UNIVERSITY OF
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This is a thesis on partial fulfilment for the degree of Master of Science in Energy Systems and the Environment

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"COMBINING WIND AND SOLAR ENERGY TO MEET DEMANDS IN THE BUILT ENVIRONMENT"

(GLASGOW-HERAKLION CRETE ANALYSIS)

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Abstract

This thesis is based upon the combined use of solar and wind energy, in the hope to discover and determine to what extent the energy produced is capable of satisfying the energy demands of a building. The analysis took place in two different locations, in Dalmarnock (nearby Glasgow), Scotland and Heraklion, a Greek city on the island of Crete. The buildings used in both cases were a typical three-bedroom domestic building. In addition, the same type of photovoltaics and ducted wind turbines were used for both analyses.

The weather data used in the two cases were obviously not identical. The weather data for Glasgow was already installed in "Merit", the programme used for the analysis, while for Heraklion the data had to be collected from several research centres in Crete. In addition, the energy demands of the building in Glasgow were already inputted in the programme while for Crete, once again, the demands were collected from local research centres.

The ability of the systems to match consumer demand, with varying amounts of energy storage capacity included, was assessed using the "Merit" software. It was assumed that any energy deficits would be made up by purchase of electricity from the national grid. For each site, two promising system configurations were identified and subjected to an economic analysis, making the appropriate assumptions for levels of subsidy, maintenance costs and interest rates for repayments.

It was concluded that none of the renewable energy installations could presently be justified on economic grounds, compared to the alternative of simply purchasing electricity from the grid. Changes in electricity prices, subsidy levels or costs for renewable energy equipment might alter the position in the future.

1 Project Overview

1.1 Introduction

This project deals with the production of energy from a hybrid system which constitutes a number of ducted wind turbine and PV panels. These are going to be implemented on the roof of a typical 3 bedroom building in Glasgow. With the use of specific hybrid systems we will discover the extent these systems can span the energy demands of the building. The same analysis will be utilized for a similar building in Heraklion, an established town in Crete. These similar energy needs are used in order to illustrate a crystal clear image of the results and to compare them effectively.

1.2 Methodology

The following paragraphs are the methodology process of this project and will be presented thoroughly step by step.

1. Firstly, the weather data shall be collected from the solar and wind laboratory in Heraklion Crete; this exists presently for Glasgow. Then it will be presented in a more understandable and rational figures and numbers, i.e. a language easier to understand than the use of Excel. Furthermore it would be installed into the software programme that is going to be implemented for the demonstration of this project. This programme is called "***Merit***".

2. Secondly using the appropriate tools of measurement, the calculations measured will be conducted on the ducted turbine and PV panels in order to evaluate their technical characteristics and efficiency. Afterwards these values are collected they will be entered into the "merit" software and this unambiguous data will be run an analysis.

3. Thirdly with the help of my supervisor the building's energy demands, which have already been measured, will be identified. The same is going to be conducted for the Greek analysis, using hourly energy demands of a typical building which have already

been measured. Thereafter the analysis with the appropriate software and the operation of the hybrid system will be checked in order to see what extent it can cover the energy demands of the building.

4. Fourthly the results which have previously been executed are going to be compared with the analysis from the Glasgow and the analysis from Heraklion Crete. Nevertheless useful conclusions and observations will result from this.

5. Finally an analysis will take place and create an economic point of view. This will illustrate how feasible the installation of a hybrid system is likely to be in practice for the future. These results will be used for the final outcome project.

1.3 Why a Hybrid System?

Over the present years hybrid technology has developed and upgraded its role in renewable energy sources while the benefits it produces for autonomous power production are unchallenged. Nowadays many houses in rural and urban areas use hybrid systems. Many isolated islands try to adopt this kind of technology because of the benefits which can be received in comparison with a single renewable system. As has been previously explained this system used in my project is based upon a wind ducted turbine and PV panels, its function is similar to the picture below.

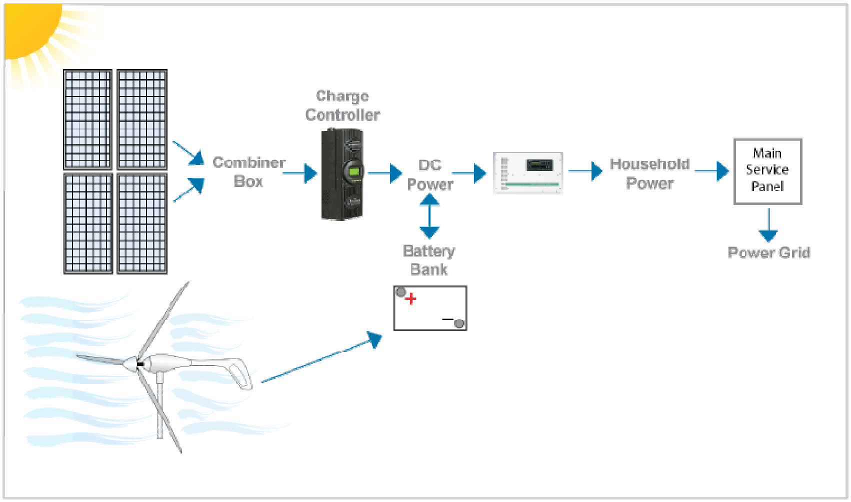


Figure 1: Operation diagram of a Hybrid System PV/WT

This specific hybrid system presents many benefits. More specifically for a wind/solar hybrid system the assessment is focused on the wind and solar potential of the region. Therefore it can be operated during the day using the energy from the sun and after the sun has set it can utilise the potential wind energy to continue its function. For this reason, wind and solar systems work well together in a hybrid system and they provide a more consistent year-round output than either wind-only or PV-only systems. Moreover with the use of the appropriate auxiliary systems like batteries you can store energy which will be useful in compensating electrical demands used by the building for periods where there is no sun or wind. Finally, it is economically sound and advantageous to use non finite resources, i.e. solar and wind (hybrid). The investment financially and environmentally in modern technologies will win through the generations to come in the fight for energy efficiency and effectiveness.

2 *Energy Overview*

2.1 General

Humanity is at a critical turning-point of its history. A period where the use of both legitimate and illegitimate means in order to guarantee the basic quantities of fossil fuels, especially that of oil, causes conflicts between the nations. This, in combination with the daily degradation of the natural environment due to a variety of human activities, the climatic changes around the globe which are difficult to reverse and the progressive exhaustion of natural resources of the Earth, has lead to the intensification of the anxiety about the future of humanity and the quality of life for the future generations in our planet. The above factors are sacrificed in the name of human existence and growth, mainly for gaining the most valuable good in the world, ***energy***.

2.2 Etymology of the term 'Energy'

Energy is defined as the ability of producing work. Energy is a compound word and comes from the Greek words: en + ergon, which mean work inside a body. The normal technical definition is that energy is the capacity or ability to do work. A more scientific definition of energy was given by the famous physicist Max Planck: "The ability of a system to produce outside activity".

Energy is something that we cannot touch, see, smell or hear. People and civilizations couldn't survive without it. The energy is an essential part of our daily life. Nothing could happen without energy. We depend on the hundreds of different ways which it appears in nature. Our organisms need energy to move and our machines need energy to function as well.

Energy constitutes the main motivator for each human activity. In their entire history humans used with inventiveness the capabilities that nature provided generously; solar power, wind power, water power and fire with a view to improve living conditions and environmental quality.

2.3 Human and Energy

The research for environmental quality constitutes an ancestral tendency that aims for the establishment of harmonious equilibrium between the person and nature that surrounds him. Environmental quality considerations fell into disuse after the industrial revolution, in an era where man believed in his omnipotence and exhausted without measure the resources in the planet.

Nowadays, energy is deeply implicated in each of the economic, social and environmental dimensions of human development. Energy services provide an essential input to economic activity. They contribute to social development through education and public health, and help meet the basic human need for food and shelter. Modern energy services can improve the environment, for example by reducing the pollution caused by inefficient equipment and processes and by slowing deforestation. But rising energy use can also worsen pollution, and mismanagement of energy resources can harm the ecosystems. The relationships between energy use and human development are extremely complex.

The environmental and social dimensions of human development have attracted increased attention in recent years. According to valid opinions of experts, the effort of mankind for continuous rise of his biotic level in combination with the rapid increase of the world's population and the unwise use of energy reserves of our planet, threaten to lead humanity to a long energy winter. The above becomes more comprehensible as long as it will be considered that almost a quarter of world's population which was about 1.6 billions people until 2002 didn't have access to electricity in their homes. [5]

Trying to realise the extent of waste of the available energy resources of our planet, it is worth noting that humanity, in the last hundred years has spent large amount of reserves of raw material and sources of energy. This of course is caused by the ignorance of people and from the prevailing opinion that the reserves of energy and raw material are unlimited, thus leading to waste of energy and to the thoughtless use of raw material, without us realizing the catastrophic consequences for the future of humanity.

2.4 *World Energy Demand*

The world primary energy demand presented a significant increase especially during the last half of the 20th century. In the below table we can see the energy world demand from each source for the last 30 years and the prediction for the next 30 years. As unit of measurement for energy 1 Quad is used, which is equal to 10^{18} B.T.U= $2.929.10^{14}$ kWh. Also 1 Quad is approximately equal to 25 Mtoe (*tones of oil equivalent*). [1]

From the below table we can observe that there is an important increase in the demands of energy, which during the last 30 years has almost doubled. For the next 30 years until 2030 is observed an increase in the use of renewable energy sources and a small but remarkable increase in the use of fossil fuels. An important role during recent years and especially for the years which are coming, in the world energy balance, is going to be played by the nuclear energy.

Sources/Years	1971	2002	2010	2020	2030	2002-2030
Coal	1407	2389	2763	3193	3601	1.5%
Oil	2413	3676	4308	5074	5766	1.6%
Gas	892	2190	2703	3451	4130	2.3%
Nuclear	29	692	778	776	764	0.4%
Hydro	104	224	276	321	365	1.8%
Biomass	687	1119	1264	1428	1605	1.3%
Other Renewables	4	55	101	162	256	5.7%
Total	***5536***	***10345***	***12194***	***14404***	***16487***	***1.7%***

Table 1: World Primary Energy Demand (Mtoe)

Moreover fossil fuels are estimated to cover up 85% of consumed energy in the developed countries by 2030 and 55% of consumed energy in the developing ones. For fossil fuels, demand will reach 16.5 billion tonnes of oil equivalent compared to 10.3 billion tonnes that was in 2002. In the developed countries there is a tendency of reduction in the use of fossil fuels and particularly that of oil, with a gradual infiltration of renewable sources of energy. This would be a very good first step in an effort to reduce overdependence on fossil fuels. However the share of renewable energy sources will remain flat, at around 14%, while that of nuclear will drop from 7% to 5%. It is estimated that the existing reserves of fossil fuel sources will suffice for the next, 200 years for coal, 60 years for natural gas and 50 years for oil. [5]

These deadlines show the cruel reality of what is going to happen to our world the next decades. This remarkable decrease of fossil fuels reserves around the globe creates political and economic tensions. In fact, many wars have already started in the Middle East (Iraq, Kuwait) and in these countries people every day pay, sometimes with their own lives, the price of the ***black gold***. On the other hand, each coin has both sides and thus there are alternative predictions for a more viable growth in the world. These can become reality only if humanity makes a turn in covering its electricity demands by using renewable sources. But this will be mentioned extensively in the following paragraphs.

2.4.1 Fossil and Nuclear Fuels

Fossil fuels will continue to dominate global energy use. Of course fossil fuels are part of the energy sources that human has in his daily disposal and are called *non renewable* energy sources. The reason they are called non renewable sources is because they required special conditions of pressure and temperature for their creation over an immense time period, confirming that they constitute the heritage and the constant “energy bank” of our planet. The main sources of energy that are used today are coal, oil, gas and nuclear energy.

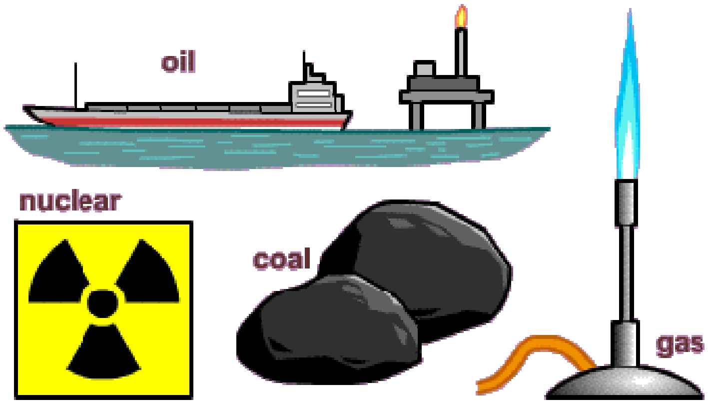


Figure 2: Fossil and Nuclear Fuels

Coal constituted for many years the main fuel for many countries around the globe. Often it is connected with the industrial revolution. A big part of current world industrial production is based on the energy from the combustion of mining coal, for example energy from coal covers about 50% of the electricity demands in U.S and 28% in U.K. Coal consumption will increase slowly in end use sectors and until 2030 is expected to increase by 1.5% per year. [5]

Oil will remain the single largest fuel in the global primary energy mix and the demand for oil is expected to increase by 1.6% per year until 2030. Oil was used by the ancient Egyptians but it was extensively developed during the industrial revolution. Oil world production intensified in the middle of 19 century. From the middle of the twentieth century the use of oil accelerated enormously. In the recent era 2 oil crises in 1973 and 1979 significantly reduced these trades and led to the utilisation of advanced technological solutions. This has resulted in a shift in the direction of renewable energy sources and the application of a stricter policy in the sectors of orthological use and saving energy. Oil prices still strongly affect the health of the world economy. On ***07/06/06*** the oil prices first rose above ***75$*** a barrel, due to geopolitical tensions (the war in Iraq, the Middle East war nowadays and the instability in Nigeria) creating financial instability around the world. For as long as oil prices remain high and unstable, economic prosperity will remain at risk. [5] [54]

Natural gas is nothing new. In fact, most of the natural gas that is brought out from under the ground is millions of years old and one of the first civilization who discovered natural gas were the ***Greeks*** around 1000 B.C. Natural gas is a vital component of the world's supply of energy and will remain the most competitive fuel in new power stations in most parts of the world. It is one of the cleanest, safest, and most useful of all energy sources. The demand for natural gas is expected to increase at a steady rate of 2.3% per year until 2030 and by that year gas consumption is estimated to be about 90% higher than it is now. In addition natural gas will have overtaken coal as the world's second largest energy source. [5]

Nuclear power is the controlled use of nuclear reactions to release energy for work including propulsion, heat, and the generation of electricity. Nuclear energy provides 17% of the world's electricity. In Europe the nuclear production from the nuclear plants is estimated at about 173 GW, France being the pioneer with a production estimate of around 60 GW and generating 75% of its electricity from nuclear. The use of nuclear energy started during the Second World War for military purposes but after that period it extended its use to serve peaceful purposes covering mainly energy demands. Nowadays nuclear energy is expected to be increase until 2030 at a steady rate of 0.4% per year. Nuclear energy is projected to fall in Europe over the next few years and especially after 2010 but is going to increase in many Asian countries. Of course all these predictions may change as a result of future views on nuclear energy and cause nuclear power to become much more significant that projected today. [5] [53]

2.4.2 Renewable Energy

The only thing that is inarguable is that renewable energy will bring radical changes in many aspects of social life and is going to solve many environmental problems associated with fossil fuels and nuclear energy. Renewable energy at a global level at the moment can only replace a small quantity of fossil and nuclear fuels but we hope to replace them entirely in the long term.

More precisely renewable energy nowadays covers 14% of the world's primary energy demand as we can observe from the table below and is estimated at 1400 Mtoe, aiming to increase to 2226 Mtoe by 2030. The first and by far the largest renewable energy source is biomass which covers two thirds of the energy demands, especially used for cooking and heating in developing countries. Following is hydropower while solar, wind, geothermal, tide and wave energy each accounts for only a small part of global energy demand. [5]

Sources/Years	2002		2030	
	Renewables use	Share of total demand	Renewables use	Share of total demand
Biomass	1119	11%	1605	10%
Hydro	224	2%	365	2%
Other Renewables	55	1%	256	2%

Table 2: World Renewable Energy Consumption (Mtoe)

More than three quarters of renewable energy is consumed in developing countries. For example countries like Paraguay, Nepal and Congo cover their electricity needs using renewable energy and mostly hydropower. So as we can observe from the above table renewable power is going to play a major role in the near future for the world's energy demands. It is expected to increase significantly in the following years, though the share of total energy consumption around the world is expected to remain largely unchanged around 14%.

2.5 Orthological Use of Energy

In recent years the mean annually global energy consumption increased at a rate which oscillates between 4% and 5% doubling of the quantities of energy consumed every 10 or 12 years. This is worrying for humanity, especially if it is combined with the expected exhaustion of reserves of the conventional fuels.

Electricity, hot water, heating and transport, comforts that influence our daily life, depend on the natural resources of our planet. The reserves of oil and natural gas are decreasing fast and the exports of them are more difficult and costly. The restriction of consumption of these mineral forms of energy with a view to reducing the greenhouse effect constituted one of the main obligations of the conference for the environment and development in Rio de Janeiro in 1992.

2.5.1 The Earth Summit in Rio de Janeiro 1992

The principles of the Rio statement are connected with a growth program for the twentieth first century which is called agenda 21. Agenda 21 constitutes a complete and creative approach for the guarantee of a more viable growth. These obligations have a social and economic dimension: they fight poverty, they keep the global population under control, they provide sanitary protection, they modify consumption patterns and they promote a viable urban model for the developing countries. Agenda 21 was the first world effort for the creation of an action plan for ***sustainable development*** for the world in the 21st century.

2.5.2 Sustainable Development

Sustainable Development was first developed as a concept in 1987 where the World Commission on Environment and Development (WCED), which had been set up in 1983, published a report entitled «Our common future». The document came to be known as the «Brundtland Report». Sustainable development is defined as follows: ¨***Sustainable development is development that meets the needs of the present without compromising the ability of future generations to meet their own needs***.¨ In Our Common Future, the Brundtland commission proposed the definition for sustainable development that was to become so broadly used by many scientific teams. The Brundtland report described seven strategic imperatives for sustainable development:

- Reviving growth,
- Changing the quality of growth,
- Meeting essential needs for jobs, food, energy, water and sanitation,
- Ensuring a sustainable level of population,
- Conserving and enhancing the resource base,
- Reorienting technology and managing risk and
- Merging environment and economics in decision-making.

Within sustainable development, as we can see from the below table, three broad interacting aspects are involved: environment, economics, and social equity. These three aspects can be labelled the ecological imperative, the social imperative, and the economic imperative, respectively. Robinson and Van Bers (1996) said that: *“**These three aspects are inseparable and our ability to develop a deeper understanding of this linkage is critical to our prospects for sustainability**”*

Figure 3: The criteria to achieve sustainable development

The sustainability of development can be assessed in economic, environmental and social terms. No matter how we define sustainable development, most current systems of energy supply and use are clearly not sustainable in economic, environmental or social terms. In practise, sustainable development is about finding acceptable trade-offs between economic, environmental and social goals.

*The challenge of energy for **sustainable development** will require a concerted effort on the part of international organizations, national governments, the energy community, civil society, the private sector, and individuals. Whatever difficulties are associated with taking appropriate action, they are small compare to what is at stake. Because humankind is in a dynamic and critical period of economic, technological, demographic, and structural transition, and because energy systems take decades to change, the time to act is now.* [6]

2.5.3 Kyoto Protocol 1996

Contrary to the Earth Summit which had a social and cultural dimension, the summit of Kyoto in 1996 was strategically orientated. In the protocol that was signed at this international conference, the signatory states undertook the obligation not to exceed the average level of gas emissions of the greenhouse effect in 1990, for the years between 2008 and 2012. This means for example that **United Kingdom** emissions reductions are estimated 98 millions tones of equivalent coal by 2010 and **France** 16 millions tones of equivalent coal by 2010 as we can observe from the diagrams below.

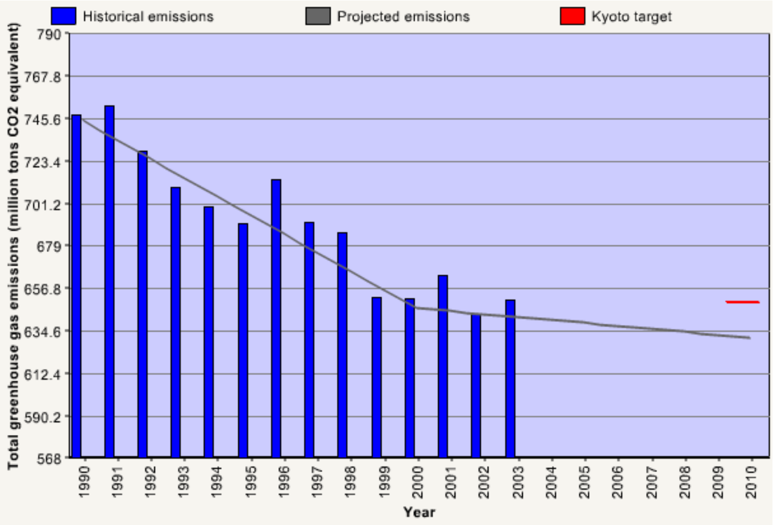


Figure 4: Greenhouse Gas Emissions for UK

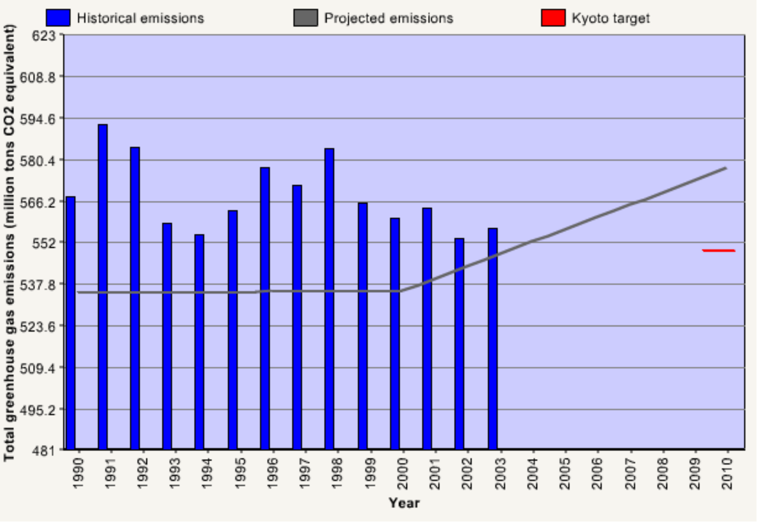


Figure 5: Greenhouse Gas Emissions for France

On the other hand **Greece** didn’t have any problem with gas emissions until the year 2000 when they exceeded the Kyoto target and now should reduce by about 6 millions tones of equivalent coal by 2010. This can be better demonstrated by the following diagram.

