**Energy Engineering Eco Gym**

**Group 10**

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# 1 Introduction

This report looks at the economic feasibility of an eco-gym in the city centre, where no energy is taken from the grid. There is reasonable evidence that suggests this is possible, as it has been done in places across the world such as in Illinois in America (Eco Gym Worldwide, 2015) and in Bristol in England. (Business Green, n.d.)

A dedicated team worked together on this task in order to come up with feasible solutions. The primary method was to do research, and copious amounts of research was undertaken around group brainstorming sessions.

Setting up an eco-gym in the city centre is deemed to be viable, provided there is enough capital initially, and if the gym is able to use the grid as an energy storage device, where energy is sold to it in summer and bought back in winter. In this instance the payback time would be around 9 years; however, if the gym needs to be completely off grid, it is less economically feasible as payback time on the initial investment is significantly more at just under 15 years.

Issues surrounding sustainability and the environment are major concerns in the world today, and the green nature of the gym can be used to build and establish a strong brand that will attract customers. This brand will take into consideration our eco-friendly customer policy, which includes that:

* Customers will bring their own towel.
* There will be no hand dryers in the toilets.
* The showers will be token operated to limit the user to five minutes of hot water. This will ensure that no hot water is unnecessarily wasted.
* There will be an award for the person who spends the most amount of time in the gym, so is therefore likely to have generated the most amount of energy each month, whether this be a month’s free membership or food/drinks vouchers for local establishments. This will also help to support local businesses. The time will be monitored by swiping your gym card as you enter the gym room, and this will not include the changing rooms.

# 2 Methodology

To design a suitable city centre gym that completely uses off-grid energy, two main points need to be addressed:

* The amount of energy required to operate the gym on a daily and yearly basis.
* The amount of energy that can be generated from the off-grid energy system.

The gym can only be feasible if the energy generation system outputs more than the energy the gym is expected to consume. To address both these points, smaller problems need to be resolved first.

## 2.1 Energy Consumption

Energy consumption was calculated by summing all components that consumed electrical or thermal energy. Consumption of general appliances (computers, vending machines etc.) was calculated from researching the energy rating of the device and deciding how many hours per day the appliance would run for; the results of which can be viewed in section 4.

## 2.2 Heating the Building

The calculation of how much energy is needed to heat the gym and maintain a room temperature of 19oC (DeCosta, 2011) was done by using the specific heat coefficient values of the building materials, the assumed building dimensions and the differential temperatures of the inside of the building and outside during winter and summer. These results are shown in section 4.

## 2.3 Heating and Water Pumping of the Swimming Pool

The heat energy the pool requires was calculated from the heat loss rate of the swimming pool during opening hours and closing hours, including the consideration that when the pool is not in use there will be an insulating pool cover in place. This was done using the differential temperature between the room and swimming pool, in addition to the application of heat loss from radiation and convection. These results can be viewed in section 10.1.

Power consumption from the swimming pool pump was calculated from a recommended turnover time (the time it takes to pump the pool volume once round) related to the swimming pool volume, therefore giving a flow rate the pump is recommended to operate at. This can be converted into power and therefore an energy value as the pump should be run for the whole day. See section 10.2 for these values.

## 2.4 Energy Generation

There was research and discussion into what would be the best off-grid energy solutions for the gym situated within the city centre. It was decided that a predominant amount of the electrical energy would be generated from solar panels on the roof of the gym. Other energy generation methods that were chosen to implement in the gym were: wind power from vertical axis wind turbines, human power from cardiovascular machines and solar thermal from black pipes on the roof.

Further research was done on statistical averages (data on weather trends) to allow the calculation of how much energy could be generated on a regular basis from solar and wind. See section 5.2 for the full amount of energy that will be generated.

## 2.5 Consideration of Energy Storage

Energy storage is an important consideration as it is expected that there will be more energy generated than produced at certain times in the day, and a net energy deficit during the winter months. This is due to there being less generation from solar power, which is the main energy source of the gym. Research on the practicality of storage and energy density led to the decision of using Lithium-ion batteries as the main method of energy storage. As Lithium-ion batteries are one of the most energy dense, light and safe forms of storage, they are a very practical energy storage system for the gym. (Fiakas, 2013)

A flywheel will be used to store the energy generated through gym members using the cardiovascular machines. Flywheels perform slightly more efficiently than Lithium-ion batteries when storing energy from a regenerative system, as seen in figure 1. The capability of a flywheel is approximately 1Wh per kg at 225 rpm, which is a practical scale when considering the amount of energy that will be generated from people using cardiovascular machines. (MacKay, 2008)

*Figure 1, right, displays the energy density and efficiency values for some energy storage systems.* (MacKay, 2008)

# 3 Assumptions

## 3.1 The Gym Building

The gym building size will be: 50 metres long, 32 metres wide and 9 metres tall.

