

**Introduction To**

**ENERGY ENGINEERING**

**GROUP 8**



**Date submitted: 16/03/2015**

**Supervisor: Professor Clive Roberts**

**CHRISTINE TAMBE 1483076**

**DHRUV PRASAD 1456337**

**RAFY PRALYADI 1469146**

**SAM PURLE 1422127**

**WILL HILLMAN 1445628**

Table of Contents

[1. Introduction 3](#_Toc413953169)

[1.1 Background 3](#_Toc413953170)

[1.2 Aims and Objectives 3](#_Toc413953171)

[1.3 EcoGym Facilities 3](#_Toc413953172)

[2. Consumption 4](#_Toc413953173)

[2.1 Assumptions and Calculations 4](#_Toc413953174)

[2.2 Summary of Consumption 5](#_Toc413953175)

[3. Conservation 6](#_Toc413953176)

[3.1 Lighting 6](#_Toc413953177)

[3.2 Ground Source Heat Pumping 6](#_Toc413953178)

[3.3 Double Glazing 7](#_Toc413953179)

[3.4 Cavity Wall Insulation 8](#_Toc413953180)

[3.5 Loft Insulation 8](#_Toc413953181)

[3.6 Summary of Conservation 9](#_Toc413953182)

[4. Generation 10](#_Toc413953183)

[4.1 Solar Power 10](#_Toc413953184)

[4.2 Wind Power 13](#_Toc413953185)

[4.3 EMF Machines 15](#_Toc413953186)

[4.4 Summary of Generation 16](#_Toc413953187)

[5. Energy Storage 16](#_Toc413953188)

[5.1 Batteries 17](#_Toc413953189)

[5.2 Summary of Energy Storage 17](#_Toc413953190)

[6. Feasibility and Total Payback Time 17](#_Toc413953191)

[7. References 19](#_Toc413953192)

[8. Appendices 20](#_Toc413953193)

# 1. Introduction

## 1.1 Background

Over 90% of electricity generated in the UK comes from gas, coal-fired power stations and nuclear energy (Hi energy, 2014). Primarily, fossil fuel reserves are limited and will soon run out. This necessitates the exploration of alternative sources of energy. The solution is unlikely to be one technique, rather a combination of many, for example: Solar, Hydro, Wind and Nuclear. In addition, the biggest contributor to climate change is the carbon dioxide produced when fossil fuels are burnt in order to provide the energy needed by the growing population. This has led to global warming, another compelling reason to find alternatives (Mackay, 2008).

## 1.2 Aims and Objectives

The aim of this project was to determine if it was technically and economically feasible to run anEcoGym with specified requirements, completely isolated from the national grid. The idea was to see whether it will be possible to maintain the current standards and efficiency when fossil fuels run out and renewables take over.In order to achieve this, it was constructive to organize an implementation plan which included:

1. An estimate of the average energy consumption of a gym with certain dimensions.
2. Energy conservation methods to reduce consumption and therefore generation.
3. Energy generation from a range of renewable sources.
4. An energy storage system to handle daily and seasonal supply variations including a re-charging system.
5. Government policies to help reduce costs (by the provision of grants).
6. A business plan with a variety of options.

All these features will determine whether the EcoGym is commercially viable.

## 1.3 EcoGym Facilities

One assumption is that the specified gym building has already been constructed but without a swimming pool, insulation, double glazing or equipment. The gym is located in Exeter and has an area of approximately 1500m2 (38.7 x 38.7m). It has a planned membership of 1500 and will open for 15 hours daily from 7am to 10pm. When completed, it will offer:

1. A range of cardiovascular machine including 10 treadmills, 20 elliptical bikes, 2 Stairmasters, 3 steppers, 15 gym cycles, 2 rowing machines and 8 resistance machines, all found on the top floor.
2. An indoor heated 25x12m pool located on the basement.
3. Changing rooms and showers.
4. A cafeteria serving hot drinks and snacks.

# 2. Consumption

## 2.1 Assumptions and Calculations

To gather data on energy consumption, it is worthwhile to assume that some of the devices used in the gym are the same as their domestic equivalents. Detailed calculations for energy consumption are provided in the appendix.

Firstly, the only gym equipment that needs powering is the treadmills and the Stairmasters. Other cardio-equipment are self-powered. The average power used by a Precor 932i treadmill moving at 3.5, 5.0, 7.0 and 9.0 MPH is 632.83W (Life fitness, 2010). At any given point in time, 4 treadmills are assumed to be in use. Throughout the 15 hour working day, this results in a daily consumption of 38kWh. Step mill 5 requires 1725 W (Owner’s manual, n.d.), and it is assumed that each Stairmaster will be used for 5 hour a day (Energy Efficient gyms, n.d.) resulting in 8.6kWh of energy used per day.