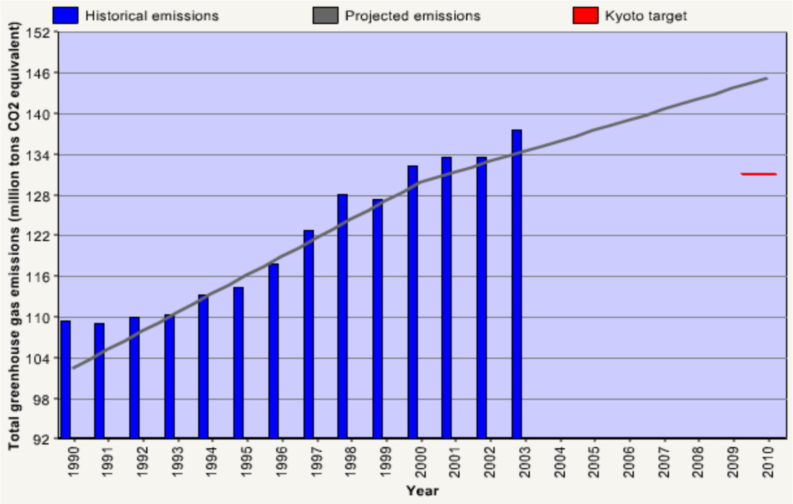


Figure 6: Greenhouse Gas Emissions for Greece

Therefore if the industrial countries want to keep their obligations of Kyoto Protocol, they should be led at the same time to the following three types of action:

- To reduce the consumption of energy,
- To replace the energy from mining fuels with energy from renewable sources,
- To reduce the consumption of coal and the carbon emissions.

Despite the negative reaction which is displayed by some of the most powerful countries of this world, sensitization and mobilisation of citizens around the globe continuously increases. The expressed, intention to confront the greenhouse effect on an international scale, shows that we realise, that technology, as a fruit of superior intellectual work, should have only one target: to serve the person, with respect to the ecosystem that surrounds him. This ecosystem, place of growth and existence of all forms of life, are not the property of certain human generations. It needed 5 billion years in order for the climatic conditions to be idealized in our planet, to such a degree, that they can contribute in the creation of life.

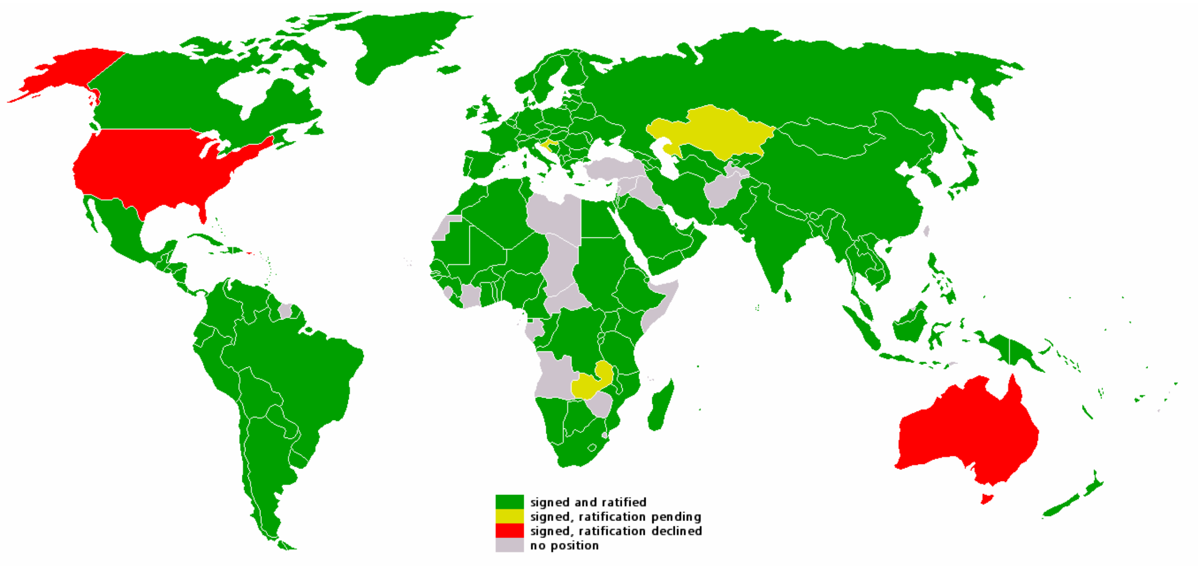


Figure 7: Kyoto Protocol Participation Map

Is an unambiguous fact how important is the contribution of powerful energy sources has been in technological progress. Through the historical necessity of the conventional fuels, sprang up new methods of sustainable energy production and the improvement of older ones, without ecological burdens as well. A sustainable future in which energy from **sun** and **wind** is going to play the major positive role in supporting human well being is possible.

2.6 *Renewable Energy Sources*

Renewable sources of energy are independent, naturally and not artificially existing and they are already being economically exploited or will become so in the near future.

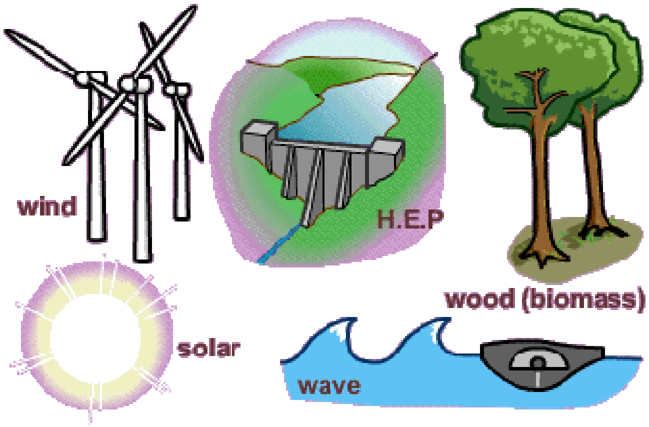


Figure 8: Renewable Energy Sources

Renewable energy sources have as their basic origin the sun. The radiation from the sun that reaches the Earth's ground, apart from the vital contribution in the creation, growth and maintenance of life of our planet, provides our planet with energy in various forms. Moreover solar radiation heats directly and evaporates large quantities of marine water and it maintains the natural cycle of the water, creating lakes and rivers that constitute an additional source of energy (Hydroelectric energy). Solar radiation puts in movement the air masses of the atmosphere (Wind energy) and it creates waves (Wave energy). Finally is absorbed from combined materials and produces electricity (Photovoltaic effect) and it contributes in the growth of flora via the photosynthesis phenomenon and with the combustion of plants produces energy (Biomass).

Renewable sources are safe and unlimited in the sense that there is no possibility of reserves being run down. With some exceptions, proposed renewable energy sources are local and so cannot be exploited by a foreign power as has happened with oil over many years. Further more renewable sources can add diversity to energy supply and almost none of them releases gaseous or liquid pollutants during the operation.

Of course renewable sources, with the current economic and technological facts, are not able, at least for the moment, to give a clear and a radical solution to the energy problems of humanity. However if their use is combined with an effort to save large amounts from existing conventional energy resources, it is possible that a progressive removal of humanity's nightmare, a befalling energy winter, may be accomplished.

3 SOLAR ENERGY

3.1 The Sun

The sun is the largest energy source of life while at the same time it is the ultimate source of most of our renewable energy supplies.

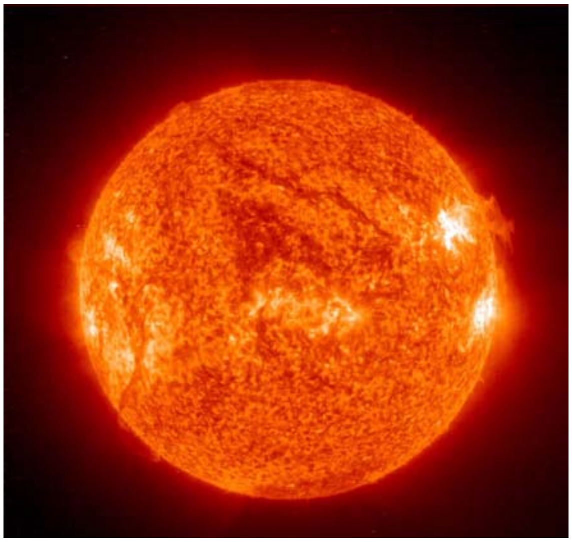


Figure 9: Sun the largest energy source of life

The sun is a typical star with the following characteristics: mass 2×10^{30} kg, beam length 700.000 km, age 5×10^{9} years and it is calculated that it still has roughly 5 billions more years of life. Its surface temperature is about 5800 K while the internal temperature is approximately 15.000.000 K. This temperature derives from reactions which were based on the transformation of hydrogen in helium. The process of the nuclear fusion, which is characterized from the following reaction $4\ {}_{1}^{1}\mathrm{H} \rightarrow {}_{2}^{4}\mathrm{He}$ + Energy, is the result of the high temperature of the sun and the continuous emission of large amounts of energy. It is calculated that for each gram of hydrogen, that is converted to He, sun radiates energy equal with U= 1.67×10^{5} kWh. The solar energy is emitted to the universe mainly by electromagnetic radiation.

The earth spins in an elliptic orbit around the sun while the distance from the sun is estimated to be 150.000.000 km. The light in order to cover this distance, having the speed of 300.000 km/sec, requires approximately 8.5 min. The emitted radiation is removed actinic by the aster to the space and the intensity of the radiation J, is calculated according to the equation below:

$$J=\frac{P}{4\pi d^2}$$

Where P is the power of electromagnetic radiation and d is the distance from the sun. Approximately one-third of this radiation is reflected back. The rest is absorbed and retransmitted to the space while the earth reradiates just as energy as it receives and creates a stable energy balance at a temperature suitable for life.

Solar energy can be used to generate electricity in a direct way with the use of *photovoltaic panels*.

3.2 History of Photovoltaics

Photovoltaic is defined as the generation of electricity from light. The term photovoltaic is a compound word and comes from the Greek word for light *photos* and the word *volt* which is the unit of electromotive power.

The technology of photovoltaic cells was developed rapidly during the second half of the twentieth century, even though the photovoltaic effect had been observed by Edmond Becquerel in 1839. In 1877 the first report of PV effect was published by two Cambridge scientists Adams and Day and in 1883 Charles Fritts built a selenium solar cell similar to contemporary solar silicon cells with efficiency less than 1%. In 1954 Chapin, Fuller and Pearson announced the first manufacture of solar element with p-n junction and efficiency 6%. The initial commercial manufactures were very costly, 1000\$/W_P in 1956, with relatively small efficiency of about 5-10% and they were made by crystalline materials, mainly by crystal silicon (c-Si).

Nowadays the efficiency of the best crystalline silicon cells has reached 24% for photovoltaic cells used in aerospace technology and about 14-16% overall efficiency for those used for industrial and domestic use. The cost is around 5\$/W_P if they are purchased in large quantities.

3.3 Photovoltaic Technology

3.3.1 Photovoltaic Structure

The structure of photovoltaic cells is quite simple. They constitute from 6 different layers of materials as we can see in the picture below. Firstly there is a black cover glass surface which helps in increasing the photons absorption and protects the cell from the atmosphere elements as well. After that, there is an antireflective coating which reduces the reflection losses from the photons to less than 5%. The contact grid which follows helps to minimize the distance which the photons have to travel in order to reach the semiconductors. The two thin layers of semiconductors p and n follow and they are the heart of the photovoltaic system. Finally there is the back contact which allows a better conduction.

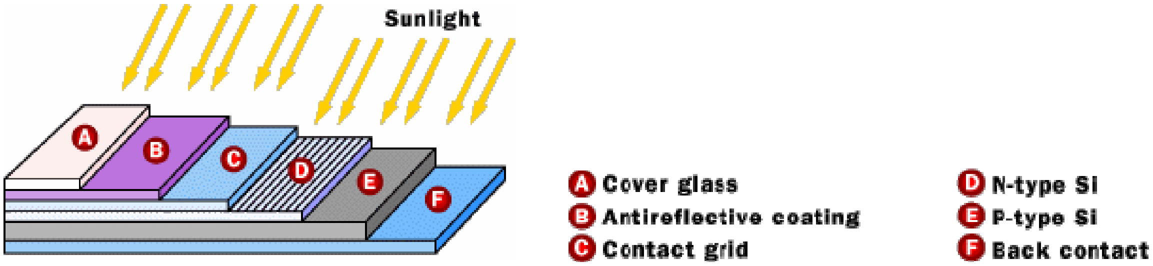


Figure 10: Basic structure of a generic silicon PV cell

3.3.2 Semiconductors p-n type

The photovoltaic cells as we mentioned before consist of 2 semiconductors p-n which are both made of crystalline silicon. The n-type semiconductor is created when some of their atoms of the crystalline silicon are replaced by atoms of another material which has higher valence band like phosphorus. Consequently an n-type semiconductor is being created which has a surplus of free electrons in its valence band. On the other hand a p-type semiconductor is created when some of the atoms of the crystalline silicon are replaced by atoms with lower valence like boron and the result is the creation of another material with deficit of free electrons and is known as p-type semiconductor. These missing electrons are called holes.

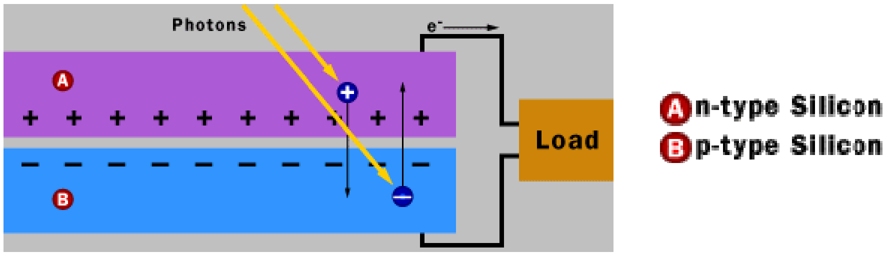


Figure 11: Operation of a PV cell

When the above semiconductors get in touch they create what is known as a p-n junction while an electric field is set up in that region which is called depletion region. As we can observe from the picture above electrons are moved by diffusion from one semiconductor to the other and create negatively charged particles in one direction and positively charged particles in the opposite direction.

3.3.3 Photovoltaic Effect

The photovoltaic effect is created by the sun light beams. When the photovoltaic cell becomes exposed to the light beam which consists of photons, the electrons are stimulated. The electrons start moving rapidly, jump into the conduction band and they leave holes in the valence band. Some of the electrons are attracted from n-side to combine with holes on the nearby p-side. Similarly, holes on the near p-side are attracted to combine with the electrons on the nearby n-side. The flow of the electrons from one semiconductor to the other creates the electric current into the photovoltaic cell. Furthermore the absorption of the photons in a PV cell can be maximized if anti reflective coatings and surfaces with grooving of Si will be used.

Moreover when the resistance in a circuit is infinite and the current is at its minimum (zero) and the voltage is at its maximum then it is said that an open circuit voltage exists. On the contrary, when the resistance in the circuit is zero and the current in the circuit reaches its maximum then it is said that a short circuit current exists. Furthermore if the resistance between zero and infinity varies, the current and the voltage will be found to vary as well and this is known as the I-V characteristic curve of the PV cell. The specific curve, which represents this and is called maximum power point (MPP) of a PV cell, can be seen in the following diagram.

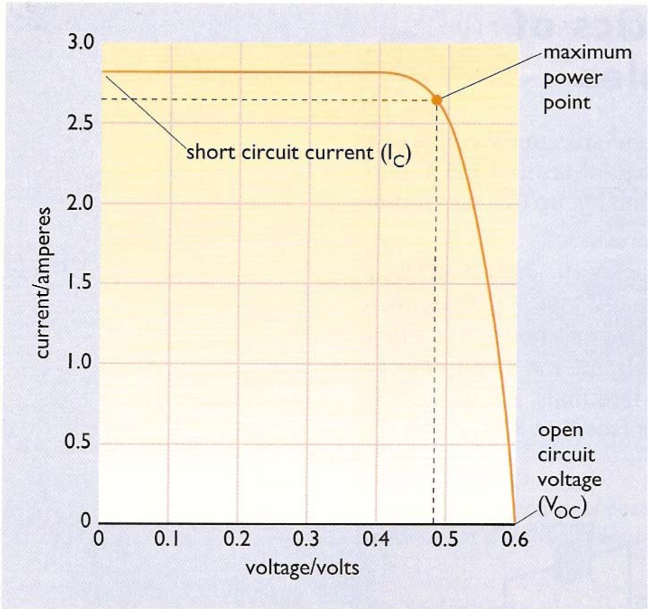


Figure 12: I-V Curve of a typical silicon PV cell under standard test conditions

Finally in order to measure the photovoltaic cells output power the following standard test conditions are established internationally. The irradiance level is 1 000 W/m², with the reference air mass 1.5 solar spectral irradiance distribution and cell or module junction temperature of 25°.

3.3.4 Main Cell Types

The material that is used widely in the industry for the production of photovoltaic cells is silicon. Silicon can be found inside the sand in the form of silicon oxide (SiO_2). The final product is characterized by high purity 99.99999%. The photovoltaic cells of silicon are distinguished in four categories, depending on the structure of the basic material from which they are made and the particular way of their preparation. The types are the following ones:

1. Single-Crystal Silicon: The basic material is monocrystalline silicon. In order to make them, silicon is purified, melted, and crystallized into ingots. The ingots are sliced into thin wafers (Wafer~300μm) to make individual cells. The efficiency of a single crystal silicon cell oscillates between 13-16% and it is characterized by a high cost for the manufacture and has a dark blue colour.

2. Polycrystalline Silicon: The particular cell is relatively large in size and it can be easily formed into a square shape which virtually eliminates any inactive area between cells. Its efficiency oscillates between 10-14% and it is characterized by lower cost silicon which is used for its manufacture and has light blue colour.

3. Ribbon Silicon: Ribbon-type photovoltaic cells are made by producing a ribbon from the molten crystal silicon instead of an ingot. Its efficiency is around 13% and is very expensive with a limited industrial production.

4. Technology which uses thin film solar cells while the total thickness of a semi conductor is about 1μm. Amorphous or thin film silicon cells are solids in which the silicon atoms are much less ordered than in a crystalline form. By using multiple junctions this kind of photovoltaic cells achieve maximum efficiency which is estimated at about 13% while the installation cost is reduced. Furthermore the output of an amorphous silicon cell isn’t decreased as temperature increases and is much cheaper to produce than crystalline silicon.

3.3.5 Main Parts of a Photovoltaic System

As it can be observed by the picture below a photovoltaic system consists of different devices. Except from the photovoltaic cells which are the major parts of a PV system and their function which has been already mentioned, batteries, charge controller and inverter constitute a complete photovoltaic system.

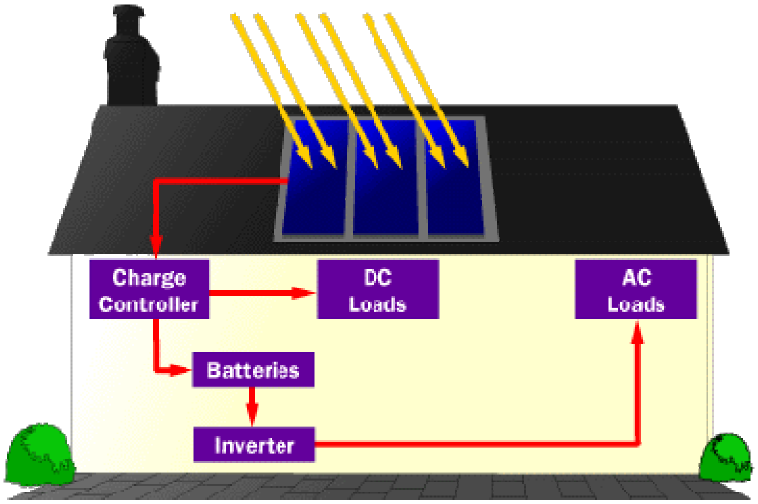


Figure 13: General schematic of a residential PV system

Batteries are used to store the energy which is produced by PV cells. Afterwards, they provide that energy in intervals into the system usually during cloudy days, nights and days where the electrical demands are high enough. The most common type of batteries which is used is the deep-cycle batteries. Deep-cycle batteries are lead-acid which are used in a great range and nickel-cadmium which are more expensive but they last longer and can be discharged at a higher level.

Batteries have characteristics which should be taken into consideration before they are connected to the grid. The most important of them are the following:

1. The total capacity which represents the total load, in Ah which is stored in the battery
2. The battery voltage which depends on the type of the electrolyte and on the number of the elements
3. The discharge depth which shows the level of discharge that the battery can reach daily
4. The cost per KWh, which the battery will provide during its life cycle, in order for the total electrical energy to be calculated.
5. The operating temperature shows the capacity of the battery and decreases when temperatures decrease.
6. The operational life which shows the life cycle of the battery in a PV system. Usually it has to be replaced after a particular number of years of about 5-6.

Charge controller is a vital device for the life cycle of the battery. When the battery is overcharged, its life is reduced. This is when the charge controller starts to operate. When the batteries are fully charged, the charge controller doesn't allow the electrical load to continue flowing into them and in that way it increases the life of the battery.

The inverter is a device which converts direct current (DC) into alternative current (AC). The usage of the alternative current is essential because it has been widely used for all kinds of domestic uses and in the industry sector as well. It is used, generally, in cases where a source of continuous electric voltage is allocated and where an alternative electric voltage is used, as it happens with the installed PV cells on the buildings. The efficiency of the inverter is quite high and varies between 93% and 96%.

3.4 Main Principles of PV Systems

A photovoltaic cell is rarely used individually because it is not able to supply an electronic device with enough voltage and power. For this reason, many photovoltaic cells, connected parallel or in series, are used, in order to achieve as higher voltage and power output as possible.

A typical photovoltaic system is made of 36 individual 100cm^2 silicon photovoltaic cells and auxiliary devices which are lead-acid batteries with a typical voltage of 12 V. This system has the capacity of producing more than 13V during cloudy days and can charge a 12 V battery.

In order to use efficiently our system it is necessary to know how it behaves when connected to various electrical loads. As it has been mentioned before, the most important for a PV cell is its I-V curve, which generally characterises a photovoltaic cell. Using the I-V curve, each parameter of a PV cell can be calculated.

