Hilbre Sustainability Strategy

Report for the British Art and Design Association

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Introduction

Disused buildings on a site on Hilbre are to be renovated by the British Art and Design Association (BADA) for use as an Art and Science Study Centre, with an overall guiding theme of sustainability. The art / science activities including education, research, and art production, related to ideas and practice around the topics of sustainability. Other buildings within the site boundaries will be occupied by Hilbre Bird Observatory (HiBO) and the Friends of Hilbre (FoH).

This report describes the sustainability strategy for the centre. It describes the physical and practical sustainability aspects of the project and provides recommendations for refurbishment work to the buildings, the use of resources, and gives broad details of the energy systems including generation and provision of heat and electricity. Also covered are recommendations for water and waste systems. The approach to and implementation of these aspects of the project will greatly affect its qualities of sustainability. The report also provides information on the general topic of sustainability and how it can be measured or assessed on Hilbre.

Section 1 provides a brief description of the buildings and site, followed by Section 2 which provides information on aspects of sustainability that are particularly relevant to the buildings and site. Section 3 outlines in some detail the proposals for the renovation of the buildings and Section 4 describes the renewable energy systems. Sections 5, 6 and 7 cover water, waste, and materials respectively. Section 8 summarises the schedule of provision of services.

Section 9 provides general information on the wider aspects of sustainability and is intended to provide context and a reference for the future development of the Centre. Section 10 discusses various methods of measuring sustainability, and Section 11 summarises the recommendations of this report.

1. Site and buildings

1.1 Site

Hilbre is a small island situated at the mouth of the Dee estuary, having a close and immediate connection to the natural elements of sea, wind and sun. The island is part of a Site of Special Scientific Interest (SSSI) that covers the wider Dee estuary, and the outstanding natural environment of the island calls for an environmentally responsible and sustainable development. The island is not connected to the electricity grid, the mains water supply, or to sewerage. Therefore, renewable energy systems, a water supply and a means of waste treatment will be required.

A sustainable approach to refurbishing and reinhabiting the buildings and site is appropriate to the environment of the island and will add design quality and will be an advantage when applying for the required planning permissions.

1.2 Buildings

The buildings within the site are of traditional stone construction and some are Grade 2 listed. They are currently unused, and although parts are in poor condition are largely structurally sound with many original features. However, the buildings are not well insulated and there are damp problems in some areas, and some new fabric and materials are needed internally. Insulating the buildings will contribute to the sustainability of the development by reducing heating fuel use and the associated CO_2 emissions, and new materials can be specified such that their negative environmental impacts are reduced, and their positive impacts increased.

1.3 Requirements

Refurbishment of the buildings to be occupied by BADA will be phased over three years, starting with provision of daytime shelter and basic facilities for small groups, and eventually expanding to cater for up to 12 residential visitors.

BADA currently require the following spaces for when there is full occupation.

- Artist rooms for 4-6
- Scientist rooms for 4-6
- Display space
- Communal space
- Kitchens
- Bathrooms
- Sleeping Arrangements for 8-12

Although there will eventually be the capacity for 12 residential occupants, it is not yet known how long they will stay. It is assumed that there will be a mix of short term and longer-term residents, plus day visitors. It can be anticipated however that visits will tend to be shorter in winter than in summer, and the main use in the first year will be for day visitors in summer with small numbers staying overnight. Currently the plan is that the centre will not be open to groups in January or February, therefore reducing the peak heating and electrical loads that need to be provided by the renewable energy systems.

1.4 Renewable energy resources

The site is exposed to the wind and unshaded by other building or topography, and electrical power can be generated by wind turbines and photovoltaic cells. The annual average wind speed on Hilbre at a height of 10 meters above ground level is over 6 m/s which exceeds the figure of 5m/s which is the required speed for an economically viable wind turbine (see Section 2.3.).

2. Sustainability of buildings and energy supply

This section provides an overview of the fundamental sustainability issues concerning the main physical elements and services of the project. These are space heating, domestic hot water heating, energy supply, provision of services (waste and water), and use of materials. Some basic considerations and principles are described, which sets the context for the solutions proposed in Section 3.

2.1 Space heating, reduction of heat demand, fuel use and greenhouse gases emissions.

One of the main practical issues is heating the buildings and doing so in a sustainable way. A sustainable approach will provide sufficient levels of thermal comfort with minimal emissions of greenhouse gases, at a financial cost that is not prohibitive, meeting the logistic and management requirements of bringing fuel to the island and/or generating electricity for heating at an acceptable cost.

2.1.1 Heat demand and demand reduction

The demand for heat energy depends on several factors including the required internal temperature, the schedule for provision of heat, and the external temperatures throughout the year. An important factor is the rate of heat loss through the building fabric by conduction through the fabric of the building external envelope and by radiation from the external surfaces of the building to the surrounding environment. Additional heat losses result from stale air being ventilated from the building, and through exfiltration (or leaking) of warm air through cracks in the building fabric. Heat demand can be reduced by lowering the internal temperature, reducing the times in which the building is heated, reducing conductive heat loss through the building fabric by adding insulation, recovering heat from stale air that is being removed from the building, and by draughtproofing to prevent infiltration and exfiltration.

2.1.2 Insulation

Insulation can reduce conductive heat flow by conduction through the solid elements of the exterior envelope of walls, ground floors, and roofs. Any changes to these building elements during the refurbishment process requires that they also be insulated at least to the levels demanded by building regulations, unless exempted by the listed building authorities. Space heating of buildings can be provided by electrical heaters or by combustion of fuels. Electrical heating of uninsulated buildings would require far more electricity than can be generated onsite economically, and heating of uninsulated buildings by combustion of fuel would require the transport (and expense) of large quantities of fuel from the mainland and lead to higher CO_2 emissions.

These factors taken together suggest that the buildings should be insulated as far as is practicable, such that heat demands are reduced to a minimum. This will make the buildings far more habitable and cheaper to run and will extend the length of time during the year that heating is not required. However, if parts of the building are not to be insulated then other strategies to provide comfortable conditions while not using excessive fuel are needed and are described in Section 3.

2.1.3 Building regulations and listed buildings

Building regulations apply to listed buildings, but such buildings may be exempt from compliance with energy efficiency regulations (Part L) where compliance would unacceptably change their character or appearance or be harmful to their significance. Whether the non-listed buildings will also gain exemption (by falling within the curtilage of a listed building) will be a matter for consideration by the conservation officer. New extensions to listed buildings however must meet the regulations. A key consideration on Hilbre is the limited amount of energy available, so where possible every effort should be made to meet or exceed the U-values shown in Tables 1 and 2 which are applicable to all building work commencing after June 2022.

Table 1. Revised 2022 Part L Target Thermal U-values

Domestic U-values / W/m²K			
Application	New build	Existing Building Extension	Existing Building Refurbishment
All roof types	0.11	0.15	0.16
Wall	0.18	0.18	0.3 / 0.55 (Note 1)
Floor	0.13	0.18	0.25

Note 1. 0.55W/m²K for cavity insulation, 0.3 W/m²K for internal and external insulation.

Table 2. Revised 2022 Part L Target Thermal U-values

Non-Domestic U-values / W/m²K			
Application	New build	Existing Building Extension	Existing Building Refurbishment
Pitched Roof – Ceiling level	0.16	0.16	0.16
Pitched Roof – Rafter level	0.16	0.16	0.18
Flat Roof	0.18	0.18	0.18
Wall	0.26	0.26	0.3 / 0.55 (as Note 1, table 1)
Floor	0.18	0.18	0.25

Walls may be insulated by internal, external, or cavity insulation. The Hilbre buildings have solid stone walls so insulation will be either internal or external. It is far more likely that internal insulation will be acceptable to the conservation officer and is generally less costly to fit than external insulation.

2.1.4 Draughtproofing

Reduction of exfiltration losses will be achieved through draughtproofing where required, typically around doors and windows, at places where pipes pass through the external envelope, and at junctions of the elements of the envelope including floor to wall and wall to roof. The need for draughtproofing will be assessed at each stage of the renovation project, particularly where insulation is being installed and pipes, cabling, ducts, and flues are being taken though the external envelope elements.

2.1.5 Ventilation control and heat recovery

Ventilation is needed for the health and comfort of occupants, to prevent moisture and damp building up in the building fabric, and to provide an air supply for combustion appliances such stoves. Ventilation can be supplied through opening windows or vents in the building envelope such as in the window frames (trickle vents). This method of ventilation is known as natural ventilation. Another method is mechanical ventilation using fans and ducts to supply and remover ventilation air. In the event of using mechanical ventilation, heat exchangers can be used to recover the heat in the stale air which is being expelled from the building, and which is lost when natural ventilation is the method used.

Heat losses through ventilation can typically amount to a third of building heat losses, and so are usually significant. In buildings with little heating these heat losses are of course smaller. It is not thought that the Hilbre buildings will be heated all the time, and when they are they will not be heated to very high temperatures. Therefore, mechanical ventilation with heat recovery will not be especially useful in many of the spaces but heat recover will be advantageous where mechanical ventilation must be supplied anyway.

2.2 Fuels and heating methods

Biomass (logs, wood chips, wood pellets), fossil fuels (coal, oil etc.) and potentially electricity are available for heating. Approximate CO_2 emission figures are shown in figure 1 for various fuels. Emissions from grid electricity are the result of the various power inputs to the national grid (mainly fossil fuels, nuclear, and renewables). Electricity generated onsite has no emissions although some emissions are generated during the manufacture and transport of the renewable energy technology. However, this embodied carbon is not accounted for here.

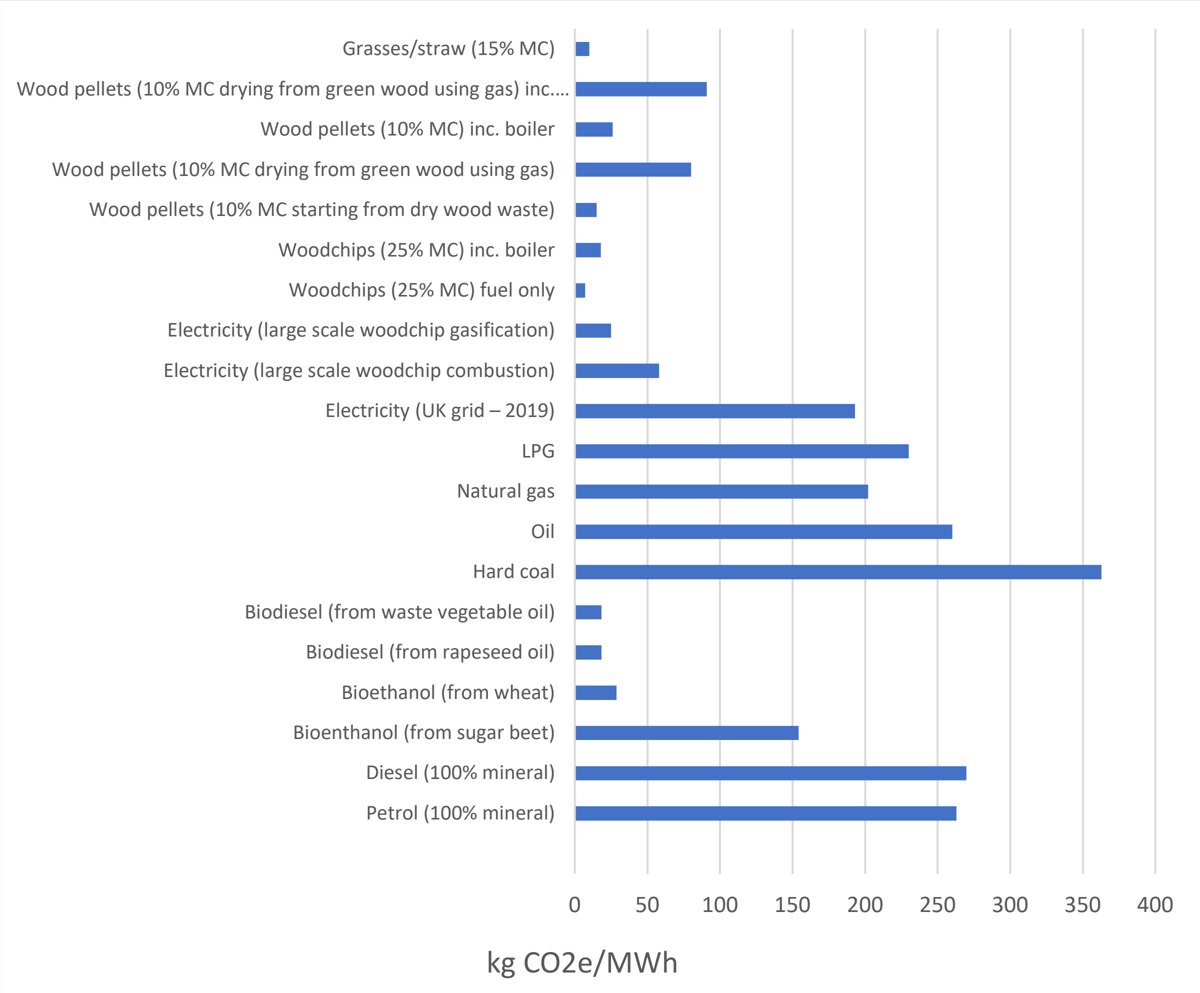


Figure 1. Approximate life cycle CO_2 emissions from fuels per unit of energy. Source: Forest Research (2022)

CO_2 is released into the atmosphere when biomass is burned, but if it come from sustainably managed woodlands and forests then CO_2 is taken up by the replacement trees. There is a net release of CO_2 however, due to processing and transport of biomass, but compared to fossil fuels this is small if transport distances are not very high.