An energy consumption estimate of the 25 228W 4-lamp T5HO light fixtures which are on throughout gym hours is 85.5kWh per day. The 50W music stereo uses 0.75kWh per day. A typical digital 38-inch TV uses an average power of 150W. 5 TVs consume 11.3kWh of energy in a day.

The cafeteria consists of a fridge, a coffee maker and a microwave. The fridge, coffee maker and microwave have an average power usage of 500W, 1000W and 1500W respectively. The cafeteria uses, in total, 11kWh per day.

The pool pumps and heaters are used for 6 hours a day. A large swimming pool heat pump uses 32kW of power. Two 2250W pool pumps use 4.5kW. Pool pumps and pool heater use a combined total of 219kWh per day.

The peak electric heating requirement per square meter is 50W. So energy required to heat the gym daily is 1125kWh. The standard cooling factor is 23BTU per square feet. The air conditioning will be used 10 hours a day, based on the fact that in the UK, temperatures do not really go above 30°C (Mackay, 2008). Therefore, 1088.3kWh of energy is used per day by air conditioning.

The power used by the water heater for a family of four is 4.5kW. Assuming the power used by the gym is four times the energy used by a family of four, the energy used by the water heater for six hours a day is 108kW per day. The water heater is for the hot taps and showers. This is reasonable because a family of four has at least two showers and the gym has ten showers.

## 2.2 Summary of Consumption

All the equipment and devices are used throughout the year except the electric spaceheaters and air conditioning. Air conditioning is used for the three summer months of June, Julyand August, while the gym is heated for the rest of year. Table 1, below shows the dailyand annual energy consumption used by the gym.

|  |  |  |  |
| --- | --- | --- | --- |
| Device | Daily energy use  (kWh) | Annual Usage Period  (Days) | Annual Energy Use  (kWh) |
| Equipment | 46.5 | 365 | 16,972.5 |
| Lighting | 85.5 | 365 | 31,207.5 |
| Miscellaneous | 12.05 | 365 | 4398.25 |
| Snack bar | 11 | 365 | 4,015 |
| Pool pumps and heaters | 219 | 365 | 79,935 |
| Electric heater (for rooms) | 1125 | 308 | 346,500 |
| Water heater (for showers) | 108 | 365 | 39,420 |
| Air Conditioning | 1088.3 | 84 | 60,944.8 |
| Total | 2,683.6 |  | 579,104.3 |

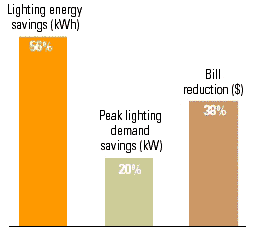
Table 1: A table summary showing the breakdown of the energy consumption in a single day and over the course of a year (Refer to appendix for complete table).

# 3. Conservation

As well as research being done into generating the maximum amount of energy, it is also paramount to look at different methods of conserving to reduce waste. Several alternatives were considered which would all save energy but the cost of installation and payback times also had to be taken into account before making any final choices. Throughout this section, when calculating the money saved per year through conservation, an average cost of £0.10 per kWh, which is what it would cost from the grid, has been used for the purposes of comparison. All calculations are based on the annual energy requirements listed in table 1.

## 3.1 Lighting

The main way to save energy in lighting is to convert to more efficient bulbs but the value used for the energy consumption in the lighting area already took into account the use of CFL bulbs so the energy saved was already accounted for in the original value.

Another technique for reducing the amount of energy consumed is to reduce the amount of time the lights are on, especially when they’re not in use. Passive Infrared sensors (PIR sensors) can detect a moving, warm object and will trigger the illumination of the lights in that particular area or room. PIR sensors are more efficient than an ultrasonic sensor because PIR sensors are resistant to false triggering. With a PIR sensor in place, an energy saving of up to 56% is possible (Energy Saving Sensors, 2010).

With the use of a PIR system the total energy saving on the lighting would be:

Figure 1: Bar chart showing savings made from the use of a PIR system.

Over the course of a year this would lead to a saving of £1,746 per year. Because the cost of installation is small (£500), the payback time for such a system is well under a year, making it well worth the time and money.