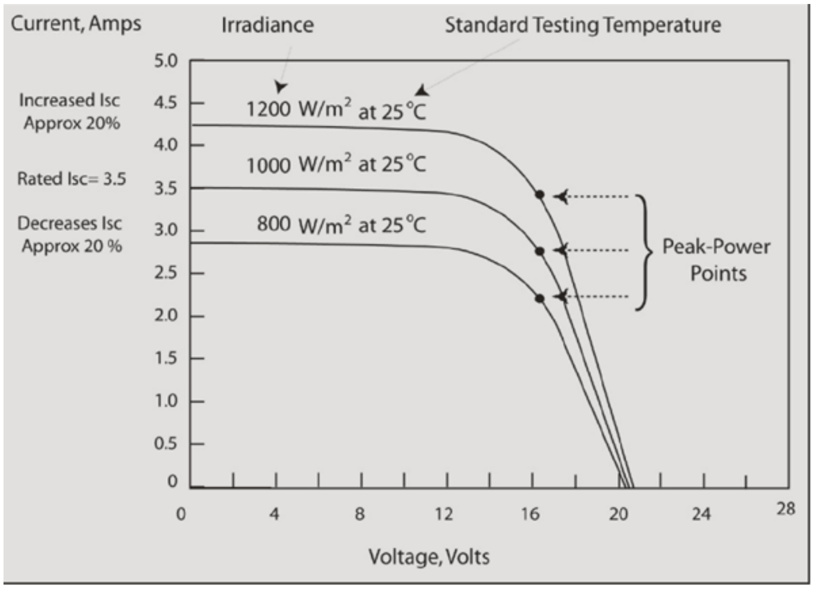


Figure 14: I-V curve in different intensities of solar irradiance

Certainly, in real conditions the function of a PV system differs because of the fluctuation of the intensity of the solar radiation over a period of time. When the light of a PV cell, which supplies an electrical resistance, changes, the power point shifts. This point can be seen experimentally, if the electric power, which is provided by the PV cell with a given power density E and applied on a variable electric resistance, is illustrated graphically. As the resistance varies, fluctuations can be measured in current and voltage using the appropriate measurement devices; ammeter and voltmeter. The graph, as it can be observed, presents a peak point in the "knee" of the I-V curve. The values of the electrical current in the maximum power point are symbolized with I_m and V_m. The max power, which a PV cell can produce, is calculated as follows:

$$P_{max}=V_{max}\times I_{max}$$

Using the max power and the appropriate I-V curve, the fill factor can be easily calculated. Fill factor is the key characteristic in evaluating cell performance of a PV cell, while it can also show how efficient a photovoltaic system is. As the values of the fill factor are closer to the unit 1, the efficiency of the system performance will be increased. Typical values of the fill factor for a PV cell which has a quite high efficiency are between 0.7 and 0.9.

$$\text{FF=}\ \frac{V_{\max} \times I_{\max}}{I_{sc} \times V_{oc}}$$

In order to calculate the electrical power generated from a photovoltaic panel, P_{out}, the total solar irradiance, $G_{total,}$ and the efficiency of the electrical conversion, $\varepsilon_{E,}$ have to be calculated. The solar radiation which reaches the earth has two different components; the beam radiation and the diffuse radiation. So by adding these two values, the total solar irradiance for a point on the surface of the earth, can be calculated.

$$G_{total}=G_{beam}+G_{diffuse}$$

The electrical conversion can be calculated using the following formula:

$$\varepsilon_E=E_{stc}\times(1-P_p\times(T_{module}-T_{reference}))$$

Where: $E_{stc}=\frac{P_{\max}}{Gtot \times A}$ measuring in standard testing conditions

A is the floor area of the panel and

$P_p=\frac{power.drop.off}{P_{\max}}$

So as to calculate the electricity generated from a PV component, the following equation is used:

$$P_{out}= G_{total} \times A \times \varepsilon_E$$

Also the power entering the system can be calculated using the formula below:

$$P_{in}=\tau\alpha\times A\times G_{total}$$

And the system's power loss from the component can be calculated using the following formula:

$$P_{loss}=U\times A \times (T_{module}-T_{air})$$

Where U is the overall heat transfer coefficient (W/m^2*K)

Using all the above values, the useful power supply from a PV cell can be derived from the equation below:

$$Q_h=P_{in}-P_{out}-P_{loss}$$

Finally, the effectiveness of the electrical power output from a PV cell and the efficiency of a PV system can be calculated as follows:

$$\frac{P_{out}}{P_{\max}} \times 100 \textit{ (Effectiveness)} \qquad \frac{(P_{out}+Q_h)}{P_{in}} \times 100 \textit{ (Efficiency)}$$

3.5 Advantages of PV Systems

Photovoltaic modules can easily penetrate in isolated areas since the electrical power they produce comes from an independent and reliable source, the sun. Photovoltaic systems can be economically feasible while their use can help in a large extent the viable growth of a region. Moreover they can produce electric current during cloudy periods and the current that they produce is a direct current (DC). Photovoltaic systems are manufactured in order to function in unfavourable conditions and they have a very small weight. They are installed on the ground, on the roofs of buildings or on any other location where light beams can reach them easily. The principal advantages of PV systems are:

- Low maintenance cost.
- Zero operation cost, because they do not consume raw materials

- A long life cycle; they can provide power for more than 20-25 years.
- Not much variability in their efficiency and more reliable results.
- No noisy effects during their operation.
- Conservation of energy.
- Protection of the environment from pollution of the atmosphere with CO_2 emissions.

A PV system which is installed with an optimum power output of about *1 kW*, in a year's period operation can save around *1300 kWh* of electrical energy and *800 kg* of CO_2 emissions.

4 WIND ENERGY

4.1 The Wind

Wind is the continuous movement of atmospheric air masses and is determined by its speed and its orientation. This movement derives from the changes and the different values of the atmospheric pressure while these values are the result of the solar heating of different parts of the earth's surface. Despite the fact that the atmospheric air moves horizontally and vertically as well, only its horizontal movement is actually considered as wind.

The wind energy derives from the air as a result of its movement. Wind energy is the conversion of a small percentage, about 0.2%, of the solar radiation that reaches the surface of the earth. The wind power around the globe is estimated in 3.6×10^{9} MW while, according to valid estimations of the world meteorology organization, the percentage which is available for energy exploitation in various parts of the world is only 1% and it is estimated around 0.6Q (175×10^{12} KWh).

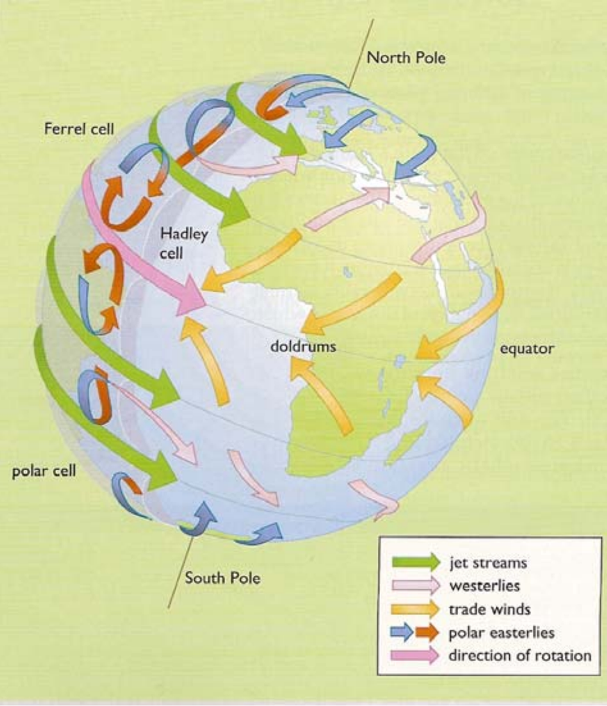


Figure 15: The global wind circulation

Many scientists support that the proper exploitation of the wind energy can resolve in a way the world's energy problem. For example the energy needs in United States hardly constitute the one tenth of the wind energy potential of the country. Nowadays a total of 59,100 MW of wind generated capacity is installed around the world, with an average annual growth rate of 29 percent over the last ten years as it can be seen from the picture below. Although each coin has two sides and thus wind energy can't be easily predicted neither can its continuous operation. Wind is a form of energy with low density, something which implies that large structures have to be made for its exploitation.

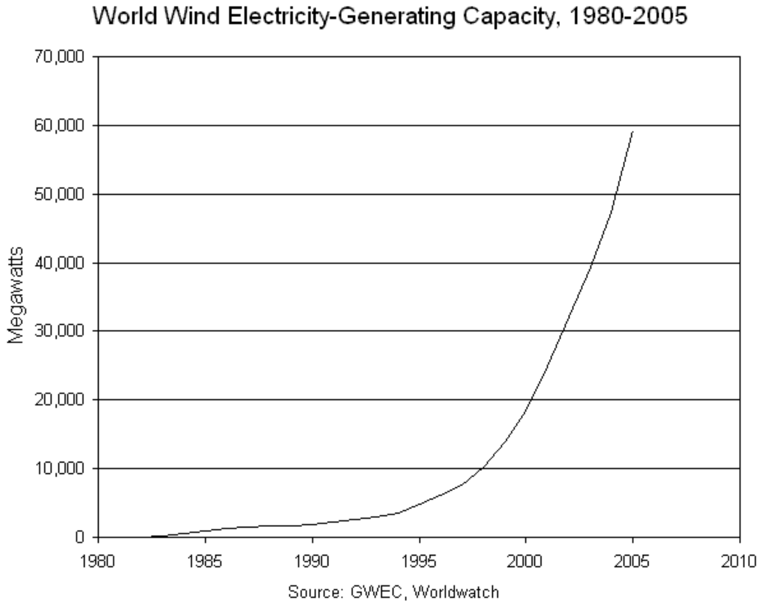


Figure 16: Worldwide installed wind capacity the last 25 years

Undoubtedly the wide use of the wind energy and its efficient exploitation is going to improve the global energy balance without overloading at the same time the environment with dangerous gases.

4.2 History of Wind Energy

The exploitation of the wind energy is as old as the human existence on the Earth. It played an important role in the humanity's improvement mostly the use of the wind energy in sailing, irrigation and agriculture. According to the Greek Mythology all winds were governed by a god named Aeolos, who was considered as the administrator of the winds and this highlights the importance of wind energy in the economic and productive activity during those years.

The wind energy was firstly used by man in sailing boats. In addition historical and archaeological reports support that wind machines were used by Chinese and Egyptians. Specifically wind energy propelled boats that were used by Egyptians along the River Nile in 5000 B.C while Chinese were pumping water with the use of simple windmills in 200 B.C.

In Europe, it is assumed that windmills appeared just before 1200 AD and they were transferred by the crusaders on their way back. The first recorded reference was in 1185 AD which mentions a windmill in the village of Weedley in England.

During the dark ages windmills appeared in Holland, in Spain, in Portugal, in France and in Italy. In Holland they were used for the pumping of waters from areas that were located in a lower level than that of the sea. The type of windmill that was used during that era in Europe was mainly horizontal axis with four blades. Another type of windmill which was widely used during the renaissance period was a slow multi blade windmill as illustrated in the picture below.

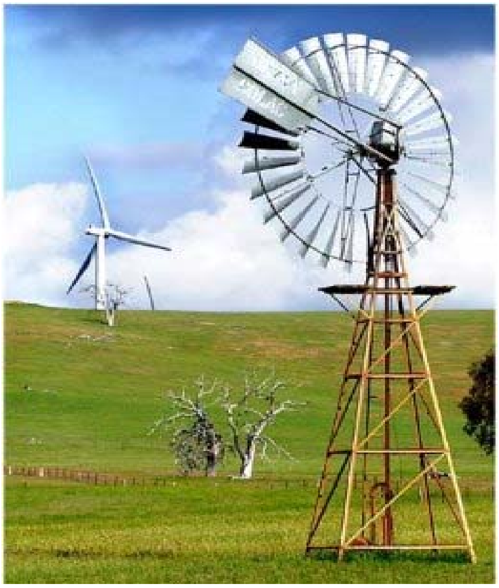


Figure 17: A multi-bladed wind turbine

In the beginning of our century the Danish produced electricity from the wind, while in America windmills with a metallic structure were used for electricity production as well. From 1870 until 1930 Chicago became the biggest industrial centre for windmills production with an estimated production of about 6 millions units over that period. In 1891 an experimental wind turbine was operated in Denmark with 2 electric generators and a rotor blade with a diameter of 22.8 metres under the supervision of professor P.La.Cour. In addition during 1930 the Baltic machine was manufactured with a power potential of 100 KW with the design supervision of Sabanin and Yuriev. Finally in 1940 an experimental wind turbine with two blades was manufactured in the Vermont in U.S.A which was rated at 1.25 megawatts in winds of about 30 mph.

In the recent years that followed after the Second World War, the use of the atomic energy along with the low prices of the oil significantly limited the interest for the exploitation of wind energy. However the environmental pollution and the energy crisis made the technologically developed countries to show an intensive interest for this pure and ancient energy source.

4.3 Wind Turbine Types

The machines, which were proposed to harness the wind energy, are considered as wind turbines. Wind turbines are categorized according to the orientation of their axes in comparison with the flow of the wind. There are various types of modern wind turbines, which are distinguished in the following two main categories: horizontal axis and vertical axis turbines.

Modern wind turbines are also classified as high rotation speed ones and low rotation speed ones, depending on a non dimensional value known as the tip speed ratio (λ); this is defined as the ratio of the speed of the extremities of a windmill rotor to the speed of the free wind, and is illustrated below. A useful measure is provided by this ratio, based on which the different characteristics of the wind turbines can be compared.

$$\lambda = \frac{\omega \times R}{v}$$

Where ω is the angular velocity in radians per second, R is the radius of the rotor in meters and V is the wind velocity in meters per second.

In addition, the rotation speed of a wind turbine depends on its aerodynamic parameters and its wind blades size. Moreover, the interconnection of the turbine to the electric grid plays an important role because all the modern wind generators which are interconnected to the grid produce electric current which have the frequency of the central grid. For example, Greece and the rest of the European countries operate at a frequency of 50 Hz in comparison to UK and U.S.A which operate at a 60 Hz frequency.

Finally the parameter of solidity, as illustrated below, is used to distinguish the wind turbines. Solidity is usually defined as the percentage of the area of the rotor, which contains material rather than air.

For horizontal axis machines it is defined as:

$$\sigma = \frac{z \times c \times R^2}{\pi \times R}$$

For vertical axis machines it is defined as:

$$\sigma = \frac{z \times c}{R}$$

Where parameter σ is the solidity of the turbine, z is the number of the blades, R is the radius of the rotor and c is the chord (width) of the blade.

4.3.1 Horizontal Axis Wind Turbines

The horizontal axis wind turbines have their axis parallel to the earth's surface and to the winds direction (head on), although sometimes their axis can also be vertical to the winds direction (cross-wind). They operate with the blades in front of the wind (up-wind) or behind the wind (down-wind). They have one, two, three or a large number of blades and they cover approximately 90% of the installed wind turbines around the world.

One of their basic characteristics is that their power coefficient is quite high and their operation at high values of the tip speed ratio is excellent. Moreover horizontal axis wind turbines had a rapid increase during the last 20 years and they are almost universally employed to generate electricity. Every day companies design small or big scale wind turbines with a power production of some Watt up to many MW as in the picture below.

Figure 18: The ENERCON E-82 wind turbine

4.3.2 Vertical Axis Wind Turbines

The vertical axis wind turbines in comparison to the horizontal ones can harness the wind from any direction without the need of reallocating the rotor when the wind changes direction and they constitute simple structures. The most common types of these kinds of turbines are Savonius and one of the most popular in the world market, Darrieus. They hold approximately 2-3% of the winds world's trade.

Figure 19: A Darrieus-type vertical axis turbine

Vertical axis machines have very good aerodynamic efficiency, are also independent of the winds direction, have low manufacture cost and simple control systems. Moreover their mechanical parts and the generator are usually settled on the ground so the turbine tower is lighter than that of the horizontal ones and the maintenance of the system is easier, while the power output can reach a maximum value of one MW.

4.4 Wind Turbines Technology

4.4.1 Operation of a Wind Turbine

In the previous paragraph, reference was made to the extensive use of horizontal axis wind turbines around the planet for electricity production instead of vertical axis turbines. Therefore it is considered appropriate to comment on the main parts of a horizontal axis wind turbine.

A wind turbine consists of the following four main parts: the base, tower, nacelle, and blades, as shown in the picture below. The blades capture the wind's energy and spin a generator in the nacelle. The tower contains the electrical circuits, supports the nacelle, and provides access to the nacelle for maintenance while the base is made of concrete and steel and supports the whole structure.

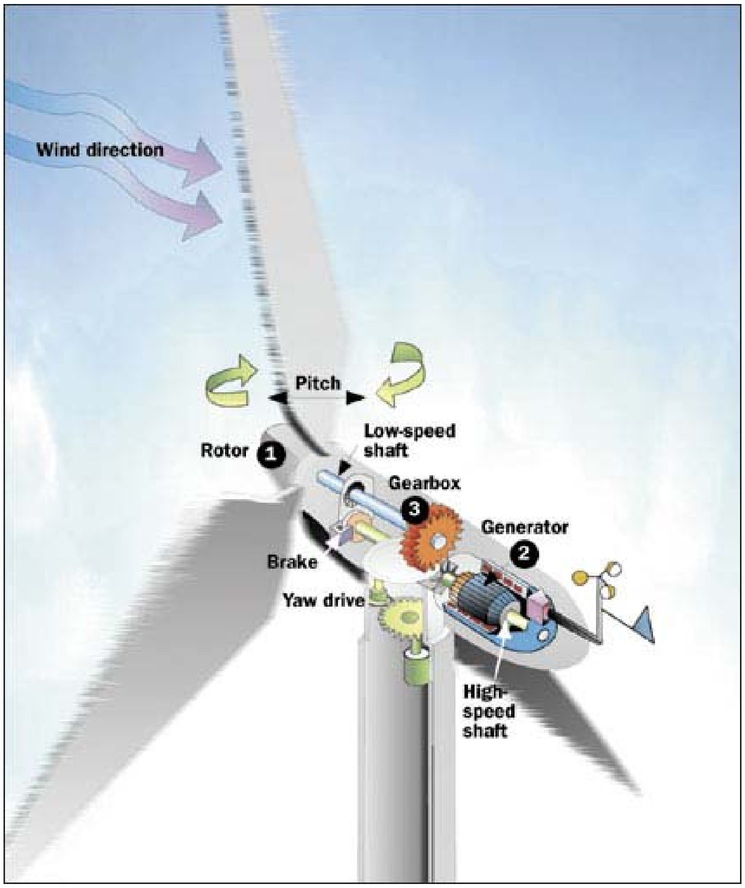


Figure 20: Main parts of a wind turbine

Moreover modern wind turbine rotor blades capture wind’s energy and convert it to rotational energy of shaft**.** The shaft, which is connected to the generator and transfers the rotational energy to it, is distinguished in two types: high-speed shaft which drives the generator and low-speed shaft which operates about 30 to 60 rotations per minute. Inside the nacelle there is the generator and the gear box. The gearbox connects the low-speed shaft to the high-speed and increases the rotational speed from about 30 to 60 rpm to about 1200 to 1500 rpm. Generator uses rotational energy of shaft to generate electricity using electromagnetism while induction generators that produce 60-cycle AC electricity are widely used. In addition electronic control is used to shut down the turbine in case of malfunction and yaw controller is used to keep the rotor facing into the wind as the wind direction changes.

Towers are usually designed in a white steel cylinder of about 50 to 70 meters tall and 3 meters in diameter. They have a ladder running up the inside and a hoist for tools and equipment. Tower supports rotor and nacelle and lifts the entire system to higher elevation where blades can be safely put in operation. Finally the base is made of concrete reinforced with steel bars and supports the whole structure.

4.4.2 Distribution Network

Distribution network allocates properly the electricity to the grid. The grid is the link between wind turbines and the consumer and consists of the transformers, the high voltage transmission lines, the substations and the consumer. The philosophy concerning the electricity grid distribution network from national electricity companies all over the world is the same. This which changes is the different levels of the distribution voltage.

The electricity which is carried from the generator down, through electric cables of the tower flows to a transformer. The transformer increases the voltage of the electric power to the distribution voltage. Then the distribution voltage power travels through high voltage transmission lines and reaches a substation which decreases it. After that the distribution voltage travels again through transmission lines and supplies farms, industries, villages and towns.

In the UK the electricity from the wind turbines reaches the transformer which increases the voltage of the electric power to 25.000 volts. Then the voltage is transferred to a substation where the voltage increases more to 275.000 or 400.000 volts and travels through transmission lines. The local network operating companies receive that electric voltage and distribute it at 132.000 volt. Finally, after the appropriate reduction of the electrical voltage with the use of substations, industries receive the electrical voltage at 33.000 volts, towns receive it at 11.000 volts, while villages, farms and houses at 230/400 volts. [1] [26]

In contrast to the UK, the distribution network in Greece differs because of the different values of the electrical voltage. The transformer increases the electric power voltage to 15.000-20.000 volts. Then the substation increases the voltage to 150.000 volts which is transferred through high transmission cables. The local network operating company (DEH) receives that voltage and distributes it to 20.000 volts. Finally, industries receive electricity at 690 volts, farms at 380 volts and houses at 220 volts [64] [65]

4.4.3 Main Principles of Wind Turbines

When a force is transferred from an air stream to a solid object, it is very different than the force which is transferred between solid objects. Moreover when an object experiences a force from an air stream, it can be distinguished in two equivalent components. In the first component the force is acting in the direction of the flow and is known as drag force while in the second one the force is acting perpendicular to the flow and is known as the lift force. Lift and drag forces are proportional to the energy of the wind.

The drag force can be resolved in two more components; pressure drag and friction drag. Pressure drug acts on the front side of the object, pushes the object along with the flow and the more perpendicular this pressure drag is, the bigger is the drag force experienced on the object. On the other hand, friction drug acts when the fluid is in line with the front side of the object and as it becomes more parallel, the drag force which occurs on the object becomes less. Objects are designed to reduce the drag forces as much as they can and they are described as streamlined objects, lines which follow a smooth stream. These kinds of shapes can be found in sharks, airships and the ***aerofoils*** (the shape of a wing or blade). A body which is designed to produce large quantities of lift is an aerofoil.

The Lift force is the component of aerodynamic force which is perpendicular to the airfoil and makes things rise like the planes. Daniel Bernoulli, a Swiss scientist, observed that the more quickly a fluid travels over a surface, the less time it has to push on the surface, in other words an increase in the velocity of flow will result from a decrease in the static pressure.

