INTRODUCTION TO ENERGY ENGINEERING - EE1IEE

FIT & GREEN - ECOGYM REPORT

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Abstract
The task accomplished was to find the solution to powering an EcoGym in the city-centre with off-grid electricity and preferably using alternative fuel sources over fossil fuels. This project was handled by the members of Group 6 who invented 'Fit & Green.' This reports justifies the concept of being economically and technically feasible, with complete costs and details of the chosen power sources.

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1. Introduction

This report refers to a project that was developed in response to a request of a potential client that would like to install an eco-friendly gym (called Fit & Green) in a city centre location. The main characteristic of this gym is that it would have to be powered by electricity generated using renewable energy sources; also, it would have to be independent of the grid in terms of energy consumption, which still gives the possibility of connecting to the grid in order to sell the surplus energy generated.

The work was delegated to the team members and each of us contributed to the successful accomplishment of this project. Although the tasks were individual, the members worked as a team the whole time, helping each other and cross-referencing information. A breakdown of the contribution of each team member to the project can be found in **Appendix G**.

2. Methods

The project was approached by investigating the major energy uses for a gym and research was conducted through articles, journals and online sources. By calculating the overall daily usage of a gym from assessing energy demands and totalling up the energy costs for heating, lighting, air conditioning, other amenities and power for gym equipment, it became obvious to look at various energy sources such as fuel cells, solar cells, wind power and self-powered gym equipment, to delegate for our energy demands wherein we evaluated their technical and economic feasibility.

With respect to evaluating values for energy and power requirements, whilst some figures could be researched, others had to be calculated in a marginally more complicated manner. An example of this is regarding the air conditioning and hot water requirements. The air conditioning and hot water heating requirements are major components of electrical load to the building. It is proposed to cool the space with air source heat pumps which can also heat the gym if required.
Nasir El Bassam (2013) claims that the cooling load on the building will be:

$$\mathbf{E}[MWh] = \mathbf{\gamma}[W/m^2] \times \mathbf{[h/y]} \times \mathbf{F}[m^2] \qquad (2.1)$$

ɤ = energy requirement per reference area which was found in a journal article by Ian Knight (2012). **h/y** = year requirement of energy in 1 full load hour. This converts the power needed per reference area into an annual energy consumption figure.
F = floor space of the gym to be cooled. The gym area was determined by drawing a model of the layout considering all of the equipment and facilities needed.
The energy requirement for hot water can be calculated using another equation from Nasir El Bassam (2013):

$$\mathbf{Q}[kJ/y] = \mathbf{m}[kg/day] \times \mathbf{[t_2\text{-}t_1]}[°C] \times \mathbf{C_p}[kJ/kg°C] \times \mathbf{365}[day/y] \qquad (2.2)$$

m = daily mass of hot water to be heated.
(t_2-t_1) = temperature difference of the incoming water (t_1) and that supplied to the appliances (t_2).
C_p = specific heat capacity of water. It varies with temperature but can be assumed constant at 4.18 kJ/kg°C.
'**m**' was first a standard value for the water use in gyms from The Pacific Institute (2013). The value we give was estimated using typical hot water demands for the different appliances in the building with data from Bhatia (2012). Knowing approximate energy requirements then enabled us to search for suitable systems from manufacturers to achieve pleasant indoor conditions from the air conditioning as well as the capability to produce and store enough hot water to meet the expected peak load from the end user.

3. Development

3.1 Fuel Cells

Figure 1: DFC300 appearance (FuelCell Energy, Inc.)

Currently, electricity produced from fuel cells is being harnessed on an industrial scale for profitable outcomes. Fuel cell technology is highly attractive as an alternative energy source to fossil fuels simply because there is virtually no carbon emissions. The concept of fuel cells is to generate an electrical current via chemical reactions using catalysts and an electrolytic medium. After some research, it was found that a company in California, USA called FuelCell Energy, Inc. have a patented product to suit the 'eco' and 'city-centre' objective - the Direct FuelCell® (DFC®). DFC®'s are a form of Molten Carbonate Fuel Cells (MCFC) and are manufactured in the form of plants, being complete with fencing to border off the public as a safety precaution - see **Appendix A - Figure A1** for a schematic diagram of how DFC®'s work. You can see from the table below that the best option is MCFC for the gym, with relatively high efficiency of around 50%, use of biogas as fuel and a greater range of system sizing, thus fitting the bill to be the main power source.

	MW Class	Sub-MW Class		Micro CHP	Mobile
Technology	Carbonate (MCFC)	Phosphoric Acid (PAFC)	Solid Oxide (SOFC)	PEM / SOFC	Polymer Electrolyte Membrane (PEM)
System size range	300kW – 2.8MW	400kW	up to 200 kW	< 10 kW	up to 100 kW
Typical Application	Utilities, large universities, industrial – baseload	Commercial buildings – baseload	Commercial buildings – baseload	Residential and small commercial	Transportation
Fuel	Natural gas, Biogas, others	Natural gas	Natural gas	Natural gas	Hydrogen
Advantages	High efficiency, scalable, fuel flexible & CHP	CHP	High efficiency	Load following & CHP	Load following & low temperature
Electrical efficiency	43%-47% (higher w/ turbine or organic rankine cycle)	40% – 42%	50% – 60%	25% – 35%	25% – 35%

Table 1: Comparing different types of fuel cells (FuelCell Energy, Inc., 2013)

Given the secrecy of patented technology, the costs of fuel cells could not be procured from the company itself within the time limit, and so they had to be received from Prof. R. Steinberger-Wilckens - Chairman of Hydrogen Fuel Research at University of Birmingham. He provided a list of estimated installation costs for the fuel cell system. These values can be found under **Appendix A - Figure A2.**

3.2 Solar

Solar power will be used to run the air conditioning system for Fit & Green gym. Photovoltaics use the principle of converting solar energy into electrical energy. They work on the basis of the photoelectric effect which is when a photon with a distinct energy level hits the surface of a metal to release an electron (Science.nasa.gov, 2015).