It is assumed that 85% of the building will need to be lit by LED lights.

## 3.2 The Swimming Pool

* The swimming pool will be 25 metres long, 9 metres wide and 1.9 metres deep on average.
* The temperature around the pool will remain constant at 26oC. (DeCosta, 2011)
* The pool surface is modelled as a flat plate.
* Heat loss through conduction on the sides of the pool is negligible; therefore, most heat loss occurs through natural convection and radiation through the top of the pool.

## 3.3 Gym Members

It is assumed that in summer only 60% of the members will attend the gym due to more members exercising outside.

It is assumed that members of the gym will:

* Use the gym around three times a week.
* Spend about two hours in the gym each time.
* Use cardiovascular machines for 30% of their time in the gym.

## 3.4 Energy Generation

* Wind speed is taken to be constant.
* 0.1kWh will be generated from cardiovascular machines in one hour. (Gibson, 2011)

## 3.5 Cafeteria

As opposed to having a general café, customers will be able to purchase hot drinks and snacks from vending machines in a cafeteria area. This saves energy and also reduces the number of staff that need to be employed.

It is therefore assumed that:

* The vending machines in the cafeteria will have frequent use.
* The vending machines will use around 7kWh of energy each day. (Coca Cola, 2014)

# 4 Results

|  |  |  |  |
| --- | --- | --- | --- |
| **System Component** | **Summer - per day** | **Winter - per day** | **Annually** |
| **Energy Use (kWh)** | **Energy Generated (kWh)** | **Energy Use (kWh)** | **Energy Generated (kWh)** | **Energy Use (MWh)** | **Energy Generated (MWh)** |
| **Heating** | 68.0 |  | 480.0 |  | 100.0 |  |
| **Pool heating and pumps** | 74.0 | 74.0 | 27.0 |
| **Lighting** | 14.9 | 21.2 | 6.6 |
| **Café and appliances** | 42.0 | 42.0 | 15.3 |
| **Solar Panels** |  | 498.9 |  | 434.5 |  | 170.3 |
| **Wind Turbines** | 33.6 | 33.6 | 12.2 |
| **Human power** | 12.1 | 20.1 | 5.8 |
| **Total** | 198.9 | 544.6 | 617.2 | 488.2 | 148.9 | 188.3 |
| **Difference** | 345.7 | 129.0 | 39.4 |

*Table 1, above, shows the gym’s energy use and the amount of energy generated in summer, winter and annually.*

*Figure 2, above, displays the gym’s energy input and output during summer.*

*Figure 3, above, displays the gym’s energy input and output during winter.*

# 5 Analysis

## 5.1 Energy Consumption

### 5.1.1 Lighting

To calculate the amount of energy the lights will use in the gym, the number of lightbulbs needed was ascertained. As the floor space will be 3200m2, and it is assumed that 85% of the building needs to be lit, it was calculated that approximately 500 bulbs will be needed. (Charlston, 2013)

The gym will save energy on lighting by using movement sensors that turn lights on, only when someone is in the room. It is estimated that this will reduce the expected lighting energy requirements by 30%.

From this, and by matching the opening hours of the gym with the hours of daylight in summer and winter, it can be found that the gym will use approximately 14.9kWh per day in summer and 21.2kWh per day in winter for lighting. (See table 1)

### 5.1.2 Heating

Heating will be the main energy consumer in the gym, especially during winter when the outside temperature is much lower. Using the specific heat coefficient values of the building materials, it is found that in summer it will take 68kWh per day to heat the gym and 480kWh in winter, as seen in table 1. (The Concrete Society, n.d.) (Sunparadise, 2015)

### 5.1.3 Swimming Pool

From table 1, it can be seen that the swiming pool will require approximately 74kWh per day to maintain temperature and an additional 20kWh per day will be needed to pump water through the filtration system.