The total drag force is: $F_D = C_D \frac{1}{2} \rho v^2 A$ and the total lift force is: $F_L = C_L \frac{1}{2} \rho v^2 A$

Where C_D is the drag coefficient and depends primarily on the shape of the object, ρ is the fluid density (kg/m^2), v is the fluid velocity (m/sec) and A is the frontal area of the body (m^2).

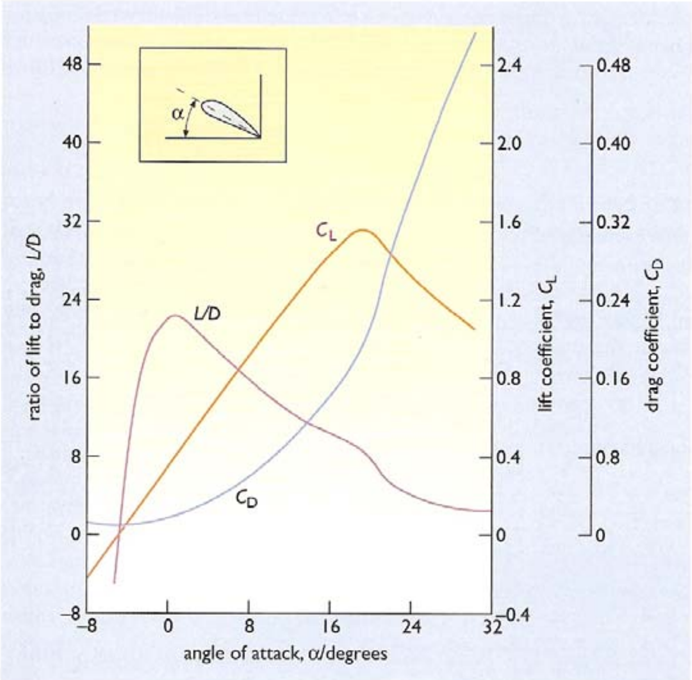


Figure 21: Lift coefficient CL, drag coefficient CD, and lift to drag ratio (L/D) versus angle of attack, a, for a Clark Y aerofoil section.

Lift and drag forces are characterized by the lift and the drag coefficients which are essential when selecting an aerofoil section for wind turbine blade design. These coefficients for different range of angles of attack are measured in wind tunnels and catalogue over the last decades. Typical coefficients for an airfoil section are illustrated above.

The amount of power (watts) that can be harnessed from the wind is a function of the air density (ρ) in kilograms per cubic meter, the swept area of rotors blades (A) in meters, and the instantaneous wind speed (V) in meters per second as shown below:

$$P=0.5\times Cp\times\rho\times A\times V^3$$

Where: Cp is the power coefficient of the turbine

A is the swept area and is equal to $A = \frac{\pi \times D^2}{4}$

D is the Rotor's diameter (m).

It can be observed that the cube of the wind velocity has a strong influence on power output. Thus whereas doubling A may produce twice the power, a doubling of wind speed produces eight times the power potential. Moreover by increasing the rotor diameter by 30 percent (for example from 3m to 3.9m) you can increase the swept area by nearly 70 percent (actually 69% from 7.07m2 to 11.95m2). The power coefficient Cp also varies depending on the wind speed for individual machines.

The power coefficient Cp is the ratio of the actual power output compared to the theoretical available. Moreover Cp is a function of blade tip speed and pitch angle. Blade tip speed varies with wind speed, and the blade pitch angle is variable for pitch regulated turbines. In the market for horizontal axis turbine the Cp is approximately 36% and for vertical axis it is approximately 45%. For an ideal turbine without losses and for maximum power extraction, the power coefficient, equals the Betz limit (Cp = 16/27=59%).

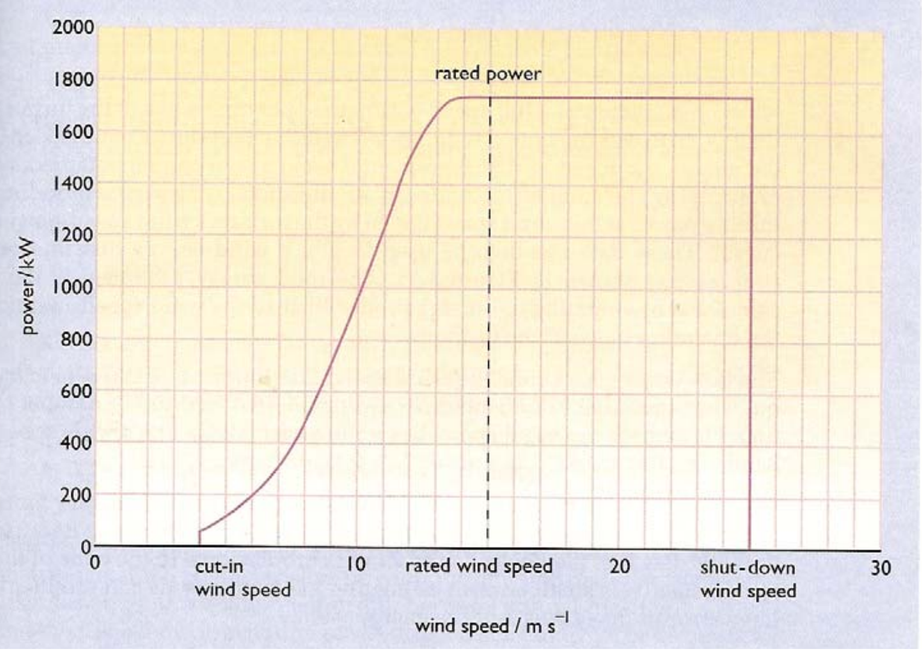


Figure 22: Typical wind turbine wind speed-power curve

The power output varies with the wind speed and every turbine has a characteristic wind speed-power curve. The power performance curve of a turbine includes cut-in speed, rated speed and cut out speed as it can be seen from the above picture. Cut in speed is the minimum speed which the turbine starts operation, rated speed is the speed at which the maximum output from the turbine can be delivered. Cut out speed is the maximum speed which the turbine can produce power, beyond this point stops the operation. However in practice many machines do not cut out in high wind speeds because of stall regulation, but continue to operate at greatly reduced efficiency at reasonably large power.

4.5 Ducted Turbines

4.5.1 Introduction in DWT

Ducted turbine is an innovative new device. It was the result of an original idea of a Glaswegian engineer called Webster in 1979. After the death of Webster his family came in contact with the University of Strathclyde in order to continue this innovative idea. The mechanical engineering department of Strathclyde evaluated the idea and continued trying to develop that concept.

During the recent years some ducted turbines were installed on the roof of the lighthouse building in the centre of Glasgow for demonstration purposes while some others were installed on the roof of James Weir Building in Strathclyde University in order to help students to make measurements for their projects. Nowadays, the improvement in the operation of ducted turbines is a matter of concern for many scientists; although they are still in an experimental stage, the future seems promising.

4.5.2 Operation of a DWT

The ducted turbine is mounted at the edge of a building and uses the updraft of the air flow in order to start its operation. The air as shown in the picture below flows linear with a perpendicular direction to the façade of the building. When it reaches the building the flow becomes turbulent and the air enters the turbine. Of course only a small part of the air enters into the turbine, the rest is deflected downwards, upwards or around the building. A spoiler is also settled on the roof of the device due to pressure variation through the turbine.

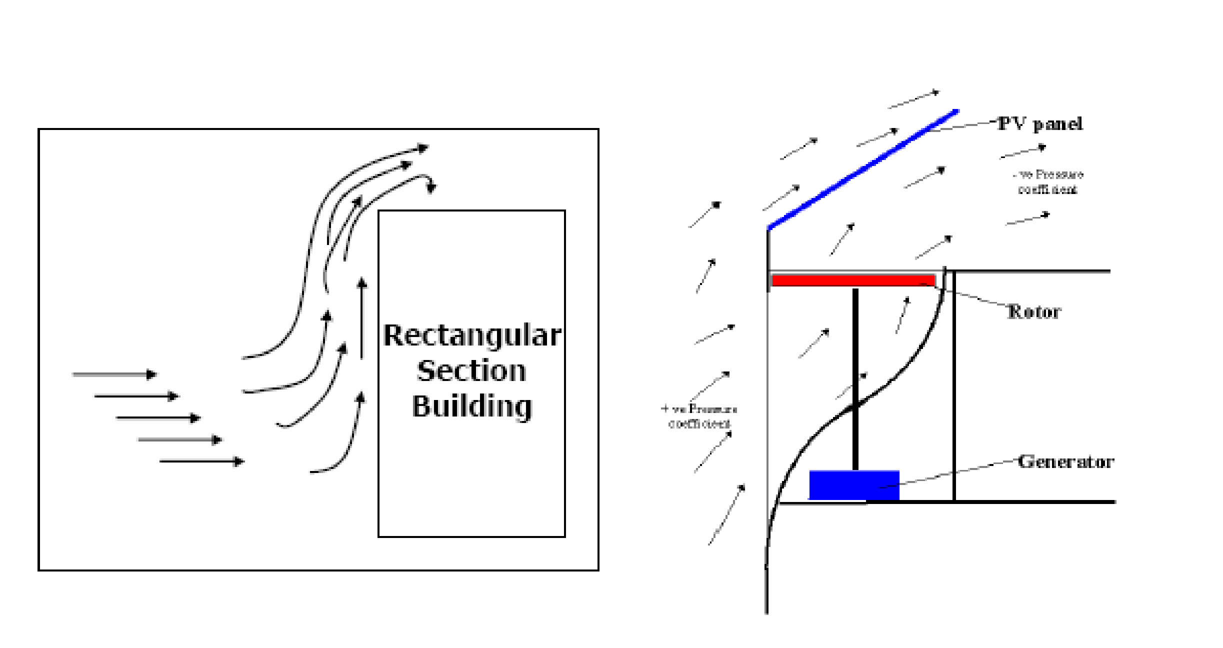


Figure 23: Wind flow over the building and wind flow through a DWT

Usually a PV panel is mounted on the spoiler and then the operation of a hybrid system is feasible. In our case a PV installed next to the ducted turbine is going to be used and the power output will be the combination of them both. A further reference to the operation of the system will be made in chapter 6.

The use of ducted turbines in an urban environment can be efficient for offices and industries but not for residential houses. This is because they have quite small coefficient, about 0.2 and they operate in winds over 5m/sec. Moreover the power output is low, about 90 watts maximum and the cost of installation is quite high. However, they are dependent upon the wind blowing in the correct direction, in contrast to most of the turbines, which use yaw motors to find the correct position of the air flow.

4.5.3 Basic Equations for DWT

In order to calculate the power which comes out from a ducted turbine the following equation is used: $\Delta P_T \times q = Av_2 \left[\frac{\delta \rho v_\infty}{2} - \frac{\rho v_2^2}{2C_v} \right]$

Where: ΔPT is the pressure which the turbine creates when put into the duct

V is the velocity of the air stream (m^2/sec)

A is the duct cross sectional area (m^2)

q is the volumetric flow rate of the air (m^3/sec)

C_v is the velocity coefficient

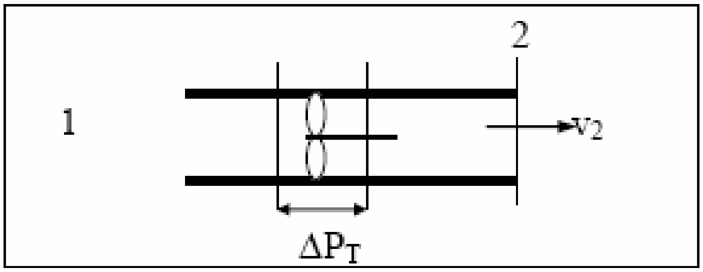


Figure 24: A simple duct with a wind turbine

Assuming that the bracket on the above equation is equal to zero and by doing the appropriate calculations, the maximum power which is extracted by the turbine is calculated as follows: $\Delta P_T = \frac{1}{3} p \delta v_\infty^2$

Where δ is the differential pressure coefficient

Finally the power coefficient is calculated by using the equation below:

$$C_p = \frac{2}{2\sqrt{3}} \times C_v \delta^{\frac{3}{2}}$$

Where C_v is the duct velocity coefficient

Experimental conditions with a pressure differential at about δ=1.5 and a duct velocity coefficient at about $C_v = 0.5$ have shown that the power coefficient C_P for the rotor of the ducted turbine reaches approximately 0.35. This is however reduced by the generator losses to approximately 0.20 – 0.25. In order to improve the efficiency of a ducted turbine, during its operation, the losses from the generator have to be reduced, the parameter δ has to be maximised and the losses inside the duct have to be reduced so as for Cv to move towards 1.

5 PV/WT: Situation in UK and Greece

5.1 PV Systems in UK-Greece

The total available solar resource varies from place to place and depends on the country's latitude, cloudiness and climate. Therefore the amount of electricity that can be produced from a system varies and depends from the available sunlight and the efficiency of the system. From following illustration it can be observed how the levels of total annual solar radiation vary around Europe.

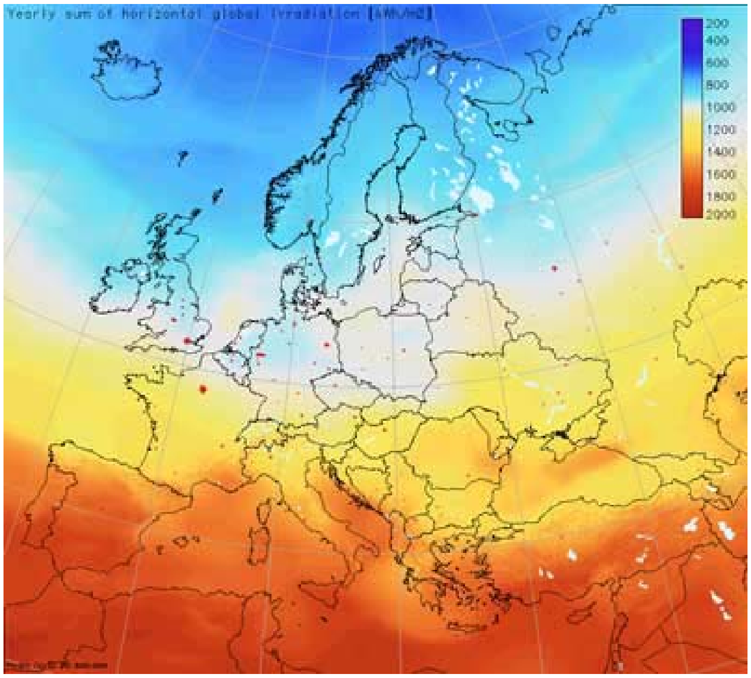


Figure 25: Total annual solar radiation levels in Europe (kWh/m^2)

The overall resource which is available from the use of PV systems is massive. Using a simple calculation shows that if a PV systems with an average efficiency of 10% installed on 0.1% of the earth's surface (about 500.000km^2), they would be capable to produce electricity which can be cover all of the world's current energy needs.

In addition total installed capacity worldwide was estimated at 2.2 GW by the end of 2003. More specifically in Europe solar production was 200 MW in 2003 with installed capacity reaches approximately 560 MW and with a realistic prospect to have 3 GW of installed capacity by 2010. Focus is on Portugal which is already constructing the biggest solar park in the world with a potential of 11MW and hopes will start operation in January 2007. This park is going to cover the electrical needs of 8.000 households while it will help in reducing CO2 emissions by about 30.000 tonnes per year. Pursuing Portugal is Spain which already puts in operation (the current largest solar park in the world) of a total capacity to over 10MW and with another 30 MW pipeline. [15]

On the other hand, UK and Greece have low rates of solar capacity and their contribution in the total percentage of electricity around Europe is also less. The following table is shown the total solar PV installed capacity in Europe in 2003. Germany can be observed as being the first country in Europe with installed solar capacity about 398 MW and with an installed capacity in 2005 over 600 MW of new PV. [12] [60]

Country	**Capacity (MW)**	**Pct. of Total**
Germany	397.6	70.7%
The Netherlands	48.6	8.6%
Spain	27.3	4.9%
Italy	26.0	4.6%
France	21.7	3.9%
Austria	16.8	3.0%
United Kingdom	5.5	1.0%
Sweden	3.6	0.6%
Luxembourg	3.5	0.6%
Finland	3.4	0.6%
Greece	3.3	0.6%

Portugal	2.1	0.4%
Denmark	1.9	0.3%
Belgium	1.1	0.2%
Total	**562.4**	**100%**

Table 3: Total installed solar PV capacity in Europe in the year of 2003

Presently the installed solar PV capacity has been increased for both UK and Greece. There is a remarkable turn in the use of PV systems during the last 4-5 years. The development in this sector is similar for both countries as it can be seen from the following picture. For Greece this seems interesting because from a simple observation of the above ***(figure 25)*** it can be seen that Greece has almost double the irradiation intensity of the UK. This should be fed as a motivation for Greece to increase its PV technologies and to become more independence from fossil fuels.

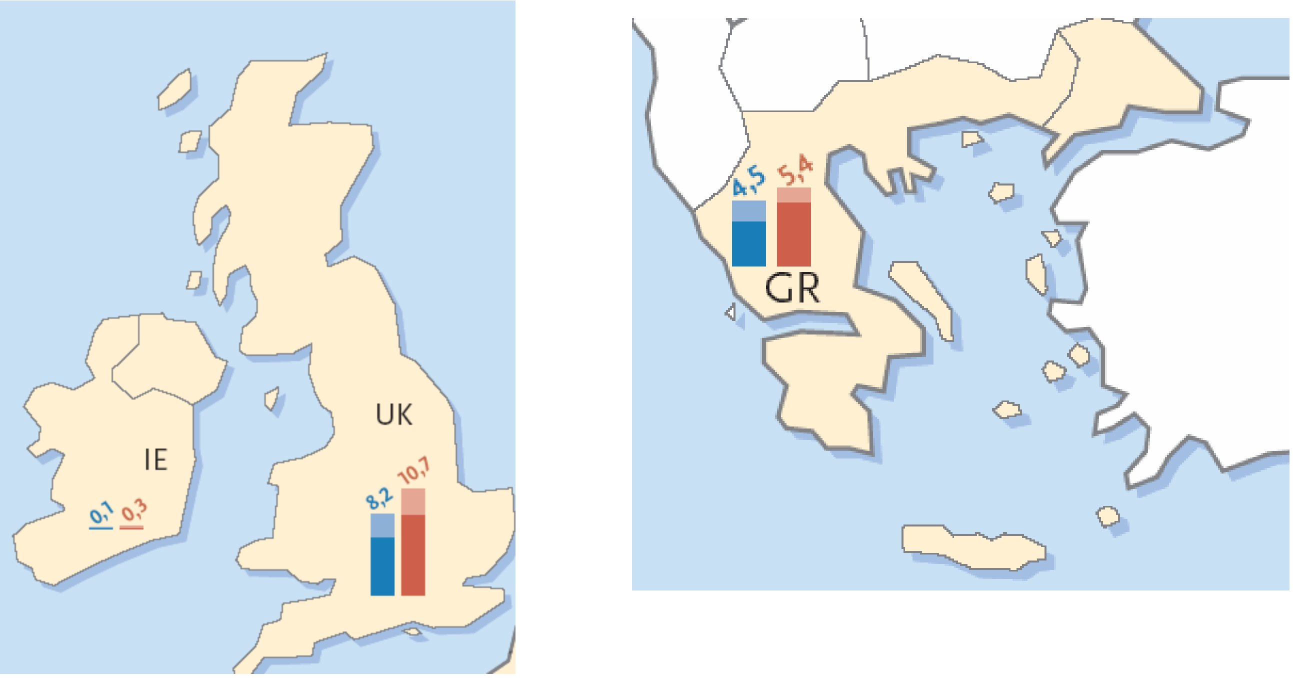


Figure 26: Installed PV capacity in UK-Greece in the year 2004(blue) and 2005(red)

The use of solar power in Greece reduces the need for conventionally generated energy by about 1.4 billion KW per year. A 50-MW parabolic trough-type solar power plant is under construction in Crete. DEH is planning a 100 KW photovoltaic park for the island of Gavdos in Crete, in addition to already-existing PV capability on the island. Energy Photovoltaics Company (**Heliodomh**) announced in July 2001 that it would build a $22 million manufacturing facility for PV panels in Kilkis situated in the north of Greece, with annual production capacity of 5 MW. The company is also implementing a 400 KW photovoltaic power station on the roof of its manufacturing unit building (EIA Country Analysis Briefs 2003). As it can be observed from the following table there is a rapid increase in the installed PV system capacity in Greece during the last 10 years. The cumulative installed PV generation capacity increased by 50 % during 2004 reaching a total of 5.4 MW in 2005 as is mentioned previously. [21] [64]

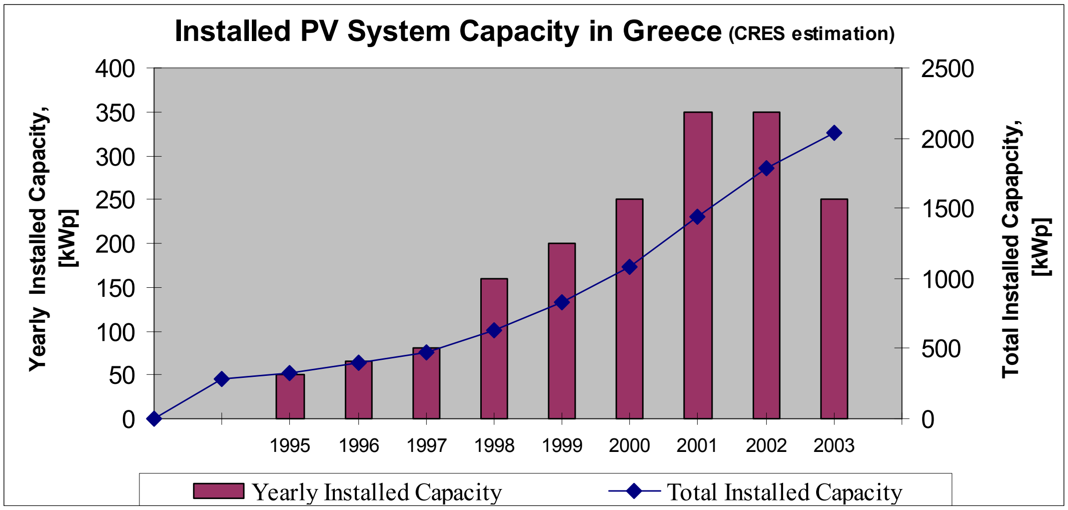


Figure 27: Installed PV capacity in Greece between the years 1995-2003

The use of solar power in UK had a significant increase in the annual installed PV generation capacity during the last 10 years as it can be observed from the below graph. Especially the last 5 years there is a rapid increase in the installed PV generation capacity by 38% during 2004 and 2005 reaching a total of 10.7 MW as is shown previously (***figure 26***). Much of this increase is due to the rapid expansion of the grid-connected market, accounting for 97 % of the 2004 installations. Government support of the Major Demonstration Programme launched in 2002 (which it would be mentioned more analytically in a following paragraph) as well as Field Trials accounted for approximately 93 % of the total new capacity. Finally many large projects launched during 2005 and 2006 including Eden Project in Cornwall, Quadrant Project in Sheffield, Spinal Injuries Association Project in Milton Keynes and the CIS Tower Project in Manchester which they brought the total amount of PV installed technologies in the UK during this period to over 2 MW. [1] [23]