Semiconductors are used in photovoltaics because they have both a conducting nature of electrons and some insulating properties (Physics.org, 2015). The semiconductors are doped with other elements, creating an n-type semiconductor and p-type semiconductor, one with more electrons and the other with not enough. This creates an electric field because the excess electrons want to travel to the “holes”. In turn, this electric field drives the photoelectrons through the circuit to power components (Callister and Rethwisch, 2008).

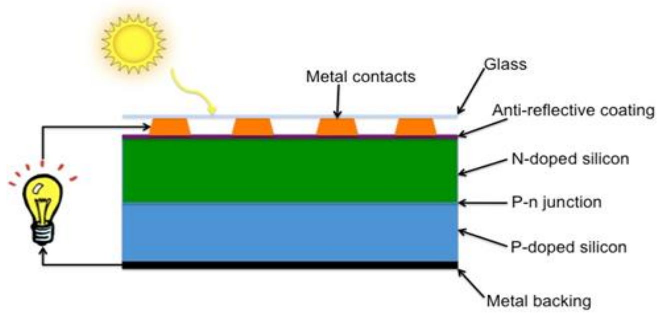

Figure 2: Schematic Diagram of a Solar Cell (Frompo, 2015)

There are several types of solar panels, however, the three main types for the domestic and commercial industry are: monocrystalline, polycrystalline and amorphous “thin film” photovoltaics (Atlantechsolar.com, 2015). Mono-crystalline solar panels are made out of a single crystal of silicon, and with high durability and long life span, they are the most efficient of the three types. The usual efficiency ranges from 15-20%, however these solar panels are the most expensive to buy and install. The next type, polycrystalline solar panel, is made out of several crystals of silicon this means the panel is slightly less efficient and isn’t as strong although they are slightly cheaper than monocrystalline panels and there is less waste in material. Its efficiencies range from about 13-16%. The last type, thin film amorphous photovoltaics are the least efficient and aren’t recommendable for commercial and residential applications. However they are fairly cheap, can be made flexible and can easily be mass-produced (Us and Maehlum, 2012).

Out of these three types the most recommended for Fit & Green gym is the monocrystalline photovoltaic due to its high efficiency and although they are more expensive than polycrystalline panels, a 4 kW system would still cost just under £7,000 (MoneySavingExpert.com)

3.3 Wind

The possibility of wind power was also considered. Wind turbines were a very expensive option that were space consuming and caused noise pollution despite being a renewable energy source. However, we did take a closer look at wind spires which were a more commercially viable energy source (Windspireenergy.com, 2015). Wind turbines/spires work on the principle of converting kinetic energy- from the wind blowing to turn its turbines- to electrical energy using a generator. The wind spires we initially considered using were 1.2 kW at the cost of ~£3500 per unit but weren’t particularly efficient or reliable due to the unpredictable nature of the wind. Therefore we decided not to include them in our energy sources, as solar and fuel cell power generated more than enough energy to run Fit & Green gym.

3.4 Storage, Monitoring and Control

Since Fit & Green gym is based on off-grid, on-site energy generation, a suitable monitoring and control system needs to be implemented in order to monitor the power requirements of the gym and control the power output of our different energy sources. The monitoring system chosen is the Medem EMS16 Energy Monitoring System, which is specific for commercial applications and will monitor the energy output of the fuel cells and solar panels, as well as the energy consumption throughout Fit & Green gym. The monitoring is undertaken via an online portal, shown in Figure 3, and the hardware comprises a main control panel and up to 16 field devices. (Medem.co.uk, 2015).

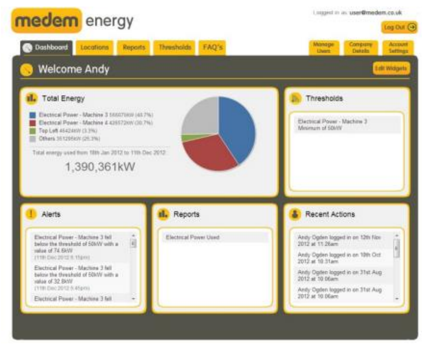

Figure 3: Online portal for monitoring system (medem.co.uk, 2015)

Due to the excess energy outputs from both the fuel cells and the solar panels that will be available, stated in section 4.2, a suitable storage system will be needed. Lithium-ion batteries will be used as the advantages they offer include low maintenance, a low self-discharge of around 1.5% per month and a high energy density (Nexeon, 2015). The batteries will be 48V 120kWh Rolls 5000 Series lithium-ion batteries, shown in Figure 4, of which we will have 6, capable of storing 720kWh in 24 hour cycles, in total. (cclcomponents, 2015). The battery storage will be utilised to store excess energy, either for utilising it the following day, or to sell.

Figure 4: Lithium-ion battery. (Taken from cclcomponents.com, 2015)

3.5 Air Conditioning and Hot Water

Sport England (2008) state that gyms should be maintained at 16-18℃ so customers doing intensive exercise do not get too hot inside or experience the build up of odours. Figure 2 shows that the energy requirement per reference area is 195 kWh/m^2/annum. The area needing air conditioning is 375 m^2 so the electrical requirement is 73 MWh/annum or **260 kWh/day**. To heat the building we decided to achieve this with an air source heat pump system. The decision to use these was made because they could be powered electrically so could be fed from the renewable energy sources. It has been shown (Sager 2014) that they consume less energy than standard gas systems. These systems operate by transferring heat from a heat dump into a cooler area. With regards to the efficiency of these systems it is best to talk about Seasonal Energy Efficiency Ratio (SEER), which is the power ratio of heat output to electrical input normalised over the seasonal changes in a location across one year (McDowall, 2006). ECOAIR (n.d.) supply and install heat pumps and split systems to meet this and costs are detailed further on in the report. A split system comprises indoor and outdoor units where condensers are found outside (where cooler) and have an SEER of 8.5 (EIA, 2013) meaning they are capable of efficiently cooling the space.