## 3.2 Ground Source Heat Pumping

Ground source heat pumping (GSHP) could be seen as a generation technique but it could also be viewed as a way of minimising the energy required to heat the gym which would have otherwise come from other generation techniques. GSHP works by pumping water just below the surface, typically 10 metres or so, and absorbing heat energy from the ground into the water flowing inside the pipes. The temperature of the ground at this depth is fairly consistent (around 8 – 12 degrees) all year around so the thermal energy absorbed doesn’t fluctuate from season to season. This makes it very reliable. Heated water is compressed and exchanged to piping inside the building so that it can be circulated and eventually used. Kensa heat pumps have quoted “1kW of electricity = 4kW of heat … Effectively meaning the cost per kilowatt hour is quartered.” (Kensa Heat Pumps, 2015).The GSHP would contribute to all the heating areas in the gym so would affect the water heating, air heating and pool heating. Therefore, with an energy saving of 75%, the total energy saved by using GSHP:

The use of the GSHP system, although costing approximately £325,000, would save £34,939 per year so would have a payback time of approximately 9 years.

## 3.3 Double Glazing

Double glazing reduces the amount of energy lost through and around windows. A layer of thermal insulating gas between two panels of glass prevents heat radiation from passing through the window. By installing high quality double glazing, potential drafts or exclusions around the seal can be prevented which can save up to 20% of energy.

Figure 2compares single glazing to double glazing to establish the total energy saved by upgrading to double glazing. Energy is saved in both lighting and heating. Assuming a glazing ratio of 50%, where sufficient light can get through to illuminate the room but not enough for the room to overheat, a ratio of total energy saved can be found. This value, as a percentage is about 33% (figure 2), so total energy saved is:

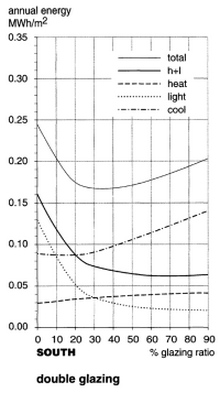
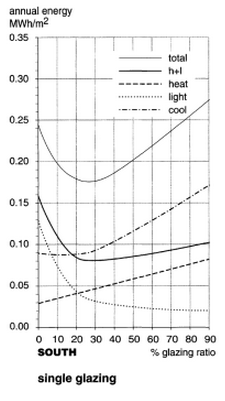


Figure 2: Energy consumption for heating, lighting and cooling for a south facing window in southern UK (Energy Saving Sensors, 2010).

This would therefore create a saving of £12,464 per year. Initial costs for the installation of double glazing is around £32,400 so the newly installed windows would have a payback time of just over 2 and a half years.

## 3.4 Cavity Wall Insulation

Cavity wall insulation prevents radiation heat from escaping through the walls and so reduces the energy needed to heat the rooms. An assumption was made that there was no insulation already installed. The insulation needs were based on figures from a standard four bedroom detached house and simply scaled it up to the size of the gym. Using the average energy bill of a large house (UkPower, 2015), and the average annual savings from cavity wall insulation (EnergySavingTrust a, 2015), a house’s heating bill would be reduced by roughly 17% after insulation installation. Due to the large windows in the gym however, we expect our insulation to be about 75% as effective as in a house, so an annual saving of 13% would conserve:

This would result in an annual saving of £4,504 on the average tariff of electricity. Before the payback time can be calculated, the values for a four bedroom detached house must be scaled up to the size of our gym. The figures for a four bedroom detached house was based on dimensions: 14.2 x 7.2 metres and the dimensions for the gym are: 38.7 x 38.7 metres. Therefore:

However, because some heat is lost through and around the windows, this ratio needs to account for this by multiplying it by the heat lost through windows.

This multiplier can then be used to work out the cost and ultimately, the payback time of the cavity wall insulation:

Thus, with an initial cost of £2100 and an annual saving of £45045, the payback time is around half a year.

## 3.5 Loft Insulation

Loft insulation works along the same principle as cavity wall insulation apart from the fact that more heat escapes through the roof as heat rises so in some ways, it is more important than cavity wall insulation.

Using an average energy bill (Uk[Power,](http://www.ukpower.co.uk/home_energy/average-energy-bill) 2015) and annual savings for a large house (EnergySavingTrust b, 2015), 15%of energy can be saved through loft insulation over the course of a year, this leads to a total saving of:

This produces a saving of £5197.5 per year.

In a similar manner to cavity wall insulation, a ratio of the area of our gym compared with that of a four bedroom detached house needed to be established so that the values found online could be scaled up to match our gym.

Since the total savings of around £5197.5 per year, the total payback time is just over a year.

## 3.6 Summary of Conservation

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
|  | Saving  (kWh/year) | Saving  (£/year) | Initial Cost  (£) | Payback Time  (Years) |
| Motion Sensors | 17428.32 | 1,742.83 | 500 | 0.3 |
| GSHP | 332073 | 33,207.30 | 325,000 | 10 |
| Double Glazing | 28586.25 | 2,858.63 | 32,400 | 11 |
| Cavity Wall Insulation | 7545.07 | 754.51 | 2,100 | 3 |
| Loft Insulation | 7574.10 | 5197.50 | 5,925 | 1 |

Table 2: A summary of each energy saving method with a breakdown of each individual aspect.

