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Group 9

Feasibility and Potential Design of a Renewable Off-Grid Eco-Gym

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# Executive Summary

As a business proposition the off grid eco-gym is not feasible due to the high costs of power storage and necessary equipment costs for renewable energy. With an on grid scheme there is only a need for payment of energy usage by the given entity whereas renewables will have high initial costs as well as maintenance costs. Therefore the money effectively earned back by not paying for energy requirements does not outweigh the extensive capital required for renewable resources.

# 1.1 Introduction

85.1% (RenewableUK, 2014) of the United Kingdom’s electricity production is through non-renewable sources such as oil, gas and nuclear energy. At current rates of consumption it is estimated that we will not have enough oil to meet our demands by 2040 (IME, n.d). Renewable energy sources are becoming more important than ever and need to be taken up on both a global and commercial scale to insure our energy demands are met. For changes to be made there must be an incentive, businesses must have to see that they can profit from renewable sources to make them make the switch. The objective of this report is to come up with a recommended plan for a fully off-grid eco-gym for a client and discuss its feasibility in the current market.

# 2.1 Brief

The Client requires that the gym has these features:

* 1500 members
* 25m indoor swimming pool
* Modern cardiovascular ad resistance training machines
* Fully heated and lit building
* Changing rooms and hot showering facilities
* Small Café serving snacks and hot drinks.
* Must be fully self-sufficient with its power demands requiring nothing from the national grid

The following reports shows our findings on estimated power requirements for the gym and discusses what currently viable renewable energy generation sources could be used to meet the demand but also be cost efficient.

# 3.1 Eco gym energy consumption

Our gym has a number of energy hungry aspects which need to be considered so that we are able to come to a relatively precise conclusion on the total energy usage so that we know how much energy is needed to up-keep the system.

# 3.2 Swimming Pool

For a gym of our calibre the pool will without a doubt consume a large amount of energy. It will need certain pieces of equipment such as a dehumidifier, pump, ventilation and heat pumps.

In order to calculate the energy consumption of the pool, a pool of a similar size was researched. Data from SportEngland (2012) showed a pool which was the required size of four lanes and of twenty five metres. For our gym we undertook a pool of this size as the membership was relatively low. The value of energy required for a pool of this size was 186kWh/day.

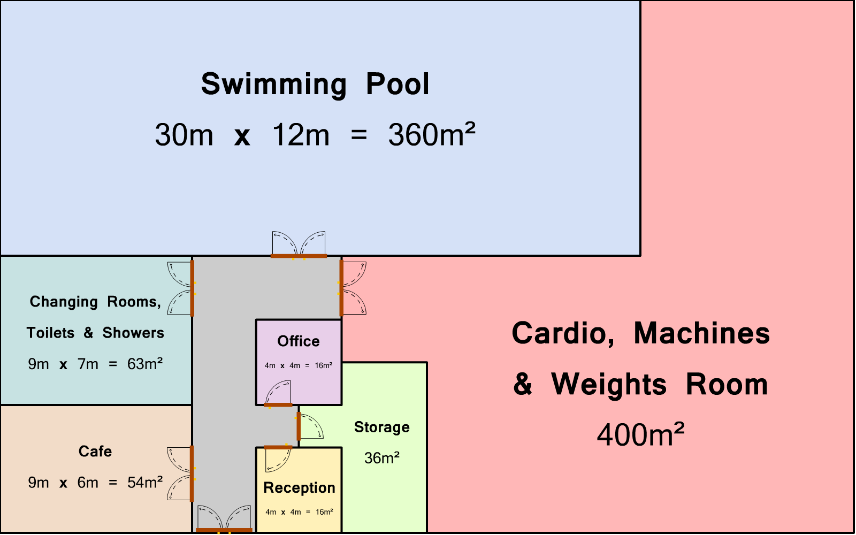
Further, to calculate the total consumption of the entire pool it would require extensive knowledge of the other pieces of equipment. Hence this required external research which proved useful after obtaining a website by Sedac (2012) with the proportions of energy usage of an indoor pool in USA. After disregarding cooling we produce a pie chart of including: pool heating, space heating, changing facilities, lighting, dehumidification, pumps, other (café and reception) and ventilation. Using the value from earlier of ****186kWh/day this accounts for a total of twenty seven percent this will give a total of 691kWh/day. As one of my team-member had already calculated the energy required for lighting and I have added the value for space heating to the heating section hence have removed these values from the total for the pool as they will be included for the final value. Total of energy is about 505kWh/day which is equal to about **184MWh/year**