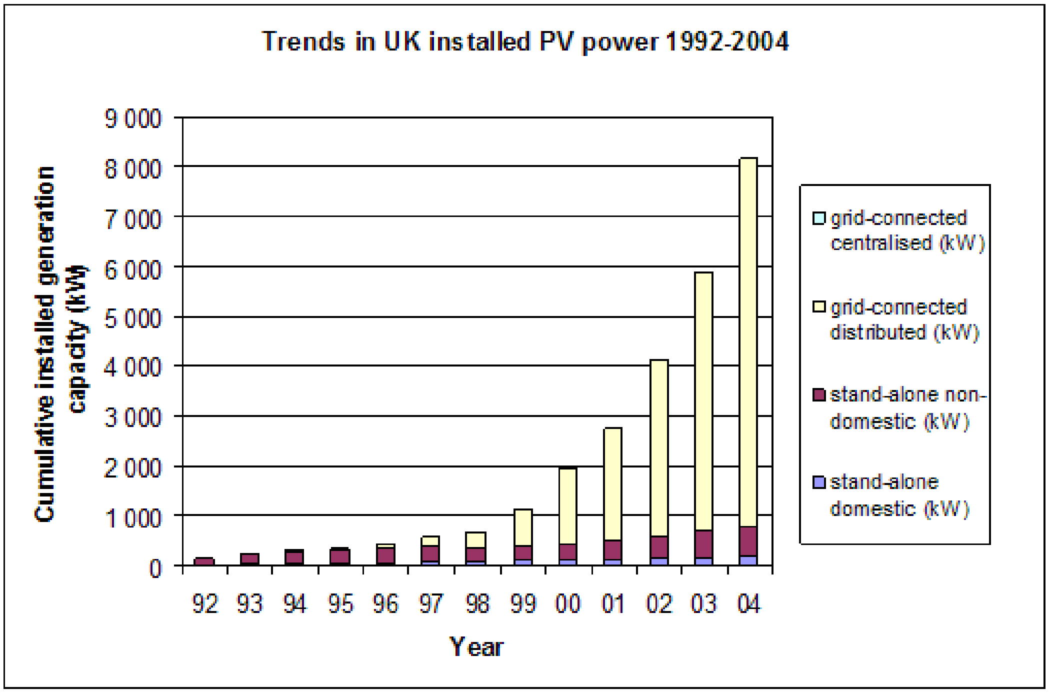


Figure 28: Installed PV capacity in UK between the years 1992-2004

5.1.1 Cost of Energy from PV

The cost of a KWh that is produced by PV systems**,** internationally oscillates from 0.25$ to 1$. In Greece, the average cost for a KWh, for grid-connected systems is roughly 0.6 €/W. Of course the cost varies, depending on the nature of the system, autonomous or grid-connected, and the climatic region that is installed within. [24]

The installation costs for a PV system vary as they depend on its application. The autonomous PV systems are more expensive than the grid-connected because of the auxiliary system costs. The average cost of an autonomous system in Greece is approximately 11-12 €/W, while for a connected system to the grid the average cost oscillates about 9 €/W. These costs are much higher than the prices of more mature markets like Japan and Germany where the cost for an interconnected system is approximately 6 €/W, while in large scale PV systems these costs can fall approximately to 4 €/W. [24]

In UK the average cost for a KWh, for grid-connected systems is approximately £0.4. The cost is similar to Greek standards and the installation system cost is quite expensive as will be demonstrated below. [1] [23]

Average PV system prices are typically in the range £2.5 to £3.7 per W for reasonable volume orders. For small orders retail prices range from approximately £2.7 per W up to £5 per W. Lower minimum prices have also been achieved. The lowest module price achieved during 2004 was £2.28 per W for crystalline modules imported from mainland Europe. On-grid prices ranged from £4.2 per W to £9.7 per W. However the average turnkey price for a standard 1 to 3 kW system was £6.2 per W, compared to £6.7 per W in 2003. This was because of the high capital costs and low value of the electricity generated. However payback period times on the capital investment on this system were very long. Over 100 years! [21] [24] [64] [65]

5.1.2 PV Systems for Domestic Buildings

PV systems prices in the UK, Greece and a number of other countries are often substantially higher as it has been mentioned in the previous paragraph. In UK conditions, roof-top PV systems are not yet an attractive investment at least in narrow financial terms. UK has lagged behind many European countries in the use of PV technology (as it shown in *table 3)* and many people are not willing to use this kind of technology because of the bad climatic conditions during the year, especially in the north part of the country with high costs of installation and maintenance.

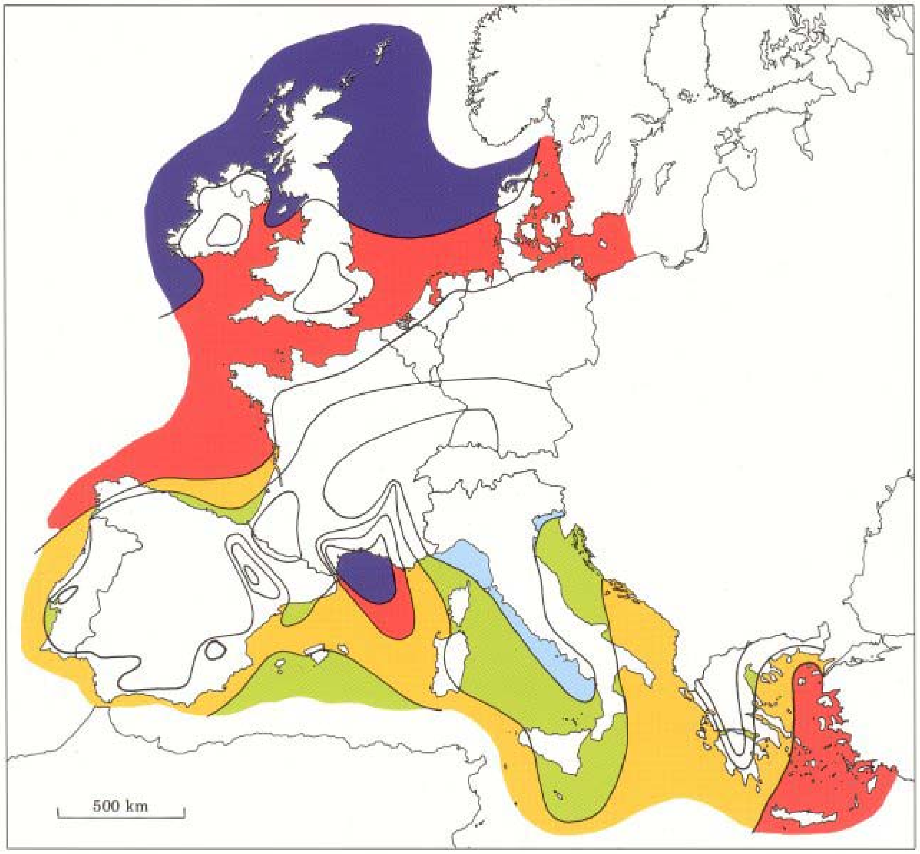
Within the domestic sector many housing associations and local authorities are beginning to install PV into homes when refurbishing them. However as mentioned previously in 2002 the UK Department of Trade and Industry launched a Major Photovoltaics Demonstration Programme, which should result in 3000 domestic roofs and 140 large non-residential buildings having PV systems installed by the end of the year 2006. Moreover photovoltaic installations can be found in a whole range of different applications such as traffic lights, parking meters and other electrical equipment often incorporated with small PV systems. [1]

Nowadays the growth of the PV market in Greece is in a developing stage. Few companies are active in this sector and a small number of installations of PV systems maintain existence. However, the excellent meteorological conditions have to encourage the growth of this technology. Today about 40 companies are active in this specific field. The biggest companies in the photovoltaic sector scarcely install 20-250 kW every year, while the current potential of the Greek market absorbs just a few hundred kW annually with a low power production in comparison to the country's active solar potential and the rapid development of other countries. [24]

Until 2000, the Greek market was dominated by the autonomous systems. The first grid-connected systems in building applications were installed during the last five-year period, while in 2001, thanks to the Ministry of Development subsidies of the Operational Program, certain hundreds of grid-connected kilowatts in solar applications were installed around Greece and mainly in Crete. [24]

5.2 Wind Energy UK-Greece

Wind resource assessments indicate the potential for wind power. However the maximum available wind resource will vary amongst different global areas. Furthermore it is influenced by the local topography and ground cover. It is generally recognised that wind has a higher potential over the oceans than over the ground as illustrated by the picture below.

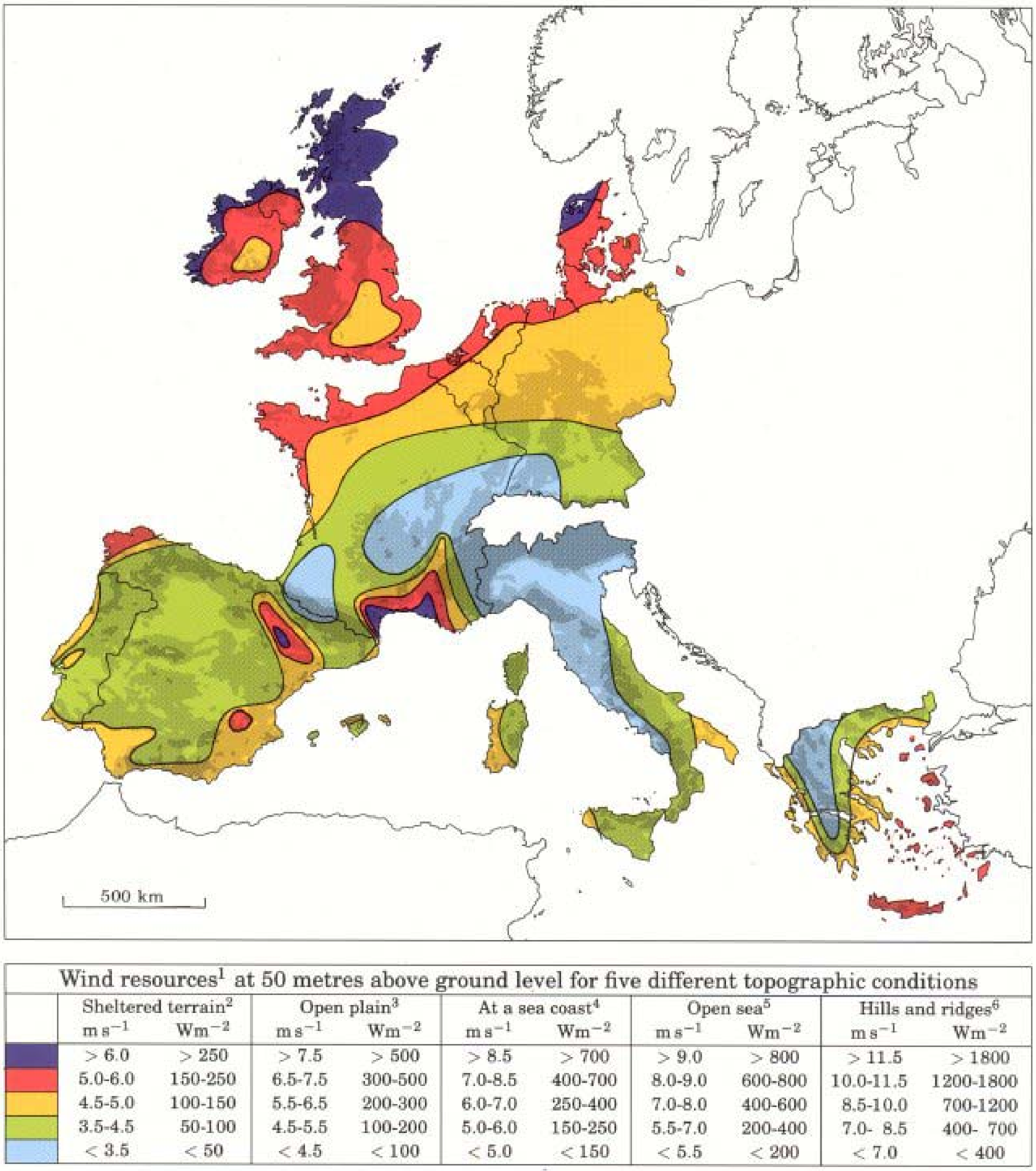


Wind resources over open sea (more than 10 km offshore) for five standard heights										
	10 m		25 m		50 m		100 m		200 m	
	$m\,s^{-1}$	Wm^{-2}	$m\,s^{-1}$	Wm^{-2}	$m\,s^{-1}$	Wm^{-2}	$m\,s^{-1}$	Wm^{-2}	$m\,s^{-1}$	Wm^{-2}
🟪	> 8.0	> 600	> 8.5	> 700	> 9.0	> 800	> 10.0	> 1100	> 11.0	> 1500
🟥	7.0-8.0	350-600	7.5-8.5	450-700	8.0-9.0	600-800	8.5-10.0	650-1100	9.5-11.0	900-1500
🟨	6.0-7.0	250-300	6.5-7.5	300-450	7.0-8.0	400-600	7.5- 8.5	450- 650	8.0- 9.5	600- 900
🟩	4.5-6.0	100-250	5.0-6.5	150-300	5.5-7.0	200-400	6.0- 7.5	250- 450	6.5- 8.0	300- 600
🟦	< 4.5	< 100	< 5.0	< 150	< 5.5	< 200	< 6.0	< 250	< 6.5	< 300

Figure 29: Annual mean wind speed over the sea

In the European wind atlas, the wind resources above 50 meters ground level are measured in metres per second and are distinguished in 5 different categories.

Countries like Ireland, Scotland, Denmark and France have large areas with the highest level of wind speed, more than 8 m/sec (Purple) while countries like Greece, Holland and England have large areas with wind speed between 7-8 m/sec as can be seen by the picture below.



Wind resources[1] at 50 metres above ground level for five different topographic conditions

	Sheltered terrain[2]		Open plain[3]		At a sea coast[4]		Open sea[5]		Hills and ridges[6]	
	$m\,s^{-1}$	Wm^{-2}	$m\,s^{-1}$	Wm^{-2}	$m\,s^{-1}$	Wm^{-2}	$m\,s^{-1}$	Wm^{-2}	$m\,s^{-1}$	Wm^{-2}
🟪	> 6.0	> 250	> 7.5	> 500	> 8.5	> 700	> 9.0	> 800	> 11.5	> 1800
🟥	5.0-6.0	150-250	6.5-7.5	300-500	7.0-8.5	400-700	8.0-9.0	600-800	10.0-11.5	1200-1800
🟨	4.5-5.0	100-150	5.5-6.5	200-300	6.0-7.0	250-400	7.0-8.0	400-600	8.5-10.0	700-1200
🟩	3.5-4.5	50-100	4.5-5.5	100-200	5.0-6.0	150-250	5.5-7.0	200-400	7.0- 8.5	400- 700
🟦	< 3.5	< 50	< 4.5	< 100	< 5.0	< 150	< 5.5	< 200	< 7.0	< 400

Figure 30: Annual mean wind speed over the Europe

From the above maps it appears that UK has the best wind resource in Europe especially Scotland. Conversely the eastern part of Greece which includes Crete has a very reliable wind potential with annual wind speeds of more than 5 m/sec. Moreover as it can be better observed from the picture below the wind speeds on the Islands of the South Eastern Aegean Sea and in some parts of Eastern Crete, are very high reaching annual values of more than 8 m/sec.

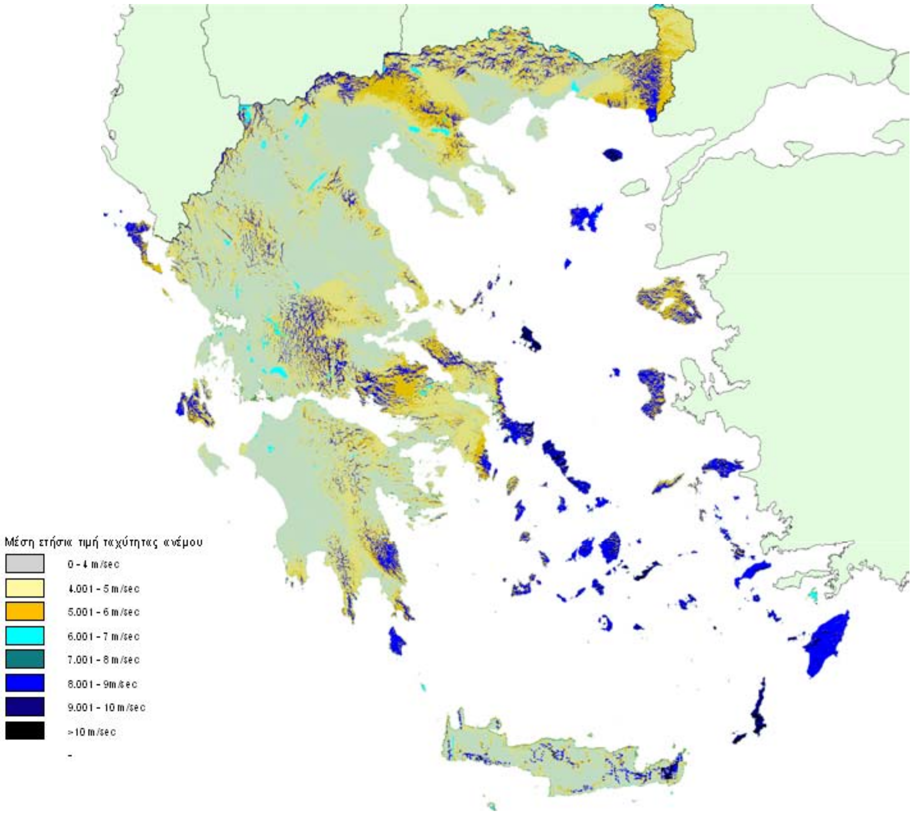


Figure 31: Annual mean wind speed over Greece

During the last 10 years there was a rapid increase in wind power installation around Europe as it is shown in the table below. Germany is Europe’s pioneer country as they embarked upon installing wind power as well as photovoltaic panels.

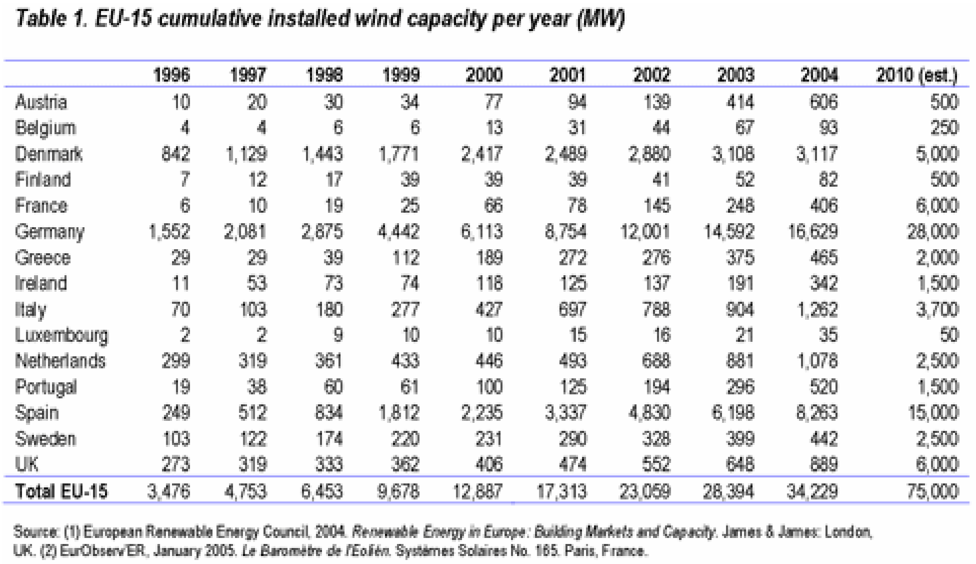


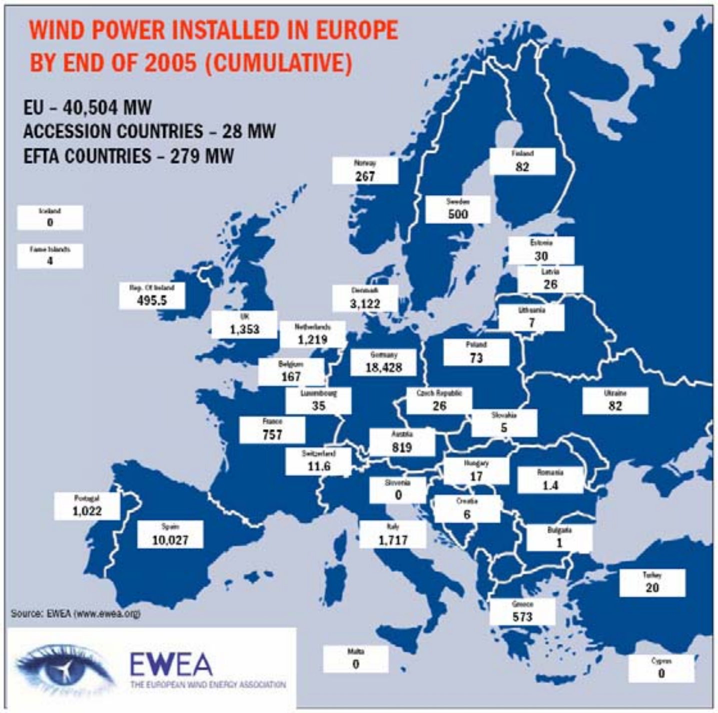
Table 1. EU-15 cumulative installed wind capacity per year (MW)

	1996	1997	1998	1999	2000	2001	2002	2003	2004	2010 (est.)
Austria	10	20	30	34	77	94	139	414	606	500
Belgium	4	4	6	6	13	31	44	67	93	250
Denmark	842	1,129	1,443	1,771	2,417	2,489	2,880	3,108	3,117	5,000
Finland	7	12	17	39	39	39	41	52	82	500
France	6	10	19	25	66	78	145	248	406	6,000
Germany	1,552	2,081	2,875	4,442	6,113	8,754	12,001	14,592	16,629	28,000
Greece	29	29	39	112	189	272	276	375	465	2,000
Ireland	11	53	73	74	118	125	137	191	342	1,500
Italy	70	103	180	277	427	697	788	904	1,262	3,700
Luxembourg	2	2	9	10	10	15	16	21	35	50
Netherlands	299	319	361	433	446	493	688	881	1,078	2,500
Portugal	19	38	60	61	100	125	194	296	520	1,500
Spain	249	512	834	1,812	2,235	3,337	4,830	6,198	8,263	15,000
Sweden	103	122	174	220	231	290	328	399	442	2,500
UK	273	319	333	362	406	474	552	648	889	6,000
Total EU-15	3,476	4,753	6,453	9,678	12,887	17,313	23,059	28,394	34,229	75,000

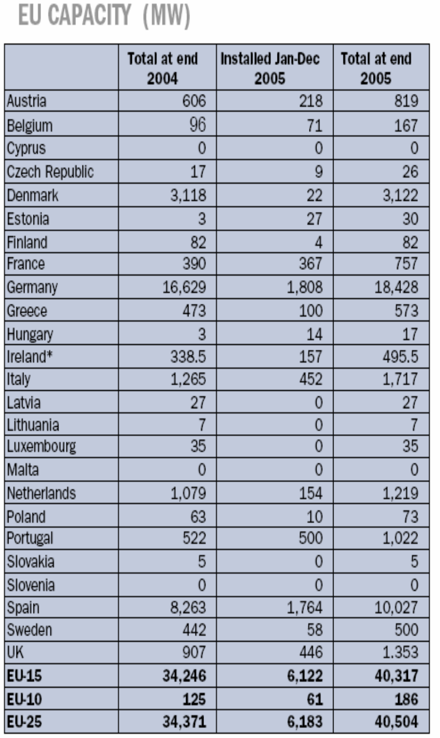
Source: (1) European Renewable Energy Council, 2004. *Renewable Energy in Europe: Building Markets and Capacity.* James & James: London, UK. (2) EurObserv'ER, January 2005. *Le Baromètre de l'Eolien.* Systèmes Solaires No. 165. Paris, France.