It was assumed that water will come in to the building at around 4℃ but it could be up to 10℃ in summer. Water must be stored at or above 60℃ in order to kill legionella bacteria in the water (TMVA, 2000) although to avoid scalding it is also advised not to store it any hotter. The first estimate from the Pacific Institute (2013) gave 153 thousand acre-feet per year (~190 000 m^3/y). This seemed unreasonably large at 680 m^3/day (given 280 day/y operation). Instead we took an inventory (Figure 5) of the fixtures that would require hot water to produce our value specific to this project. Bhatia (2012) gave typical hourly water demands. The gym will need 220.8 m^3/day.

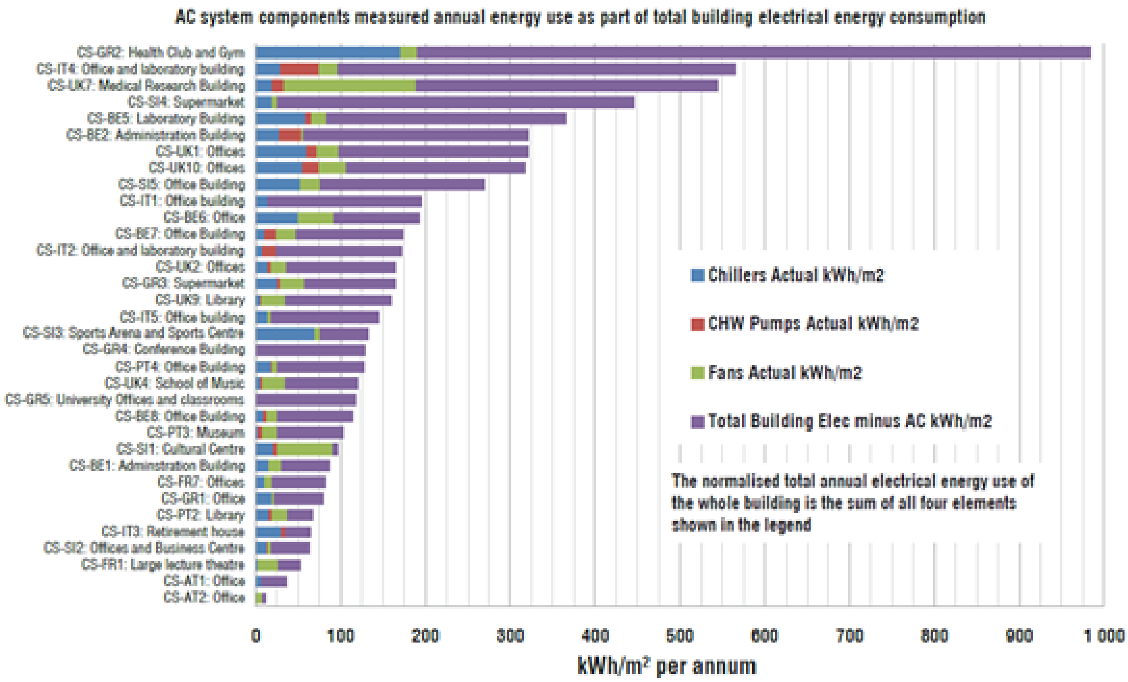

Figure 5: Bar graph displaying energy consumptions from a variety of buildings (Knight, 2012).

According to the HSE (2014) provision of toilets is only required for staff. We based our toilet facilities closely on what the regulations were for a workplace of about 150 people so at peak times customers would find sufficient toilets provided. The thermal energy needed to heat the water up from 4℃ daily will be:

220.8 kg x 4.18 kJ/kgK x 56 K = 51 685 kJ/day = **14.4 kWh/day**

The seasonal efficiency of commercial electric boilers is 98% (EIA, 2013) so **14.7 kWh/day** of electrical energy will be needed to fulfill the maximum possible hourly demand. According to Bhatia (2012) the probable maximum demand for gyms is 0.4 x the maximum possible demand = 88.32 kg/day. This is heater capacity which, when multiplied by the storage capacity factor (1.00 in this case) gives the storage tank capacity. Therefore, an insulated water tank of 90 m^3 will be required. The new daily hot water load is 20 675 kJ/day which is **~6 kWh/day**. Heatrae Sadia supply electric combi boilers capable of meeting this demand (PlumbNation Limited, 2015).

3.6 Swimming Pool

a. Sizing and regulations

The swimming pool in this gym is a heated pool, which can be used throughout the whole year. The dimensions of the pool are 25 m long, 10.5 m wide and 2 m deep, with the space for five lanes. The capacity is designed for maximum 83 people use as Sport England (2011) states ‘for un-programmed recreational swimming a minimum water area (occupancy ratio) of 3 m^2 per bather should be allowed to ensure physical safety.’ As in the regulation, the water temperature should be kept about 28°C, the air temperature should be approximately 30°C, 60% ± 10% humidity. (Sport England, 2011)

b. Heating facilities

In order to heat the pool up and keep the water at the same temperature, a water heater needs to be installed. Its power rating is determined according to the total energy requirement for the pool. For this calculation, the temperature of tap water has been assumed in each season, 20°C in spring and summer, 10°C in autumn and winter. The total energy can be calculated by the formula $Q=mc\Delta T$, heat loss from the surface of water during the initial setup can be negligible as the pool cover would be used. The maximum energy requirement should be in the autumn and winter season, equivalent to 10500 kWh. A 15 kW water heater will be used for the initial setup and be running for 7 hours per day to keep temperature constant, aided by the use of a pool cover to minimize the heat loss.

