Abernethy Trust

Ardgour Hydro-Powered Heating System

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Client: Abernethy Trust

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1 Introduction

This report details the findings from our site visit to Ardgour House (at the Ardgour Centre) on 9 January 2013. We attended site along with Barry Edmondson from Abernethy Trust and Marty Fox from Solar & Wind Applications Limited (SWAL); the proposed suppliers and installers of the power management system (EMMA).

Realise Renewables has been commissioned by the Abernethy Trust to review the technical feasibility and design options for a system which uses power from the on-site hydropower scheme. The system would be designed to take any 'spare' power being generated and put it to meaningful use on-site; minimising the amount of power that is exported to the grid.

The main electrical side of the project is being handled by SWAL. Realise's main focus is the heating system side, and review of the existing heating and hot water systems in the building.

2 Ardgour House – Review

Ardgour House is the principal office and accommodation building for the Ardgour Centre. The building is old and generally poorly-insulated, and heated by an aging heating system. However, the heating system still functions, albeit inefficiently, and there are limited funds at present to make major changes within the building.

The total floor area of the building is approx. 350 m^2 over two storeys. This has been approximately measured from non-scaled plans.

There are proposals to add a two-storey, approx. 80 m^2 extension to the back of the building, which would bring the heated floor area to approx. 420 m^2. The extension would be built to current Building Standards, and therefore would have a minimal heating demand compared to the existing building.

Rooms are gradually being refitted and windows replaced with double-glazed units. The roof is being repaired and will be insulated in stages. We recommend that it is fully-insulated to currently-advised levels (250 – 300 mm of glasswool or equivalent rigid board insulation).

Ventilation systems are sparse and could be reviewed to improve their effectiveness and reduce condensation damage (mould growth, poor air quality, etc.).

2.1 Existing Heating Systems

The main focus of this project is how to replace the current, oil-fired heating system with an electrically-heated system, which will utilise power generated by the hydro turbine. The existing heating systems have had to be surveyed, to determine how well they can be adapted to the proposed changes.

2.2 Space Heating

The building is heated by a wet central heating system, supplying heat to radiators in most rooms. Some rooms have pipe runs instead of radiators. The system is a traditional flow & return type, with water (LTHW[1]) temperatures probably set at 82°C flow and 71°C return. Whether these temperatures are achieved is not known.

The radiators at the front of the building appear to be in a ‘one-pipe’ configuration, where water flows in a loop and radiators branch-off the pipe and return to the same pipe; the water gradually cooling as it returns to the boiler and radiators gradually increasing in size as a consequence. This type of system is out-dated and is difficult to control effectively. Radiators at the back of the building seem to mainly be running on a ‘two-pipe’ system, which is more controllable and efficient. Here, each radiator is connected to a flow pipe from the boiler and to a return pipe back to the boiler, so each radiator (should) receive water at the same temperature.

The age of the heating system probably means that radiators and pipes contain significant amounts of sludge and have corrosion issues. Any new heat source should ideally be protected by separating the water circuits using a ‘plate heat exchanger’. This concept is detailed later.

Some radiators have been fitted with TRVs (thermostatic radiator valves) although more radiators are to be retrofitted with TRVs as rooms are refurbished. This allows better control of temperatures, although the bare pipe running under the radiators and round the room will give off heat regardless.

The radiators on the ground floor at the front, and upstairs in the large, eastern-most bedroom are an unusual type not commonly found, see Figure 1. They are radiant panels; built into walls, either below or either side of the windows. It is thought that their effectiveness is limited by being in the walls, and they probably lose a lot of heat back into the walls. However, limited funds and their relative permanence as a feature in the rooms, means that the panel radiators are likely to be retained for now. There may be asbestos present behind the radiators, but it is enclosed and possibly stable at present.

Figure 1: One of the unusual panel radiators - in the hall

We recommend that a re-sizing check is done for radiators and most of them replaced with new radiators at some point, along with the pipework.

[1] Low Temperature Hot Water, to differentiate between Domestic Hot Water (DHW), i.e. hot tap water.

Heating system water (LTHW) is heated by a boiler, which was installed about 5 years-ago. It is a reasonably efficient **Grant Vortex Utility 58-70** condensing oil-fired boiler, which has an efficiency of about 90 – 94%. The boiler is installed in a small boiler room in the extension which is proposed to be demolished.

The boiler is reasonably new and efficient, so it can be retained for re-use as a back-up heat source in the new heating system.

The heating system is controlled by a single room thermostat; located at high level outside the Staff Resources room on the ground floor. It is an electro-mechanical dial thermostat manufactured by Danfoss, and was probably installed when the boiler was replaced. There does not appear to be a time control for the heating system; staff activate the heating by adjusting the thermostat.

Room temperatures therefore vary quite widely and there are probably significant energy demands required to heat up the cold building each time. It will also take quite a while for the building to warm up. It may be preferable to adjust the temperature so that it sets-back to a higher temperature when unoccupied, e.g. 17 or 18°C and then is brought up to comfort temperature just before occupancy, e.g. 20 – 21°C. This can be easily achieved using a programmable room thermostat, although if staff are always present and one of them is tasked with adjusting the manual thermostat, this can suffice.

2.3 Domestic Hot Water (DHW)

The DHW in the building is heated by a separate system to the radiators. In theory, this is an efficient way of heating, as it means the central heating system and boiler can be shut-down in warmer weather.