Figure 32: Installed wind capacity the last 10 years for the EU-15

Despite the high rates of wind speeds which UK and Greece have, they are following other countries in wind energy capacity levels, with similar or less amount of wind resources. Of course during the last 10 years there has been a significant increase in the installation of wind power in both countries. More specifically in the UK there was a rise of ***30%*** and in Greece ***34%*** and as it can be observed from the picture and the table below, today both countries are competitive in Europe's wind energy market. However it is difficult for both countries to reach the target in terms of annual installations until 2010, according to the target that the White Paper poses.



Source: EWEA (www.ewea.org)


EU CAPACITY (MW)

	Total at end 2004	Installed Jan-Dec 2005	Total at end 2005
Austria	606	218	819
Belgium	96	71	167
Cyprus	0	0	0
Czech Republic	17	9	26
Denmark	3,118	22	3,122
Estonia	3	27	30
Finland	82	4	82
France	390	367	757
Germany	16,629	1,808	18,428
Greece	473	100	573
Hungary	3	14	17
Ireland*	338.5	157	495.5
Italy	1,265	452	1,717
Latvia	27	0	27
Lithuania	7	0	7
Luxembourg	35	0	35
Malta	0	0	0
Netherlands	1,079	154	1,219
Poland	63	10	73
Portugal	522	500	1,022
Slovakia	5	0	5
Slovenia	0	0	0
Spain	8,263	1,764	10,027
Sweden	442	58	500
UK	907	446	1.353
EU-15	**34,246**	**6,122**	**40,317**
EU-10	**125**	**61**	**186**
EU-25	**34,371**	**6,183**	**40,504**

Figure 33: Wind power installed in Europe for the year 2005

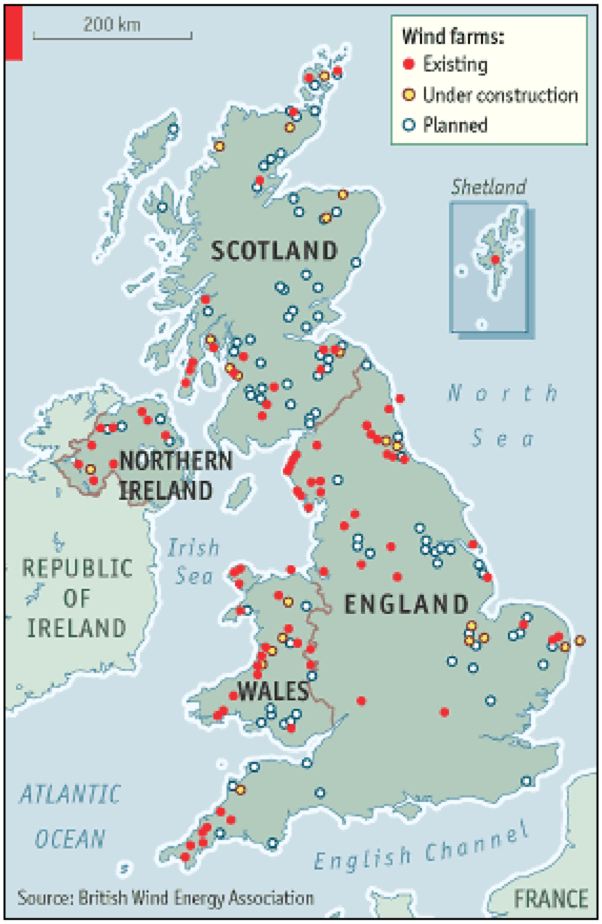
In Greece wind energy is gradually becoming a considerable player contributing in the development of the country as it can be comprehended by the above. The distribution of installed wind farms all over the country is graphically depicted in the picture below. It can be observed that many installations have been made in various areas around Greece. Specifically in Crete the installed capacity is about 105.4 MW which is quite high in comparison to the electrical needs of the island. Moreover this which makes Crete differ from all the other wind energy sites around Greece is that Crete isn't an area interconnected with the national grid. This of course on the one hand gives higher value to electricity produced by wind farms but on the other hand large amounts of electricity are wasted, as storage without interconnection is impossible.

Figure 34: Distribution of the wind farms over the Greece

Of course all the above give hope for a better wind energy future in Greece but actually the things are not exactly the way they seem to be. Wind energy market in Greece has remained stagnated in the last months. From September 2005 no licences have been granted, resulting in the stabilization of wind energy installed capacity at 605 MW. Moreover the evaluation procedure for all the new renewable energy structures licences of a total capacity over 9000 MW was stopped by the Regulatory Authority for Energy on the 20th of July until further notice. These licenses are not granted due to some problems in the licensing procedure. Therefore legislators are trying to improve the current licensing regime by entering into force new laws. However the compliance with the white paper seems unreachable. [19] [20]

All these take place in a period where other countries utilize in the maximum the availability of their wind resources. Portugal installed more than 500 MW during 2005 as much as Greece in the last 20 years. Spain constitutes the most powerful country in developing wind energy installations around the world. With 10.000 MW total wind energy installed capacity is on close pursuit of Germany, the world's wind energy market. [15] [16] [17] [24]

The UK is the fourth most attractive onshore wind market in the world (Report Ernst&Young 2006) and analysts confidently expect it to be one of the most important markets around Europe by the end of the decade. As it can be observed by the following picture the UK has a large amount of wind power farms, especially in the west coast yard of the country and in Scotland. Moreover many wind farm projects are planned to be launched over the coming years while a minority are already under construction.



Source: British Wind Energy Association

Figure 35: Distribution of wind farms over the UK

In addition the UK has begun the production of the largest wind farm to date in South Ayrshire with a power output of 120 MW. The 52 installed turbines will be able to supply the electrical demands of 80.000 households. A further total of 665 MW new installations are expected by the end of this year. [15] [16] [27]

5.2.1 Cost of Energy from Wind Turbines

The energy balance/payback period of wind energy can be compared to competing technologies. Under normal wind conditions it takes between two and three months for a turbine to recover all of the energy involved (manufacturing, installing, maintaining, and scrapping).

The electricity production cost from wind parks varies by location and oscillates internationally from 6 to 8 eurocents/KWh at average wind speeds. In areas with higher wind speeds as the ones mentioned in the above paragraph, thus Ireland, Scotland, Denmark, France and Greece the onshore wind power costs fall to 4-5 eurocents/KWh. In addition experts predict that a robust growth in installed capacity, thus the power generated from high-speed wind resources could fall to between 3.1 and 4.4 eurocents/kWh by 2010 (EWEA, 2003).

Specifically in Greece the power generation system is separated in two categories, the interconnected systems for the mainland and the autonomous systems mainly for the islands. The wind power installation cost varies between 970 and 1170 €/KW of output and is influenced by the international market prices and the interconnection costs. The production cost of wind energy for both systems is the same and oscillates between 26 and 47 eurocents/KWh depending on the site and the project cost. [23] [64] [66]

In the UK the capital cost of wind turbines currently ranges from approximately £600 to £1000 per kilowatt of output, or £280 to £420 per square metre of rotor swept area. The produced wind energy cost is approximately 3.2 p/KWh as results from the synthesis of three different studies which took place in the year 2005 (Oxera, Windpower Monthly, and IEA) about wind energy costs. [1] [29]

5.2.2 Small Scale Wind Turbines

Nowadays the use of small scale wind turbines in domestic areas around Greece is limited. The companies which are activated in the specific field aren't investing in projects concerning the development and the wide use of wind turbines in domestic areas. People are afraid to use this kind of technology, because of the installation high cost and the fact that they believe that small wind turbines lack reliability, which is not necessarily the case.

In comparison to all the above, the Greek Government made a step forward and gave further motivation to people for wider use of small wind turbines. In May of 2006 in an effort to comply with the *White Paper Obligations,* the Government tried to turn consumers to the use of renewable energy systems by implementing tax discounts for those who would install in the domestic sector. Hence it would be profitable, as far as taxable income is concerned, for people with high or middle incomes. [30]

On the other hand UK promotes to a larger extent than Greece does, the use of small scale wind turbines for domestic use. Of course as it happens in Greece in most cases the cost of the produced power is not competitive with main electricity and, because so much of the UK is connected to the national grid, the small scale wind turbines potential has been limited.

However, the UK Government had introduced a Renewable Obligation in 2002 to achieve the Non-Fossil Fuel Obligation. This as a result gives a subsidy to renewable electricity sources and makes wind power projects more attractive to investors. The UK government continued in 2006 with a program which gives more support specifically for the use of small scale wind turbines and is called Clear Skies. This programme aimed to provide grants to the public for installation of renewable systems. The Scottish community and Household Renewable Initiative (as the same programme is called in Scotland) will provide funding for small scale renewable energy installations through the Low Carbon Buildings Programme. [15] [16] [40]

6 MERIT ANALYSIS

Merit is a quantitative evaluation tool developed at the University of Strathclyde designed to assist users in making informed decisions about the potential of certain types of renewable technologies to meet various demands. The program uses location parameters, manufacturers' specifications and weather data to simulate power production in order to determine at which point the capacity of the required energy storage system becomes minimum while the capacity factor of the renewable energy systems is at its maximum.

6.1 COMPONENTS OF MERIT

The most important components of Merit are the five following ones.

- Boundary Conditions Specification
- Demand Specification
- Renewable Supply Specification
- Storage/Grid connection Specification
- Matching

6.1.1 Boundary Conditions

Under boundary conditions, one needs to specify the climate file, and period of simulation. In this project a weather climate from Greece is used. Specifically a climate file for the island of Crete was collected, was modified properly using the excel program and was installed into Merit software. The measurements, for the completion of the weather data, were taken hourly from 01/01/2003 until 31/12/2003. Moreover another climate file, which already exists for Glasgow in the database of Merit, was used for the needs of this project for the same period of time.

6.1.2 Demand Profile

In this section the demand profiles for the analysis are determined. These profiles can either be selected from the standard demand sets which are available in the database of Merit or they can be measured in a number of time steps per hour or half an hour and then they are installed in the Merit software. Any number of demand profiles can be specified and they can be treated either each profile separately or all profiles may be combined into one.

In this project the demand profile of a typical 3 bedroom house for UK in the region of Dalmarnock is used, which already exists in the database of Merit, while another demand profile for a typical 3 bedroom house for Greece in the region of Heraklion is used as well. For the specific Greek house the energy demands were provided by the Electrical department of the Technological Institute of Crete.

6.1.3 Supply Profile

In this section various supplies will be defined either from the options available in the database or by designing new supply profiles. Again any number of supplies can be defined. Like demand profiles, a number of supply profiles can be specified separately or all profiles combined into one. The databases of Merit consists of a variety of supply profiles ranging from Combined Heat and Power, PV cells, to hydropower and of course wind turbines.

Different combinations of ducted turbines and PV panels for both British and Greek houses are used to attain the best temporal match. At the end the best combination, for each house separately, was used and the reasons of choosing this combination will be analyzed in paragraph 6.4. The specifications for these two systems are presented in paragraph 6.2.

6.1.4 Storage/Grid connection Specification

Next section is the storage or grid connection options. Again the database consists of various storage options such as battery and pumped storage, each of them in turn containing a number of specification sets. Also grid connection option is available under different tariff plans from which any one plan can be selected. For this project, for both analyses, a number of single 215 Ah batteries operating at 12 Volts, which were connected in series, were used. This type of battery is a very high quality and was used in order to increase the performance to the maximum for both hybrid systems. The number of the batteries which were used differs from one analysis to the other and the number of them and the specifications will be presented in the next session.

"Moreover the operation of the specific type of batteries connected in series could be improved connecting secondary cells in parallel. This in theory leads to a greater current capacity but in practice, poor current sharing during both charging and discharging will cause serious cell imbalance and early failure. The effects of this phenomenon are not accounted for and parallel batteries are modelled theoretically" [42]

6.1.5 Matching

Finally the most important section is the matching. This section intends to find out to what extent the already estimated supplies and the storage capacity can cover the demand of the house. The main purpose was to use different combinations, as it can be seen in paragraph 6.3 in order to observe which combination gives the best match and can make the building capable to perform in a realistic scenario.

The supplies that were used to cover the demands of the house do not only depend on the quantity but on the timing of the supply as well. The best match is the one with the highest correlation factor, the smallest inequality coefficient and the highest amount of shared area. The out of phase demand/supply is reflected in terms of excess and/or deficit energy.

6.2 SPECIFICATIONS

The specification of the parameters which were used for each of the above components of Merit are presented as follows.

6.2.1 Weather Data

As it was mentioned in paragraph 6.1.1 a climate file from Greece is used for the analysis in combination to the existing one for Glasgow. The Greek climate data were provided by 2 different laboratories in Heraklion Crete, the wind energy laboratory and the solar energy laboratory. The first lab provided the wind speed, the wind direction and the dry bulb temperature of the area while the second one provided the direct and the diffuse solar radiation. The climate diagram for Crete and Glasgow is illustrated as follows:

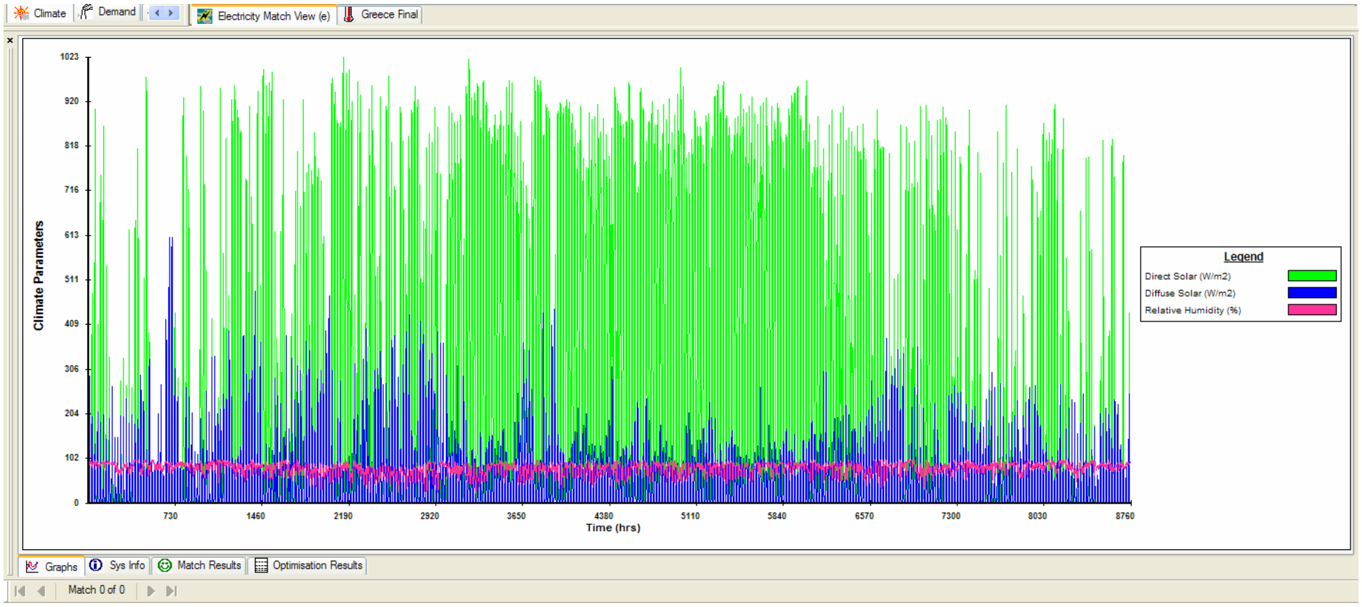


Diagram 1: Heraklion Crete Climate Data (Direct Solar, Diffuse Solar, Relative Humidity)

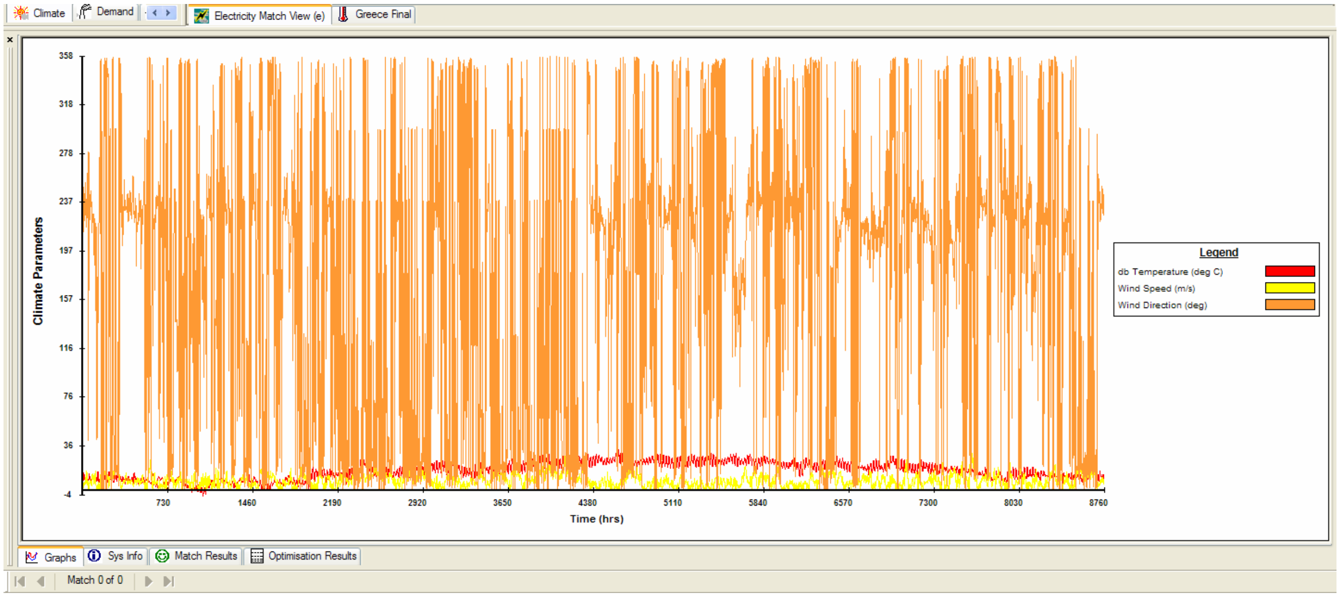


Diagram 2: Heraklion Crete Climate Data (DB Temperature, Wind Speed, Wind Direction)

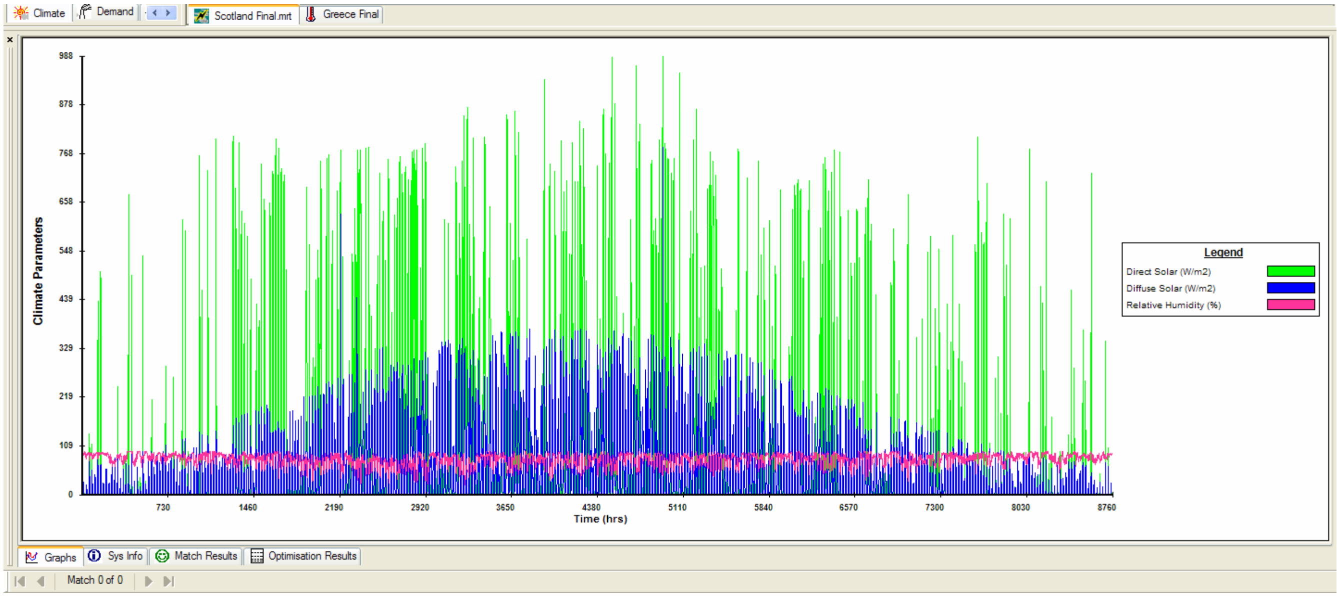


Diagram 3: Glasgow Climate Data (Direct Solar, Diffuse Solar, Relative Humidity)