Table 2 shows the payback time for most of the energy saving techniques are around 10 years, after which these methods will produce 100% profit. As well as economic gain, they also reduce the amount of energy needed at any one time in the gym, reducing the strain on the generation techniques.

# Optimise solar energy with our services4. Generation

## 4.1 Solar Power

The location of the gym was selected to be in the city of Exeter, such that the potential for solar power generation was maximised. This was done as it was evident that solar generation would play a constitute a large portion of the overall energy production at a very early stage in the project, due to the fact that it relies upon relatively established technology, and its use is widespread in both industrial and residential applications.

The average electricity generation for 20% efficient photovoltaic panels under 110Wm-2 solar irradiation can be found to be 0.5kWhm-2day-1 (Mackay, 2009). However, as stated in the source for this figure, 20% efficient solar panels are relatively expensive, and due to the large roof space needing to be covered for our purposes, it was decided that the initial outlay for such panels would potentially deter investment. As such, panels of a more reasonable 15% efficiency were used, which reduces the amount spent on the panels but also the power output by 25%, such that they can be assumed to produce an average of 0.375kWhm-2day-1.

**Figure 3: A map of the UK showing the amount of solar radiation. (Met Office, 2015)**

Once values had been attained for the average energy output of our solar panels in terms of area, the area available for solar power generation had to be calculated. In order to do this, it was necessary to calculate the expected roof area of our gym which was done by measuring two gyms:

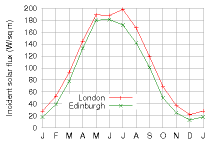
1. Scotch Horn Leisure Centre, Nailsea with roof area of 2,500 m2 and surrounding area population of 18,000.
2. Munrow Sports Centre, Birmingham with roof area of 4,500m2 and surrounding area population of 30,000.

Upon finding this data, it was necessary to find the number of memberships held at each establishment. In order to do this, some overall membership data was requested of the Munrow Sports Centre. Unfortunately, however, no useful reply was received. As such, estimation was required. It was found that, throughout the UK, 14% of adults hold gym memberships (BBC, 2000). Some assumptions that were required to figure out an estimate were that the relationship between membership count and roof area of gyms is linear and that the surrounding populations conform to the 14% average of membership subscription. Using these assumptions, the expected gym memberships is 2525 in Scotch Horn Leisure Centre and 4200 in Munrow Sports Center.

It was subsequently decided that each membership required 1m2 of roof space (this has an average error of 4%). As such, the roof space of our 1500 membership gym was calculated to be 1500m2. This equates to dimensions of 38.7m by 38.7m, which seemed reasonable for our purposes. However, it was decided that it would be unreasonable to expect to be able to cover the entire roof with solar panels. Due to this, it was decided that covering 90% of the roof would be a reasonable target, which is roughly equivalent to leaving a 2m border around the outside of the roof which is to be left uncovered by solar panels. This gives 1350m2 of available roof space.

*Daily electricity output from solar panels: 506.25kWh*

Figure 5 gives the annual average for solar generation. However, in order to asses our potential need for energy storage capacity, it was important to take into consideration the power output as it varies annually.



**Figure 4: A graph showing the amount of solar power per square metres over the course of a year in London and Edinburgh (Mackay, 2009)**

As can be seen in figure 5, solar irradiation can be modelled as a sine wave, where x is the calendar month. Using equation 1 below (derivation in Appendix A), values for kWh per day for each month can be calculated. The results are summarised in table 3.

|  |  |  |  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| Month | Jan | Feb | Mar | Apr | May | Jun | Jul | Aug | Sept | Oct | Nov | Dec |
| Power  (kWh/day) | 180 | 320 | 510 | 690 | 830 | 880 | 830 | 690 | 510 | 320 | 180 | 130 |

Table 3: A table to show the amount of power received from solar radiation across the gym roof.

Figure 5: A graph showing the power output over the course of a year in Exeter.

## 4.2 Wind Power

Average wind speeds in Exeter are also higher than in most parts of the UK, so through the use of wind turbines, the kinetic energy in the wind can be converted into useful electrical energy for out EcoGym. It was decided that small wind turbines in each of the 4 corners of the building would be enough to generate sufficient electricity. The wind turbines will have 3 blades which are going to be of length 3m.