c. Pump and filter

The power rating for the pump is 1.5 kW, which can generate 24 m^3 per hour flow rate. The filter is going to be placed beside the pump which can clean the water. The water will be kept circulating through the pipe system in order to meet pool water quality standard. There is a regulation for water cleanness that 30 litres of water per swimmer has to be filtered (Sport England, 2011), which means at peak time the water should be circulated about 2.5 m^3.

d. Other facilities & equipment

The pool cover, Figure 6, is an important aspect that can save some energy during the period of time that the pool is not used. According to U.S. Department of Energy (2012), 26°C water could lose 1048 Btu of heat. The covers are able to save 50%-70% of energy. This equipment also can 'conserve water by reducing the amount of make-up water needed by 30%–50%' and 'reduce the pool's chemical consumption by 35%-60%.' (U.S. Department of Energy, 2012)

Figure 6: Pool cover

The dehumidifiers should also be installed in the swimming pool as the air temperature has to be kept 30°C and 60% ± 10% humidity. This machine is going to use 0.51 kWh per litre and, in order to maintain the environment, it needs to dehumidify 43 litres per day, so the total energy usage per day will be 21.93 kWh.

The swimming pool would be one of the sites that needs a large amount of energy, but by using a pool cover and limiting the running time of pump and heat pump, a substantial energy saving can be made. This would cut cost significantly and energy consumption which increases the possibility of feasibility.

3.7 Layout

Firstly, we thought of a 3D Model as an extra for the project, which would give the client a nice visualization of the layout. However, during the development of the project we noticed that the model is a great tool for helping with tasks such as quantifying the gym equipment, electrical equipment and heating and cooling requirements. The drawings can be found in the Appendix C.

On the ground floor, we have the reception, cafeteria, an administration room, and the changing rooms, as well as the pool. This ground floor has a total area of roughly 509 m^2, 177 m^2 for the facilities, and 332 m^2 for the pool area. Upstairs, in the top floor, we have the exercising space itself, with the resistance and cardio-vascular machines, as well as free-weights, and two toilets for customer's convenience. The top floor has an area of 180 m^2, which gives us a total public area of 689 m^2. Besides these two floors, the project includes the basement, where the electrical equipment will be located. It will house the batteries for energy storage, the boilers for water heating and the machinery for the pool. The fuel-cell plant will be located outside, next to the building, and the solar panels will cover the roof of the building and partially the roof of the pool area.

The main design considerations regarding the energy efficiency of the building were the use of light colours, multiple windows and see-through roof on the pool area; all this aiming the reduction of energy consumption used to light the ambient. In addition, for improving the heat efficiency of the building, it has triple glazed windows and cavity wall insulation.

3.8 Electricity generation from exercise equipment

In order to essentially eliminate electricity requirements of exercise machines, all equipment will be self-powered. However, the treadmills, cross-trainers and exercise bikes will be equipped with DC electromagnetic power generators of peak 300 W capacity. The mechanical motion of the exercise equipment is translated to electrical energy via the use of a generator dynamo, connected physically by a v-belt pulley to the treadmill belt, bike wheels and cross-trainer pedals. The direct current produced can be used to charge tablets, which can function as display screens, and operate televisions.

The basic circuit for this system is showing in Figure 7, where the 'rechargeable battery' represents the tablets and televisions and the diodes ensure current doesn't flow from the tablets to the dynamo.
The power ratings of the exercise equipment are 80 W for the treadmills (Mankodi, 2012), and 100 W for the exercise bikes and cross-trainers (GreenMicroGym, 2015).

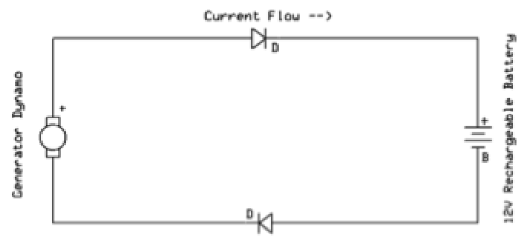

Figure 7: Basic circuit for generator dynamos. Source: Mankodi, University of Minnesota, 2012.

Assuming an average workout time of 30 minutes per machine and each machine being used a certain number of times a day, the daily power and energy output was calculated. On average, the energy output across all machines in one day is 9 kWh, which is enough to power 30 tablets and 7 televisions. A breakdown of these calculations can be found in **Appendix D**.

4. Feasibility and Calculations

4.1 Total power and energy requirement and technical feasibility

Regarding technical feasibility, calculations were undertaken to determine if the power and energy requirements of the gym could be met by our fuel cell and solar panel solution. Therefore, the power requirements of units requiring electricity and their total hours of use in the gym were researched to calculate the total energy requirement over one gym day of 15 hours.
Table 2 displays the total power and energy requirements in Fit & Green gym over one day.
The total power requirement of all units in the gym totals to almost 50 kW, with the total energy requirement over one gym day is around 645 kWh.

The proportion of the energy requirement that is met by the solar panels and fuel cells is around 40% and 60% respectively. The air conditioning, requiring 260 kWh over one day, will be powered by 10 x 4 kW solar panel systems of energy outputs of 560kWh and 280kWh in the summer and winter respectively. The remaining 385 kWh will be powered by fuel cells. The 24-hour operating fuel cells used have a power rating of 30 kW, producing 450 kWh over 15 hours that the gym is open for and 720 kWh over 24 hours.