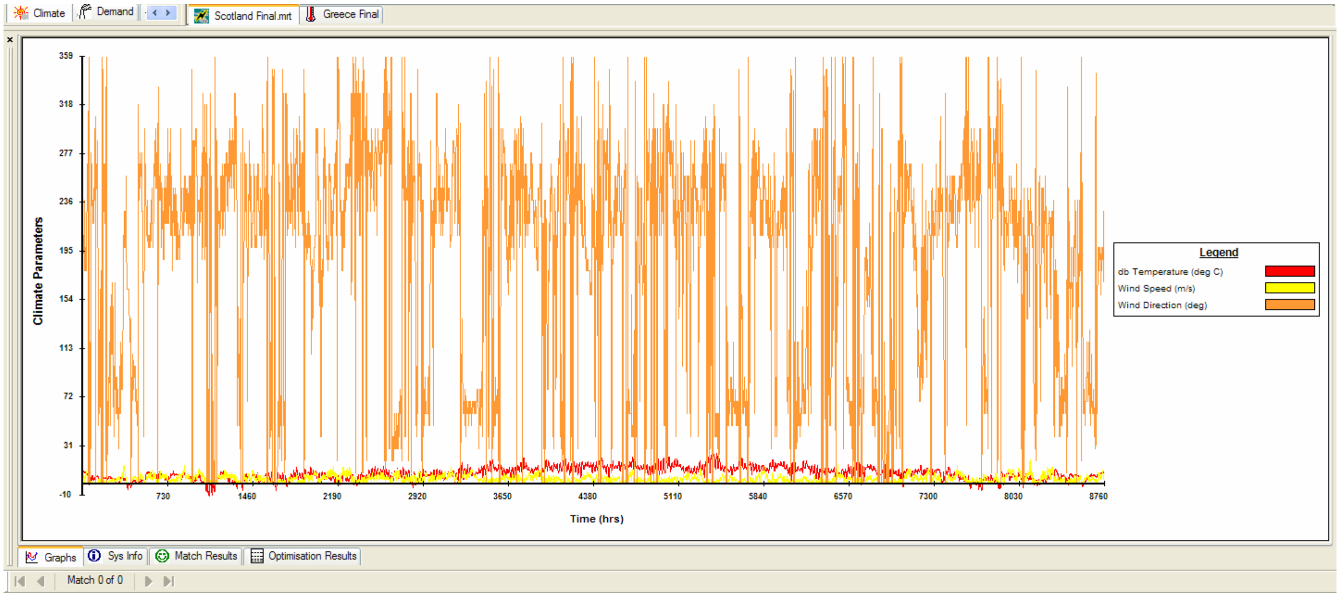


Diagram 4: Glasgow Climate Data (DB Temperature, Wind Speed, Wind Direction)

6.2.2 WIND TURBINE

As it has already been mentioned in the project overview, in chapter 1, for the analysis a number of ducted wind turbines were used. In the picture below the ducted wind turbine which was used for this project is illustrated and the photo was taken on the roof of James Weir Building.

Figure 36: DWT Mounted on the roof of James Weir Building

The ducted wind turbine consists of a rotor with a diameter of 0.6 meters and the turbine's hub height is 0.46 meters above the base. Using the appropriate formula,

$$P=0.5\times Cp\times\rho\times A\times V^3$$

which has already been mentioned in paragraph 4.4.3, the power curve was calculated, with the intent to scale up the production version of the ducted wind turbine so as to produce 250W. The power was calculated using velocity values from 5 m/sec which is the cut in speed of the turbine to 10 m/sec which is the maximum value of the power and reaches 250W. Furthermore, for the velocity values from 10 m/sec to 23 m/sec, the power of the turbine remains stable reaching 250W. Below the power curve of the ducted wind turbine is presented.

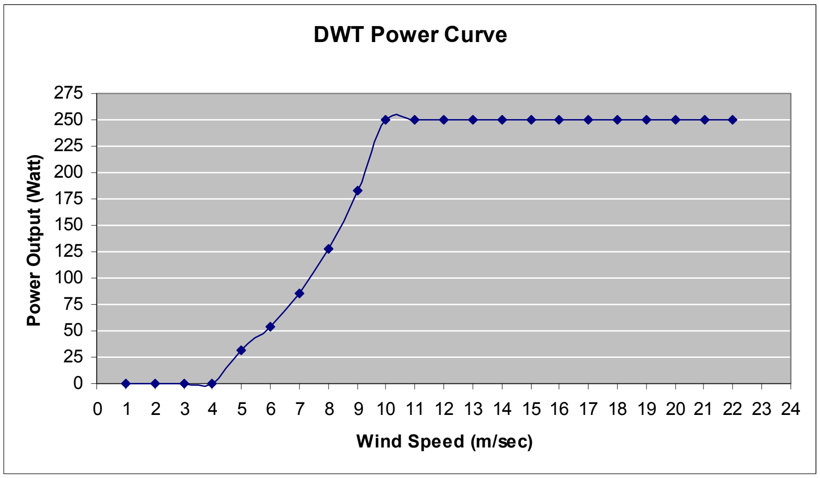
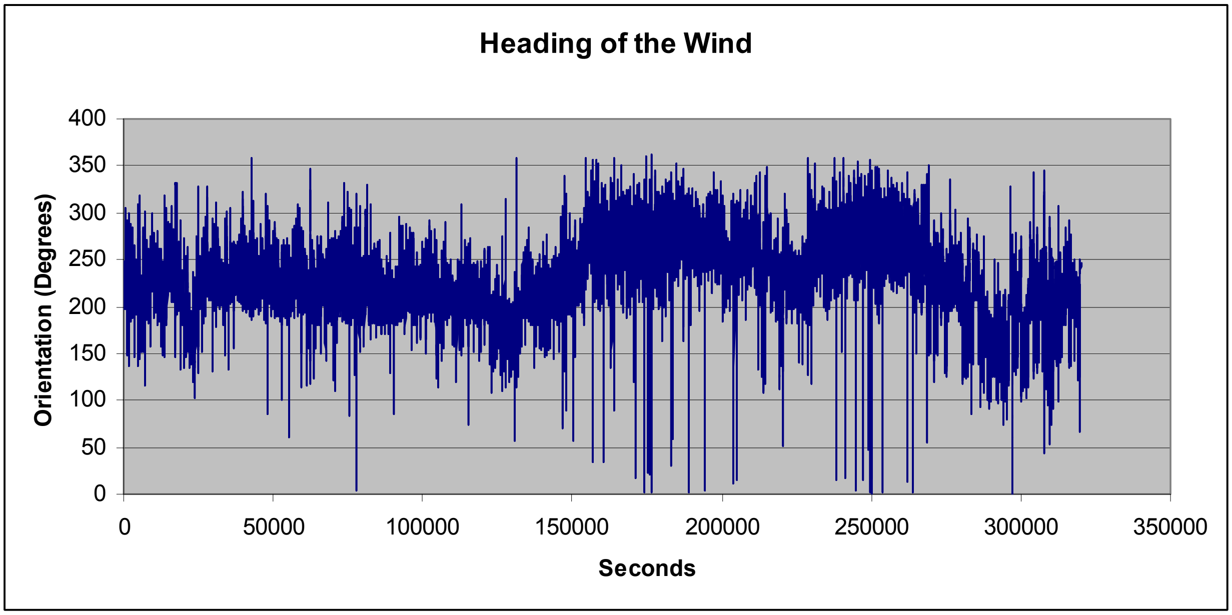
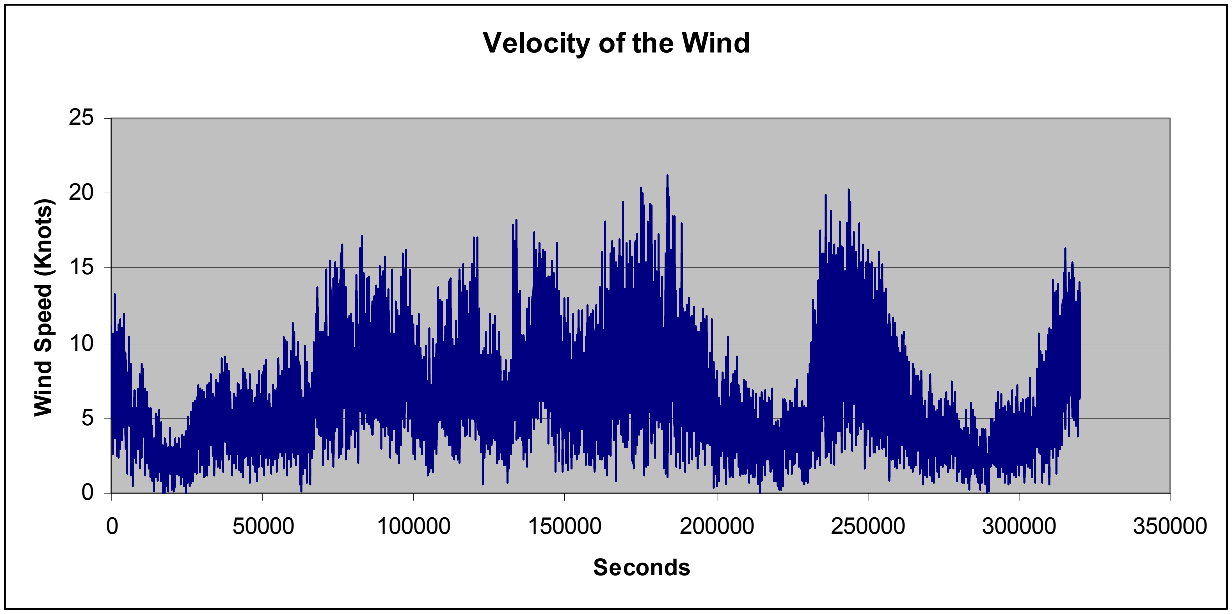


Figure 37: Power Curve of a Ducted Wind Turbine

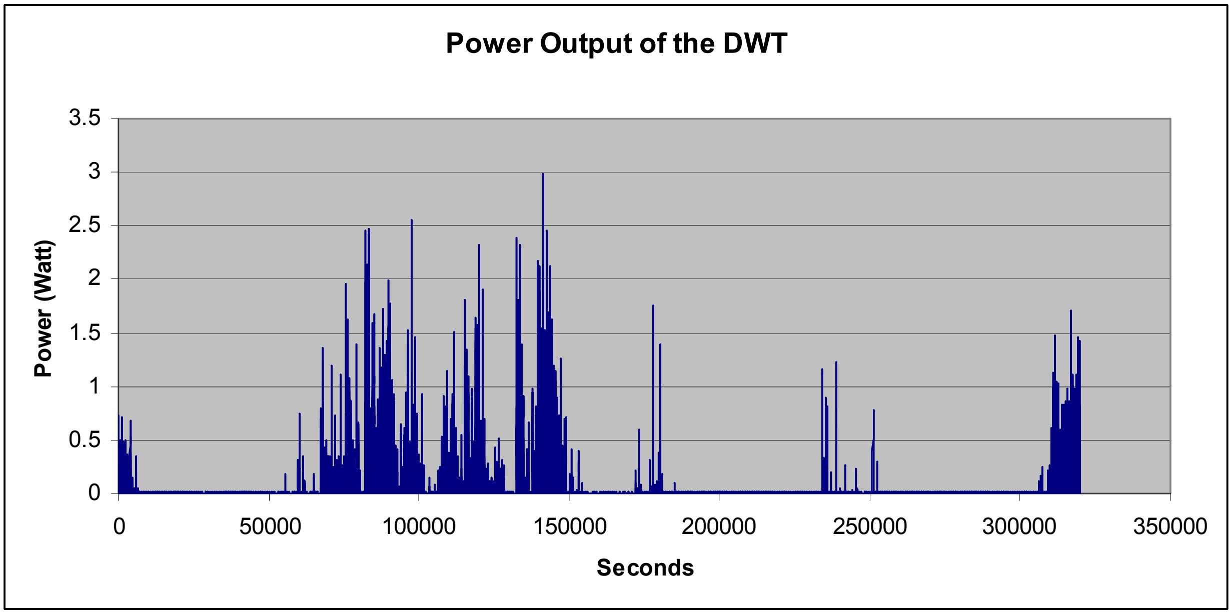
An effort took place in order to have some accurate measurements for the operation of the turbine and to use them for the analysis. The measurements were taken in a month's period between 23-07-06 to 23-08-06 on the roof of the James Weir Building in Strathclyde University where a ducted turbine is implemented.



Graph 1: Heading of the wind measurement period 04-08-06 until 08-08-06



Graph 2: Velocity of the wind measurement period 04-08-06 until 08-08-06



Graph 3: Power Output of the wind measurement period 04-08-06 until 08-08-06

Unfortunately the quality of the results was not the best while the measurements also suffered serious time restraints which did not allow results accurate enough so as to produce a power curve of the turbine and to accurately evaluate the results as it can be seen from the diagrams above. Moreover, the turbine was implemented with the wrong orientation and the rotation of the wind was not reliable enough. Hence I was forced to use the specifications which were provided by the author's supervisor which are the typical ones for a ducted wind turbine. It has to be indicated that the above specifications have not been used in a real project but are retrieved from Strathclyde's University systems which are located on the roof of James Weir building and are used as data files stored in the Merit software or elsewhere for future use.

6.2.3 PV PANELS

For the analysis a number of PV panels were used. The solar module is the SM 110 by Siemens Company and is illustrated by the picture below.

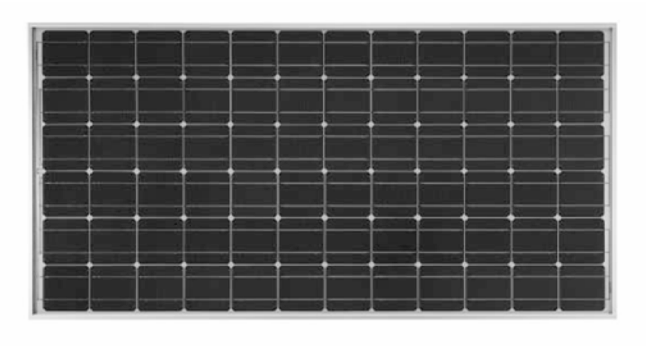


Figure 38: Siemens PV Cell SM 110

The PV module consists of single crystalline Power Max solar cells for maximum operational efficiency and is used in grid-connected systems and for grid-independent rural/stand-alone power supply systems. The module has a rated output of 110 Wp and is available in a 12 volt and a 24 volt version. The efficient design of the SM110 module, with its large surface area, is ideally suited for medium and high output applications. Below the I-V curve is illustrated for the specific type of the module SM110.

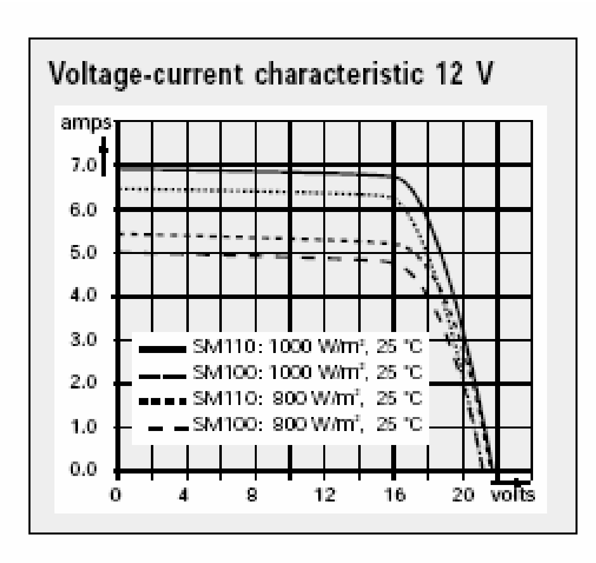


Figure 39: Characteristic I-V curve for Siemens PV cell SM 110

6.2.4 Building Demands

As it was mentioned before, the type of building which was used for the analysis is a 3 bedroom typical UK residential building. The data for the particular type of building already exists in the database of merit. The performance of the building during a year's period and the energy demands are presented in the following diagram**.**

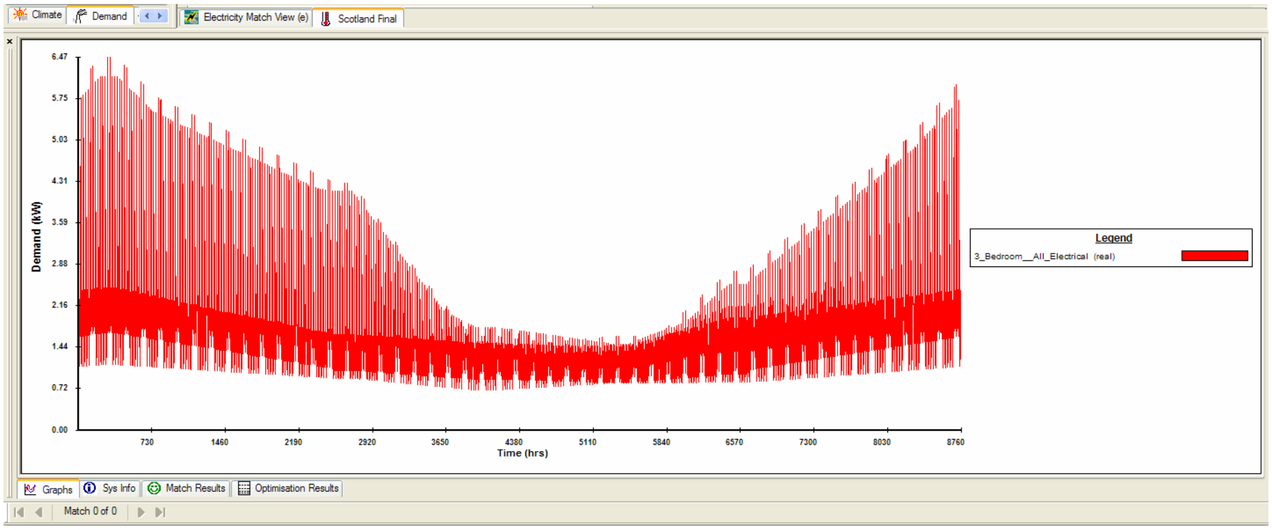


Diagram 5: Energy Demand Graph for a typical 3 bedroom house in North UK

Additionally, a similar 3 bedroom typical residential building in Greece was also used in the analysis. The energy demands of that building were collected after a year's hourly measurements and were installed into the Merit software. The performance of the building during a year's period and the energy demands are presented in the diagram below.

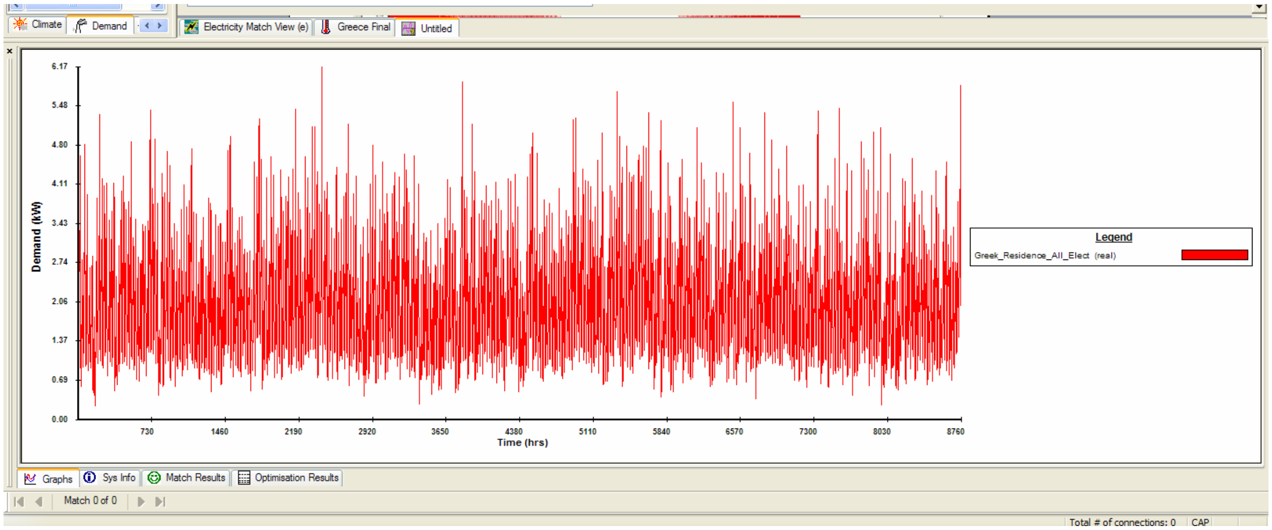


Diagram 6: Energy Demand Graph for a typical 3 bedroom house in South Greece

Using these two buildings, the British and the Greek one, an effort will be made in order to examine their behaviour in a cold climate such as the UK's climate and in a warm climate such as Greece's climate. The results will be evaluated in order to observe to which extent the energy demands may be covered by ducted wind turbines and photovoltaic panels. In addition, another objective of this analysis will be to determine the ideal combination of wind turbines and photovoltaic cells. A comparison of the efficiency of the two systems will follow, in order to examine which is the most economically viable alternative. The findings of this analysis are presented in the following section.

6.2.5 Results/Outcomes of the Analysis

For Heraklion Crete after many different combinations which were conducted using ducted turbines, photovoltaic panels and batteries, the most appropriate combination was chosen. The system was constituted by 8 ducted wind turbines, 40 photovoltaic panels with a tilt angle 60^0 and Southwest orientation 330^0 and 70 batteries connected in series with 215 Ah capacity and 12 V voltage. In the table below the results of the Heraklion Crete analysis are presented.