DHW is heated in two, 182 litre Andrew's water heaters, which burn LPG. The age of the heaters is unknown, but they appear to be in poor condition with badly-fitted flues. Each water heater has a heat input of 11 kW and heat output to water of 8.4 kW. This means they are approx. 76% efficient – not ideal.

Water from the heaters is circulated by natural convection (see note about towel rails in the Legionella section) around to the various outlets in the building. The circulation is probably not comprehensive and there may be significant dead-legs to certain outlets. Pipework appears to be largely un-insulated, which is not recommended.

The anticipated maximum demand at any one time from the water heaters is thought to be (will be) 7 showers, a kitchen sink and a couple of basins. Some of the showers are electric – thought to be the 2 new showers, fitted in the Morar bedroom en-suite and in the adjacent single shower room; and one electric shower in the female shower room.

There are in total:

- 7 showers (3 electric and 4 DHW)
- 10 basins
- 2 sinks (one in scullery and one in kitchen)
- 1 dishwasher (currently supplied by cold water only – best to have hot fill)
- 2 washing machines

For the future:

- Provision for a further 3 - 4 showers and probably 4 - 6 basins in the new extension.

Water is currently supplied from a header tank in the loft, which feeds the water heaters and most cold taps and WCs. Some basins – perhaps in the bedrooms – are fed from mains cold water, as will be the sinks.

Water is supplied to the header tank and to mains-fed taps from a private water supply, which is detailed separately.

Legionella Risk

During the survey it was identified that there is a potentially major risk of there being Legionella bacteria infection in the DHW system at the Ardgour. It is our professional responsibility to highlight this issue and state that it is the client's responsibility to ensure that the risk is minimised.

The design, installation and maintenance of the existing DHW system is such that there is a very real danger that occupants could be at risk of contracting Legionnaire's Disease by exposure to, primarily, water spray from showers and taps. We identified the following main issues, which we recommend are addressed and advice sought from a suitably-qualified and insured Consultant Engineer:

- Uninsulated DHW pipework.
- No clear monitoring or indication of temperatures of DHW at source or in the system.
- Hidden and unknown pipe runs and potential dead-legs in pipes.
- Gravity circulation (partial) – meaning poor temperature control and dead-legs in pipes.
- DHW supplying heat to towel rails in the male and female bathrooms – causing DHW temperatures to be lowered below safe levels (50 – 60°C).
- Temperature mixing valves and booster pumps supplying grouped showers (pairs) in male and female showers, with long lengths of dead-leg pipe run un-insulated at low temperature (post mixing).
- No pumped and ideally, temperature regulated, secondary return system around the building – supplying correct temperature of DHW to each outlet with minimal waiting times.

Because of the condition of the existing DHW system, we recommend that it is comprehensively replaced. Doing so will also allow all outlets (showers in particular) to be supplied with DHW from the proposed new hydro-powered heating system, rather than any electric showers.

The work required is significant and may not be feasible for the client at present. However, sources of funding should be sought and works done to remove the Legionella risk, as soon as practicable.

Again, we advise seeking suitably-qualified independent advice as to the level of risk and the best solutions to remove the risk.

Figure 2: The existing Andrew's water heaters in the kitchen

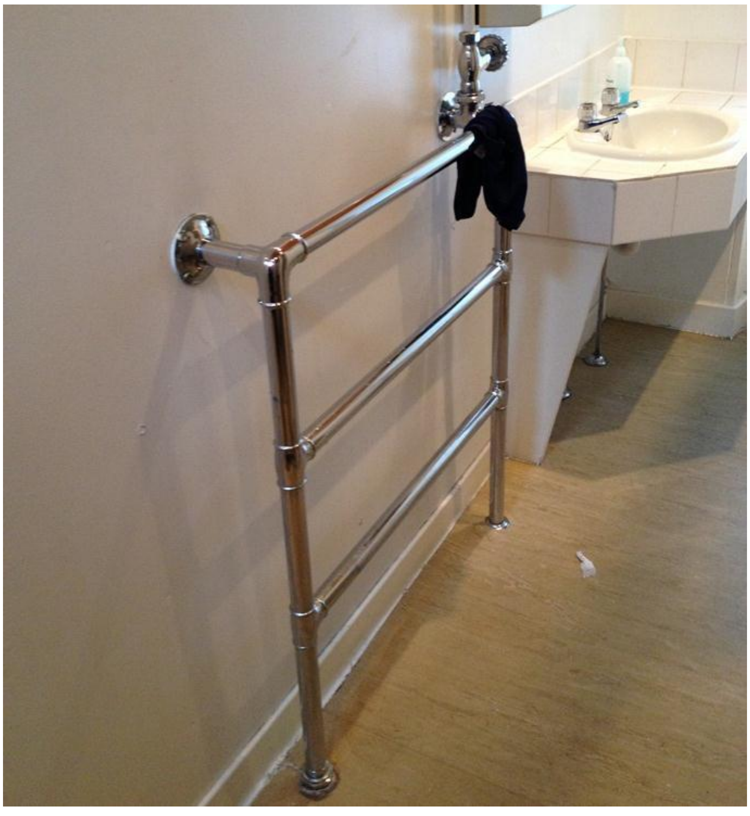


Figure 3: One of the towel rails heated from the DHW system

2.4 Mains Water

Mains water to the building is supplied from a private water supply via a header tank on the hill behind the centre.