Each of these fuels can be used to heat water and/or air and/or provide radiant heat if consumed in an appropriate device. Water is heated by boilers (gas, oil, electrical, or biomass stove with back boiler), immersion heaters (electricity), heat pumps (electricity) and solar hot water panels or evacuated vacuum tubes. Heat is delivered to spaces by one or more of three methods. These are waterborne (central heating and underfloor heating), warm air supplied through ducts, and radiant heat emitters (wood-burners and electric radiators).

Hot water for washing and showering is heated by one or more of the methods above and can be heated at point of use (instantaneous heating using electricity) or heated and stored in an insulated hot water tank.

2.3 Energy generation

2.3.1 Electrical energy

Generation of electrical power is a fundamental requirement of this project. Electricity will be needed for lights, utilities and equipment, and can also be converted to heat energy. Wind power and photovoltaic (PV) panels are both feasible technologies for this site.

The annual average wind speed on Hilbre at a height of 10 meters above ground level is 6.1 – 6.2 m/s (appendix G, figure G.1), which easily exceeds the figure of 5m/s generally taken as being the required speed for an economically viable wind turbine. This speed does not account for obstructions such as buildings or small-scale topographical features, but the site is open and unobstructed. This data is produced by a computer model and onsite monitoring is usually recommended for an accurate assessment.

Tidal energy is potentially available but as this technology is not yet at a commercial stage it would be an extremely expensive way to generate electricity even if the significant planning obstacles of locating generators in the tidal stream could be overcome. Similarly, wave power is not financially feasible and would face the same planning challenges. Both wave and tidal power would however be interesting options for the future and might be linked to research projects.

PV is available in a range of formats including panels, tiles, façade cladding, or printed onto glazing, each of which is available at a range of efficiencies and costs. Given the listed building status of some of the buildings, and the desire of the client to minimise the visibility of the project (particularly from nearby towns on the Wirral), free standing PV panels to the north of the buildings are preferable to roof mounted PV on the south roof pitches. This option will also cost less.

Wind turbines are also available in a range of sizes, efficiencies, power outputs, and blade arrangements (e.g., horizontal axis or vertical axis). Wind turbines are specified for the power output required and the environmental conditions of the site including the wind regime and the presence of salt spray in the wind. Some turbines have upper and lower limit cut-out speeds, and this will be a factor on Hilbre where the winds can be very strong.

2.3.2 Heat energy

2.3.2.1 Biomass

Biomass combustion produces thermal heat energy needed for space and water heating. Biomass powered Combined Heat and Power (CHP) systems produce electricity in addition to thermal heat energy. However, commercially available CHP systems that use biomass are only available at a large scale, for example to provide heat and electrical power to campus type developments and will not be suitable for Hilbre. A limited amount of biomass is available on the island in the form of bracken which could potentially be used if dried out after harvesting. However, there is not enough to provide the quantities of heat that will be required, but it would be interesting to experiment with this fuel source when the centre is operating.

Three types of biomass fuel are readily available commercially, and in order of physical scale (large to small) these are logs, woodchips, and wood pellets. Logs are generally used in large systems where the logs are available locally, wood chips are used in intermediate sized installations, and wood pellets are generally used in small to intermediate sized systems. Each of these types of installation are available with automatic operation (such as timers, ignition etc.), ash removal, and cleaning mechanisms.

All biomass fuel will need to be transported to the island and stored in a dry place. The easiest and cleanest to transport and handle of these three types is wood pellets, which are available in plastic sacks of 10-15 kg that can be carried by one person.

Hilbre is a domestic sized project that will be used mainly in spring, summer and autumn, by up to twelve occupants. Given that heat demands are intermittent and not particularly high, and that users will not all be familiar with large industrial style burners, it is recommended that an easy-to-use pellet system is used.

2.3.2.2 Solar hot water

Solar hot water (SHW) panels or vacuum tubes make use of solar irradiation from the sun to heat water. A small amount of electricity is needed for pumping the water (unless the system is gravity fed) but otherwise this is a passive technique and one of the most cost effective of all renewable energy technologies. The hot water can be used for washing and showers and / or to contribute towards space heating. Solar panels cannot provide all the hot water needed particularly in winter (unless the system is hugely oversized) but typically can produce half of the hot water requirements when at domestic scale.

Because SHW cannot meet all hot water requirements, if it is used it must be in combination with one or more other heat sources. These could be a wood fired boiler, a heat pump or an immersion heater.

2.3.2.3 Heat pumps

Heat pumps take heat from the surrounding environment (air, water or ground) and transfer it to a fluid (liquid or air) for use in the building. Heat pumps need electricity to run and their use on Hilbre would depend on having sufficient electricity, and so are unlikely to be used as a main source of heat, particularly in the first phases. However, in the future they could possibly be used alongside the SHW for heating water, and perhaps for testing and experimental work. A great advantage of heat pumps is that they extract up to three or four times more heat energy from the environment than they use in electrical energy.

If used, air source heat pumps would probably be the most suitable as the ground is most likely solid rock at the depths that earth source collector tubes must be installed (one to two meters), and the sea is outside the area that BADA are proposing to lease. Air source heat pumps are the least efficient of the three types but are the most practical for the site.

2.4 Materials and construction

The use of materials is related to sustainability in several ways including the health of occupants, the longevity of materials and the effects on the environment of producing and eventually disposing of the materials. Effects on the environment include the pollution and green-house gases emitted to the environment at all life cycle stages of the materials.

The choice of approach to the renovation of the buildings will greatly influence the sustainability of the project as it will determine the need for labour and the quantities and types of materials transported, all of which have implications for carbon emissions. Care must be taken with the specification of materials and construction because of these considerations of embodied carbon, the need to transport materials to the site, suitability for the Hilbre weather, listed building considerations, and the appropriateness of the material for the use of the spaces. The logistical difficulties in carrying out the work could be considerable, as the island is cut off by tides twice per day, and vehicle access is only possible for off road vehicles for three hours on each side of low tide.

Therefore, the general approach should be one of repair, recycling, and re-use of existing fabric and materials where possible, and minimal additions of new materials to meet the needs of occupants, energy consumption, and financial targets.

2.5 Water

Potable (drinkable quality) water is needed for drinking, cooking, washing, and bathing. Water is also needed for flushing toilets unless waterless toilets are used (e.g., composting or incinerating toilets).

There is no fresh water supply on Hilbre apart from a disused well on the site which has been reported by the site warden as containing salt / brackish water. Rainwater harvesting of water from the roofs of the buildings has previously been used to supply water, and a 3600 litre rainwater storage tank remains on the site. There is a possibility that there is also an old tank below ground just to the south of the building. Apart from rainwater harvesting, water can be transported from the mainland, or sea water can be desalinated. However, the latter is expensive and energy intensive and is not a realistic option at this time.

2.6 Wastewater

Wastewater is the discharge from sinks, showers and toilets. Wastewater can be categorised as ‘grey-water’ which is the water drained from sinks and showers, and ‘blackwater’ which is the waste from toilets.

Greywater is discharged to a sewer, septic tank or sewage treatment tank, drainage field or soakaway (if local topography and geological conditions permit), or to a reed bed.

Blackwater is discharged to a sewer, septic tank, sewage treatment tank or treated using a complex system of settlement tanks reed beds or other filtering methods. Alternately, waterless toilets such as composting toilets or incineration toilets treat the waste. Blackwater can also be treated by machines that mimic ecological cleaning systems (‘Living Machines’) although these are generally used for larger scale projects (e.g., village scale).

3. Strategies and solutions

This section provides details and options for how the challenges outlined in Section 2 may be met and sets out information that will allow design choices to be made as the project develops over time.

3.1 Balancing insulation levels, energy use, CO2 emissions and energy costs

The use of biomass for heating, and renewable generation of electricity on site mean that CO2 emissions will be low even if energy use is relatively high and therefore it may be argued that high levels of insulation are not so important as it would be if fossil fuels and/or grid electricity were used for heating. However, the financial costs of generating electricity onsite and purchasing biomass for heating could be very high if the buildings, services and appliances are inefficient, so a balance will be needed between insulating the buildings, the costs of the biomass supply and the insulation itself, and the scale and sizing of the renewable energy technologies. A further factor is the practicality and convenience of delivering large quantities of wood pellets on a regular basis, and it is assumed that it will be preferable to minimise such deliveries

Other factors to be considered include the architectural ambition to allow some parts of the building to remain unmodified such as the slate floor of the Buoy-masters workshop. Also, the details of the lease are not yet known so the extent of works that are feasible are also not known. Ideally the buildings would all be highly insulated to reduce energy use to a minimum, but some of the buildings are listed which can limit the amount of insulation that can be installed, and providing high levels of insulation will at any rate be quite expensive given the difficulties of bringing materials and labour to the site. For these reasons it is useful to understand the relationship between insulation levels and the costs of providing energy through modelling some options. This can help to inform alternative solutions, for example whether to insulate a large space or to construct a temporary smaller, insulated space within the larger uninsulated space.

3.2 Results of modelling

Modelling has been carried out to determine the effects on energy use of insulation of various parts of the building. The results can be used to inform decisions taken as to how much insulation is used and where.

A computer simulation model was made of the buildings and energy-use figures obtained for the building as existing (pre-refurbishment) and with insulation options added. Appendix A gives details of the model parameters and the full results. Table 3 shows selected results including average energy use per day in the heating season (assumed to be October, November, February, March), the mass and cost of wood pellets required to continually heat the spaces to 19C between 08.00 and 22.00, and the cost per hour.

Installing insulation to building Regulations levels approximately halves the energy use and the cost of the fuel needed. The figures for the existing building are quite possibly too low because a ventilation rate of 1 air change per hour (ac/h) and an infiltration rate of 0.25 ac/h has been assumed for both before and after the addition of insulation, whereas the current rate of infiltration particularly in the buoy-masters workshop is probably much higher than this, leading to greater heat losses and energy use than have been shown in table 3.

Table 3. Results of modelling existing buildings and insulated buildings.

Space	Scenario	Average energy use per day (kWh)	Average mass of pellets used per day (kg)	Cost per day of pellets (£)	Cost per hour of pellets (£)
Buoy-masters house	Existing[1]	118	24.3	14.6	1.0
	Scenario 1[2]	83	17	10.2	0.7
Buoy-masters workshop	Existing	122	25.2	15.1	1.1
	Scenario 1	63	13	7.8	0.6
	Scenario 2[3]	1.3	0.3	0.2	0.01
Buoy-masters store: studio and accommodation	Existing	122	25.2	15.1	1.1
	Scenario 1	51	10	6.3	0.4
Buoy-masters store: kitchen and bathroom	Existing	36	7.5	4.5	0.3
	Scenario 1	18	4	2.2	0.2
Buoy-masters store: office	Existing	41	8.5	5.1	0.4
	Scenario 1	10	2	1.3	0.1
Whole building	Existing	439	90.7	54.3	3.9
	Scenario 1	225	46.4	27.8	2.0
	Scenario 2	163	33.6	20.2	1.4

[1] Existing: current levels of insulation

[2] Scenario 1: Insulated to Building Regulations levels

[3] Scenario 2: As Scenario 1 but with unheated workshop containing heated snug (dimensions 4m x 4m x 2.5m)

Heating costs can be further decreased by installing more insulation, by heating for fewer hours, or by heating only parts of the building. For example, the bedrooms in the house and buoy-masters store could be heated for just one or two hours per day, rather than the 14 hours modelled. Therefore, the energy use and costs in table 4 can be seen as maximum figures for space heating.