Unit	Number of units	Length of time each used for in a day/h	Total hours of use in a day (all units)/h	Power rating per unit/kW	Energy requirement in a day/kWh
Dehumidifier: Changing Rooms (meaco.com, 2015)	3	9	27	0.7	18.9
Dehumidifier: Pool (meaco.com, 2015)	1	15	15	1.462	21.93
Heater: Pool (spas-pools.co.uk, 2015)	1	7	15	15	225
Pool Pump (completepumpsupplies.co.uk, 2015)	1	15	15	1.5	22.5
Hot Water Supply (section 3e)	1	15	1.6	9	14.4
Vending Machine (vendingsolutions.com, 2015)	4	24	96	0.3125	30
Air Conditioning (section 3e)	1	15	15	17.3	260
Hand-dryer (commericalwashroomsltd.co.uk, 2015)	6	0.17	1.02	0.88	0.8976
Radiators: changing rooms (electricalradiatorsdirect.co.uk, 2015)	2	15	30	0.75	22.5
Coffee machine (clifford-james.co.uk, 2015)	1	6	6	0.8	4.8
Outdoor lighting (screwfix.com, 2015)	10	6	60	0.06	3.6
Indoor Lighting (bltdirect.com, 2015)	33	9	297	0.008	2.376
Fridge (carbonfootprint.com, 2015)	1	24	24	0.74	17.76
TOTAL				**48.5125**	**644.6636**

Table 2: Table to show the power and energy requirements in Fit & Green gym

The significant excess energy supplied by the fuel cells denotes that in any time where there is suddenly a greater demand for energy in the gym or the solar panels are not providing sufficient energy, demand can easily be met.
Through conducting these calculations and considering the reliability of our system, we determined the Fit & Green gym to be technically feasible.

4.2 Cost and economic feasibility

Secondly, economic feasibility will be considered. The assumption was made that the client will have already purchased the building with the swimming pool built therefore costs of building materials and insulation were not considered in our cost estimations. Costs of fitting out the gym with all units, such as lighting, vending machines, air conditioning units and dehumidifiers were considered. Annual payments were also considered, broken down into maintenance, water bills, gas supply for the fuel cells and staff pay. A breakdown of the costs can be found in **Appendix E**.

In summary:
- Initial purchasing cost: £350,029.45
- Installation costs: £204,687.50
- Annual costs: £335,780.72

To estimate the total profitable income into Fit & Green gym, the membership fees, feed-in tariffs and café profit were considered. To account for the annual costs above, these were subtracted from the membership fee profit. With regard to feed-in tariffs, it was considered that all of the excess energy from solar panels will be sold back to the grid, equivalent to 300kWh in the summer and 20kWh in the winter, and a total excess energy from fuel cells of 300 kWh per day would also be sold.

Annual profit revenue:
- Membership fee profit, annual costs deducted: £114,219.28
- Feed-in tariffs (fitariffs.co.uk, 2015): solar panels: SUMMER: £82.24 per day, WINTER: £34.91 per day, AVERAGE: £21,381.70
- Feed-in tariffs (fitariffs.co.uk, 2015): fuel cells: £16,709.70
- Café profit (quora.com, 2015): £10,950

TOTAL ANNUAL CAPITAL: £163,261.22

To calculate the overall payback time, the initial and installation cost was divided by the annual capital per year, resulting in a payback time of **3.40 years,** which is the length of time before the client will begin to profit from Fit & Green gym. This figure is an estimate, however; there may be unexpected costs and other bills to pay, as well as consideration of initially purchasing the building itself therefore in reality the payback time may be slightly longer.

5. Conclusion and Recommendations

Our sources of electricity, being the main focus, are fuel cells and solar photovoltaics for the gym; this excludes workout machines as they will be self-powered. Choosing these sources, along with the eco-friendly units to be purchased for the gym, will come with certain limitations, such as requiring a large initial investment of £326,449. In addition, experts will have to be hired to sustain the production of electricity for the gym, and be prepared with a contingency in emergency cases. Moreover, there was the issue of seasonal power production, where it is obvious that solar panels will barely be successful during Autumn and Winter and could also be limited during Spring and Summer due to unforeseen overcast. However, this is all solved by having the powerful DFC® systems for constant power when desired and rechargeable Li-ion battery banks (of an approximate 99% charging efficiency (Energy-solutions.co.uk, n.d.)) to store and dispense sufficient electricity in order to power the gym during the bleak times.

We can conclude from the above results that running an EcoGym with off-grid electricity is economically and technically viable. The solar panels that would be in place would power an amazing 260 kWh in a day for the air conditioning system. Fuel cells can cater more than enough electricity for the remainder of the gym. The provisional value of 450 kWh will be covered by a multi-plant system of combining two DFC300's (for a maximum possible 600 kWh output) from FuelCell Energy. The Feed-In Tariffs (FiTs) provide two benefits in the set circumstance: generation tariff - generating electricity via renewable source, whether you use it or not, is paid for at specific rates respective to the type of alternative energy source used; export tariff - where the client is practically selling their excess electricity onto the grid at a fixed rate of 4.85 p/kWh (Ofgem e-serve, 2015). Ergo, it is clear that the client will be financially comfortable by having surplus electricity sold to the grid, especially after the 3.40 years of payback time that is inclusive of maintenance, overhead and utility costs.