Water enters the building through a cartridge filter and UV-light filter, before supplying mains-fed taps and the cold water header tank.

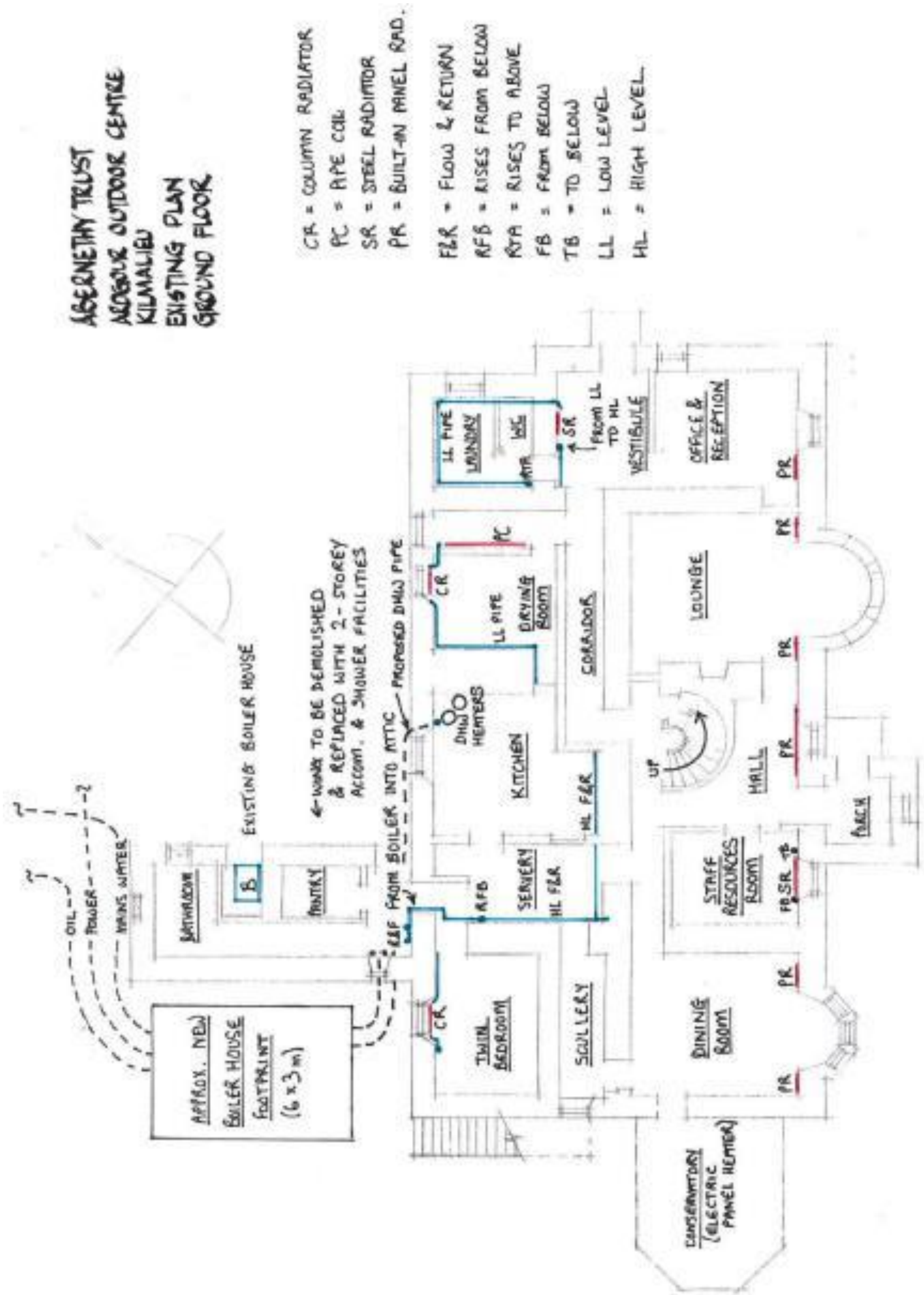
We have been informed that pressure and flow varies greatly.