## 5.2 Energy Generation

### 5.2.1 Vertical Axis Wind Turbine

From table 1, it can be seen that a vertical axis wind turbine will generate around 10.6kWh per wind turbine per day. There will be three turbines on the roof, so scaling linearly, around 31.8kWh will be generated each day from wind turbines. This is whilst making the assumption that there is an average wind speed of 5m/s. (Weather Spark, 2012)

It is found that wind speed varies over the day and depending on the time of year; however, these variations appear to follow no trend that is easily measured. Therefore, an average constant value of 5m/s is assumed. Figure 4 (shown below) allows the energy generated at this speed from our selected wind turbine to be determined.

Vertical wind axis turbines are chosen over horizontal axis wind turbines as they have low noise, low maintenance costs, no maximum speed and a lower start up speed than horizontal axis wind turbines. (Aeolos, n.d.)



*Figure 4, shown above, displays a comparison between measured and predicted monthly energy production from the vertical axis wind turbine.* (Wind Power Program, n.d.)

### 5.2.3 Solar

Sunpower E70 solar panels will cover 1160m2 of the gym’s roof space, which will then produce a daily average of 522kWh, as seen in table 1. This was calculated from using a UK case study where the homeowner had installed the same solar panels on 16.3m2 of roof space and generated 2704kWh per year. By making the assumption that the value of energy generated per square meter will be the same, this allows it to be scaled linearly to give a value of 522kWh per day for the gym. (Sunpower, 2011)

### 5.2.4 Human Power

From the assumption that people will spend 30% of their time in the gym on cardiovascular machines, and figures from the IEEE (Gibson, 2011), the energy generated from human power each day can be calculated. From this, it is found that 20.2kWh per day is generated in winter and 12.1kWh per day in summer, as seen in table 1. This also accounts for the difference between energy generated per day in summer and winter, as more people attend the gym in winter.

## 5.3 Total Energy Consumption and Generation

In total, 565.9kWh of energy is generated per day in summer, and around 468kWh is generated per day in winter, as seen in table 1. This gives an annual total energy generation of 184,872kWh.

Figures 2 and 3 show the energy generation vs energy consumption of the gym during the course of an average day in summer and in winter. It can be seen from these that during the summer months, more energy is generated than needed, approximately 350kWh daily. However, in winter there is an energy deficit of approximately 100kWh per day. If this is averaged over the year, there is an annual energy profit of 45MWh.

Due to having energy profits and deficits at different points over the day and year, energy storage will be required. A flywheel is a novel way of storing kinetic energy generated by human power on cardiovascular machines. The flywheel will not have to spin at very high speeds as it is highly unlikely that more than 10kWh will need to be stored at any one time from human power. Scaling linearly from a case study in which a flywheel capable of storing up to 50kWh cost £30000 (Roberts, 2015), it is implied that the flywheel will cost approximately £9500. Taking into account the drive train for this flywheel, it is estimated that there will be a total cost of £12500 for the flywheel.

A large bank of Lithium-ion batteries will be required to account for energy storage requirements. If the gym was able to buy and sell energy to and from the grid, the battery system could be small and only ever need to store approximately 100kWh in preparation for the energy needs of the next day. However, as the gym is an eco-gym that needs to be completely off-grid, it is necessary to have a Lithium-ion battery which is capable of storing enough energy to cope with around six months of an energy deficit. It can be estimated that the battery will therefore need to store 5MWh of energy, which will be much more expensive.

# 6 Recommendations

From the analysis of results, several recommendations as to what form of energy generation and what form of energy storage should be used, in addition to other energy saving methods.

For energy generation:

* There will be three Aeolos V 3kW vertical axis wind turbines on the roof.
* Sunpower E70 solar panels will cover 1160m2 of the gym’s roof space.
* There will be 10 cross trainers, 30 bikes and 10 rowing machines whose kinetic energy will be harnessed.

For energy storage:

* There will be a flywheel which has a 2m diameter and will store up to 10kWh of energy.
* There will be a bank of Lithium-ion batteries capable of storing 5MWh to ensure the eco-gym will run completely off-grid.

To save energy:

* There will be 500 motion sensor LED lights which are also dimmable throughout the gym.
* Toilets will have a dual flush facility.
* There will be a highly insulating swimming pool cover that will be in place at night.
* Pipes carrying hot water for the swimming pool will run underneath the changing rooms and act as underfloor heating.