Figure Floor plan of Eco-Gym Office and Reception 4x4m = 16m2

# 3.3 Lighting

In order to calculate the total power needed for lighting, we have divided the whole gym into two sections. Section one encompasses the swimming pool and the cardio vascular area. Section two includes the rest. For section one we had to use high bay lights due to the height of the swimming pool and cardio area. As for section two we have use standard LED lights.

The numbers of light is given by the formula: (Student Notes, 2003)

Where,

N  =          number of lights needed.

E   =          light intensity required (lux)

A  =          area (m2)

F   =          average energy per unit time provided by each light (lm)

UF=          utilisation factor, an allowance for the light distribution of the luminaire and the room surfaces.

MF=         maintenance factor, an allowance for reduced light output because of deterioration and dirt.

* The recommended luminance required for swimming pool and exercise area is 300 lux. (Sport England, 2012)
* Area = 360+400 = 760
* Each high bay light fitting’s performance and specifications: (Vivid LEDs, 2013)
* 120 watts, 10039 lumens, UF 0.7, MF 0.65.

50 lights

* The recommended luminance required for office, reception and café is 250 lux. (The Engineering Toolbox, ND)
* Each spotlight light fitting’s performance and specifications: 6 Watts, 580 lumens, UF 0.5, MF 0.80. (Light Rabbit, 2015)

259lights

* As the average day light in England is 12 hours, therefore, we have considered using large windows and roof windows which will compensate 70% of the lightings. (Project Britain, 2013)

# 3.3 Heating

The average temperature in Bristol is 11°C (YR, 2014) and the minimum temperature required for the office, reception, cafeteria and hallway is 21°C. (Seppänen, O et al, 2006)

The formula for heating is given by H = (kA / x) x (Tinternal – Texternal) where H is the heat, k is the thermal conductivity, A is the area in meters cube, x is the width of insulation and T is the temperature. We have considered the wall material to be foamed concrete as standard. (METBD 330, ND)

* Foamed concrete has a thermal conductivity of 0.1 W/mK. (EAB Associates, ND)
* Insulation has a standard thickness of 100mm. (Brinkley, M, 2011)
* The total area for Office, reception and cafeteria including setting area is 160 with the height of 2.5.

/0.1) × (21-11.3) =3880W

* We assume that the heating will be on 30% of the time.
* The cardio vascular area has a dimension of 400 and height of 4m. The minimum temperature required is 16°C.

/0.1) × (16-11.3) =7520W

186 x 13/21 = 115 kWh per day

115kWh x 365 x15/24 = ***26234KWh Per Year***

Total heating power required =

# 3.4 Air-conditioning

Total BTU needed 68000, Cooling Output 20kW, Supply Airflow m3/h: 2960

We assume that the number of days that air conditioning will used per year is 189 days and it will be used 30% of the time.

# 3.5 Miscellaneous

As shown above the heating, lighting, air-conditioning and swimming pool energy consumptions have all be calculated. Other parts of the gym need to be taken into consideration such as the gym and café equipment.

**Café** (Hedrick, R, 2011) **Reception** (Energy Usage Calculator, 2015)

Refrigeration - 35kwh/day Two computers – 4.32kWh/day

Coffee machine/boiler - 11kwh/day Printer – 0.0225kWh/day

Juicer - 9.5kWh/day Phone – 0.048kWh/day

Total = **55.5kWh/day = 20258kWh per year** Total **= 4.593 kWh/day = 1676kWh per year**

# 3.6 Gym Equipment

Pieces of equipment that need to be taken into consideration are three rowing machines, six bikes, eight cross-trainers and eight treadmills.

As plenty of these machines can output a reasonable amount of power some of them can be used to produce energy.