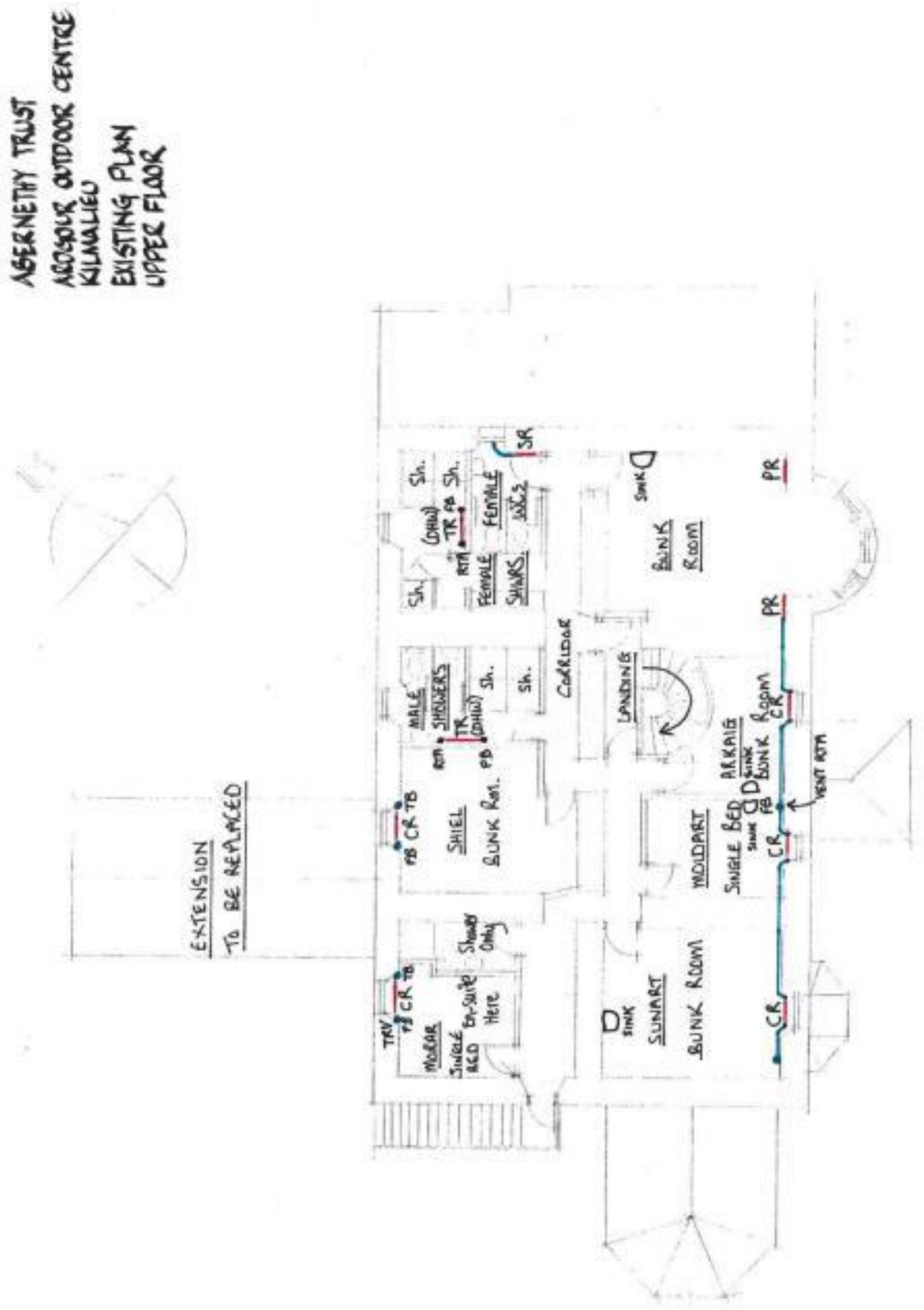
We recommend that as part of the new boiler house works, provision is made to allow the mains water supply to be redirected into the boiler house. There should be a separated area containing the water treatment plant and a new, water booster pump set (twin-pump) and accumulator tank (pressure vessel). This will need to be sized to suit the maximum expected simultaneous demand (from cold and hot outlets), but will ensure pressure and flow from each outlet is guaranteed to be sufficient.

We recommend that WCs remain connected (should be connected) to the header tank in the loft, which can be used as a back-up for flushing toilets in case of power failure/water supply failure.

3 Existing and Proposed Heating System Plans

The plans on the next couple of pages show the ground and first floors, and the locations of various radiators, pipes and items of plant, as noted from the initial survey. We have also indicated where the new boiler house could be located and routes for underground pipework and power supply.




ABERNETHY TRUST
ARDGOUR OUTDOOR CENTRE
KILMALIEU
EXISTING PLAN
UPPER FLOOR
EXTENSION
TO BE REPLACED
CORRIDOR
LANDING
MALE SHOWERS
SHIEL
BUNK Rm.
FEMALE SHWRS.
FEMALE WCs
BUNK ROOM
ARKAIG BUNK ROOM
MOIDART
SINGLE BED
SUNART
BUNK ROOM
MORAR
SINGLE BED
En-suite Here
Shower Only
VENT RTA

4 System Design

4.1 New Boiler House

We recommend that a new boiler house is constructed adjacent to the proposed extension. It should be a minimum of 4 m x 6 m and 3 m high, to accommodate the EMMA system, switchgear, thermal store, heat exchangers, pumps and the mains water supply treatment and pressurisation plant.

The boiler house can be constructed using a thick, reinforced concrete base and insulated, timber-clad or blockwork walls. A sandwich-construction insulated (e.g. Kingspan) metal roof of either mono-pitch or traditional pitch construction would suffice. We have listed some of the key requirements in the separate Notional Bill of Quantities. The NBOQ needs to be completed, e.g. with information on the building, and can be then be used for obtaining tenders along with this report and other details, e.g. EMMA quote.

The client's Architect will be looking into the boiler house construction in more detail, along with requirements for Building Warrant and possible Planning Permission. This is separate to this project, although the cost of the building will need to be included in the project costs if it is to be covered by the CES grant.

4.2 Heating System

In order to utilise the on-site generated power from the hydropower scheme, some form of thermal storage tank needs to be provided, which can be heated using immersion heaters.