# 7 Costings

## 7.1 Initial and First Year Costs

The chief costs involved are detailed below:

|  |  |
| --- | --- |
| **Item** | **Price in British Pounds** |
| Solar panels | 850,000 |
| Wind turbines | 36,000 |
| Flywheel system | 12,500 |
| Batteries | 1,700,000 |
| Gym Equipment | 50,000 |
| Staff(per annum) | 275,000 |
| Swimming pool | 2,500,000 |
| Ground source heat pump | 24,000 |
| Vending machinesx2 | 6,200 |
| Lighting | 3,495 |
| **Total**  | **5,457,195** |

*Table 2, above, shows the main costs involved with setting up the eco-gym.*

### 7.1.1 Solar Panels

For solar power, the gym will use Sunpower E20 solar panels which have a cost of £850,000, as seen in table 2. (Sunpower, 2011)

### 7.1.2 Wind Turbines

There will be three vertical axis Aeolos-V 3kW wind turbines on the roof of the gym that will have a cost of £36,000, shown in table 2. (Xzeres, 2013)

### 7.1.3 Flywheel System

From table 2, it can be seen that the cost of the 2 metre flywheel will be around £12,500. This value was estimated from information provided by professor Clive Roberts who spent £30,000 on a high quality flywheel capable of storing 50kWh. The flywheel used in the gym will not be of the same high quality, so will therefore cost less.

## 7.1.4 Batteries

The cost of a 5MWh battery system will be £1,700,000, which is necessary if the gym needs to be completely off grid. (Street Insider, 2013)

### 7.1.5 Gym Equipment

Values were taken from Fitness Superstore for thirty bikes, ten rowing machines, ten cross trainers, and a multitude of different gym equipment, generally sold in bulk packs.

A phone conversation with the manager of the Newcastle branch indicated they would consider fairly large discounts of up to 20% for big orders such as setting up a gym. This has been taken into account to give a cost of £50,000, as seen in table 2. (Fitness Superstore, 2014)

### 7.1.6 Staff Salary

Table 2 shows that £275,000 is spent on staff each year. This allows for 10 full time staff earning about £27000 a year. This figure is particularly generous, and will only be paid to members of staff in a supervisory position. Most of the staff positions will be filled by part time members of staff who are paid hourly.

### 7.1.7 The Swimming Pool

The cost of the swimming pool, including filter systems is £2,500,000, shown in table 2. (Sport England, 2011) (Sunesis, n.d.)

### 7.1.8 Vending Machines

Two vending machines will be used in the cafeteria to provide drinks and snacks, at a total cost of £6,200. (Vendtrade, 2006) (Coca Cola, 2014)

### 7.1.9 Ground Source Heat Pump

Table 2 shows that the cost of the ground source heat pump will be £24,000. This value was calculated by scaling up values given by the Energy Saving Trust. (Energy Saving Trust, 2014)

### 7.1.10 Lighting

There will be two floors to the gym building, therefore the total floor area will be 3200m2. From the assumption that 85% of the building needs to be lit, this gives a lit floor space of 2720m2. Therefore, 500 lights will be needed. (Charlston, 2013)

Each LED light bulb costs £6.99, thus the total cost of lights will be £3,495. (Philips, 2015)

## 7.2 Financial Income

### 7.2.1 Feed in Tariffs

Under the government scheme of feed in tariffs, they will pay 6.6p per kilowatt hour of solar energy produced. Therefore the gym will gain £12,500 from the government each year. (Energy Saving Trust, 2014)

Any excess energy generated can be sold back to the grid at a rate of 4.5p per kilowatt hour. If the eco-gym is to sell energy to the grid in summer, and buy this energy back in winter, £2,500 can be gained each year. (Ofgem, 2015)

### 7.2.3 Membership Fees

The membership fee that will be charged is £35 per month. This takes into account that the gym is in the city centre, and is environmentally friendly.

There will be 1500 members, so therefore the gym will make £630,000 each year from membership fees alone.

## 7.3 Total Income and Payback Time

The total income of the gym per year will be £642,000 and there will be an annual outcome of £275,000 for staff salary.