* Three rowing machine can produce 0.6kWh and therefore 0.6x (15-5) = **6kWh/day**. 15-5 was used as the gym is open for 15 hours and we have assumed that each machine will only be used for two thirds of the time. (University of Minnesota Duluth, n.d)
* Six bikes can produce 1.92kWh and therefore **19.2kWh/day** (Data taken from pedal-a-watt stationary bike) (Life Fitness, 2010)
* Eight treadmills will use 4kWh and therefore **40kWh/day**. (Life Fitness, 2010)
* Eight cross-trainers will use 0.8kWh and therefore **8kWh/day**. (Life Fitness, 2010)

Hence the total amount of energy used will be 48kWh/day and the total amount produced will be 25.2kWh/day. Therefore the gym equipment will require 48-25.2=**22.8kWh/day.** This is **8322kWh/year**.

# 3.7 Total Power Consumption

Adding up all the previous values we obtain a total power consumption of:

184,309 + 13,240 + 46,207 + 11,904 + 20,258 + 1,676 + 8,322 = **286MWh/year**

# 

Figure – Total Power Consumption of Gym

# 4.1 Possible Sources of Renewable Energy

The Bristol area has very good potential in renewably sourced energy due to its location in the UK. It is far south enough to be in an area of high light intensity averaging at 137 Wm-2 (Met Office, 2014)throughout the year, as well as being elevated enough to have a high average wind speed of 5.5 ms-1 (ESRU, 1999). Bristol is also situated on the river Severn which is the largest river in the UK. The Severn is also unusually fast for its size travelling at an average of 4.4ms-1(BBC, 2014). This collection of factors can all be exploited using varying methods of capture as shown below.

## 4.2 Solar Cells

In the UK a 4kW system that is 28m-2 in size is expected to cost around £6000 at current prices (theecoexperts, 2015). This is the equivalent of 15-20Wm-2 at £215 per square metre. With total building area of 1000m2 once can expect to be able to fit around 400m2 of solar arrays on the roof providing the benefits in ***Table 1.***

***Table 1 – Possible Power Output and Savings from a 400m2 Solar Array***

|  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- |
| **Item** | **Power Output (W)** | **Cost (£)** | **Quantity** | **Total Power (kW)** | **kWh per year** | **Total Cost (£)** | **Savings per year (£)** | **Payback Time (yr)** |
| Solar Cells | 20.00 | 215.00 | 400.00 | 8.00 | 70,080.00 | 86,000.00 | 7,358.40 | 11.69 |

Solar Photovoltaic cells are often seen now as a very modern and realistic approach to renewable energy. They have a 20 year lifetime and could pay for themselves within 12 years making them a viable option for the gym, providing that there can be enough of them to provide and meaningful wattage.

## 4.3 Transparent Solar Cells

Transparent Solar Cells as explained by Anthony, S (2014) in the same way as traditional solar cells put have the bonus of being transparent. This allows increased area in which to install them as they can be used in place of glass windows. They work by absorbing light below the frequency of visible light but allowing visible light to pass straight through. An example of a possible scenario is shown in ***Table 2.***

***Table 2 – Possible Power Output and Savings from a 600m2 Transparent Solar Array***

|  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- |
| **Item** | **Power Output (W)** | **Cost (£)** | **Quantity** | **Total Power (kW)** | **kWh per year** | **Total Cost (£)** | **Savings per year (£)** | **Payback Time (yr)** |
| Transparent Solar Cells\* | 3.00 | 200 | 600.00 | 1.80 | 15,768 | 120,000 | 1,655.64 | 72.48 |

Despite the ability for increased area and the opportunity to have lower lighting costs (sky lighting) the technology is currently behind and is far too expensive for the cost to make it a feasible idea.

## 4.4 Solar Heating Panels

Like Photovoltaic (PV) Solar Panels, these use light to provide free energy. Unlike, PV cells these use the solar energy to create heat instead of electricity. Cool water can be pumped in and be heated by the sun then pumped out at a higher temperature. See ***Table 3*** for a scenario.

***Table 3 – Possible Hot Water Output and Savings from a 150m2 Solar Water Heating Panels (WorcesterBoschGroup, 2015)***

|  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- |
| **Item** | **Power Output (W)** | **Cost (£)** | **Quantity** | **Total Power (kW)** | **kWh per year** | **Total Cost (£)** | **Savings per year (£)** | **Payback Time (yr)** |
| Solar Water Heat Panel | 0.00317L hot water per second | 2,500 | 6.00 | 0.01902L hot water per second | 600000L hot water per year | 15,000 | 5000 (≈ 50000kWh to heat per year | 3.00 |

This 100m2 is enough to provide complete heating of an indoor 200m2 pool providing that it is covered at night as well as the hot water needed for the facilities taps and showers all year round. It needs to be noted however that these will occupy the same space as the PV Cells and a compromise will have to be met to enable their use.