Our calculations show, as best as can be determined, that the annual heat demand for the building (including the proposed extension) is:

- **85,000 kWh for space and DHW heating – excluding inefficiencies of heating system**

Of which:

- **54,700 kWh is for space heating**
- **30,300 kWh is for DHW heating – this is more of an estimate as some of the hot water is currently used to heat two towel rails**

These figures have been calculated based on existing fuel consumption (oil – for space heating, and LPG – for DHW heating), and normalised against degree-day data for the space heating. An allowance has been added for the proposed extension.

The existing oil-fired boiler has a heat output of 64 kW, which appears to be sufficient.

We noted that it is likely that radiators in some of the rooms are undersized, but that they are unlikely to be changed for the foreseeable future.

The estimated peak heat load for the building has been calculated to be **48 kW**, of which 15 kW has been nominally allocated for DHW heating, assuming a buffer storage solution to allow for high peak demands.

The recommended EMMA solution (see SWAL quotation and report) is for a 54 kW unit, which controls the output to a heat load according to the available spare power from the hydro turbine.

Power supplied to the thermal store/accumulator tank is available in a 3 kW variable output and then in stepped 3 kW stages up to the 54 kW maximum.

There will be times when no spare power is available from the hydro turbine, due to other on-site demands (lighting, power, etc.). At these times, if sufficient heat has not been stored-up in the thermal store, a thermostat in the thermal store will activate the back-up oil-fired boiler. The boiler will heat the thermal store from the top, down.

4.2.1 Accumulator Tank

The tank or thermal store is proposed to be part of a packaged unit. We have been in discussions with

The thermal store will have the following features:

- 2,000 litre capacity (2,350mm high x 1,100mm diameter).
- Allow approx. 35 kWh of heat to be stored, if max. temperature is 85°C.
- Vented – using an expansion tank above the store, within the boiler house – safer than an unvented store and less reliant on regular checks.
- Contain 6 x 9 kW immersion heaters, mounted from the base, upwards, through holes formed in the side of the store (see schematic).
- Each immersion heater will be a three-phase unit, to allow supply from the EMMA in 3 kW @ 230V stages.
- Well-insulated, with at least 100 mm of foam insulation and a protective jacket.
- Sufficient 'bosses' for connecting inlet and outlet pipes, temperature sensor pockets and temperature gauges.
- Be sized (height:width) to allow it to be accommodated in a boiler house of max. 3 m ceiling height.
- Be constructed of mild steel or copper.

4.2.2 Space (LTHW) Heating

As the thermal store is new and potentially quite sensitive to poor water quality and sludge from the heating system, it is proposed that it is isolated from the LTHW and the DHW heating circuits by plate heat exchangers (PHE), with return pipes fitted with strainers.

PHE are compact heat exchangers, contained inside an insulated housing. They can be sized to cater for any heat capacity. A unit that could heat the building, e.g. of 50 kW output at 82°C flow and 71°C return, will only be about 50 cm tall and 20 cm deep and wide.

The attached schematics (see Figure 5 and Figure 6 on the next few pages) show the PHEs and how they can be linked to the thermal store and the various heating circuits.

For space heating, we propose drawing out thermal store water using a high-efficiency, variable-speed pump. A mixing valve is controlled by a weather compensated controller, which measures the outside air temperature and adjusts the heating water temperature accordingly. This can save about 25% energy compared to a constant temperature system, and significantly improves comfort.

This solution will also reduce unnecessary 'stirring' of the thermal store and wasting of the hydropower-generated heat.

We propose that the weather compensation control is installed and will provide more even heating throughout the building. Overall temperature control can be done using the existing or a replacement room thermostat. The new extension may benefit from a separate control and zoning, as it will have less heat losses than the main building.

LTHW is circulated through a 50 kW PHE. On the other side of the PHE, flow and return header pipes lead off into the building. A new, high-efficiency, variable-speed pump will circulate the LTHW across to the existing building.

We propose that the new boiler house is linked to the existing building through a section of pre-insulated twin pipe. This pipe can be buried and brought into the building near the back wall of the main building, for example adjacent to where the pipes drop from the ceiling in the extension, see Figure 4 below.

Figure 4: Existing flow & return pipes proposed location for linking to new heating pipes

4.2.3 DHW Heating

We recommend that the Legionella contamination issues are reviewed and the necessary action taken, as recommended previously. DHW supplies should be taken to all outlets, including all showers, and suitably-connected to a secondary pumped return pipe system.

The towel rails must be switched-over to run on the LTHW (space heating) system.

From the side of the hydro-powered heating system, we propose to install a twin PHE unit, which will instantaneously heat water using the heat in the thermal store. The concept can be seen in the schematic in Figure 5.

Water heated in the boiler house should be supplied into the building through pre-insulated twin pipe, either underground or by above ground route. The twin pipe will contain the DHW flow and the secondary return pipes. The supply pipe will have to be sized to supply the maximum expected simultaneous DHW demand.