Domestic hot water heating costs have not been calculated but should not increase the totals in table 1 greatly, because at low occupancy sufficient water can be heated within an hour or two, and higher occupancy will not take place until the solar hot water has been fitted and significant amounts of electrical power are being generated, some of which can be used to heat water. The hot water can also be used to offset use of the pellet stoves for space heating, so it is expected that quantity of wood pellets needed will decrease over time.

3.3 Space and water heating strategy

The buoy-masters house and in the buoy-masters store will each have a wood pellet stove or boiler fitted. Both will provide hot water for a hot water store and radiators (figure 2). If a snug is built in the buoy-masters workshop it will be heated either by an additional small pellet stove or more likely by a radiator supplied by the heating circuit of the buoy-masters house. If the buoy-masters workshop is insulated and heated it will be by radiators connected to the hot water store and boiler in the buoy-masters house. A small pellet stove could be installed in the buoy-masters workshop if a local source of radiant heat is needed in addition to the hot water radiators on the coldest days. Two hot water and heating systems mean that if one system is under repair the other can still be used, but the main advantage is that a smaller single system can be fitted initially when occupancy is relatively low, rather than one very large system.

The use of hot water stores (one in the house, and one near the bathroom / kitchen in the buoy-masters store) will enable the future addition of further heat sources such as solar hot water, heat pumps and immersion heaters. Because the buildings are intermittently occupied during the heating season there will sometimes be excess electrical power available when unoccupied, and this power can be used to either heat water directly through immersion heaters and/or to run heat pumps, with hot water being circulated through the heating system giving the internal mass of the buildings some warmth, reducing the need for heat when visitors arrive and keeping the building fabric in a dry condition.

Solar hot water will supply the hot water storage in the buoy-masters store, and there is a suitable area for mounting panels on the south elevation. Solar hot water for the buoy-masters house should be mounted a small distance away from the house to the west to prevent excessive overshading from the buildings. A rule of thumb for SHW is $1m^2$ per person for sufficient summer hot water, so a total area of about $12m^2$ is recommended. Appendix F gives further details.

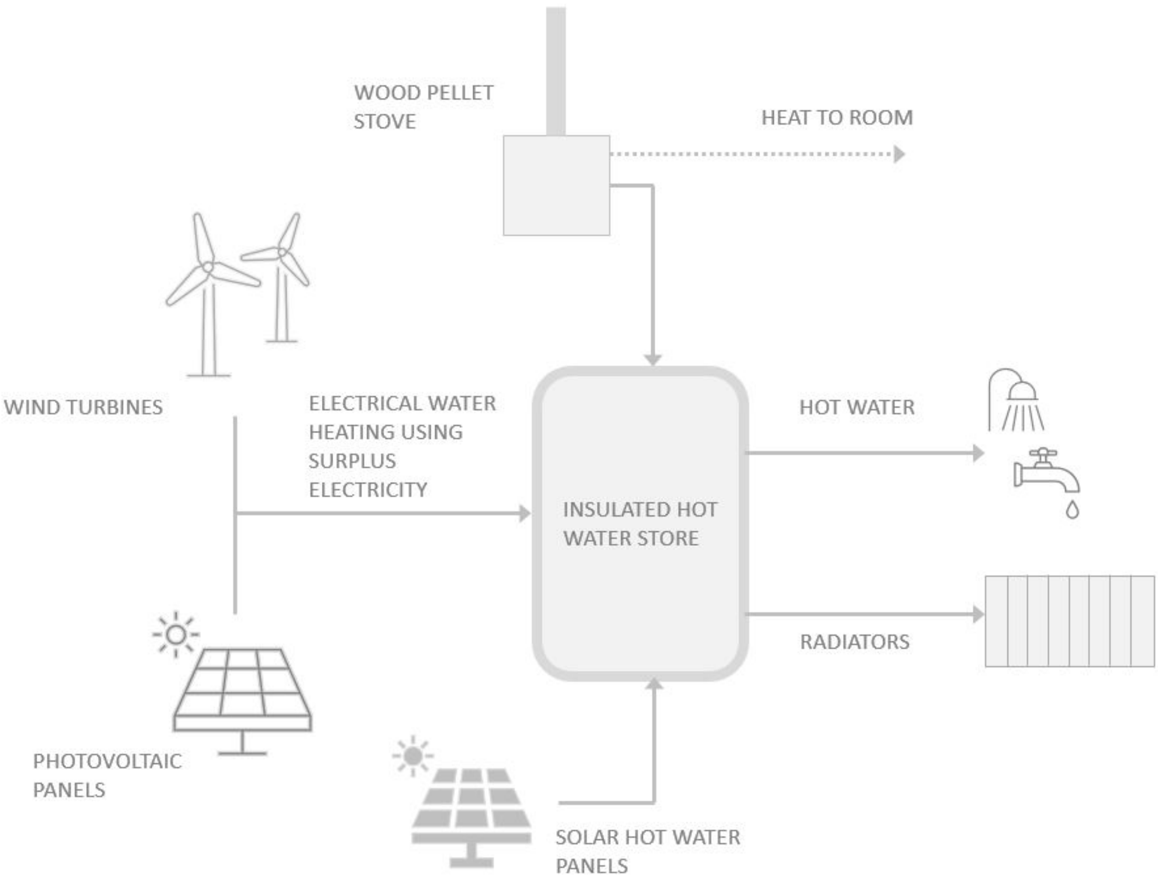


Figure 2. Heating and hot water system

3.4 Ventilation strategy

Ventilation of the buoy-masters house will be through windows and trickle vents. Secondary glazing fitted must allow for adequate ventilation, probably through trickle vents in the frame. Rooms with open fireplaces should retain some controlled ventilation through the chimney using adjustable vents.

A similar strategy applies to the studio space in the buoy-masters store. Natural ventilation in winter will be provided by trickle vents in the window frames, and in the summer by opening windows. The form and location of the accommodation in the buoy-masters store has not been decided at the time of this report. An earlier proposal put the accommodation at first floor level with the studio at ground level, in which case mechanical ventilation of the accommodation will be useful during the heating season.

If a snug is built in the buoy-masters workshop and the workshop remains uninsulated, the snug should be mechanically ventilated. This could be extract only or supply only with vents in the envelope of the snug as sufficient fresh infiltration air is available within the workshop itself. The details will be decided when the details of the snug are known. If the workshop is fully insulated and the snug not built then ventilation will be needed, and the large volume of the workshop suggests that mechanical ventilation with heat recovery will be worthwhile. If natural ventilation is used then vents will be needed as there is only one window to the east.

Throughout the buildings adequate ventilation must be supplied to underfloor voids, which should already be ventilated by means of air bricks in the walls. Existing roof build-ups should also be checked for adequate ventilation, and any new roof insulation must be fitted in such a way that building regulations are met and adequate ventilation is provided.

3.5 Summaries of environmental strategies for each space

3.5.1 Buoy-masters house

The renovation of the buoy-masters house was to be completed in a later phase but now will be completed in phase 1. This means that a wood pellet boiler will be needed to provide heating via radiators in each room. The boiler will heat a hot water store which will feed the heating circuit and provide domestic hot water. Because the buildings are intermittently occupied during the heating season it is likely that there will be excess electrical power available once the wind turbine and PV is operational. This excess power can be used to either supply heat to the hot water store directly from immersion heaters and/or from an air source heat pump.

Table 4. Buoy-masters house environmental strategy.

Buoy-masters house		Notes
Heating	Radiators supplied from hot water store which is heated by wood pellet boiler.	Future heat input to hot water store by immersion and/or heat pump subject to generating sufficient electrical power.
Ventilation (summer)	Opening windows.	Secondary glazing detailed to allow ventilation
Ventilation (winter)	Trickle vents.	Secondary glazing detailed to allow trickle ventilation.
Insulation (walls)	Polystyrene beads (40-50mm) injected into gap between wall and lath/plaster.	See figure 3. Polystyrene beads are preferable to blown cellulose insulation due to the possibility of damp within the walls, particularly where close to the ground or facing west.
Insulation (roof)	Ceiling level insulation (loft space).	Maximum U-value = 0.16W/m2K. A small loft space is already fitted with some insulation, and more will be added to give a total depth of 240mm and achieve the required U-value.

Insulation (floor)	Insulation under suspended timber ground floors if possible. Slate floor in kitchen to remain uninsulated.	There is sufficient space under the ground floor timber suspended floors to install flexible insulation between the floor joists, providing that enough floorboards can be lifted and re-laid without damage.

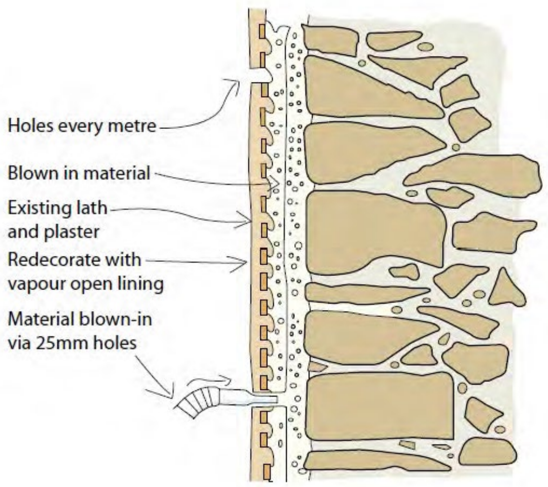


Figure 3. Insertion of insulation between lath/plaster layer and stone walls.
Source: Jenkins and Curtis, 2021.

3.5.2 Buoy-masters store: studio

A medium sized pellet stove with back boiler will supply heat directly to the space and to radiators around the space and in the kitchen, and to a hot water tank in the bathroom / utility room. In later phases heat inputs to the tank from solar hot water and possibly from an air source heat pump and/or immersion heater will reduce the heat needed from the pellet boiler.

Table 5. Buoy-masters store environmental strategy

Buoy-masters store: studio		Notes
Heating	Wood pellet stove, with a back boiler supplying heat to radiators and hot water store.	Replace existing wood stove
Ventilation (summer)	Opening windows	Secondary glazing detailed to allow ventilation.
Ventilation (winter)	Trickle vents	Secondary glazing detailed to allow trickle ventilation.
Insulation (walls)	120mm wood fibre insulation. Fixing to be decided based on internal wall surface needed. See note 1.	Insulation should be breathable as walls are damp in places. Maximum U-value = 0.3W/m^{2}K
Insulation (roof)	Minimum of 240mm wood fibre	Buoy-masters store is not listed and full building regulations could apply. Maximum U-value = 0.16W/m^{2}K
Insulation (floor)	See note 2.	Maximum U-value = 0.25W/m^{2}K

Notes

1. Wall insulation: The most sustainable approach is to use a type of wood-fibre insulation that is designed to be attached to masonry walls and which can absorb instantly any condensation at the wall – insulation interface. This means that a vapour barrier is not needed. Alternately a vapour barrier can be used (e.g., foil backed plasterboard on studs attached to wall with insulation between studs).
2. To reach the U-value maximum of 0.25W/m^{2}K, 100mm of typical insulation (conductivity = 0.035 W/(m.k)) is needed. As this is difficult to fit the roof insulation may need to be increased.

The existing floor construction consists of a timber floor on battens resting on a damp slate floor in direct contact with the ground below. Floor insulation under the slate would require major work to excavate the ground to the required depth for the insulation. As the timber floor is in good condition three options are available.

