on Oil Cost	£8,089
Savings on Electricity consumption	£833
Extra Electricity to operate plant	-£2,000
Net Fuel Savings in year 1:	£6,922

Table 4 Net Fuel Savings

10.3 Transmission Heat Loss

Previously heat was produced by the oil boiler which was located in a boiler room within the building. Thus any heat losses in the system were within the castle and could be regarded as ‘useful’ heat. With the biomass system the heat is produced 50 metres away in a separate boiler house and transferred via a twin-core underground pipe to the boiler room. Heat meters record the production of heat by the two biomass boilers and a third meter records the heat imported into the old boiler room. It is therefore simple to determine the losses. Transmission losses are larger than anticipated at 15%. These could have been reduced by improving the performance of the pipes used to transfer the heat from the boiler to the house. The twin-core pipe used (Fig 10) has thinner insulation at the 3 o’clock and 9 o’clock positions. A twin-pipe solution (Fig 10) is more costly to install but would probably improve efficiency.

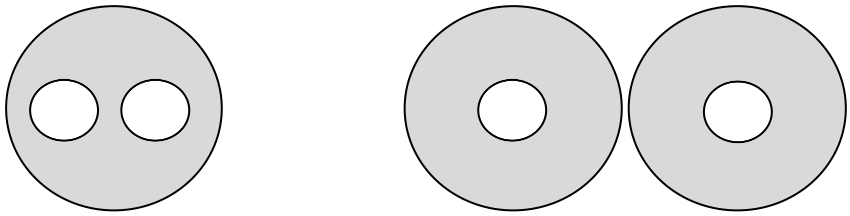

Fig 10: Diagram showing twin-core and twin-pipe systems

11. Evaluation

11.1 Payback

The total cost of the installation, including the boiler house and the extra log boiler was £201,538. Provision of RHI funding made this project viable. RHI funding is payable annually for up to 20 years. Under RHI, for the 153kW installation at Kincardine Castle, the first 201,042kwh of energy used (i.e. imported into the castle) is counted as Tier 1, which pays £0.079 per kWh. Energy usage above that amount gives a much lower Tier 2 payment of £0.019p per kWh. The payback from RHI is shown in Table 5. There is a service contract with a local contractor based on the RHI to maintain the boiler. Linkage of the service contract to the RHI payments means that the company has an incentive to keep the system running.

RHI Receipts net of Service Contract Charges in First Year of Operation					
Tier	**kWh**	**RHI Payment per kWh**	**Service Contract per kWh**	**RHI net of Service Contract**	**Net RHI Receipts**
Tier 1	201,042	7.9p	1.3p	6.6p	£13,268
Tier 2	1,188	1.9p	0.6p	1.3p	£15
Total	202,230	-	-	-	£13,283

Table 5 RHI payment calculations

The annual fuel saving was estimated to be £6,922 (Table 4). Added to the RHI payments this gives a total positive cash flow of £20,205 per annum as shown in Table 6.

Total Return - Fuel Savings Plus net RHI Receipts	
Net Fuel Savings:	£6,922
Net RHI Payments	£13,283
Total	£20,205

Table 6 Annual Savings

The return on investment in the first year including the RHI payments is 10.2% (based on project cost of £201,538). This gives a 10 year payback on investment with RHI or just over 30 years without RHI. This is a simple way to calculate the impact of this funding but shows the very large contribution RHI payments have made to the project.

11.2 Sustainability Benefits

In the first year the boiler has saved around 53.6 tonnes of fossil fuel CO_2 emissions compared with burning oil as a fuel (Table 7). The biomass system has still emitted CO_2 but the emissions produced in burning wood chip are cancelled out by planting more trees to replace those used, thus recapturing the CO_2 produced by the biomass system. There are still CO_2 emissions from electricity used, the fuel needed for the wood chipper and for transportation of logs.

The installation of a biomass boiler will have reduced fossil fuel emissions from the oil extraction, transport, and refining business as well as saving fossil fuel burned to provide heat for Kincardine Castle. Fossil fuel is still used to harvest and transport timber, to chip wood and to transport wood chip from the store to the boiler, and electricity is used to run the pumps, the stoker and the igniter for the heating system. It should also be remembered that fossil fuel extraction uses considerable amounts of non-renewable energy itself.

Oil Cabon Saving*

= 58,519 (23,000 x 2.5443) - 799 (314 x 2.5443)

= 57.7 tCO_2e (57,720 $kgCO_2e$)

Net Elect. Carbon Gain**

= 7,078 (15,386 x 0.46002) - 2,948 (6,408 x 0.46002)

= 4.1 tCO_2e (4,130 $kgCO_2e$)

Net Carbon Saving

= 57.7 tCO_2e - 4.1 tCO_2e

= <u>53.6 tCO_2e</u>

***** Moving from oil system to biomass with oil backup

** Additional electricity due to boiler and changing electric heating

Table 7 Net Carbon Saving Calculations (taken from 2012 DECC/Defra conversion factors)

12. Conclusion

The rural location of Kincardine Castle means that timber is available on the estate or nearby so the owner has a readily available and sustainable supply of fuel for biomass. The castle is a large, partially commercial property, requiring a substantial heating system, making this type of project worthwhile. The availability of RHI funding was an important aspect in making the project economically viable. The project has, over-all, been a success; rooms in the house can now be heated to a comfortable temperature, and an efficient system of producing wood chip for fuel on the estate has begun. Transmission losses between the new boiler house and the boiler room within the main house are larger than expected and the owner strongly recommends investigating the potential of twin, single core pipes to reduce transmission losses. Despite some relatively minor issues, the new system does provide more efficient heating for the house.

While the project gives an acceptable return on investment the owners' feel the greatest benefit from the biomass system has been that the castle can now be kept comfortably warm all winter. In the future it may be possible to use wood chip produced on the estate to run biomass boilers for other estate properties or for general sale. Fig 11 shows both the castle and the boiler house.

Fig 11: Kincardine Castle. The Boiler House can be seen discretely located behind the holly tree to the left.

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