The payback time can therefore be calculated by:

$\frac{Initial Investment+(number of years × Salary each year) }{Income}=number of years$

$$\frac{5457195+275000×number of years}{642000}=number of years$$

Number of years = 14.869

Therefore in 15 years, the money invested initially will have been paid back by the business.

After recovering the initial investment, the profit margin will be around £367,500 per year. This is calculated by subtracting annual expenses from the total income to the gym.

This value does not account for expansion, or increase in the number of gym members; however, it is likely that in this time, the business will develop further facilities and bring in a larger revenue.

## 8 Conclusion

In conclusion, this eco-gym is financially feasible if there is the option to use the grid as if it were an energy storage device, where energy is sold to the grid in the summer months and bought back in the winter months. It is possible to have the gym completely off grid; however, there would need to be a large bank of Lithium-ion batteries which will be extremely expensive due to the amount of energy they would need to store.

Energy will be generated through solar panels and wind turbines on the roof of the eco-gym, in addition to the people exercising on cardiovascular machines generating energy. There will be an annual energy generation of 188.3MWh and an annual energy use of 148.9MWh. As more energy is generated than used, an energy storage system will need to be implemented. There will be a 2m diameter flywheel which will store 10kWh of energy, and a bank of Lithium-ion batteries that will store up to 5MWh of energy in order to allow the gym to run completely off grid.

The total cost for the gym from startup costs and the first year will be £5,457,195, which takes into account the cost of: the solar panels, three wind turbines, the flywheel system, the gym equipment, the swimming pool, the ground source heat pump, two vending machines for the cafeteria and lighting. From this, and the knowledge that the gym will gain £642,000 per annum from feed in tariffs and membership fees, it is calculated that the payback time for the gym will be around 15 years. However, if the gym can use the grid as an energy storing device, the payback time will be significantly less at around 9 years.

From this it can be deduced that the eco-gym is only economically feasible with a reasonable payback time if it has the ability to use the grid as an energy storage system where the excess energy is sold to the grid in summer, and bought back in winter.

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# 10 Appendix

## 10.1 Calculating Heat Loss for the Swimming Pool

### 10.1.1 Heat Rate Loss During Opening Hours (7am-10pm)

Assumptions:

* The air temperature around the pool is a constant 26$°C$.
* The pool surface is modelled as a flat plate.
* Heat loss through conduction on the sides of the pool is negligible.
* Most of the heat loss occurs through natural convection and radiation from the topside of the pool.
* Therefore $Q\_{loss}≈ Q\_{Radiation}+ Q\_{Convection}$
* Properties of the air and pool water taken as dry air and pure water respectively.
* The dimensions of the swimming pool are 25mx9mx1.9m

### 10.1.1.1 Heat Loss Through Convection:

Newton’s Law of Cooling $Q=hdA\_{s}(T\_{s}-T\_{\infty })$

Nusselt Number $Nu=\frac{hL}{k}$

 $Nu=a(Gr.Pr)^{m}$

For a heated surface facing up: a=0.14 m=1/3

McAdams formula Gr.Pr= 64.$10^{6}L^{3}ΔT$ (Simons, 2001)

 L=Area/Perimeter

To work out heat loss rate through convection, the average heat loss coefficient “h” must be found and applied to Newton’s law of cooling. To do this, the Nusselt number must be found using McAdams formula, which can be used as an approximation for air.

L=Area/Perimeter= 25.9/2.(25+9)=3.3m

$ΔT$=28-26=2

Once the dimension “L” and $ΔT$ between the water and room air is found, the dimensionless number Gr.Pr can be found.

Gr.Pr= 64.$10^{6}3.3^{3}2=$ 4.6.$10^{9}$

Therefore, Nu=0.14$(4.6.10^{9})^{1/3}$= 233

h=233\*0.0257/3.3=1.81$Wm^{-2}k^{-1}$

Q=1.81.(25.9)(28-26)=815W

Energy in KWh perday = 815\*15/1000 = 12.225KWh

### 10.1.1.2 Heat Loss Through Radiation

Heat loss, Q = ε σ (Th4 - Tc4) Ac

Where:

ε=0.95 (Thermal emissivity of water)

σ=5.6703 10-8 (W/m2K4) (Boltzmann constant)

q=heat transfer per unit time (W)

Th= Absolute temperature of hot body (K)

Tc=Absolute temperature of cold body (K)

A = area of the emitting body (m2)

Q= 0.95(5.6703 .0-8 )($301^{4}-299^{4})$(25.9) = 2620W

Energy in KWh perday = 2620\*15/1000=39kWh

### 10.1.2 Heat Loss During Closed Hours (10pm – 7am) (with pool covers)

Assumptions:

* An 8mm thick Polyethylene low density (PEL) is used as the pool cover. (Aspects Pools, 2015)
* There is a 1cm gap between the water surface and pool cover
* Heat loss occurs mainly through conduction, radiation and convection.