To calculate the power generated by each of the wind turbines we will use the equation stated below:

**Equation 2: General equation for power generated by a wind turbine.**

Before equation 2 can be used to find values for power, an average value for air pressure must be found. Table 4 shows air temperature, humidity and wind speeds in Exeter over the course of a year. From table 4, average values can be found in order to determine air density, ρ.

|  |  |  |  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
|  | Apr | May | Jun | Jul | Aug | Sept | Oct | Nov | Dec | Jan | Feb | Mar |
| Temperature  (°C) | 9 | 12 | 15 | 17 | 17 | 15 | 12 | 9 | 7 | 6 | 5 | 7 |
| Humidity  (%) | 80 | 80 | 80 | 75 | 80 | 85 | 85 | 90 | 90 | 90 | 85 | 85 |
| Wind Speed  (km h-1) | 15 | 14 | 14 | 13 | 13 | 13 | 14 | 14 | 15 | 17 | 17 | 16 |
| AverageWind Speed  (ms-1) | 3.8 | | | | | | 4.3 | | | | | |

Table 4: A table to show the air temperature, humidity and wind speeds in Exeter over the course of a year.

Using the data from table 4, the following averages could be made:

1. Average temperature of Exeter was 11oC.
2. Exeter is about 7m above sea level.
3. Average humidity is 84%.
4. Annual, winter and summer average wind speed was 4.05ms-1,4.3ms-1 and 3.8ms-1

Hence, the air density in Exeter is 1.232 kg m-3.

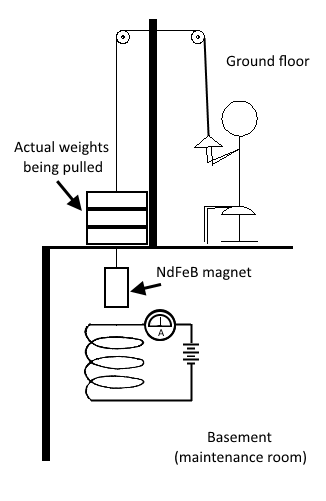
The winter and summer power generated can be calculated by using equation 2 which gives a value of 382W during the summer and 556W during winter.

Table 5 summarises the energy generated during the summer and winter as well as the total energy produced annually.

|  |  |  |  |
| --- | --- | --- | --- |
|  | Summer  (April – September) | Winter  (October – March) | Total |
| Energy Generated(kWh) | 6653 | 9676 | **16,329** |

Table 5: A table to show the total energy generated.

## 4.3 EMF Machines

Working on the basic principles of Faraday’s Law, which states that a change in magnetic flux through a coil of wire induces a voltage (also known as the electromotive force, emf), it is possible to make use of the cyclic movement of the resistance machines (Hambley, 2013). A neodymium magnet of very small weight is attached to the end of the weight rods which passes through a coil of wire. Modifying Faraday’s law for this equipment gives (derivations in Appendix A):

There are a few assumptions made to predict the power output of this machine in a typical workout. Firstly, the typical resistance machine workout consists of 3 sets of 15 reps each with a break in between each set. An average time for a single rep is 2 seconds and the total workout time is assumed to be 30 minutes. Secondly, the neodymium magnet that will be used has a magnetic field strength of 1.3T (Lee, 2015) and has negligible weight compared to the weights being lifted. Thirdly, it is assumed that there is an 80% change in magnetic flux is every time the magnet goes in/out of the loops. Last but not least, it is assumed that there are 200 loops of wire with a diameter of 12 cm. It is possible to calculate the voltage that will be induces and the resistance of the wire that will be used to calculate power.

Figure 6: Diagram showing the design of the proposed EMF machines.

The total resistance of the copper wire (with resistivity of Ω.m) is 1.632Ω. The total power generated from a 30 minutes workout of 45 reps, with a four time change in magnetic flux per rep, can be calculated as follows:

Because of the high magnetic field strength of the neodymium magnets, the magnet-coil system is kept in the maintenance room in the basement. This is due to the harm that can be caused by magnetic fields on electronics.

## 4.4 Summary of Generation

Table 6 compiles all the energy generated in a year from all of the sources that will be installed on the EcoGym.

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| Source | Solar | Wind | Human Power | Total |
| Energy Generated (kWh) | 186500 | 16329 | 6588 | **209417** |

Table 6: A table showing the total energy produced by each source in one year.