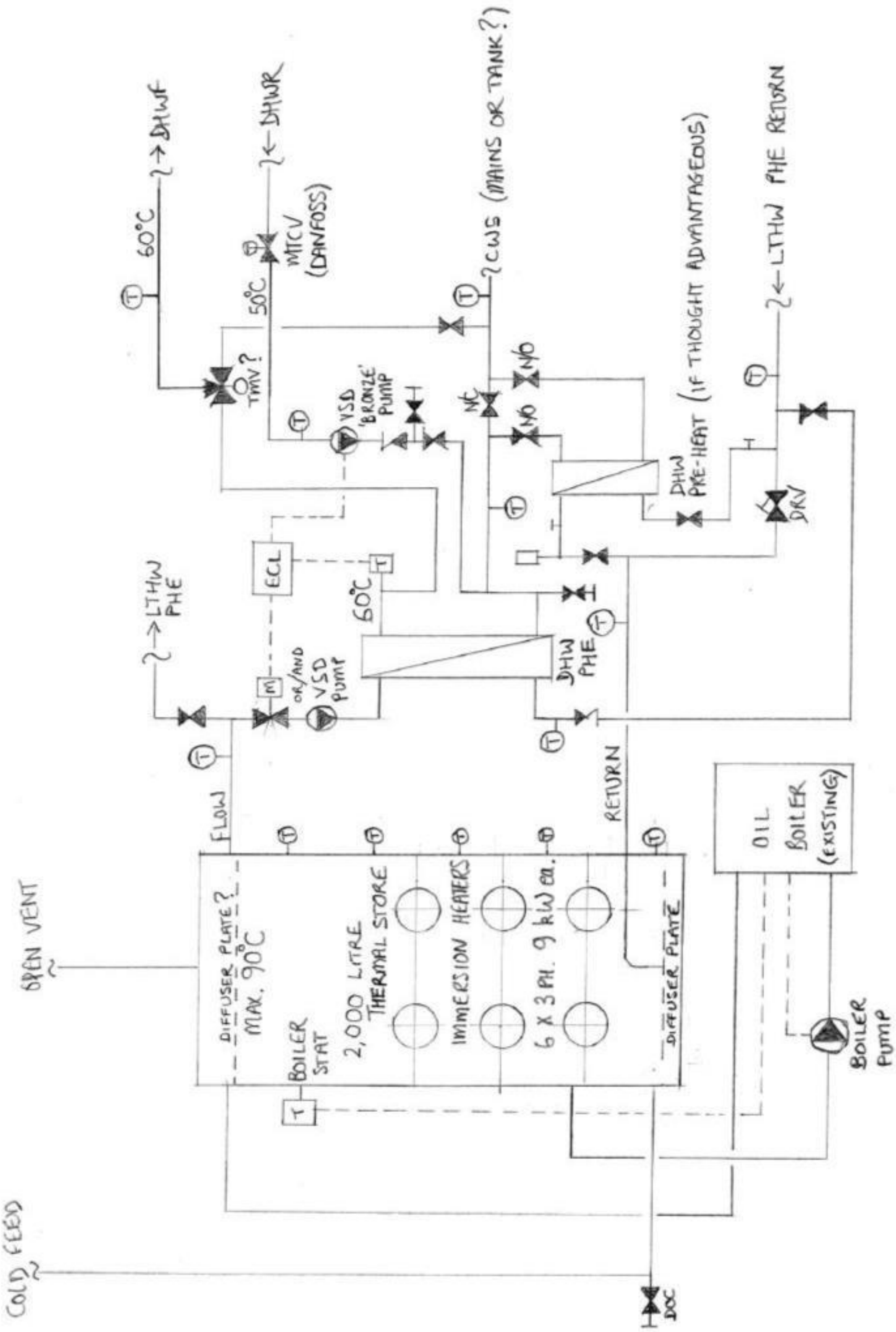


Figure 5: Schematic design for thermal store and DHW heat exchangers

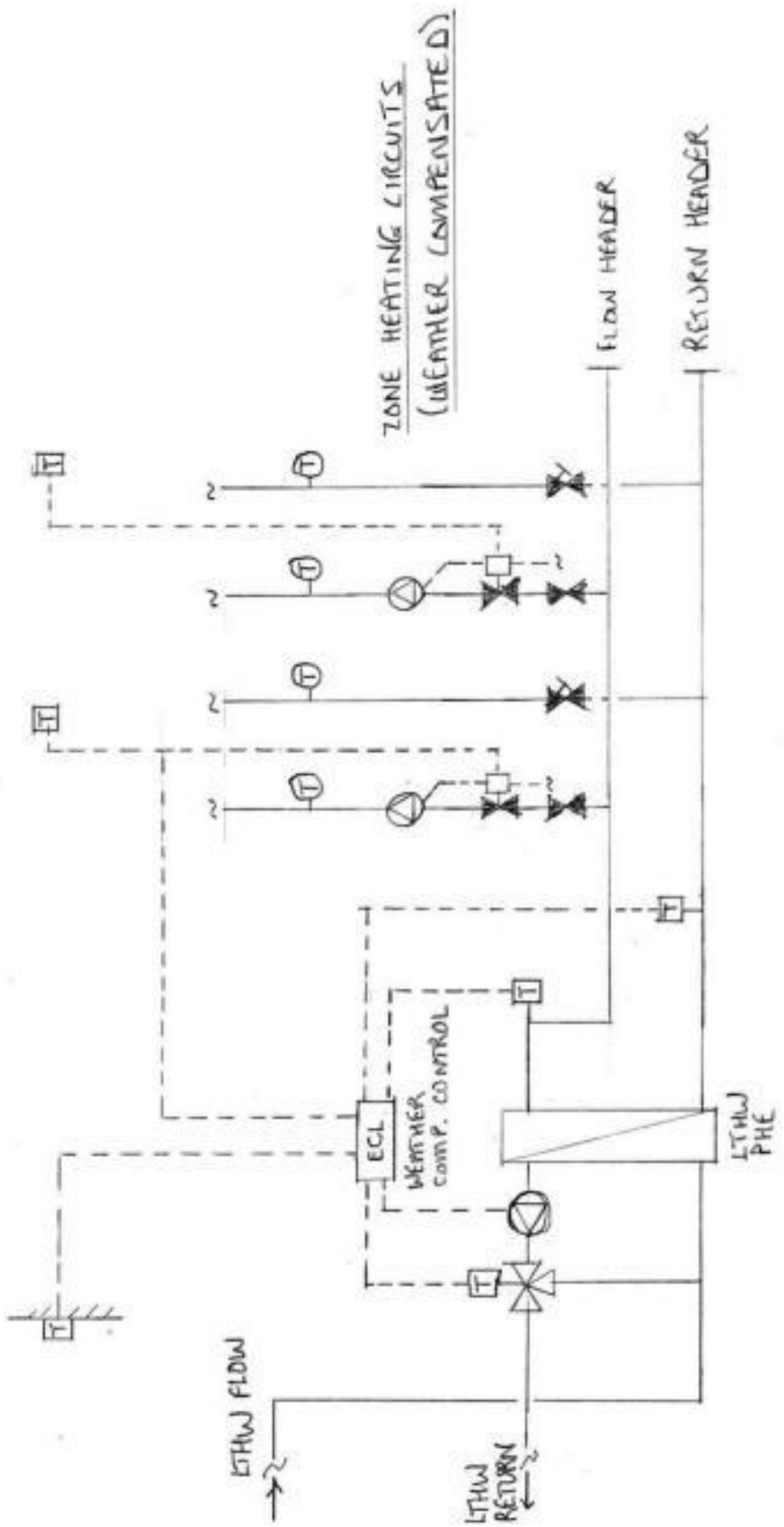


Figure 6: Schematic for the LTHW heat exchanger fed from the thermal store

4.2.4 Mains Water Supply

As mentioned previously, we propose to move the existing water treatment plant into the new boiler house.

The water treatment plant should be inspected and replaced if necessary.

We recommend that a twin-pump booster set is installed, which can supply pressurised cold water to all outlets, such as the DHW system and cold supplies to showers and sinks.

The pump will need to be sized to supply the maximum expected simultaneous demand from the building, including the header tank in the loft, if this is retained to supply the WCs.

The water treatment and pressurisation plant should be located in the boiler house away from the oil boiler and the electrics. It may be sensible to house it in an insulated enclosure and provide a frost-protection heater (electric).

Further advice on the sizing and design of the water treatment and pressurisation plant should be sought from a suitable supplier.

Whether the cost of this part of the work can be funded from the grant is unclear, but allowance could be made for its inclusion in the boiler house at a later date if not immediately.

We have allowed a sum of £5,000 at this stage.

5 System Costings

Due to the nature of the project and remit of our part of the project as currently agreed, we are not able to provide fully-detailed costs at this stage. We have secured prices for the thermal store, and allowed provisional sums for other parts of the works, to our best estimate. We have included the cost of the EMMA system from SWAL.

We have provided as much detail as can be expected at short notice, in order to allow contractors to bid for the works. However, upon completing the pricing exercise and determining the cost savings of the hydro-powered heating system, you can see in Chapters 6 and 7 that it may be unfavourable to use this as a solution.