## 4.5 Human Power

One of the main aspects of gyms is the cardio and resistance machines. In general, cardio machines run off the grid, but more and more are starting to become self-sufficient. And current early prototypes of both cardiovascular and resistance train machines are capable of outputting up to 200W (home-generator, 2014). into for the use of the other gym facilities.

***Table 4 – Possible Hot Water Output and Savings from Human Power***

|  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- |
| **Item** | **Power Output (W)** | **Cost (£)** | **Quantity** | **Total Power (kW)** | **kWh per year** | **Total Cost (£)** | **Savings per year (£)** | **Payback Time (yr)** |
| Human power | 150.00 | 1,000.00 | 15.00 | 2.25 | 13,140 | 15,000 | 1,379.70 | 10.87 |

It is estimated that on average the equivalent use of machines would be a constant use of 15 machines. It is also estimated that each machine will cost an additional £1000 more than the on-grid counterparts. Taking this into account (as show in ***Table 4***)shows that despite their reasonable payback time, they do not produce much electricity throughout the year.

## 4.6 Wind Power

As stated before Bristol has an average wind speed of 5.5m2 which opens up good possibilities for wind power. The Gym will be situated in a city centre which means that full size turbines are out of the question leaving smaller commercial wind turbines. An example of the power output of a Gaia-Wind 133-11kW (gaia-wind,2015) is shown in ***Table 5.***

***Table 5 – Possible Hot Water Output and Savings using two Gaia-Wind 133-11kW wind turbines.***

|  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- |
| **Item** | **Power Output (W)** | **Cost (£)** | **Quantity** | **Total Power (kW)** | **kWh per year** | **Total Cost (£)** | **Savings per-year (£)** | **Payback Time (yr)** |
| Wind Power | 2,000.00 | 50,000 | 2.00 | 4.00 | 35,040 | 100,000 | 3,679.20 | 27.18 |

Although the turbine has quite a high power output for its size, it is also very expensive and has a very large payback time. They could be put in quite a large array as they on have a diameter of 11m but because of the large payback time, it is unlikely that it would every pay for itself before it would need to be replaced due to wear.

# 5.1 Recommended Energy Source Arrangement

By far the most power possible can be produced by the river turbine. Clean Current (2015) manufacture one model that has a blade diameter of 2.5 metres which produces a constant 30kW and another with a diameter of 1.8 which produces 16kW. They are both rated to produce this power with a river speed of 3ms1. The River Severn runs at 4.4ms1 so we are likely able to expect even more power.

To save power it is recommended to also install the Solar Heating Panels. The 150m2 arrangement will provide the hot water for all of the required facilities with an impressive 3 year payback time.

The recommended configuration is shown in ***Table 6.***

***Table 6 – Power Output and Savings of the Recommended Renewable Energy Configuration***

|  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- |
| **Item** | **Power Output (W)** | **Cost**  **(£)** | **Quantity** | **Total Power (kW** | **kWh**  **per year** | **Total Cost (£)** | **Payback Time (yr)** |
| Large Turbine | 30000 | 250,000 | 1 | 30 | 262800 | 250,000 | 9.06 |
| Small Turbine | 16000 | 180,000 | 1 | 16 | 140160 | 180,000 | 12.2 |
| Solar Water Heat Panel | 0.00317L hot water per second | 15,000 | 6.00 | 0.01902L hot water per second | 600000L hot water/year | 15,000 | 3 |

This has an estimated total installation cost of £445,000 and can produce at least 403,000kWh/y, which is an 29% overhead over the 286,000kWh/y required. The overhead is needed to help cope with possible maintenance requirements of one turbine if it fails and not having the smaller one would result in only having a 20% overhead which is very risky in an off grid system.

The river turbines have been shown to be safe for wildlife with study’s showing that fish tend to avoid them as they can detect a disturbance in the water. Planning permission would need to be considered and local government would need to be contacted to allow construction. The turbines are installed deep in the water and have a small footprint meaning that there would be little to no disturbance to normal river function.