Therefore, the recommendations are:

5.1 EcoGym concept
To pursue the concept of Fit & Green with off-grid electricity by investing in the DFC®'s and solar PV arrays to ensure the 'eco' aim is fulfilled as they are both renewable energy sources ;

5.2 Sustainable fuelling
To use biogas from the national grid to fuel the DFC®'s, promoting sustainability whilst generating energy and essentially preventing global warming;

5.3 Gym exercising equipment
To purchase self-powered exercise machines for the gym in the sense of driving the Fit & Green EcoGym branding (good marketing) as well as making a long term saving in energy costs ;

5.4 Electrical specialists
To hire highly qualified engineers to ensure consistent feed of electricity to keep the gym functioning, prepared with a contingency plan in the event of an electrical failure occurring;

5.5 Storage of electrical energy
To purchase rechargeable Li-ion battery banks for storing and then accessing electrical energy at will because they have a high endurance of up to 10 years, charge up to 100% capacity and have a charge efficiency of 99%, so essentially keeping maintenance cost minimal ;

5.6 Membership fees
To have the membership fee ≥ £25 to keep up gross working capital and ensure the payback time is reasonable, such as at the projected 3.40 years;

5.7 Selling surplus electricity
To ensure the surplus electricity is controlled and sold on within the limits of the FiTs to make sure the gross working capital is maintained to the projection in order to keep to the projected payback time of 3.40 years.

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7. Appendices

Appendix A

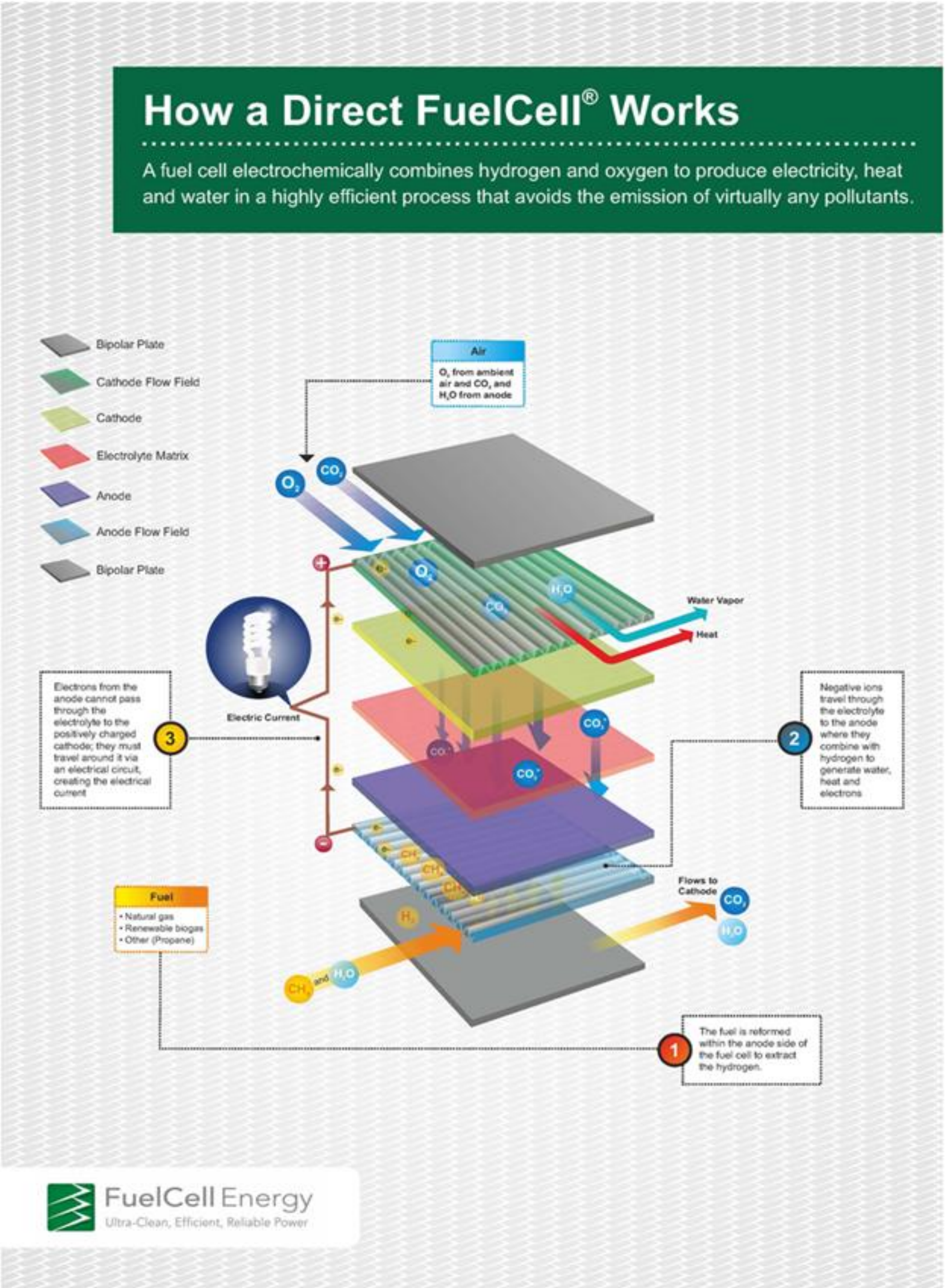

Figure A1: How a Direct FuelCell® Works

Installation costs for entire fuel cell system setup:-

- Current expected rate for system: ~£2300 / kW ;
- £10 000 for foundations ;
- £10 000 for piping connections ;
- £10 000 for installation room ventilation ;
- £ 5 000 for connection to gas grid ;
- £ 20 000 for integration into building control ;
- £ 10 000 for transport and placing on final site ;
- £100 000 for water tank for heat storage ;
- £10 000 for feed-in electricity meter.