The separate Notional Bill of Quantities (NBOQ) can be further detailed and used to provide a guide to contractors when tendering.

Please refer to the NBOQ for details on the pricing to date, include provisional sums.

The quote we received for the thermal store components is as shown below.

Part Decription	Qty	List Price	Discount	Net Price	Total (ex.vat)
X2009-16E 6kW(3 Phase) Electric Immersion Element. Product is designed for Industrial usage, unit tested by supplier to cover BS EN 60335-2-73 specification.	6	190.05	35%	123.53	741.18
BUFFER7850 2000 litre Steel Buffer Store, 3 Bar Working Pressure, 1100mm x 2350mm, with external 80mm removable Insulation Jacket. Includes 6 x 2¼inch Immersion heater bosses, 10 x ½inch bosses for sensors and stats, 6 x 1½inch Bosses for circuits, and two internal baffle plates. Price includes delivery to site.	1	7700.00	35%	5005.00	5005.00
B25THX60-FM Heat Exchanger B25THx60 1P-SC-S 4x 1inch Connections (1¼ optional), Complete with Insulated Cover, and Floor Stand.	3	1402.00	35%	911.30	2733.90
Total					£8480.08
VAT at 20%					£1696.02
Total including VAT					£10176.10

Figure 7: Quotation for thermal store components – refer also to the NBOQ

Following the NBOQ for reference, we estimate that the final price for the whole system, including boiler house and water treatment plant would be, approx. £100,000 – excluding contingency, professional fees and VAT.

The project could therefore end up costing approx. **£140,000** in total.

6 Potential Running Cost Savings of the Project

We have been notified that the hydro scheme generated a total of **275,360 kWh in 2012**.

Of this, **244,980 kWh was exported**.

An additional **24,200 kWh was imported**, probably to cover shortfall during dry spells, when the hydro scheme would not be running.