## 5.2 Feed In

To help justify the massive overhead when not in use it is suggested to feed it back into the national grid. At current rates, the UK government pays 12p per kWh (European Solutions, 2010). With an excess of 117MWh/y this could produce an additional source of income of up to £14,040 per year.

# 6.1 Back-up power generation

Despite the inclusion of multiple reliable power generation and storage technologies, it is also necessary to include a standby power source in the event of failure of a hydro-turbine or an energy shortage from the lead/acid batteries. Initially, multiple forms of backup power supply were considered and compared based on installation costs, size, running costs and power output. In order to comfortably meet the power demands of the gym as a stand-alone back up device, it is recommended that a device with a rated output of 100kW is chosen.

Due to a desire to minimise greenhouse gas emissions from our generator of choice, fuel cells were considered. A major advantage of this standby technology is the emission of only water vapour as a waste product; thus eliminating the need for a separate storage area, and allowing for onsite location of the fuel cell unit. Furthermore, the replacement of a combustion based generation method with fuel cells minimises the moving parts required and therefore increases reliability. However, fuel cells for commercial use have only recently been introduced to the market, and correspondingly, purchase and installation costs for a device large enough to meet the demands of an off grid gym are high. In fact, fuel cell standby systems are at the stage of market life where reliable purchase costs are difficult to find. A reasonable estimate based on GreenLight Innovation’s (a US fuel cell manufacturer) current commercial fuel cells puts a 100kW fuel cell in the range of £380,000 to install, with the running cost per kWh three times as high as a similarly sized diesel generator (PEM Solutions, 2013); clearly financially unfeasible for a small commercial user.

A similar issue was met whilst considering a standby measure incorporating flywheel energy storage linked to a battery bank. Although FES demonstrates a favourable efficiency of 80%, it sacrifices low cost as expensive magnetic materials and alloys for bearings along with carbon fibre blade designs push up manufacturing costs. Currently, the most affordable commercially available flywheel claims that an investment of £1,333 will output 1kW (Nelder, C, 2014), thus putting a theoretical 100kW device at £133,300; again far too large a sum for a small commercial business.

The most sensible stand-by storage device given current technical advances and prices is still a generator that relies on internal combustion. The eventual choice, Generac’s Commercial Series 100kW standby generator, costs £15,650 to install (Generac, 2015); a far more sensible figure for this purpose. Furthermore, the generator runs on natural gas which gives a few key advantages. Natural gas is a cleaner burning fossil fuel as compared to diesel, thus maintaining the image of an eco-friendly setup. Natural gas will already be piped to the location through the UK gas network, eliminating and need for storage and also ensuring that when required, the generator can immediately begin to power the gym as natural gases can remain piped for long periods without any decrease in quality. The final major advantage of natural gas is that, despite being slightly less energy dense, it is a cheaper source compared to diesel. Early 2015 fuel prices indicate that diesel costs around £2.45 per gallon, and the gasoline gallon equivalent of natural gas is around £1.40 (World Dept. of Energy, 2015). The combination of a low installation cost, low running cost and a power output that comfortably covers the demands of the whole gym place the natural gas generator as the main recommendation for a standby power system.

Table 7 - A comparison of the equipment investment required per kW produced by standby methods

|  |  |
| --- | --- |
| Backup Power Source | Investment per kW (£) |
| NiCd batteries | £3450 |
| Fuel Cells | £3875 |
| FES | £1333 |
| Natural gas Generator | £157 |

# 7.1 Energy Storage

Energy storage is essential to enable the gym to cope with power fluctuations which will occur due to the volatile nature of the power output from renewable sources especially solar power. A storage system will create a balance between power supply and demand instantaneously. Storage is also needed during periods of power outages and in case of emergencies. Our estimated peak power output is 63kW which exceeds our total power generation; therefore an energy storage system is vital to keep the gym running during this peak period. There are many different ways of storing energy *(Energystorage.org.uk, 2015)*:

* Chemical Energy storage
* Electrochemical storage
* Electrical storage
* Thermal storage
* Mechanical storage