### 10.1.2.1 Heat Loss From Conduction

 (Vlachopoulos and Strutt, 2002)

To calculate heat loss rate through conduction, thermal conductivity values of the two materials, air and Polyethylene, must be used.

K1= 0.0257 Wm-1K-1 (dry air)

K2=0.2 Wm-1K-1 (Polyehtylene)

X1= 0.01m (distance between surface of water and pool cover)

X2= 0.008m (thickness of the pool cover)

Substituting these values in the equation above gives us:

Q= 2/((0.01/(0.0257\*225)) + (0.008/(0.2\*225)))=1050W

In 9 hours this will approximately consume 8.5kWh per day of energy.

### 10.1.2.2 Heat Loss Through Radiation

Heat loss, Q = ε σ (Th4 - Tc4) Ac

Q= 0.1(5.6703 .10-8 )($301^{4}-299^{4})$(25.9) =275W

In 9 hours this will approximately consume 2.2 kWh per day of energy.

Energy loss through convection is the same as opening hour consumption. (12.225KWh)

Summing all the energy losses work out above gives:

12.225+12.225+2.2+8.5+39=74.15 KWh

Therefore the exact heating energy needed per day to maintain a pool temperature of 26$°C$ is approximately 74KWh. This is not taking into account the efficiency of the heating source.

## 10.2 Calculations for the Energy Use of a Swimming Pool Pump

From the recommended turnover time of 3 hours for a 25m pool, (PWTAG, 2014) the flow rate required that the pump would need to operate at can be calculated.

The flow rate required is approximately 140m^3/h given that the swimming pool dimensions are 25mx9mx1.9m.

*Ph(kW) = q ρ g h / (3.6 106)* (The Engineering Toolbox, 2014)

Using the equation above we can calculate the hydraulic power required by assuming the pool water has a density of water and the differential head is 2 metres.

P=140\*1000\*9.81\*2/*(3.6\*106)*=0.763kW

The pump will have to circulate for the whole day and therefore the pump will require approximately 20KWh per day.

# 10.3 Contribution of Group Members

The table below displays the work each group member has done in order to complete the project:

|  |  |
| --- | --- |
| Wenbin Shi | Research:* Energy used by vending machines and their cost
* The amount of time people spend in the gym and peak days
* The time gym members spent on specific machines

For the final report:* Compiling assumptions
 |
| Kelvin Wong | Research:* Energy use of the swimming pool
* Energy loss of the swimming pool
* Cost of the swimming pool
* Energy consumption of general appliances
* Water diagram for the presentation

For the final report:* Methodology
 |
| William Hadrill | Research:* Use of a flywheel
* Energy from solar and wind power
* Total input and output energy calculations
* Graphs for energy generation and use
* Water diagram for the presentation
* Cost of batteries and the flywheel
* Researching energy storage systems

For the final report:* Results
* Analysis of results
 |
| Mohammed Muljiani | Research:* Lighting requirements, cost and energy use
* Calculating heat loss through building walls by finding corresponding U values for efficient glass and concrete
* Finding and compiling costings including expenditure and income from membership fees and feed in tariffs
* Calculating payback time

For the final report:* Introduction
* Costings
 |
| Charlotte Welllard | Research:* Cost of solar and wind energy
* How many bike/rowing/cross trainers needed
* Use of rain water and efficient water use
* Government grants
* Overall organization, including: arranging meetings with group supervisor, organizing meetings, collecting and organizing information
* Writing and designing presentations
* Collating work from group members – compiling and editing interim documents
* Writing minutes from group meetings

For the final report:* Eco friendly customer policy
* Analysis of results
* Recommendations
* Conclusions
* Compiling and editing of the final report
 |

*Table 3, above, shows the work done by each group member.*