1. No modification at all, focussing on achieving high levels of insulation in the roof and in the walls.
2. Laying a new insulated timber floor on the existing timber floor. This would raise the floor level only a small amount (e.g., 40-60mm).
3. Removing the existing timber floor and relaying it, but with deeper joists lying on the slate floor and with insulation fitted between the joists. This would raise the floor level by the depth of the new joists (e.g., 100mm joists with 50mm insulation and 50mm ventilated cavity below)

These options will be examined in greater detail when the buoy-masters store is refurbished in phase 2 of the works.

3.5.3 Buoy-masters store: accommodation

The plan at the time of writing is to have sleeping accommodation in the buoy-masters house and above the kitchen in the buoy-masters store. A previously discussed option was to place sleeping accommodation above the main studio space in the buoy-masters store and details are given here in case this option is used at some time in the future.

The proposed cabins at first floor level are very compact and well insulated. A rooflight to each cabin will provide summer ventilation. Although some ventilation is possible through trickle vents in the rooflight, a small amount of heat will be needed for the cabins in winter, which can be supplied by mechanical ventilation. This has the advantage of providing reliable ventilation as well as heat, which is particularly important in a small and enclosed space. Stale air will be extracted and returned to an air/air heat exchanger (figures 4, 5). The extract return could also extract stale air from the studio at high level should that be necessary to clear fumes from art materials (e.g., glues, paints).

Table 6. Buoy-masters store environmental strategy.

Buoy-masters store: cabins or bedrooms		Notes
Heating	Warm air heating via mechanical ventilation.	Winter only. The small cabin volumes and high levels of insulation mean that heat demand will be small.
Ventilation (summer)	Through opening rooflights.	
Ventilation (winter)	Through trickle vents in the rooflight frames.	
Insulation (walls)	120mm wood fibre insulation. Fixing to be decided based on internal wall surface needed. See note 1.	Detailing of walls and floors to provide sufficient acoustic insulation between studio space and cabin.
Insulation (roof)	Minimum of 240mm wood fibre	Buoy-masters store is not listed and full building regulations apply. Maximum U-value = 0.16W/m2K
Insulation (floor)	N/A	Detailing of walls and floors to provide sufficient acoustic insulation between studio space and cabin.

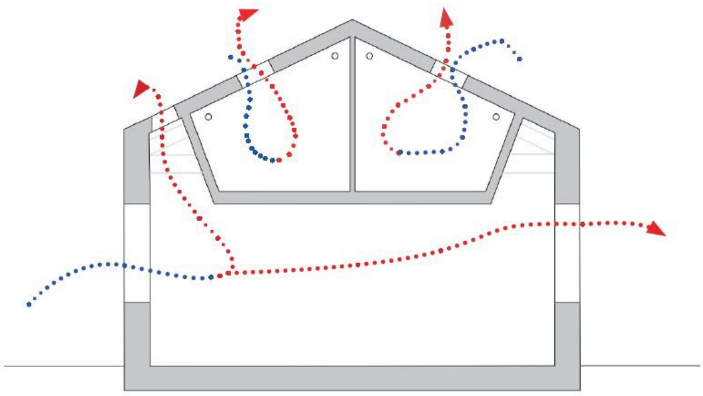


Figure 4. Summer: natural ventilation through windows and rooflights. Two cabins shown but one larger cabin with two beds is an option.

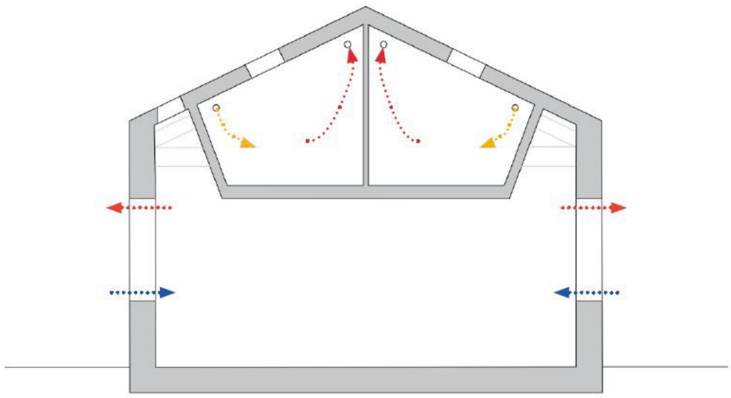


Figure 5. Winter: Mechanical ventilation of cabins. Natural ventilation of studio through window trickle vents, and mechanical extract to studio if required.

3.5.4 Buoy-masters store: kitchen and bathroom

The kitchen and bathroom will can be heated either by small radiators running from the hot water store, or from the warm air duct supplying heat and air to the cabins.

3.5.5 Buoy-masters workshop

The large volume of this space would require considerable heating, and as the floor is to remain as found (i.e., uninsulated) a strategy is proposed of inserting a small self-contained insulated, heated, and ventilated space into the main volume to act as a 'snug' for the coldest months. This space will be designed to open up to the larger unheated space during warmer months when no heating is required.

Heating of the snug could be from a small pellet stove with air for combustion supplied by a small duct, which will also supply ventilation air to the space. Alternatively, heat can be provided from a radiator supplied by the hot water store in the buoy-masters house, or by air heated using heat from the hot water store. Stale heated air will be allowed to vent from the snug into the main space which is well ventilated by infiltration through the roof and from around the doors.

Table 7. Buoy-masters workshop environmental strategy

Buoy-masters workshop		Notes
Heating (of snug)	Wood pellet stove, or radiator, or warm air (the latter two using the buoy-masters house hot water store as the heat source).	Winter only. The small volume and high level of insulation of the snug means that heat demand will be small.
Ventilation (summer)	The snug will be opened to the main space. The main space is ventilated through infiltration at roof level and by opening doors.	
Ventilation (winter)	The duct supplying combustion air for the pellet stove also supplies ventilation air to the snug. Further air is supplied through low level controllable vents between the snug and the larger workshop space. Controllable vents at higher level exhaust stale air to the larger space.	
Insulation (walls)	None.	If the whole workshop was to be heated in a future phase, then 120mm wood fibre insulation should be fitted as in the buoy-masters store.
Insulation (roof)	None.	If the whole workshop was to be heated in a future phase, then 240mm wood fibre insulation will be fitted. See note 1.
Insulation (floor)	No insulation to workshop floor. Insulation fitted below raised snug floor.	Depth of insulation dependent on height of raised snug floor. Ventilated gap of 50mm minimum to be left between insulation and existing slate floor.

Note 1. If walls are to remain existing for aesthetic reasons, then as much roof insulation as possible should be fitted (up to 400mm). Without this it will be difficult to heat this space economically as the heat load with no wall insulation, floor insulation and only 240mm roof insulation will be around 16kW on the coldest days (see appendix A).

4 Electricity demand and system sizing

The calculations in Section 4 are made using simplified methods and rules of thumb and are indicative only. They are intended to provide a good indication of the scale of demand and supply and will be recalculated by professional renewable energy and services engineers before any installation work.

4.1 Electricity demand

Predicted electricity demand for the BADA buildings has been calculated using a simple spreadsheet approach as outlined by Goss (2010) but do not include inverter losses. Both summer and winter demands are calculated because electrical power tends to be generated by different means in the summer and winter although is often by a combination of methods at any one time. Not included in the calculation is energy for pumps and fans (if needed), and this additional demand will need to be added when equipment is specified. Table 8 indicates that at the higher levels of occupancy daily electrical demands will be in the region of 26.5 kWh in winter and 17.5 kWh in summer. A detailed breakdown of the figures is given at appendix B.

Table 8. Summer and winter electrical energy demands

Energy use / kWh	**Summer**	**Winter**
Daily	17.5	26.5
Weekly	123	186
Monthly[1]	542	822

[1] Assumes 31 days/month

The Hilbre Bird Observatory and Friends of Hilbre will also have electrical demands. FoB demand will be minimal and only occasional, and HiBO demands are currently estimated at approximately 4kWh/day in summer and 6kWh/day in winter (see appendix B).

4.2 Renewable energy system sizing

The sizing of the system is characterised by three main factors.

1. Hilbre is off-grid and electrical energy cannot be imported or exported.
2. Electricity generation through wind and PV will be intermittent, depending on the light and wind conditions. In summer when there is more sunshine and less wind, photovoltaic (PV) panels will generate more electricity, while in winter when there is more wind and less sun, the wind turbine(s) will contribute a greater proportion of the total generated.
3. Occupancy of the buildings will vary in numbers and times, from continuously occupied to intermittently occupied or unoccupied.

These factors together point clearly to a need for energy storage, which can be through battery storage (electrical energy) and/or hot water storage (heat energy).

4.3 Photovoltaics (PV)

An 8kW peak PV array of approximately 60m^2 will provide approximately 30 kWh/day from May to August and about 6 to 8 kWh/day under overcast winter conditions. This is sufficient for sunny days in summer, leaving spare capacity for HiBO and FoH and for additional day visitors to BADA, and for heating additional water for showers. However, this quantity of energy meets only about a quarter of winter daily demands.

4.4 Wind turbine

A 6kW wind turbine will provide just over 14000 kWh/year at an average wind speed of 6.1ms^{-1} (ref) which if generated at a constant rate would give about 1170 kWh/month. However, due to variations in wind speed the power is not generated at a constant rate and some will be generated when the buildings are unoccupied, and sometimes no power will be generated when the buildings are occupied.

Two 3kW turbines will produce approximately 16000 kWh/year at an average wind speed of 6.1ms^{-1}. One advantage of using two smaller turbines is that they are physically smaller (e.g., blade diameter 3.9m, mast height 6m/9m for a 3kW SD3 turbine, and diameter 5.6m, mast height 9m/15m for a 6kW SD6) and that the system can be built up over time as electrical loads increase with occupancy levels. Planning permission should be made for two 3kW turbines, with one installed initially when occupancy is relatively low, and the second installed when there is a proven need for more electrical energy.

4.5 Battery store

Sizing the battery store is complex and will be done at the stage of detailed systems design. The battery store will need to supply the maximum instantaneous load and have sufficient energy storage capacity for a length of time that has yet to be decided (i.e., a period during which no energy from solar or wind is being generated but during which there is an energy demand). When the battery store is low on charge, and the PV and wind are not generating sufficient power a biodiesel generator will be used. The use of diesel fuel should be minimised as it is an intensive source of CO2 emissions, but emissions from biodiesel are considerably less (figure 1, p6).

4.6 Balancing supply and demand

On some occasions, and particularly when the buildings are unoccupied or lightly occupied, the battery store will be fully charged and there will be excess electrical energy generated. This energy can be used to heat one or more water storage tanks in the buildings. The hot water contained in these tanks can be used for domestic hot water and/or to supply heat to the heating systems to heat the buildings in winter such that they are preheated for potential occupation. This will reduce the need to use the pellet stoves when visitors arrive. Heat pumps could also use excess electricity in addition to or instead of using immersion heaters. Given the intermittency of electricity generation and building occupancy referred to above, a large hot water store will be a very useful component of the space and domestic hot-water heating systems.

4.7 Monitoring electricity use

Three groups (BADA, FoB, HiBO) will be connected to the main electrical supply. Separate metering of each supply will allow individual users to monitor their use and adjust consumption if necessary. Meters are available as MCB sized modules which fit into a standard consumer unit.

The energy generated will be monitored to provide information to inform future management and possible expansion of the energy systems, for example addition of heat pumps to generate heat and save on the transportation and combustion of biofuels. There are potential research possibilities related to the development and operation of the electrical system and monitoring will be essential in such cases.

4.8 Controls

Controls will be fitted as each system is developed. Controls could include zone controllers or thermostats, transmitters (temp, humidity, pressure, CO_2), detectors (smoke, presence), and valves and actuators. The provision of controls will also depend on whether a caretaker or warden is to be responsible for systems operation, or whether occupants will be expected to manage heating and electrical supply.

A degree of automation will be essential, for example diverting excess electrical power to hot water storage tanks when the battery store is fully charged and instantaneous demands are being met. Control systems and the monitoring system should be developed in relation to each other.