We firstly considered using a flywheel, which stores electricity as kinetic energy. An electrical input causes a rotor to spin in an almost frictionless enclosure, which gives an efficiency of 80%. When short term back up is needed because power generation fluctuates, the inertia allows the rotor to continue spinning and this kinetic energy is converted to electricity *(Energystorage.org, 2015)*.The advantages of using a flywheel for energy storages are that they’re low maintenance, whilst having a long life and small environmental impact, this will help reduce the costs of our gym. There are many disadvantages however; a flywheel that would be capable of storing our required power would need to be very large, which is not ideal in a city location. Also due to the large stresses and strains that are present when the rotor spins, there is a limit on how fast they can go before fracturing. The amount of energy that can be stored is proportional to the object’s moment of inertia times the square of its angular velocity. Due to the large size of flywheel that would be needed to provide the required power of 63kW for our gym, we have discounted the use of a flywheel.

Hydrogen storage was another storage method we considered. During this process electricity can be converted to hydrogen via electrolysis, this hydrogen can be stored in pressurised vessels for prolonged periods of time and re-electrified via combustion or in fuel cells *(Energystorage.org, 2015)*. Hydrogen energy storage uses relatively new technologies and therefore has a low efficiency of 50-60% in comparison to other methods. This is a very expensive storage method, because the process of creating hydrogen uses new technologies which are still advancing, therefore it is not feasible to use within our gym.

We chose to use batteries (electrochemical storage) as our method of energy storage due to their high efficiency, low cost and low maintenance in comparison with the other storage methods. We decided to use lead-acid batteries after doing a comparison to lithium-ion batteries, this is majorly due to a lead-acid battery being much more economical at £293,000 compared to a lithium-ion battery that costs £650,000 *(BatteryUniversity, 2015)*. We found that lithium-ion batteries have a higher energy density than lead-acid, as well as a higher life span, up to 5000 cycles from a lithium-ion battery compared to 2000 from a lead-acid battery. A Lithium-ion battery is able to charge at 100% efficiency whilst a lead-acid one can only charge at 85% efficiency *(PowerTech Systems, 2015).* Although the lithium-ion battery seems much more desirable, we will use a lead-acid battery in our gym, this is because the lead-acid battery is under half the cost of a lithium-ion battery, massively reducing our setup costs, increasing the feasibility of our off-grid gym.

## 7.2 Power Monitoring

A power monitoring system involves a level of meters connected to the internet to provide real time data on the energy system within our gym. The meter has large storage capacity and continually monitors the power, allowing a positive approach to energy management *(Hoveyelectric.com, 2015)*. A power monitoring system is needed in our gym to maximise the fuel efficiency by using battery as an energy buffer, meaning the generator is only used when required to recharge batteries, or when the loads are particularly high. Allowing the generator to run for as little time as possible at maximum load, keeping its efficiency at the optimum.

We have found a system called Eplex which is a control system that uses an iPad interface that mimics information and controls that happen within the generator, battery, and fuel sources this can display fuel levels, battery state of charge, renewable energy entering the system as well as generator loading *(Energy-solutions.co.uk, 2015).*

# 8.1 Feasibility

In order to find out whether the construction of an eco-gym would be feasible in the long-term we looked into the total costs of off-grid installation and maintenance. We looked at the life of our renewable power generators and assumed that they will have on average a life span of twenty years with batteries having a lower life span of ten years. Therefore we had to consider a battery replacement after ten years.

The total cost for initial installation and battery replacement would be equal to £1,037,000 for the period of twenty years. As we feed back some power into the grid we make a small profit of £280,800 which will reduce our total cost to £756,200.

On the other hand if we ran the gym using the grid we would pay an average tariff as suggested by Kingspan Energy (2013) of 14p per kWh which will cost £801,000 over a period of twenty years.

Which means that we can make a total saving of £44,800, realistically extra costs will be incurred if a generator fails and needs to be replaced or minor replacements of photovoltaic cells.

If the client were to invest the initial capital to a bank and with an average interest rate found from MoneySuperMarket.com (2015) of three percent he or she would make £574,000 due to compound interest. Comparing this profit to the potential income from renewable sources this would be eighteen times greater, therefore, an off-grid system would not be financially feasible due to the high cost of power storage. Despite this, with technological advances the costs of power storage systems will decrease in the future making a self-sufficient off-grid gym a realistic venture.

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