# 5. Energy Storage

By compiling the total energy generated and the total energy consumed in the EcoGym in a year as seen in Table 1, a value for the amount of excess energy that needs to be stored can be evaluated.

|  |  |  |
| --- | --- | --- |
|  | Summer (kWh)  (April – September) | Winter (kWh)  (October – March) |
| Generation | Solar: 136,100  Wind: 6,653  Human Power: 3,294  **Total: 146,047** | Solar: 50,400  Wind: 9,676  Human Power: 3,294  **Total: 63,370** |
| Consumption | Equipment: 8,486  Cafeteria: 2,007  Lighting: 6,889  Heating/Cooling: 22,038  **Total: 39,450** | Equipment: 8,486  Snack Bar: 2,007  Lighting: 6,889  Heating/Cooling: 45,699  **Total: 63,081** |
| Storage | **Total: 106,597** | **Total: -289** |

Table 7: Summations of the average energy generation, consumption and therefore storage for the gym over the course of a year.

Energy storage is vital to the gym running successfully. Table 4, above, shows that there is energy deficit during the winter. This is when energy storage comes into play. They are used to store the excess energy generated in the summer so that they can be used during the winter. Several methods of energy storage were considered as each has its own merits.

## 5.1 Batteries

Lithium-ion batteries are contemporarily the most widely used battery in the world. This is due to the numerous advantages they possess, giving them an edge to other batteries such as lead-acid battery and nickel-cadmium battery. Lithium-ion batteries are expensive, yet they have the highest energy density and the longest lifespan. They can store up to 200 Wh/kg and have very low capacity losses of approximately 1% per year at room temperature. They can have 2000 to 5000 charge and discharge cycles and lasts 5-10 years. This means that this device is an excellent long-term investment for energy storage. Moreover, lithium-ion batteries are fast in charging and charge with almost 100% efficiency. Its rivals can only charge with 85% efficiency and can only withstand 500-1000 cycles.

## 5.2Summary of Energy Storage

To find the amount of excess energy that will be stored during the summer that will be used in the winter, a budget of £100,000 is allocated solely on energy storage. The price of lithium-ion batteries is around £270/kWh, which gives us a total of approximately 370 kWh of energy stored during the summer. However, battery prices are reducing each year because of the competitive market and rapid development, which makes it possible to store more energy with the same budget.

# 6. Feasibility and Total Payback Time

In order to assess the overall feasibility of the EcoGym, it was decided that the cost of machinery, building, salaries and other costs that would be shared by on-grid establishments could be neglected. As well as this, profits gained through membership fees and sales in the Café were not calculated. This decision was made because conventional gyms have shown that they operate on a viable business model. As such we felt that we would be better able to evaluate the benefits of an off-grid business if we were to solely investigate how an off-grid gym differs from a conventional gym.

In order to do this, we estimated the additional initial outlay caused by each generation/conservation mechanism we employed, and calculated the value of energy that each device generates/saves on an annual basis. We also included a budget of £100,000 for the energy storage system, which needs to be replaced every 10 years.

|  |  |  |
| --- | --- | --- |
|  | Initial Cost (£) | Annual Value (£) |
| Solar | £340,000 | £18,650 |
| Wind | £1,200 | £1,633 |
| Ground Source Heat Pumping | £325,000 | £33,207 |
| Motion Sensors | £500 | £1,743 |
| Double Glazing | £32,400 | £2,859 |
| Cavity Wall | £2,100 | £755 |
| Loft Insulation | £5,925 | £757 |
| Human Power | £25,000 | £660 |

Table 8: Initial cost of power generation and the annual value

This gives an initial cost which is roughly £730,000 greater than that of a conventional, on-grid gym. However, once the systems are installed they allow for savings of approximately £60,000 on an annual basis. Including the cost of the storage system, this allowed us to produce the following graph.

Figure 7: A graph to show the total payback time of the EcoGym.

The y-intercept of this graph occurs at roughly 15.5 years. After this point, the gym will effectively produce £50,000/year in additional profit.

While the off-grid option appears to bring long-term economic benefit, the logistics of supplying and maintaining a range of additional equipment could bring complications and the construction time of the gym wold likely be extended. As such we would advise the client to assess their priorities: in terms of startup cost and time, how closely they are prepared to oversee continued maintenance, and how much they value long term-savings.

# 7. References

1. AquaCal.(2015). **How Much Electricity Does a Swimming Pool Heat Pump Use?**Available from: <http://www.aquacal.com/blog/post/147-How-Much-Electricity-Does-a-Swimming-Pool-Heat-Pump-Use->. [Accessed 22nd February 2015].