5. Water

5.1 Water requirements

UK guidelines recommend 150 litres of potable water per person per day, although other countries have higher and lower figures, and the UN policy is that 50 litres per person per day (l/p/d) is sufficient. The Code for Sustainable Homes sets a maximum water use of 120 l/p/d and 80 l/p/d for the best performing homes. It therefore seems reasonable to allow for 120 l/p/d if possible. This equates to 1440 litres per day for 12 occupants, with more needed for any day visitors, although such visitors could bring their own water. The figures above can be reduced if composting or waterless toilets are used, as about 1/3 of the figures above is allocated for toilet flushing. Also about 20% of water use is for washing clothes, so if no washing machine is provided there will be further savings.

5.2 Rainwater harvesting

Rainwater harvesting comprises the main source of freshwater and it is also possible that water from the existing well could be treated, probably acting an additional water source when insufficient stored rainwater is available.

Calculations show that for an estimated roof area of 140m^2 rainwater collection will gather 78907 litres per year in total and 5197 litres in the driest months (see appendix D). The latter is enough only for 3 to 4 days at full occupancy, and the total annual rainfall would only provide enough water for 55 days at full occupancy if it could all be stored (table 9).

Table 9. Number of days of water availability assuming that all rainfall is collected and available.

Policy	Water usage (l/person/day)	Number of days that water is available					
		140m^2 roof area			280m^2 roof area		
		occupancy (people)			occupancy (people)		
		4	8	12	4	8	12
UN policy	50	395	197	132	789	395	263
CfSH best practice	80	247	123	82	493	247	164
CfSH maximum	120	164	82	55	329	164	110
UK guidelines	150	132	66	44	263	132	88

The roof catchment area can be almost doubled by using the east and south facing pitches, which would need additional guttering and pipes to carry the water to the storage tank(s). This will provide 110 days water supply at full occupancy with full water use. At 2/3 occupancy there will be sufficient water for 164 days, and at full occupancy enough also for 164 days if the lower water use rate of 80l/p/d is adopted. If lower limits are set on water usage, then of course the number of days increases.

However, these figures assume that the whole year's catchment of water will be available. In practice a certain amount of water falls each month and can be stored if tank capacity is available, or lost if the tank is already full. This means that a large storage tank(s) will be needed. The capacity of the current tank is 3600 litres. A 15000-litre tank will provide 187.5 days of water for one person at the lower rate of 80 l/p/d, or just over 15 days for 12 persons. Given that waterless toilet flushing is to be used, the water use should be closer to 55 l/p/day and so this tank size will provide just over 22 days for 12 persons assuming there is no rain.

5.3 Water treatment

Water treatment will be needed to make the stored rainwater potable. It might also be possible to treat water from the existing well which is currently reported to be saline and brackish. Various treatment types are available including sand, ceramic, carbon, and polypropylene filters, ultraviolet light, and ion exchange resins. The type used will depend on analysis of the collected water. Anecdotal reports are that the collected rainwater can taste salty on occasion as result of wind driven spray mixing with the rainfall, and an appropriate filter will be needed.

5.4 Water saving measures

The figures shown in Section 5.2 draw attention to the need for water saving measures and the possible need for recycling water. Low flow taps and low flow shower heads will be fitted. Water efficient appliances (if fitted) will be specified, and their use restricted depending on the water quantity in storage. The hierarchy of sustainable water usage is known as 'reduce, recycle, reuse' and while recycling and reuse of water has not yet been considered, it remains an option for when the buildings are more fully occupied.

6. Wastewater

6.1Toilets

Currently the council provide two long-drop composting toilets for public use which are located about 50 meters from the BADA buildings They are currently not functioning as composting toilets but are emptied by pumping out to a tanker. These can continue to be used, but toilets will also be needed in the BADA buildings.

The options for toilets are as follows.

- A new septic tank which would be emptied by a contractor, with low flush conventional toilets. Water use however should be avoided if possible (see Section 5).
- A septic tank or tanks connected to settlements tanks and reed beds or other filtering methods. This system would take a relatively large amount of space for reed beds and could involve considerable excavation work.
- A sewage treatment plant is like a septic tank but with a pump to supply compressed air to promote aerobic bacteria activity such that liquids can be cleaned and discharged to a watercourse (permission will be needed for Hilbre as the site is a SSSI). The solid sludge must be emptied by a contractor (figure 6, appendix H).
- Composting toilets
    - Full access composters are waterless toilets with chambers below the WC in which composting takes place. Typically, one chamber is used while the other 'rests' for 1 year. A urine diverter separates solid and liquids with the latter diverted to a soakaway. After use, a small amount of sawdust or other organic waste is thrown into the pan to encourage microbe activity which breaks down the waste into compost. After a year of resting the decomposed waste is removed manually, which could take a few hours. An installation consideration is that the chambers are situated below the pans (e.g., 850mm below, see figures 1-5, appendix H).
    - Waterless toilets for use in typical indoor bathrooms separate liquid and solid waste. The liquids can be diverted to a soakaway if ground conditions allow, or else must be manually emptied to a suitable area where it can soak away. Solids are collected below the pan but above existing ground level and are regularly emptied to an area away from the main building where it can be composted. The toilet uses a small amount of electrical energy to run a fan for prevention of odours.
- Incineration toilets evaporate liquid waste and burn solid waste such that only a small amount of ash remains. This type can use up to 2kWh each time the toilet is used and so are energy intensive.

A critical factor in the choice of toilet(s) is whether the ground conditions under the existing buildings can be excavated to allow installation of composting chambers or septic tank, and whether a soakaway for liquid waste can be installed. The sloping site may result in a high water table under and around the building and restrict the use of a soakaway or drainage field. A ground investigation and survey of existing drains will be needed before a decision on the type of toilets to be installed can be made.

Septic tanks or sewage treatment plants should be installed seven meters from building foundations and ten meters from a watercourse. Tanks can be emptied up to 30 meters away from tanker hardstanding.

An option for the first phase of the project is to install a waterless composting toilet inside the buildings mainly for use at night, which would need to be emptied manually at regular intervals. During the day use of the public composting toilets would be encouraged. If ground conditions are unsuitable for a full access composter toilet inside the buildings, then a good option for the later phase is a composting toilet located in a structure outside the main buildings where space and ground conditions permit. A high drop toilet would require no excavations for chambers. Alternatively, a small sewage treatment plant would allow the use of conventional flush toilets but would need to be sited below the toilets as regularly pumping waste up to a tank regularly would require considerable electrical energy. Water usage would also need to be considered.

6.2 Sinks and showers

Greywater from sinks and showers can be directed to a septic tank, a drainage field, or a reed bed. As an idea of scale, a four-bed house would need a reed bed of approximately $10m^2$ so for an occupancy of 12 persons about $25m^2$ would be needed. However, a holding tank can be used to temporarily store greywater, releasing it slowly to a reed bed. This can be useful if occupancy is not continuous as it allows the use of a smaller reed bed.

A drainage field is like a soakaway (which are not now permitted by some authorities) but has a larger capacity and is constructed using plastic crates at least 500mm below the surface of the ground. A drainage field must be at least 10m from a watercourse, at least 50m from wells or other points of abstraction of groundwater, and at least 15m from a building. These regulations may well necessitate the use of reed beds or septic tanks for the BADA buildings on Hilbre.

7. Materials

As stated in Section 2.4, the general approach towards the fabric of the building will be one of repair, recycling, and re-use of materials.

New materials should be chosen with reference to the Green Guide (Anderson, 2002) and other authoritative guides to the environmental impacts of materials used in the construction industry. The GreenSpec website (see Bibliography) is a highly useful resource with information on many building products. Some assessment methods (e.g., BREEAM (see Section 8.3)) require the assessor to use the Green Guide and takes account of a range of sustainability considerations such as energy use, greenhouse effect, acidification effect etc.

Broad recommendations for some materials that will be used on Hilbre are as follows.

- Insulation: Bio-based insulations (wood fibre, hemp, sheep's wool) are preferred to man-made insulations. An exception to this when only thin layers of insulation can be installed (less than 50mm).
- Concrete: Consider carefully the structural function and use cement replacement as appropriate. LJMU Faculty of Engineering and Technology have expertise on cement replacements, and information is readily available online.
- Timber: Use FSC sourced products.

8. Schedule

It is intended to complete the work over a period of approximately three years, depending on funding success and granting of a lease. Occupation of the buildings will start at a small scale and build up to full occupancy over the three years. In Phase 1 of the works there will be funds available for basic services, and currently the emphasis is on making the buoy-masters house habitable (table 10). Phase 2 will see the installation of the Renewable Energy systems, the bathroom facilities, and services to the buoy-masters store and workshop.

Table 10. Schedule of services.

Phase	Services
1	Electricity provided by biodiesel generator.
	Buoy-masters house: Wood pellet boiler providing heat to hot water store. Radiators in each room taking heat from the hot water store.
	Rainwater harvesting system to supply potable water supply for drinking, cooking, and washing.
	Waterless toilet for use at night (emptied manually) situated in buoy-masters store: Council run composting toilets used during the day.
2	Electricity provided by wind turbine(s), PV array, battery store.
	Buoy-masters house: low flush toilet and small sewage treatment tank. Solar hot water.
	Buoy-masters store: Wood pellet stove, hot water store, solar hot water, shower.
	Buoy-masters workshop: Radiators if heated, or snug constructed. Possible pellet stove.
	Excess electricity to heat hot water stores using immersion or heat pump.

9. Sustainability

Although this report largely focuses on building and energy supply related aspects, it is useful to contextualise these within a broader picture. Sustainability is complex, and it is easy to claim that solutions are sustainable when they are only partly or selectively so. Because the arts /science study centre has an underlying theme of sustainability it is useful to outline what the term 'sustainable' can mean, such that decisions on refurbishing and operating the centre can be made with confidence. This section briefly describes the wider scope and practices of sustainability before focussing on how to measure sustainability on Hilbre.

9.1 The scope of sustainability

Since the term came into widespread use in 1980's, the concepts, ideas, and practices of sustainability have been under continual development. Figures 6 and 7 are examples of diagrams that show how sustainability must balance the needs of society, economics, and the environment.

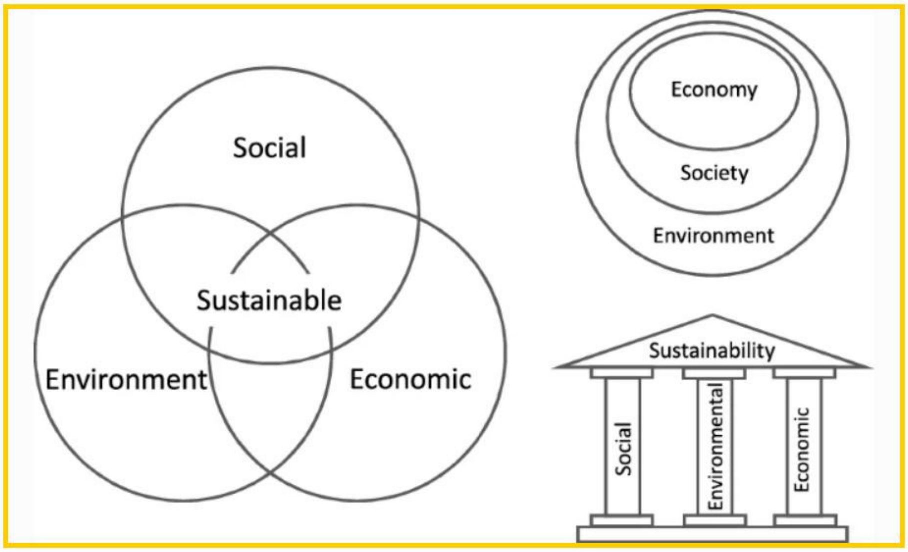


Figure 6. Common representations of sustainability. Source (Purvis et al, 2019)

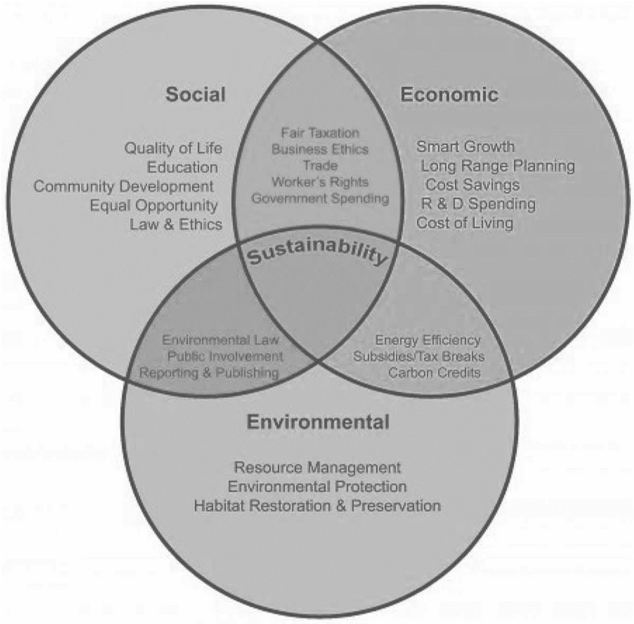


Figure 7. Relationships among social, environmental and economic sustainability (Source: Mensah and Casadevall, 2019)

The sustainability of buildings, energy supplies and technology are part of this wider scope encompassing society, economics and environment, often referred to as the 'three pillars of sustainability'. More recently it has been proposed that culture is a fourth 'pillar' or component of sustainability (Hawkes, 2002).