Figure A2: Prof. R. Steinberger-Wilckens' estimation on fuel cell costs (2015)

Appendix B

Fixture	**Hourly Hot Water Demand (m^3)**
Basin x 6	0.22
Shower x 14	14.32
Kitchen Sink	0.09
Service Sink	0.09
Total	**14.72**
Typical Daily Load	**220.8**

Figure B1: Hot water demand for the building Source: ASHRAE Handbook (2011)

Appendix C

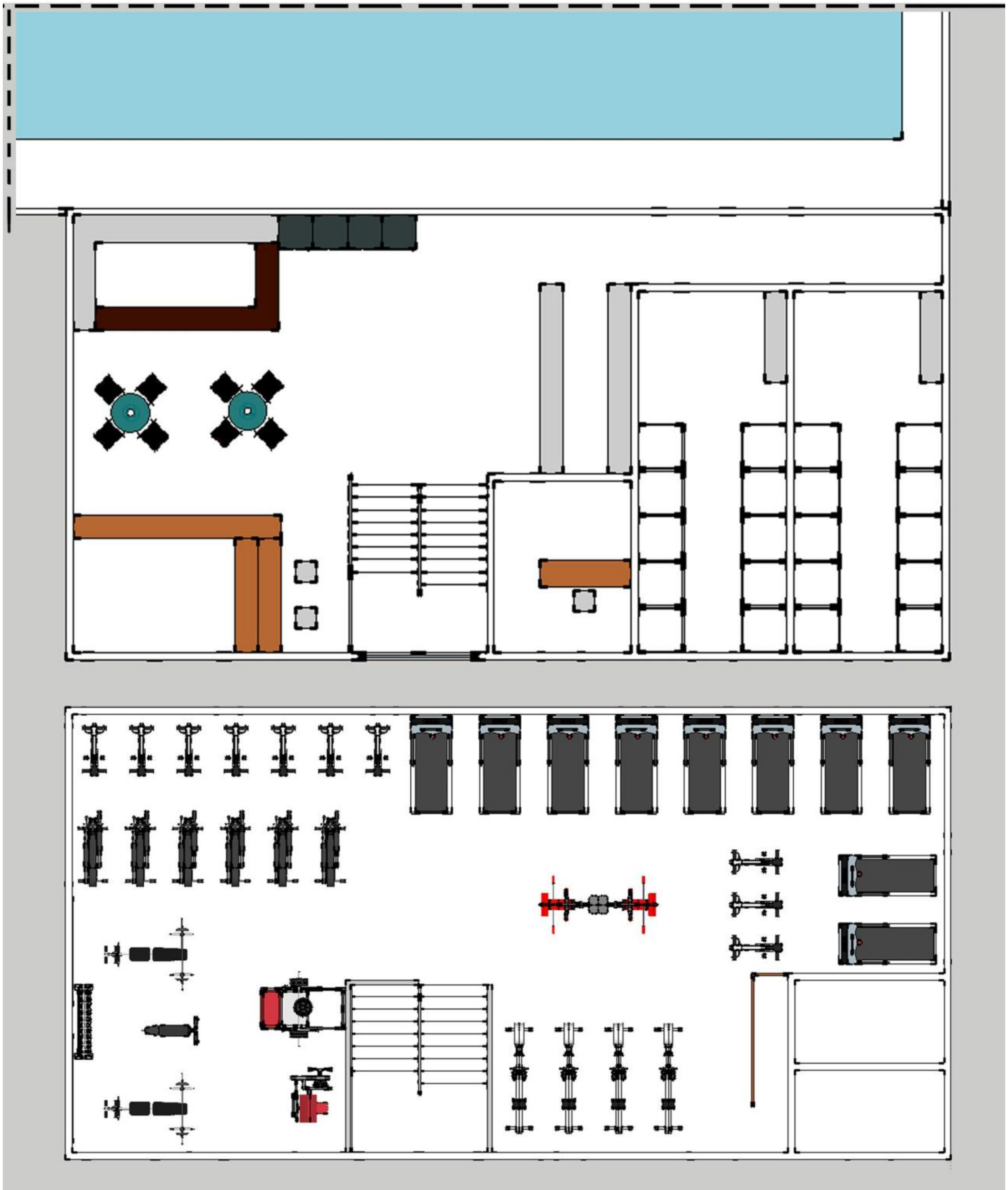

Figure C1 - Complete Layout. Ground floor with pool and top floor.

Figure C2 - Internal view, showing the exercising equipment.