# Baker, N. and Steemers, K. (2003) “Energy and Environment in Architecture: A Technical Design Guide” ISBN: 1135811180.

1. BBC, (2000). **BBC News | HEALTH | Chubby Britain heads for gym**. [online] Available at: <http://news.bbc.co.uk/1/hi/health/594526.stm> [Accessed 13th March 2015].
2. Daft Logic. (2015).**List of the Power Consumption of Typical Household Appliances.** Available from: http://www.daftlogic.com/information-appliance-power-consumption.htm.[Accessed 22nd February 2015].
3. Density of air calculator - <http://www.denysschen.com/catalogue/density.aspx> [Accessed: 19th March 2015]
4. Energy Saving Sensors: [Lighting - Occupancy Sensors / Energy Saving Sensors. Available at: http://energysavingsensors.com/General-Information.htm](Lighting%20-%20Occupancy%20Sensors%20/%20Energy%20Saving%20Sensors.%20Available%20at:%20http://energysavingsensors.com/General-Information.htm) [Accessed: 21st February 2015]
5. Energysavingtrust.org.uk a, (2015). **Cavity wall | Energy Saving Trust**. [online] Available at: <http://www.energysavingtrust.org.uk/domestic/cavity-wall> [Accessed 16 Mar. 2015].
6. Energysavingtrust.org.uk b, (2015). **Roof and loft | Energy Saving Trust.** [online] Available at: <http://www.energysavingtrust.org.uk/domestic/content/roof-and-loft> [Accessed 16 Mar. 2015].
7. Forcefield. (2015). **WONDERMAGNET.COM - NdFeB Magnets, Magnet Wire, Books, Weird Science, Needful Things**. [online] Available at: <http://wondermagnet.com/magfaq.html> [Accessed 11th March 2015].
8. Hambley, Allan. (2013) **Electrical Engineering: Principles and Applications.** 6th edition, Upper Saddle River, New Jersey 07458: Pearson Education, Limited.
9. Human Dynamo. (n.d).**Technical info.** Available from: <http://www.humandynamo.com/technical_info.html>. [Accessed 22nd February 2015].
10. Kensa Heat Pumps: The Technology – How Ground Source Heat Pumps Work. Available at: <http://www.kensaheatpumps.com/the-technology/how-gshp-works/> [Accessed: 21st February 2015].
11. Lee, J. (2015). **Magnet Material.** [online] Precisionmag.com. Available at: <http://www.precisionmag.com/magnet-material> [Accessed: 11th March 2015].
12. Life Fitness. (2010). **Power Consumption Analysis of Life Fitness Elevation Series 95T Engage, Techno gym Excite Run 900E, Star Trac P Series, Precor 932i Treadmills and Matrix T7x***.* Available from: <https://www.lifefitness.co.uk/static-assets/document/Energy_Savings/Energy_Efficiency_Test_Details.pdf>. [Accessed 22nd February 2015].
13. MacKay, D. (2009). **Sustainable energy--without the hot air.** Cambridge, England: UIT.
14. Met Office, (2015). *Solar energy*. [online] Met Office. Available at: http://www.metoffice.gov.uk/renewables/solar [Accessed 16 Mar. 2015].
15. Power calculation - <http://www.raeng.org.uk/publications/other/23-wind-turbine>. [Accessed: 19th March 2015]
16. Relight Depot. (2014).**Gymnasium Lighting.** Available from: <http://relightdepot.com/news/application-guides/2010/02/gymnasium-lighting/>. [Accessed 22nd February 2015].
17. Temperature and humidity - <http://www.holiday-weather.com/exeter/averages/> [Accessed: 19th March 2015]
18. The Home Depot. (2000). **Air Conditioners***.* Available from: <http://www.homedepot.com/c/air_conditioners_HT_BG_AP>. [Accessed 22nd February 2015].
19. U.S. Department Of Energy.(2012).**Buildings energy data book***.* Available from: <http://buildingsdatabook.eren.doe.gov/TableView.aspx?table=2.1.16>. [Accessed 22nd February 2015].
20. UkPower (2015). **What is the average gas & electricity bill? | Average energy bill – UK Power.** [online] Ukpower.co.uk. Available at: <http://www.ukpower.co.uk/home_energy/average-energy-bill> [Accessed 16 Mar. 2015].
21. Wind speed- [http://`www.myweather2.com/City-Town/United-Kingdom/Devon/Exeter/climate-profile.aspx](http://www.myweather2.com/City-Town/United-Kingdom/Devon/Exeter/climate-profile.aspx)

# 8. Appendix A: Equation Derivations

## Equation 1

Taking the midpoint to be 115Wm-2 and amplitude (by taking the average of the highest and lowest solar flux) of 85Wm-2 gives:

Because there are 12 months in a year and 360 degrees in a circle:

Because December should be the minimum and June the maximum:

Because 115Wm-2 gives 0.375kWh/day:

Because there are 1350m2 available:

**Equation 1: A general model to calculate the energy per day from solar radiation on the roof of the gym**

## Equation 2

According to Faraday’s Law, where N is the number of turns (or loops) in the coil of wire, is the change in magnetic flux over a period of time. Knowing that where B is the magnetic strength (in Tesla), A is the cross-sectional area of the loop, and is the angle that makes with the normal of the loop; it is possible to calculate the induced EMF (Hambley, 2013). Due to the magnet always being perpendicular to the loop, the only variable that changes in the magnetic flux equation is the magnetic field through the coil. Rearranging Faraday’s Law based on this changes the equation to

**ENERGY CONSUMPTION IN A GYM**

Some of the devices used in the gym are the same as their domestic equivalents.

**1.0 Gym Equipment**

* **Treadmills(Precor 932i)**

**Assumption:** An average of 4 treadmills is used within half an hour for 30 mins a piece.

Average wattage (at 3.5, 5.0, 7.0 and 9.0MPH) = 631.83W

Gym opening hours = 7a.m-10p.m (15 hrs)

Number of uses per day = 4 x 30

= 120

Hours worth of use=120 x 0.5

=60 hrs

Energy=631.83 x 60

=37.9kWh used by treadmills in a day

* **Stairmasters(Step Mill 5)**

**Assumption:** There are 20 uses of Stairmasters for 15 mins a piece in a day which is equal to 5 hrs worth of use

Wattage = 115V x 15A

= 1725W

Energy = 1725 x 5

= 8.6kWh per day

**2.0Lighting**

**2.1. 4-lamp T5HO fixture**

**Assumption:** There are 25 light bulbs and they are on throughout gym opening hours.

Power=228W

Energy=25 x 228 x 15

= 85.5kWh per day

**3.0 Televisions (Digital, ED/HD TV, >40")**

**Assumption:** There are 5 TVs

Power = 150W

Energy = 5 x 150 x 15

= 11.3kWh per day

**4.0 Music system**

Power = 50W

Energy = 50 x 15

= 0.75kWh per day

**5.0 Cafeteria**

**Assumption:** The coffee maker and microwave oven are used for a total of 2hrs and 1hr respectively in a day.

Power of coffee maker=1000W

Power of microwave oven = 1500W

Power of fridge=500W

Energy = (2 x 1000) + (1 x 1500) +(500x15)

= 11kWh

**6.0 Heating**

**Assumption:** The pool pump and heater are used for 6hrs a day

* **Pool Pumps**

Power = 2250W

Energy = 2250 x 2 x 6

= 27kWh per day

* **Pool heater(Swimming pool heat pump)**

Power = 32kW

Energy = 32 x 6

=192kWh

* **Electric heater**

Peak heating requirement per square meter=50W (http://www.tvenergy.org/factsheet-heatpumps.htm)

Area of gym=1500m2

Power require for heating=50x1500

=75kW

Energy=75x15

=1125KWh

* **Water heater**

**Assumption:** The power used by the gym to heat up the water is four times that used by the water heater of a family of four. The water heater is used for six hours a day.

Power of water heater of the family = 4500W

Gym power of water heater = 18000W

Energy = 18000 x 6

=108kWh

**7.0 Cooling**

Air conditioning will run for 10 hours a day

Standard cooling factor =23BTU/sq ft.

Area of gym =16146ft2

BTU cooling capacity= 23 x 16146

=371358BTU

1 BTU/hr = 0.29307107W

Power=108834.28641W

=108.83kW

Energy=108.83 x 10

= 1088.3kW per day

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| Device | Wattage(W) | Daily energy use(KWh) | Annual usage period(days) | Annual energy use(KWh) |
| Treadmills | 631.38 | 37.9 | 365 | 13833.5 |
| Stairmasters | 1725 | 8.6 | 365 | 3139 |
| Lighting | 228 | 85.5 | 365 | 31207.5 |
| Televisions | 150 | 11.3 | 365 | 4124.5 |
| Pool pumps | 2250 | 27 | 365 | 9855 |
| Pool heater | 32000 | 192 | 365 | 70080 |
| Electric heater | 75000 | 1125 | 273 | 307125 |
| Water heater | 18000 | 108 | 365 | 39420 |
| Air conditioning | 108834 | 1088.3 | 92 | 100123.6 |
| Coffee machine | 1000 | 2 | 365 | 730 |
| Fridge | 500 | 7.5 | 365 | 2737.5 |
| Microwave | 1500 | 1.5 | 365 | 547.5 |
| Stereo | 50 | 0.75 | 365 | 273.75 |
| Total |  | 2683.6 |  | 578908.1 |

**Annual energy consumption**