A useful definition of sustainability is given by Jeronen (2013).

> *Sustainability is seen as a paradigm for thinking about the future in which environmental, societal, and economic considerations are balanced in the pursuit of an improved quality of life. The ideals and principles behind it lays on broad concepts such as intergenerational equity, gender equity, social tolerance, poverty alleviation, environmental preservation and restoration, natural resource conservation, and building just and peaceful societies.*

Within sustainability are many individual aspects which are seen as part of the 'whole' but which could each be taken as a focus to enable a more detailed treatment. An incomplete list could include the following;

- Climate change and greenhouse gas emissions
- Pollution
- Health and well-being
- Energy efficiency
- Life cycles / circular economy
- Materials and resources
- Water
- Waste
- Recycling
- Biodiversity / ecology
- Green Economics
- Employment, skills, jobs, business
- Justice and equity

- Cities
- Transport
- Tourism
- Food production
- Culture and heritage

These aspects of sustainability and others have all been (and continue to be) explored in depth by academia, education, industry, commerce, NGO,s, charities, and individuals. Therefore much literature is available. Although this report has focussed on the immediate concerns of refurbishing the buildings at Hilbre, as the project moves ahead there is value in thinking about keeping these wider aspects in mind. Some are shown in table 11 with reference to benefits and possible research related activities.

Table 11. Some potential benefits of sustainability on Hilbre.

Aspect of sustainability	Potential benefit
Employment, jobs and business, economics	Economic benefits to individuals and the project by employing as local workers / volunteers may be more flexible with arranging work with the tide times.
Education and skills	Research opportunities and coursework. Teaching refurbishment skills to local people (volunteers) and students. Such skills are increasingly useful (e.g., how to renovate to save energy).
Health and well-being	Time in a peaceful but stimulating environment.
Greenhouse gas emissions, energy efficiency, water, waste, recycling	Reseach opportunities.
Waste / food production / lifecycles	Composting and food production. Reseach opportunities.

9.2 Measuring sustainability

9.2.1 Sustainability Assessment methods

It is important to be able to measure sustainability in order to understand what works or does not work in increasing levels of sustainability. Many methods have been developed for measuring the sustainability of proposals and can focus on one aspect or cover several aspects. Table 12 shows a range of such methods oriented toward the built environment. Other methods include guidelines, rules of thumb and case studies.

Table 12. Sustainability assessment methods.

Method	Sustainability aspects measured
Environmental Impact Assessment (EIA)	Impact on human beings, flora and fauna, soil, water, air, climate and landscape, the interaction between these factors, material assets and cultural heritage.
Life Cycle Assessment (LCA)	Inputs and outputs of materials production, energy used, and waste produced.
Carbon foot-printing	CO2 emissions over the lifecycle of a product or service.
Life Cycle Costing (LCC)	Long-term capital and operational costs of the operation and maintenance of a building.
Building energy assessment	Energy use, CO2 emissions.
Sustainability Indicators	Used for planning or building large developments (Climate change, Resources, Transport, Ecology, Business, Community, Placemaking, Buildings)
Whole building environmental assessment	Multiple criteria (e.g., energy, CO2, pollution, health and well-being, water, waste, management, land-use, transport, materials, innovation, communities).

A more informal method suggested by Williamson et al (2003) lists ways in which buildings and sites can potentially relate to sustainability and forms a starting point for design discussions on how projects can be made more sustainable through both the processes of planning and formulating a brief, and through the more quantitative methods referred to in table 12. This informal method could be very useful as a reference to ensure that important opportunities to improve sustainability are brought to the attention of the design and management teams for further consideration, and is shown at appendix I.

9.2.2 Net Zero Carbon

Net zero carbon targets are aimed specifically at mitigating climate change by ensuring that all CO2 emitted by the construction and operation of a building is removed from the atmosphere. The UK Green Building Council (UKGBC, 2019) outlines a net zero-carbon strategy as a process.

1. Establish Net Zero-Carbon Scope
2. Reduce Construction Impacts
3. Reduce Operational Energy Use
4. Increase Renewable Energy Supply
5. Offset Any Remaining Carbon

Stage 1 addresses whether construction related emissions and other emissions relating to the activities of buildings occupants (e.g., business operations) are included in addition to the operational (energy use related) emissions. Offsetting (Stage 5) as a strategy has been criticised for various reasons, for example that relying on offsets leads to a lack of effort to reduce emissions (Scott et al. 2016, Peeters et al. 2016). However, it is often necessary once all other reduction opportunities have been taken.

Net Zero Carbon strategies focus on CO2 emissions in categories known as scopes. Scope 1 emissions are defined as direct emissions from sources that the organisation owns or controls, such as those resulting from fuel burned on site or by vehicles. Scope 2 emissions are indirect emissions, and result from buying in energy that others have generated or produced such as electricity. Scope 3 are all other indirect emissions resulting from the activities of the organisation, such as products brought in (e.g., building materials, food), emissions resulting from travel to the organisation and so on. Net zero carbon is a readily understood metric that has widespread use, and Scope 1 and 2 and many Scope 3 emissions are relatively easy to calculate.

9.3 Measuring sustainability on Hilbre

The use of renewable energy on Hilbre gives a good start toward meeting a net zero carbon strategy. The only Scope 1 or Scope 2 CO2 emissions on Hilbre will come from the use of a stand-by biodiesel generator, and a small amount from wood pellets which depends on their manufacture and origin (see figure 1, p6). Scope 3 emissions in the short term will mainly result from the choice of building materials. Following a net zero carbon strategy will encourage the ongoing monitoring and development of the energy systems with the aim of increasing energy efficiency and reducing the quantity of fuel used. It can also inform decisions on building materials to be used. Therefore, it is recommended that a Net Zero carbon target is used as the main indicator of sustainability as regards climate change.

Another suitable method for measuring sustainability is that of the BREEAM (Building Research Establishment Environmental Assessment method). This 'whole building' assessment method (see table 12) will measure sustainability more widely than CO_2 emissions only and includes useful categories that can inform the management of the project. It is well understood amongst sustainability professionals that the management of a project is key to its success as regards the level of sustainability achieved and that is why BREEAM covers management in detail. The management challenges at Hilbre relate to the complexity of the logistics of refurbishment, project funding, and operation of the Centre. A version of BREEAM tailored specifically to refurbishment and fit-out is available. Other detailed guides to sustainable refurbishment are available (see Bibliography).

It is recommended that both methods are used for the Hilbre project. The net zero carbon strategy will result in accurate monitoring of emissions and ongoing development of the energy systems, while BREEAM will provide feedback on the wider aspects of project sustainability. Both methods require time resources and allocating these resources should be a part of financial planning for the next phases of the project. It may also be possible to carry out some of the work as part of student projects. If the BREEAM methodology cannot be followed due to lack of resources, then the informal approach of Williamson et al. (2013) (see appendix I) should be used alongside the Net Zero Strategy.

If these methods have not been adopted before building activities commence, then use of fuel should be monitored and a record kept of materials used, enabling retrospective calculation of embodied carbon emissions to be made when resources permit.

10. Summary of recommendations

This report has described the main sustainability issues of the project of renovating and occupying the buildings on Hilbre. It has focussed largely on the buildings themselves and the services needed to make them habitable, although has also touched on the need to bring a wider understanding of sustainability to the project and the operation of the Centre.

Because emissions from biodiesel and wood pellets will be low there is not quite so much need to focus on reduction of energy use, but the cost and difficulty of bringing these fuels to the island mean that high levels of insulation should still be considered a priority and will increase the comfort levels of occupants.

The following recommendations have been made;

- Assessment of sustainability
  - Net Zero Carbon strategy
  - BREEAM refurbishment or equivalent method
- Heating
  - Wood pellet stoves and boilers
  - Solar Hot Water
  - Heat storage (insulated hot water tanks)
  - Excess electricity used to heat water store
- Electricity
  - Two 3kW wind turbines (or one 6kW turbine)
  - 60m^2 photovoltaic panels
  - Biodiesel generator for backup
- Buildings
  - Strategy of reuse of existing materials
  - High levels of insulation using bio-insulations where possible
  - Secondary glazing
  - Draughtproofing
- Water supply
  - Rainwater harvesting
- Waste (subject to change)
  - Small sewage treatment tank for low flush toilets and greywater
  - Waterless composting toilet

Acknowledgements

The author would like to acknowledge the contributions of Dominic Wilkinson and Terry Duffy to the development of this strategy through the many useful discussions and suggestions made.

Appendices

Appendix A: Modelling of heating loads

An IES (Integrated Environmental Solutions) computer model was constructed with all spaces given the parameters shown in table A1. The daily heating profile of 0800-2200 heated to 19C reflects permanent occupancy.

Table A1. Simulation parameters.

Parameter	**Value**
Ventilation rate	1 air change / hour
Infiltration rate	0.25 air changes / hour
Hours of heating	0800 - 2200
Setpoint	19C

The schedule of development of the centre is still subject to change, and it is not known at the time of writing what the pattern of occupancy will be over time. Therefore, several calculations have been made.

- Maximum heat load on the coldest day of the year
- Maximum heat load on the coldest day of the year discounting January and February when the building will not be occupied.
- Max load excluding January and February and the 5 coldest days between March-December. BADA have indicated a willingness to adjust behaviour such as wearing extra clothing on the coldest days rather than oversize the heating systems.
- Average heat load in December and January discounting peak loads at start-up. If this figure is used to size boilers and radiators the buildings will heat up more slowly each day but will reach the design temperature. This may be acceptable given that smaller (and less expensive) boilers can be specified.
- Average energy use (kWh) per day during the heating season for heating hours of 0800-2200.
- The mass of wood pellets needed to provide this heat energy. This figure is useful as it indicates how often deliveries of wood pellets will be needed and can be used when planning the schedule of the centre.
- The daily and hourly cost of the pellets at 2022 prices (see appendix C).

Table A2. Full results of modelling existing buildings and insulated buildings.

Space	Scenario	Annual maximum heat load (kW)	Max load excluding Dec and Jan (kW)	Max load excluding Jan and Feb and the 5 coldest days (kW)	Average load Dec/Jan discounting peak at start-up (kW)	Average Energy / day (kWh)	Average wood pellets / day (kg)	Cost per day of pellets (£) (14 hours heating)	Cost per hour of pellets (£)
Buoy-masters house	Existing	26.6	24.0	~22	~12	118	24	14.6	1.0
	Scenario 1	22.4	20.1	~18	~6	83	17	10.2	0.7
Buoy-masters workshop	Existing	23.8	21.2	~19	~12	122	25	15.1	1.1
	Scenario 1	14.2	12.7	~12	~6	63	13	7.8	0.6
	Scenario 2	-	-	-	-	1.3	0.3	0.2	0.01
Buoy-masters store: studio and accommodation	Existing	26.4	23.4	~21	~12	122	25	15.1	1.1
	Scenario 1	13.8	12.5	~12	~5	51	10	6.3	0.4
Buoy-masters store: kitchen and bathroom	Existing	6.6	5.9	~6	~3.5	36	7	4.5	0.3
	Scenario 1	4.0	3.6	~3	~1.5	18	4	2.2	0.2
Buoy-masters store: office	Existing	8.2	7.4	~7	~4	41	8	5.1	0.4
	Scenario 1	3.4	3.0	~3	~1	10	2	1.3	0.1

Appendix B: Electricity demand

An estimation of electricity demands is shown in tables B1 and B2. Table B1 assumes an occupancy of 12 people inhabiting the BADA accommodation full time. Table B2 assumes an occupancy of 2 to 3 full time occupants with a maximum of 6 – 10 on occasion.