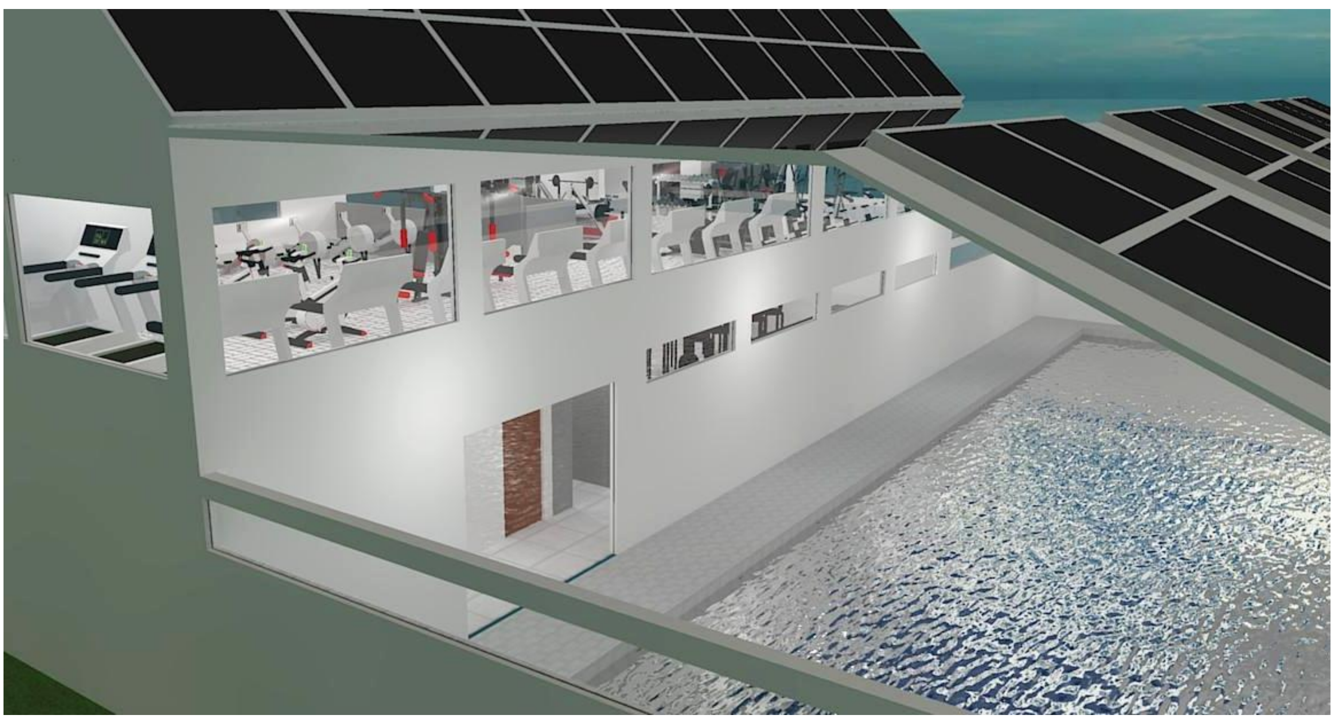

Figure C3 - External view, showing the solar panels on the roof, the equipment on the upper floor and the pool on the ground floor.

Appendix D

Table D1 to show electricity generated from equipment with dynamos.

Equipment	Number	Number of times each used per day	Length of time used for/h	Total hours of use	Wattage (kW) GENERATED per unit	kWh (over a day)
Treadmill	10	8	0.5	40	0.08	**3.2**
Bikes	10	8	0.5	40	0.1	**4**
Cross trainers	6	6	0.5	18	0.1	**1.8**
TOTAL	**37**	**22**	**1.5**	**98**	**0.28**	**9**

Appendix E

Table E1 to show breakdown of initial purchasing costs, installation costs and annual costs.

Unit	Initial purchasing cost	Installation	Sector	Annual cost
Exercise machines (sportandleisureuk.com, bikebiz.com, greenmicrogym.com, gymkituk.com, waterrower.co.uk, powerhouse-fitness.co.uk, fitness-superstore.co.uk (2015), Mankodi, 2012)	£22850	£685.50	**Exercise machines maintenance (healthyliving.azcentral.com, 2015)**	£3264.29
Swimming pool (spas-pools.co.uk, meaco.com, completepumpsuppliers.co.uk, 2015)	£25770.45	-	**Swimming pool maintenance (improvenet.com, 2015)**	£600
Washroom units and hot water boiler (meaco.com, commercialwashroomsltd.co.uk, 2015)	£14785	£16402	**Gas supply for fuel cells (Steinberger-Wilckens, 2015)**	£4815
Vending machines (vendingsolutions.com, 2015)	£1050	-	**Solar panels maintenance (ecoexperts.co.uk, 2015)**	£2800
Cafeteria (kitchensolutions.co.uk, 2015)	£1180	£500	**Inverter and rectifier maintenance (aliexpress.com, genvolt.com, 2015)**	£780
Lighting (screwfix.com, bltdirect.com)	£694	£7000	**Water bills (anglianwater.co.uk, 2015)**	£3772.06
Air conditioning (incl. installation)(airconditioner.me.uk, 2015)	£11500	-	**Air conditioning maintenance (airconditioner.me.uk, 2015)**	£294.83
Lockers (ebay.co.uk 2015)	£400	-	**Monitoring system payments (medem.co.uk, 2015)**	£3649.54
Batteries (cclcomponents.com, 2015)	£102000	£4320	**Plumbing maintenance (whatprice.co.uk, 2015)**	£400
Inverter and rectifier (aliexpress.com, genvolt.com, 2015)	£7800	£780	**Electrics maintenance (servicemagic.co.uk, 2015)**	£180
Fuel cells (Steinberger-Wilckens, 2015)	£92000	£175000	**Batteries maintenance (powertechsystems.eu, 2015)**	£6800
Solar panels (incl. installation)(moneysavingexpert, 2015)	£70000	-	**Staff pay (gov.uk)**	£308425
TOTAL	**£350,029.45**	**£204,687.50**		**£335,780.72**

Appendix F - Meeting minutes

Date:	Present:	Discussed:
4/2/2015	All except Diego	Brainstorming for Interim presentation- Overview of plan All to research general stuff, Nisha to do presentation.
9/2/2015	All except William	Discuss presentation and next steps of project
11/2/2015	All	Interim presentation done.
18/2/2015	All except Diego	Planning for final presentation
23/2/2015	All except Diego	Compiling research, drawing plan, estimating load
25/2/2015	All	Research
27/2/2015	All except Diego	Presentation
3/3/2015	All	Planning for presentation
4/3/2015	All	Presenting
6/3/2015	All	Report writing
11/3/2015	All	Finishing report

Appendix G - Team member's contribution to the Fit & Green eco-gym project

Team Member	Contribution to project
Nisha	Administration of calculations with regard to energy requirements, energy generation from gym equipment, costs and payback time
Ameenul	Extensive research over fuel cells and energy generation via renewable fuel sources; thorough clarifications and cross-referencing information with other departments (i.e. business costs and solar PV FiT's); wrote Conclusion and Recommendations.
Joseph	Calculating energy requirements for hot water supply and air con system. Research into the cost of AC installation and which systems to use.
Thivyaa	Research and write up on renewable energy sources, mainly wind and solar power. Looking and calculating feed-in tariffs for both and contributing to writing the method.
Derui Zhu	Researched and wrote about the main facilities of the swimming pool, such as heater, dehumidifiers, pumps, and filters.
Diego	Did the virtual model of the gym, quantifying the exercising and electrical equipment suitable for the building,