If all the heating was done by oil – we recommend that LPG is avoided, only to be used for cooking - the estimated annual running costs would be about **£6,632** – based on a system efficiency of 80%.

The quantity of exported hydro-generated electricity (244,980 kWh) would suggest that there is sufficient 'spare' power to be diverted through the EMMA to heat the building.

The estimated heat demand, allowing for 10% losses, would be about **93,500 kWh** per year.

Assumptions

The financial analysis at this stage does not take account of inflation in fuel prices or changes in the FiT or exported power payments.

Oil price is based on 65p/litre and exported power price based on 4p/kWh.

Scenario 1

Assuming all heat is able to be generated by the surplus hydro electricity, then:

About **£3,740** per year would be 'lost' by not exporting power.

About **£6,632** would be 'saved' by avoiding the use of oil.

The net annual 'Year 1' savings of the hydro-powered heating system would therefore be approx. **£2,890**.

Scenario 2

Perhaps more realistically, if we assume that there is a shortfall of electricity generation in the drier months, which is therefore not available for heating; most likely in the summer – so DHW heating only, then:

We might assume that about 80% of the annual space heating and DHW requirement has to be met by oil heating.

About **£2,995** per year would be 'lost' by not exporting power.

About **£1,325** per year would be spent on heating oil.

But about **£5,305** would be 'saved' by avoiding the use of oil.

The net annual 'Year 1' savings of the hydro-powered heating system would therefore be approx. **£985**.

7 Conclusions & Recommendations

The figures in the previous chapter show that the proposed system is quite sensitive to changes in the amount of power generated by the hydro scheme, and whether this coincides with and exceeds the heating demand from the building at a given time.

Heat produced by the system does not qualify for the Renewable Heat Incentive. Whilst the hydro scheme receives Feed-in Tariff payments, which goes a long way to justify the capital cost of the hydro scheme; the cost benefit of a heating system using surplus power generated by the hydro scheme does not appear to be as attractive as it might at first appear.

However, the figures do not include the anticipated steep rise in fossil fuels over the coming years, which might help to make the project more attractive.

Given the obvious gap in the figures, between capital cost and savings, we have not at this stage run detailed financial modelling.

Simple payback figures show that if 100% of the heating was produced from surplus hydro electricity, then we could be looking at a **35 year payback**. (VAT excluded in prices)

Accounting for fuel price rises, we estimate that the payback period might drop to around 25 – 30 years.

If 80% of the heating was provided by the hydro scheme, then we unfortunately see payback periods jump to around **100 years**. (VAT excluded in prices)

Upon reflection of the figures, it may be more cost and environmentally beneficial to consider one of the following options:

- Ground Source Heat Pump (GSHP)
- Biomass boiler

7.1 GSHP

Utilising the on-site generated power, without the use of an EMMA; so with the chance that imported power would be required on occasions. Heat pumps, when installed correctly, can have an efficiency of between 250% and 400%. This would make better use of the available power and help compensate power that would normally be sold to the grid.

GSHPs attract the non-domestic Renewable Heat Incentive, which would help to fund the installation and running costs of the system.

We don’t currently recommend this as an option, as the heating system in the house does not lend itself to the efficient use of a heat pump. The water temperatures in the radiator system are too high to allow the heat pump to operate efficiently. Major changes to the heating system would be required, and the building would have to be significantly upgraded to reduce heat losses and draughts.

7.2 Biomass

Allowing the hydro scheme to operate as it currently does, with surplus power exported to the grid, means that an alternative heat source could be biomass – in particular, a woodpellet boiler with the existing oil-fired boiler for back-up.

Biomass heating attracts the RHI and improves the return on investment considerably. However, even without the RHI, for an off-gas grid property, biomass can often make sense.

We have suggested a woodpellet boiler might be more suitable for Ardgour, as it is cheaper to install and less hands-on than a woodchip boiler. Woodchip fuel is cheaper than woodpellets, but would still have to be bought-in.

Our initial investigations give the following headline figures:

- Install a 40 kW woodpellet boiler in a separate boiler house or incorporate in a boiler house as part of the new extension
- Construct a waterproof pellet store adjacent to the boiler house 5 x 3 m and 3 m high
- Allow a capital cost of £60,000 ex VAT
- Annual fuel consumption: 20.5 tonnes of woodpellets – can be supplied in one delivery
- Annual heating costs (excluding oil use) £4,100 @ £200/tonne for woodpellets
- RHI payment: £5,044 per year for 20 years (excluding inflation)
- Savings from using woodpellets compared to oil: £2,540 per year and rising with oil price increases.
- Payback period: 12 – 14 years.

A woodchip boiler would see the payback period drop to around 8 – 10 years.

As we have discovered in the course of our investigations, a hydro-powered heating system is not necessarily as cost-effective as one might initially be led to believe. The significant capital cost of the various components, such as the power regulator, thermal storage and integrating into the building, cannot easily be justified.

One failing of this concept is that it does not qualify for RHI payments. Another issue is that you are removing export payments and replacing with offsetting of oil heating. Perhaps if the project was offsetting electric heating (e.g. storage heaters or panel heaters) then it may be a more worthwhile project.

It would appear that a biomass heating system could be the more beneficial option – it is cheaper to install and will qualify to receive the non-domestic RHI.

A biomass project could be made even more attractive by extending the system to heat all of the surrounding houses in a district heating network.