Table B1. Electricity demand at maximum occupancy (BADA)

AC/DC	Item	Power (W)	Number	Summer		Winter	
				(hrs/day)	(wh/day)	(hrs/day)	(wh/day)
AC	LCD/LED/TV screen	100	1	5	500	5	500
AC	Hi-Fi	25	0	0	0	0	0
AC	Radio	15	1	4	60	6	90
AC	Video/DVD	30	0	0	0	0	0
AC	Router	5	0	0	0	0	0
AC	Phone charger	25	12	0.5	150	1	300
AC	Computer (desktop)	100	2	8	1600	8	1600
AC	Computer (laptop)	50	6	8	2400	8	2400
AC	Printer	50	1	0.5	25	0.5	25
AC	Lights (LED)	8	15	4	480	12	1440
AC	Oven	2000	1	1	2000	2	4000
AC	Microwave	800	1	0.5	400	1	800
AC	Grill / hob	1500	1	1	1500	2	3000
AC	Toaster	1200	1	0.25	300	0.25	300
AC	Kettle	2500	2	0.4	2000	0.6	3000
AC	Fridge	20	1	24	480	24	480
AC	Washing machine	1500	1	1	1500	1	1500
AC	Tumble drier	0	0	0	0	0	0
AC	Sewing machine	50	0	0	0	0	0

AC	Hair dryer	2000	2	0.2	800	0.2	800
AC	Iron	1000	1	0.2	200	0.2	200
AC	Vac cleaner	600	1	0.17	102	0.17	102
AC	Immersion heater	3000	1	1	3000	2	6000
AC	Electric shower	7500	0	0	0	0	0
AC	Oil filled radiator	1500	0	0	0	0	0
AC	Towel rail	250	0	0	0	0	0
TOTAL DAILY AC LOAD					**17497**		**26537**

Table B1. Electricity demand at maximum occupancy (HiBO)

AC/DC	Item	Power (W)	Number	Summer		Winter	
				(hrs/day)	(wh/day)	(hrs/day)	(wh/day)
AC	LCD/LED/TV screen	100	0	0	0	0	0
AC	Hi-Fi	25	0	0	0	0	0
AC	Radio	15	0	0	0	0	0
AC	Video/DVD	30	0	0	0	0	0
AC	Router	5	0	0	0	0	0
AC	Phone charger	25	3	0.5	37.5	0.5	37.5
AC	Computer (desktop)	100	0	0	0	0	0
AC	Computer (laptop)	50	4	6	1200	8	1600
AC	Printer	50	0	0	0	0	0
AC	Lights (LED)	8	8	4	256	12	768
AC	Oven	2000	0	0	0	0	0
AC	Microwave	800	1	0.5	400	1	800
AC	Grill / hob	1500	1	0.5	750	0.5	750
AC	Toaster	1200	0	0	0	0	0
AC	Kettle	2500	1	0.4	1000	0.6	1500
AC	Fridge	20	1	24	480	24	480
AC	Washing machine	1500	0	0	0	0	0
AC	Tumble drier	0	0	0	0	0	0
AC	Sewing machine	50	0	0	0	0	0
AC	Hair dryer	2000	0	0	0	0	0
AC	Iron	1000	0	0	0	0	0
AC	Vac cleaner	600	1	0.1	60	0.1	60
AC	Immersion heater	3000	0	0	0	0	0
AC	Electric shower	7500	0	0	0	0	0
AC	Oil filled radiator	1500	0	0	0	0	0
AC	Towel rail	250	0	0	0	0	0
TOTAL DAILY AC LOAD					**4184**		**5996**

Appendix C: Pellet boilers and stoves

Figure C1. Example of a wood pellet boiler stove that supplies heat to the room (5.4kW - 18.1kW) and to water (4.3kW - 15kW). Suitable for a large room.
Cost: £3689 Source: Buy La Nordica Raffaella Idrohttps://www.stovesareus.co.uk/stoves/wood-burning-stoves/la-nordica-raffaella-idro-h15-pellet-boiler-stove.html [accessed 1/9/22]

Figure C2. Example of wood pellet water only boiler (14.6 kW)
Cost: Source: https://www.stovesonline.co.uk/wood_burning_stoves/Klover-Ecompact-Utility-Pellet-Boilers.html [accessed 1/9/22]

Cost of pellets £600 for 970kg or £9.23 / bag.
Source: https://www.ebay.co.uk/itm/165688402869?var=0&mkevt=1&mkcid=1&mkrid=710-53481-19255-0&campid=5338268676&toolid=10044&customid=Cj0KCQjwkOqZBhDNARIsAACsbfKQZ8bb7_KAD34Bz-7vvgpDlmc8lVajd9amnCzSZyxveT3z_-Mds0EaAsuJEALw_wcB
[accessed 1/9/22]

The calorific value of wood pellets is around 4.85kWh/kg
Source: https://www.woodco-energy.com/2019/12/13/what-are-wood-pellets/Woodco (woodco-energy.com)
[accessed 1/9/22]

Appendix D: Water

Liverpool rainfall is 835mm/year varying from 95mm/month in October to 55mm/month in February, April and May.

Table D1. Liverpool precipitation
Source:https://www.climatestotravel.com/climate/england/liverpool#:~:text=In%20Liverpool%2C%20precipitation%20amounts%20to,Here%20is%20the%20average%20precipitation.

Liverpool - Average precipitation			
Month	**Millimeters**	**Inches**	**Days**
January	75	3	14
February	55	2.2	11
March	65	2.6	13
April	55	2.2	10
May	55	2.2	11
June	65	2.6	11
July	60	2.4	10
August	70	2.8	11
September	70	2.8	12
October	95	3.7	15
November	85	3.3	15
December	90	3.5	14
Year	835	32.9	145

Roof area: Buoy-masters house west pitch + Buoy-masters store bathrooms/kitchen north facing pitch + Buoy-masters store studio/accommodation north facing pitch + Buoy-masters workshop section of west facing roof that drains to the north.

Roof area = (11.4 x 4.0) + (7.9 x 5.0) + (10.8 x 4.0) + (4.0 x 4.6) = 146.7m^2
~ 140m^2
Total roof area available ~ 280m^2 if south and east facing roof pitches are used.

Rainwater Harvested available per year
*= Roof Area (m^2) * Annual Rainfall (mm) * Run-off Coefficient * Filter Coefficient*
= 140 x 835 x 0.75 x 0.9
= 78908 litres

During the driest months 140 x 55 x 0.75 x 0.9 = 5197 litres are available

Appendix E: Solar access.

The centre will be unoccupied in December and January. Figures E1-8 show that SHW panels will receive solar radiation when the sun is out from 10.00am to 15.00pm on 1 February. The PV is array has no overshading.

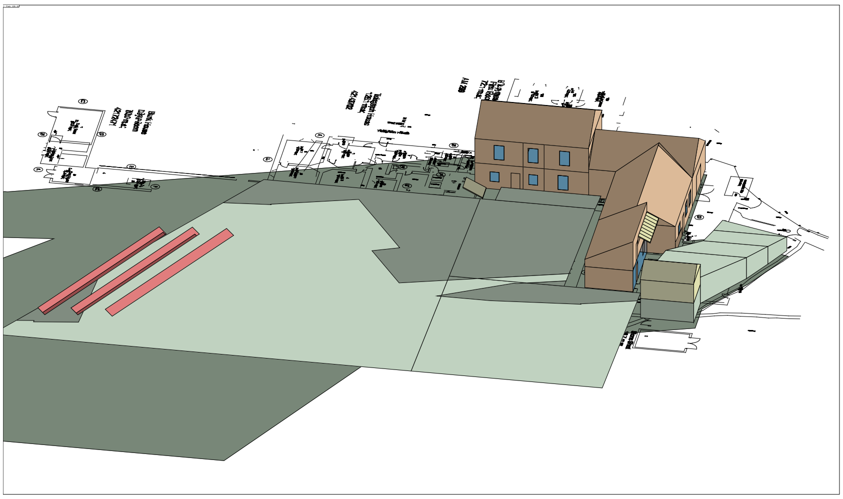


Figure E1. Shadows at 09.00, 1 February

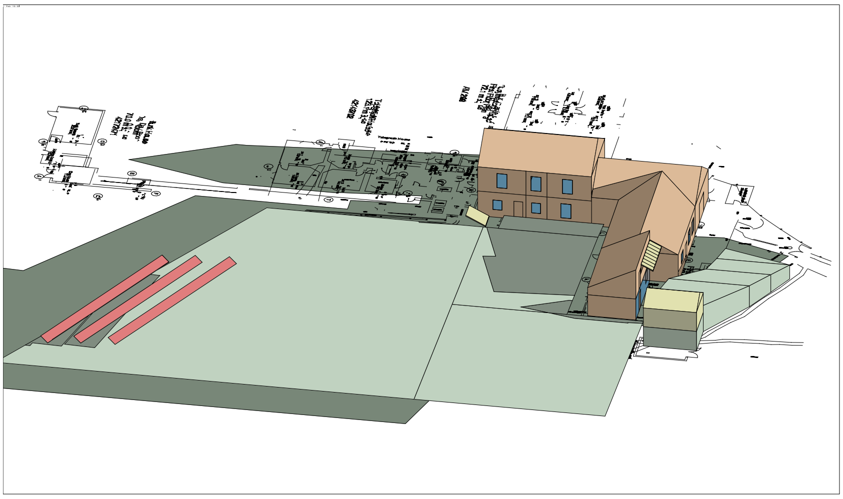


Figure E2. Shadows at 10.00, 1 February

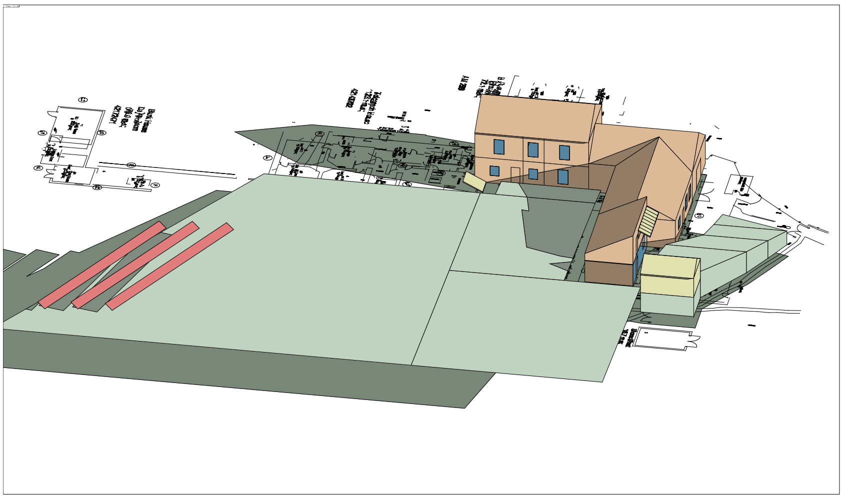


Figure E3. Shadows at 11.00, 1 February

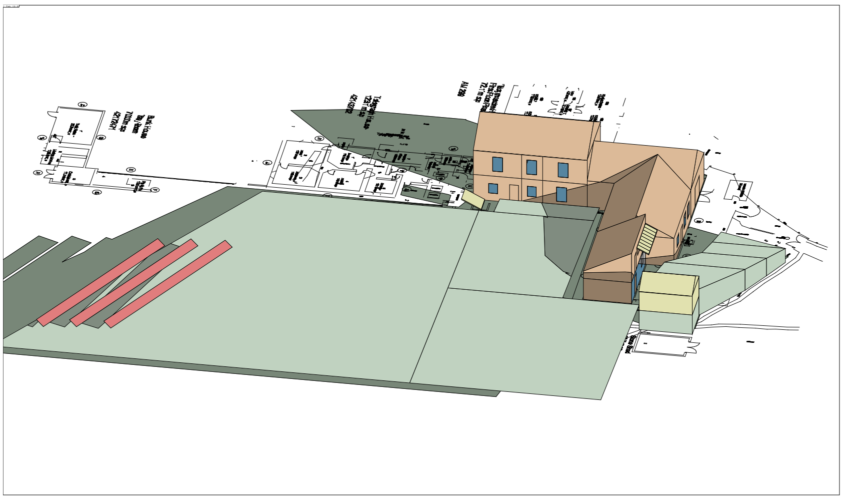


Figure E4. Shadows at 12.00, 1 February

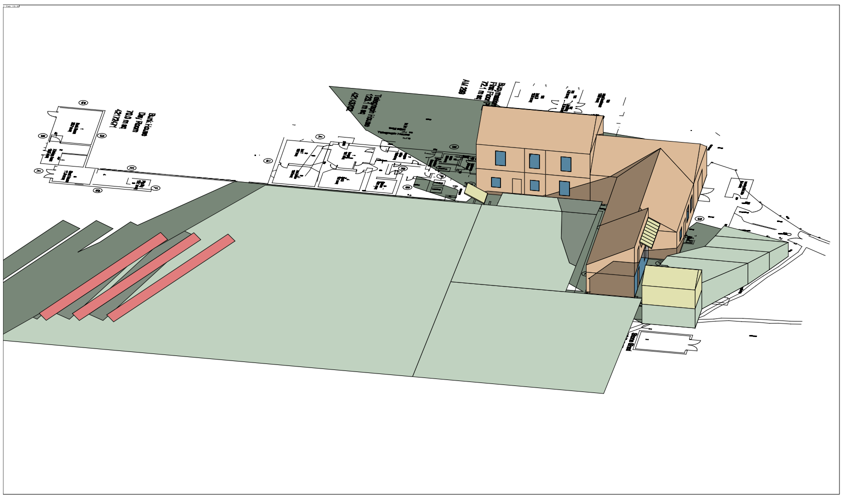


Figure E5. Shadows at 13.00, 1 February

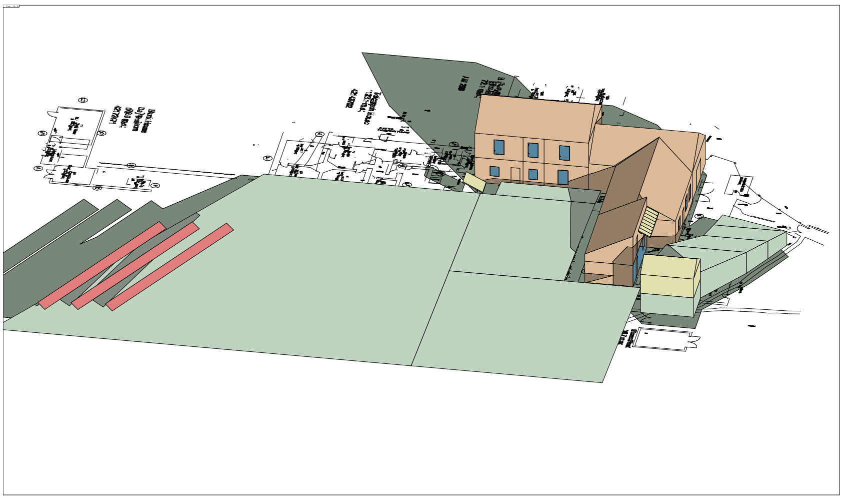


Figure E6. Shadows at 14.00, 1 February

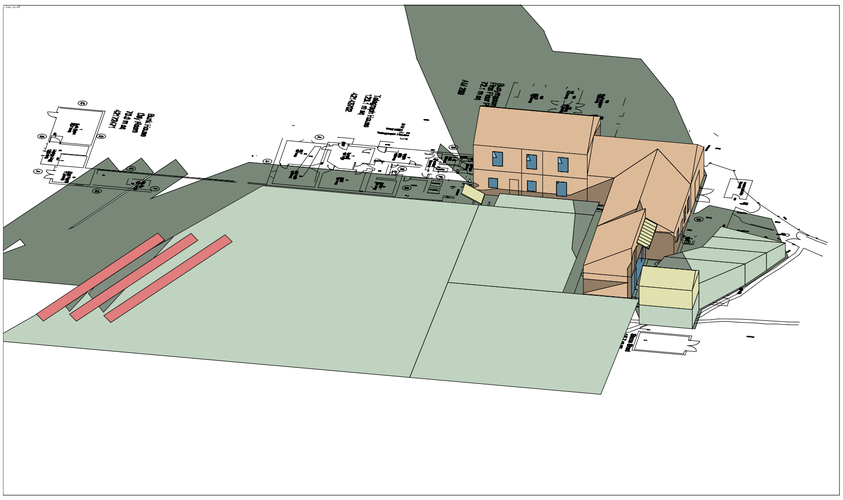


Figure E7. Shadows at 15.00, 1 February

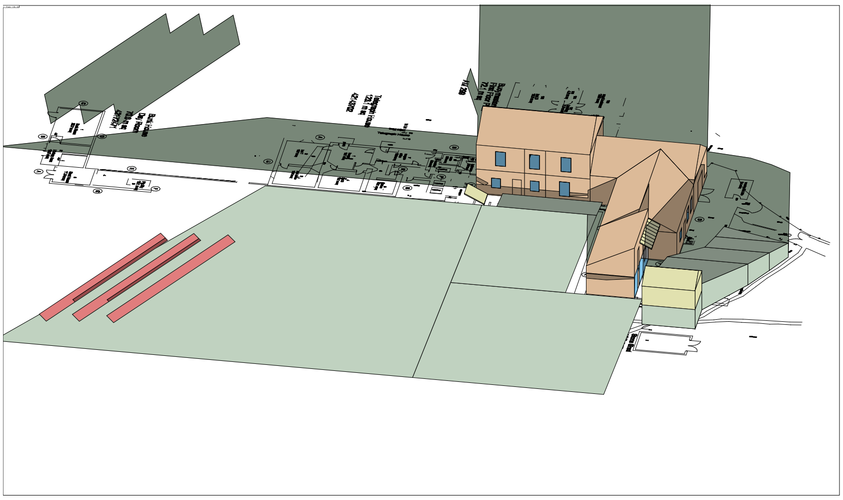


Figure E8. Shadows at 16.00, 1 February

Appendix F: Solar Hot Water

Rule of thumb: 1m^2 of panel area per person will supply;

- 40-50 litres/person/day
- 100% of hot water in summer
- 50% of hot water in winter
- 75% of annual demand

Storage required = 75 litres / m^2 collector area

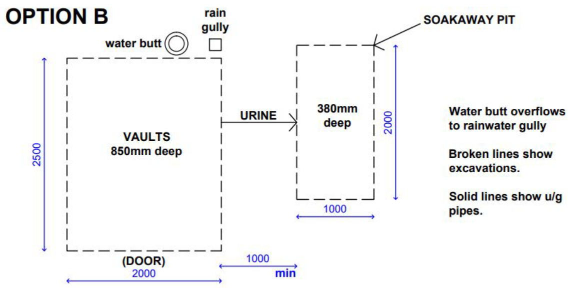
Source: Centre for Alternative Technology. Available: Solar Water Heating - Centre for Alternative Technology (cat.org.uk) [accessed 10/07/22]

Appendix G: Wind

Figure G1. Annual mean wind speed at 10m above ground level based on Numerical Objective Analysis of Boundary Layer data generated by the Hadley Centre, UK. Source: https://www.rensmart.com/Maps#NOABL

Rule of thumb: turbine + tower and installation between £2,500 and £6,000 per kW. A 6kW turbine could cost between £15,000 and £36,000

Appendix H: Waste



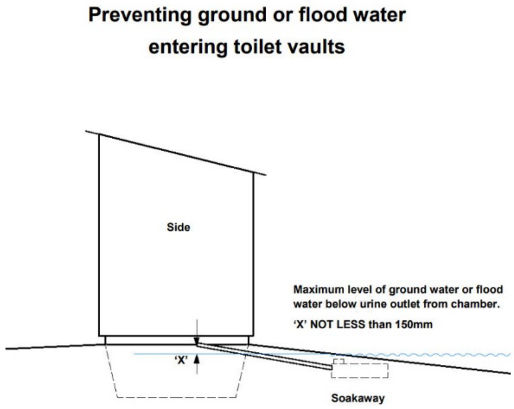


Figure H1-5. Installation of Natsol full-access composter vaults.
Source: https://natsol.co.uk/full-access-composter/ [accessed 20/10/22]

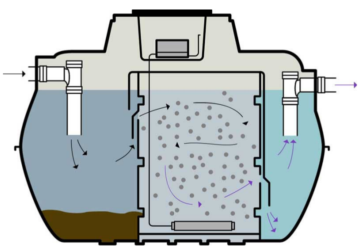


Figure H6. Sewage treatment plant. Source: https://www.drainagesuperstore.co.uk/help-and-advice/product-guides/sewage-treatment/sewage-treatment-plants-buyers-guide/ [accessed 20/10/22]

Appendix I: Architectural sustainability

The factors identified by Williamson et al. (2003) are the result of considering sustainability from an architectural perspective (table I1). This point of view recognises that in architectural design it is important to consider the relevance of many aspects of the project and to make decisions based on how important those aspects are. As such they are not as explicit as design guidance and do not measure sustainability quantitatively but do invite modification and expansion should other project specific aspects by identified. Therefore, they are flexible and comprehensive, but do rely on the genuine engagement of the design team.

Table I1. Process and product means of exploring opportunities for architectural sustainability (Source: Williamson et al., 2003)

	Objectives	process means	product means
Environmental			
Climate change	reduce life cycle GG emissions	- life cycle GG analysis - plan for future operation of building - consider wider systems	consider: - reduce heating and cooling loads through building design - use non-greenhouse gas energy forms - energy efficient appliances, systems and plan - use low greenhouse gas materials - climate change adaptive design - trees?
Pollution	reduce acid rain, air pollution, water pollution, land pollution	- life cycle pollution impact analysis - work with client to plan for future operation of building - work with client to consider wider systems	*construction phase* Consider: - reduce waste materials - use materials that cause low pollution in life cycle *building operation* - use non-polluting energy - avoid polluted surface water run-off - recycle water *end of life* - use long life materials - use biodegradable materials - use recyclable materials
Resource depletion	use resources carefully	determine renewability and rarity of resources	consider: - using renewable resources (materials and energy) - use plentiful resources - careful use of non-renewable, rare resources - build small - harvesting water
Biodiversity	avoid actions that lead to biodiversity reduction	determine which ecosystems are affected by project	consider: - avoid highly biodiverse sites - careful sourcing of timber - landscape and building design for biodiversity
Indigenous flora and fauna	minimise disturbance to flora and fauna	analyse local ecosystems	consider: - minimal building footprint - minimal disturbance to vegetation - do not disrupt wildlife movement corridors - design to avoid bird strikes
Social and cultural relevance			

Society and culture	- reflect and express culture - built form relates to social and economic activity - maintaining significant building heritage values - create future heritage value	- community consultation on social/cultural aspects - invite peer and public review	Consider: - locally sourced materials - design to enable use of locally sourced skills - maintaining scale and typologies of buildings - respecting existing built context - adapting existing buildings - using brownfield rather than greenfield sites
Occupants			
Health	- healthy occupants	- assess potential impact of design decisions	Consider: - high fresh air change rate - use non-toxic materials - design for easy cleaning / maintenance
Comfort	- thermal, visual and aural comfort	- determine context related (social / cultural expectations, activities) comfort preferences	Consider: - building design achieves comfort with minimum input of energy
Economic performance			
Cost effectiveness	- Net benefit - Return on investment	- determine life-cycle costs - work with client on wider objectives and whether / how the building meets them - recognise expertise of others (e.g., builder) in achieving cost effective design - consider building use and life in relation to uncertain future economic uncertainties - use cost planning and control	- design for low (imported) energy use - design for low maintenance
The building			
Longevity	- durability - adaptability - serviceability - maintainability	- consult potential future users - seek flexibility in fit between use and building - work with client on asset management plan	Consider: - adapting and using existing buildings - design for adaptability / future change of use - use long life materials - allow for future services - design for low maintenance / easy serviceability - design for climate change

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