Demand Name	***Supply Characteristics***	***Aux Supply Number***	***Total Demand***	***Total Supply***	***Total Aux Supply***
Heraklion Crete, 3-Bedroom Typical Residence	Ducted Turbines 8 - Panels 40, Tilt 60, Southwest 330°	NULL	17.53 MWh	4.36 MWh	0.00 Wh
Heraklion Crete, 3-Bedroom Typical Residence	Ducted Turbines 8 - Panels 40, Tilt 60, Southwest 330°	NULL	17.53 MWh	16.61 MWh	0.00 Wh
Heraklion Crete, 3-Bedroom Typical Residence	Ducted Turbines 8 - Panels 40, Tilt 60, Southwest 330°	Batteries 70	17.53 MWh	16.61 MWh	949.83 kWh

Match Rate (%)	***Inequality Coefficient***	***Correlation Coefficient***	***Shared Area***	***Fuel Consumption (m^3)***	***CO_2 Emissions (g/KWh)***
39.62	0.6	0.09	4102.16	0	0
69.55	0.3	0.12	12346.81	0	0
85.96	0.14	0.78	16685.97	0	0

Very Good Match 8/10
Percentage Match: 85.96
Inequality Coefficient: 0.14
Correlation Coefficient: 0.78
Shared Area:16685.97

Table 4: Results of the analysis in Heraklion Crete

First of all a definition is going to be given for the entities of the results described in the table above and then an overview of the results.

The inequality coefficient, IC, can range in values between zero and one, with zero indicating a perfect match and one denoting no match. The metric is best used to establish bands of match whereby an inequality between 0 and .1 is a good match and between .9 and 1.0 is a bad one. [42]

The correlation coefficient, CC, is used to describe the trend between two data sets and does not consider the relative magnitudes of the individual variables. It provides a measure of the potential match that could exist given changes to the relative capacities, i.e. through energy efficiency or altering the size of the RE system. [42]

When a demand profile is matched to a number of supplies or vice-versa, the shared area can be used to compare the individual matches. However, the shared area term becomes less meaningful when comparing matches between different demands and supplies. Thus, shared area needs to be expressed as a percentage of the demand area in order to be used as a valid means for comparing different sets of profiles. [42]

As it can be observed the match rate is very high and is assumed as a very good match because the percentage is over 80%. The inequality coefficient is very low 0.14 and the correlation coefficient is very high 0.78. Moreover, the total amount of the energy supplies (16.61 MWh), which the hybrid system can produce, are properly distributed during the year's period and coincide with the total amount of the energy demands (17.53 MWh) for the same period. Finally it can be seen that the match rate increases a lot with the attachment of the batteries and this high percentage match of ***85.96*** can be achieved.

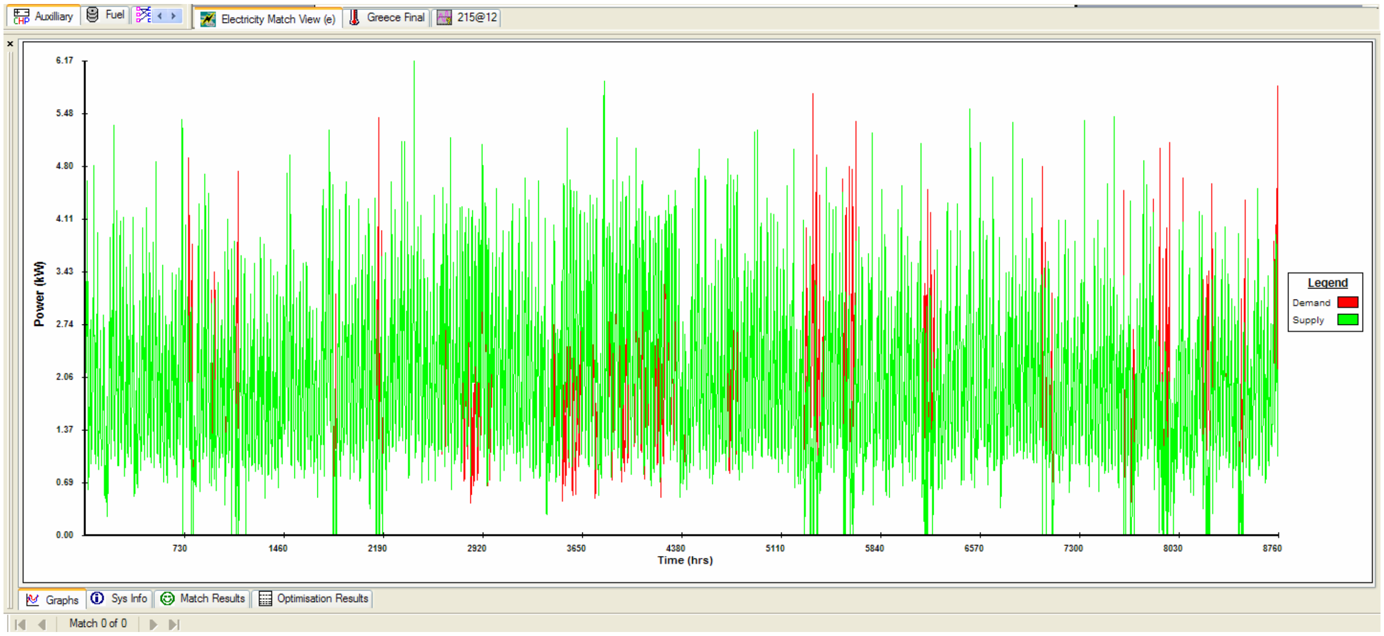


Diagram 7: Energy Variations during a year's period in Heraklion Crete

Similarly to the first analysis another one is made for Glasgow. Again after many different combinations between hybrid systems the most appropriate combination was chosen. The system was constituted by 15 ducted turbines, 26 photovoltaic panels with a tilt angle 50^0 and Southeast orientation 30^0 and 80 connected batteries in series with 215 Ah capacity and 12 V voltage. In the graph below the results of the Glasgow analysis are presented.

Demand Name	***Supply Characteristics***	***Aux Supply Number***	***Total Demand***	***Total Supply***	***Total Aux Supply***
Glasgow, 3-Bedroom Typical Residence	Ducted Turbines 15 - Panels 26, Tilt 50, Southeast 30°	NULL	16.00 MWh	2.53 MWh	0.00 Wh
Glasgow, 3-Bedroom Typical Residence	Ducted Turbines 15 - Panels 26, Tilt 50, Southeast 30°	NULL	16.00 MWh	13.98 MWh	0.00 Wh
Glasgow, 3-Bedroom Typical Residence	Ducted Turbines 15 - Panels 26, Tilt 50, Southeast 30°	Batteries 80	16.00 MWh	13.98 MWh	825.65 kWh

Match Rate (%)	***Inequality Coefficient***	***Correlation Coefficient***	***Shared Area***	***Fuel Consumption (m^3)***	***CO_2 Emissions (g/KWh)***
25.3	0.75	-0.31	2309.7	0	0
55.23	0.45	-0.11	8187.91	0	0
70.45	0.3	0.37	13087.36	0	0

Good Match 7/10
Percentage Match: 70.45
Inequality Coefficient: 0.30
Correlation Coefficient: 0.37
Shared Area: 13087.36

Table 5: Results of the analysis for Glasgow

As it can be observed the match rate is quite good and is assumed as a good match because the percentage is slightly over 70%. The inequality coefficient is in normal levels 0.30 and the correlation coefficient 0.37 as well. Moreover, the total amount of the energy supplies (13.98 MWh), which the hybrid system can produce, are distributed quite well during the year's period but they don't coincide with the total amount of the energy demands (16.00 MWh), especially during the winter period. Finally it can be seen in that case as well that the match rate increases a lot with the attachment of the batteries and this gives a good match of ***70.45.***

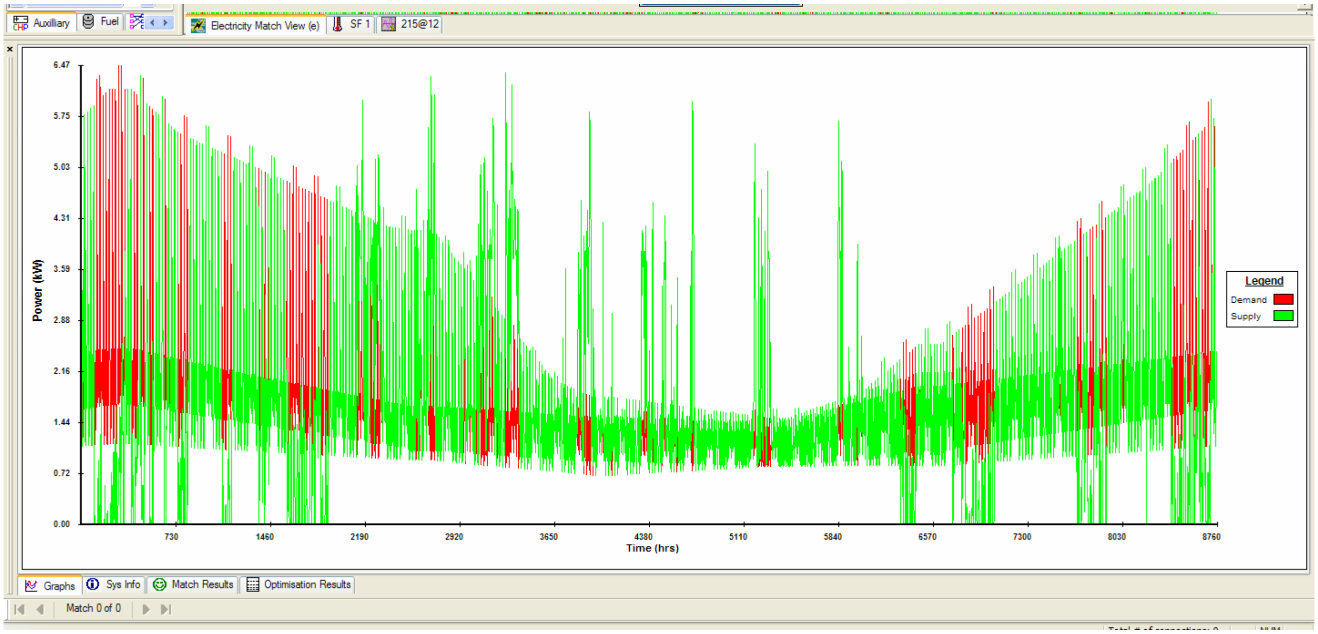


Diagram 8: Energy Variations during a year's period in Glasgow

Before the evaluation of the results presented in the following paragraphs, it must be pointed out that the results of this assessment are for the year 2003-2004 for both countries. The results can be similar to the ones analysed and can be applied for the following years, but not for periods 20 years after, since it is evident that the climatic conditions will be different and cannot be predicted at present. Thus the result diagrams below are depicting the operation of the hybrid system for the period which is analysed and not for every year to come. This means, that for example, for every April our system will not operate in the same way and will not have the same efficiency, because the climatic conditions throughout the year 2003 seem to be almost excellent for the system's operation but that will not be the case for every given year.

Moreover some diagrams show a poor match between supplies and demands for both countries. For example there is not such a good match during August for Greece and the same happens for Scotland during December and January. This means that during these months, when there is not enough energy to meet the demands of the buildings, the demands will be covered using electricity from the national grid. It must be comprehended that the specific system can turn the building as an energy autonomous one in a large extent, but this cannot apply throughout the whole year. This is ought solely to the reliability of the natural energy sources.

6.3 Evaluation of Results

In the following section there is going to be an evaluation of the above results. As it can be observed in the diagrams below, a very good match between the energy demands and supplies is performed for Heraklion Crete for the whole year while for UK for the same period the match is poorer. This of course is due to the different climatic conditions in Heraklion Crete and in Glasgow and especially, as it will be presented in a further paragraph, to the big difference of the solar radiation which reaches each area.

From a more precise observation of the diagrams it can be seen that both areas are not performing equally well at all times of the year.

For Heraklion Crete there are some days during December, January, May, June, August and September where the performance of the system is not the best one and the energy supplies do not match very well with the demands of the house. This happens because of the extensive use of air conditioners during the summer period. This is why so many demand peaks occur especially in August. Similar peaks can be seen in winter due to the heavy use of electrical heaters.

As it can be observed from the following diagrams, for January there is a small peak in the demands during the last days and this demand cannot be covered properly by the hybrid system. For May, during the first days, there is not a very good match and the same happens in June but to a bigger extent, almost for the whole month. In August and September some high demand peaks are observed and the system is unable to cover these variations. Finally for December many high demand peaks are observed and the supplies cannot match properly the fluctuations of the energy demands.

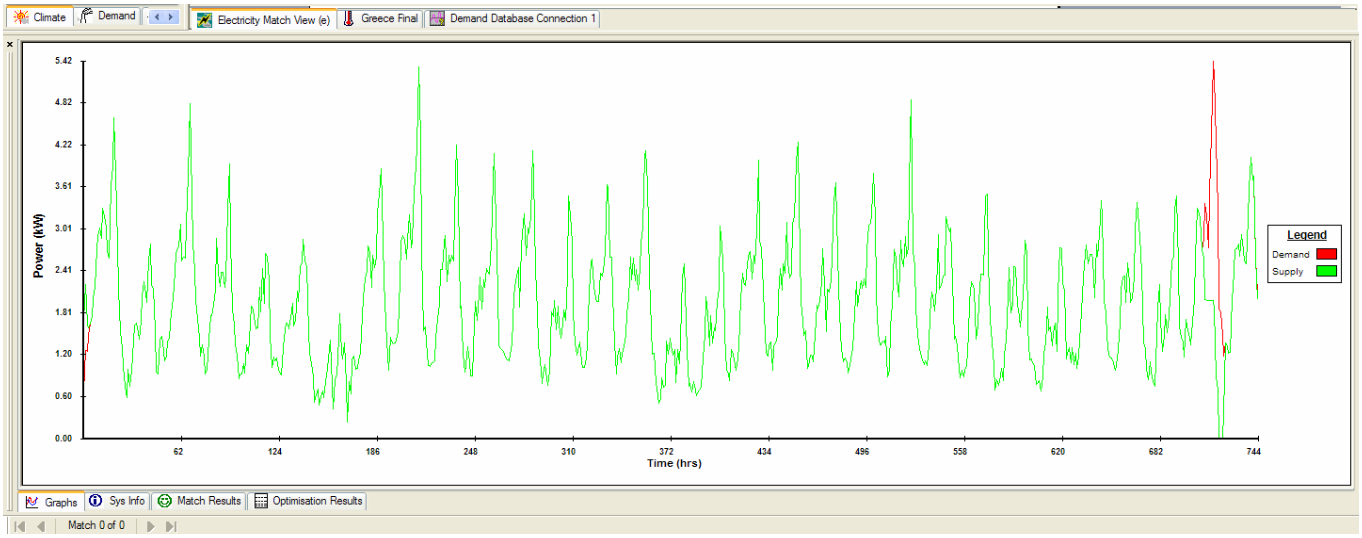


Diagram 9: Graphical match of demands-supplies in January for Heraklion Crete

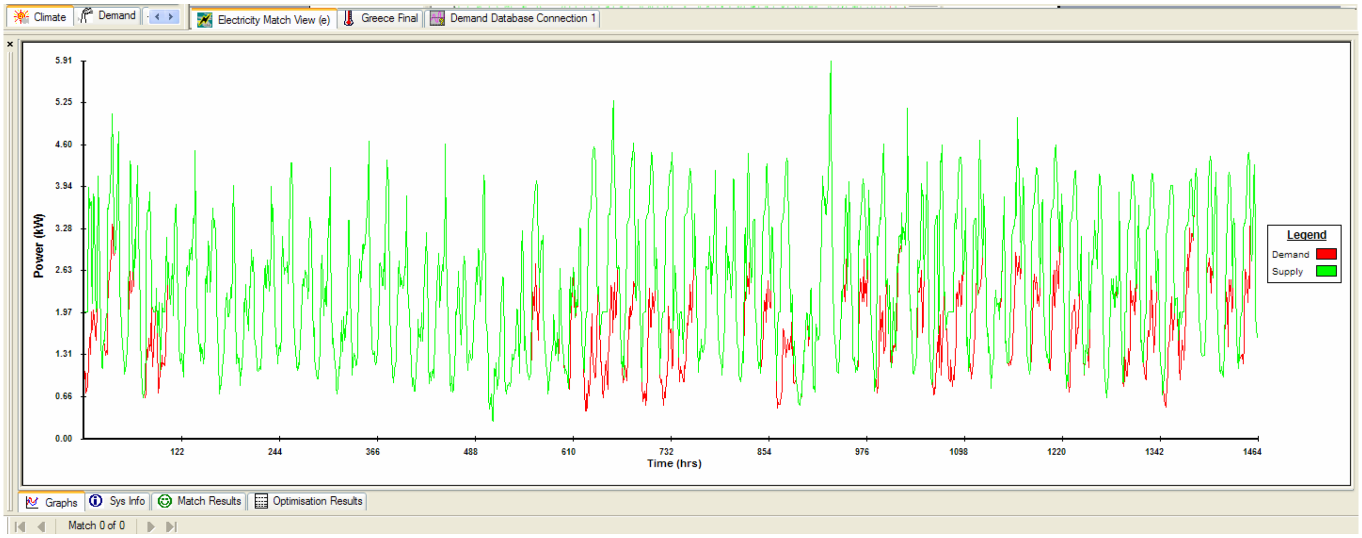


Diagram 10: Graphical match of demands-supplies in May and in June for Heraklion Crete

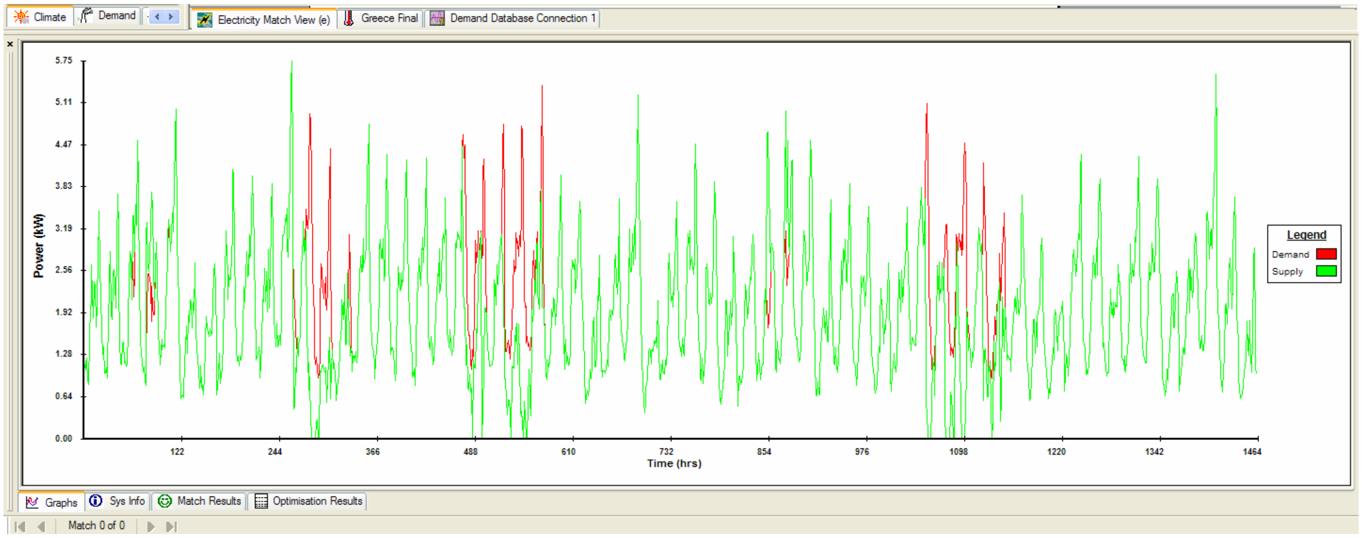


Diagram 11: Graphical match of demands-supplies in August and in September for Heraklion Crete

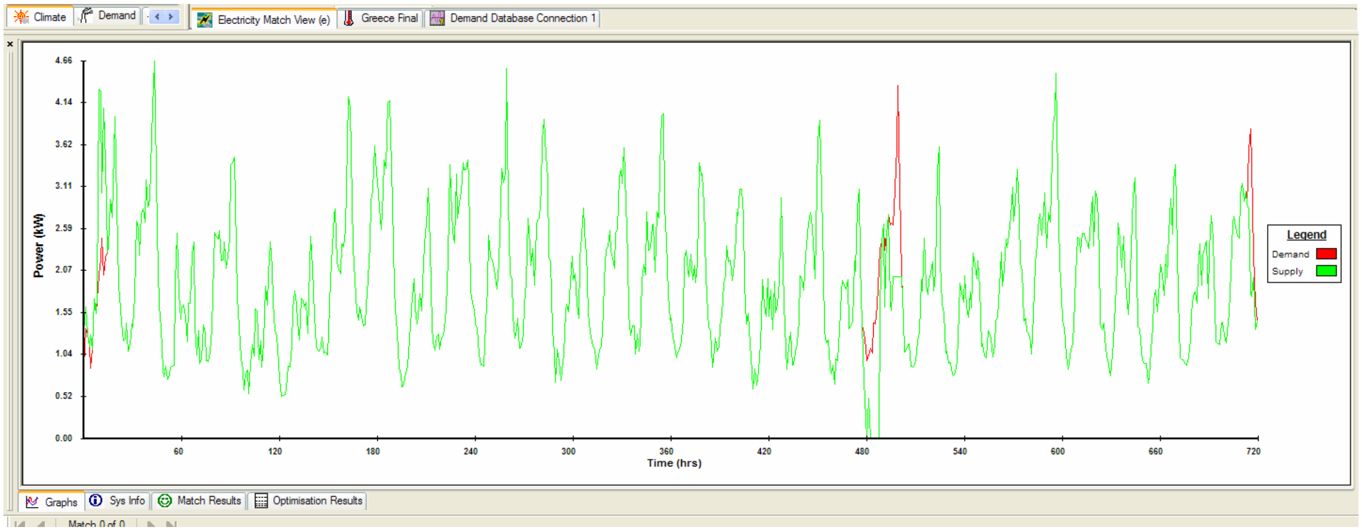


Diagram 12: Graphical match of demands-supplies in December for Heraklion Crete

For Glasgow things are different. The hybrid system in Glasgow has a very good performance during the summer months when the demands are quite low but during the rest of the year a less good match, between the variation of the energy supplies and the energy demands, can be observed. This happens because of the use of electrical heaters mostly during the winter period where many peaks can be observed and the match rate is the poorest.

For the months January, December and March many high demand peaks and high electricity consumption are observed. Especially during the first days of January, the last days of December and the middle of March the energy supply cannot match at all with the fluctuations of the energy demand and the coverage of the electrical need of the house from the system is almost impossible. For the months February, April, September, October and for most of the days in November a good match is achieved and the performance of the system is moderate. All these observations can be illustrated better by the following diagrams.

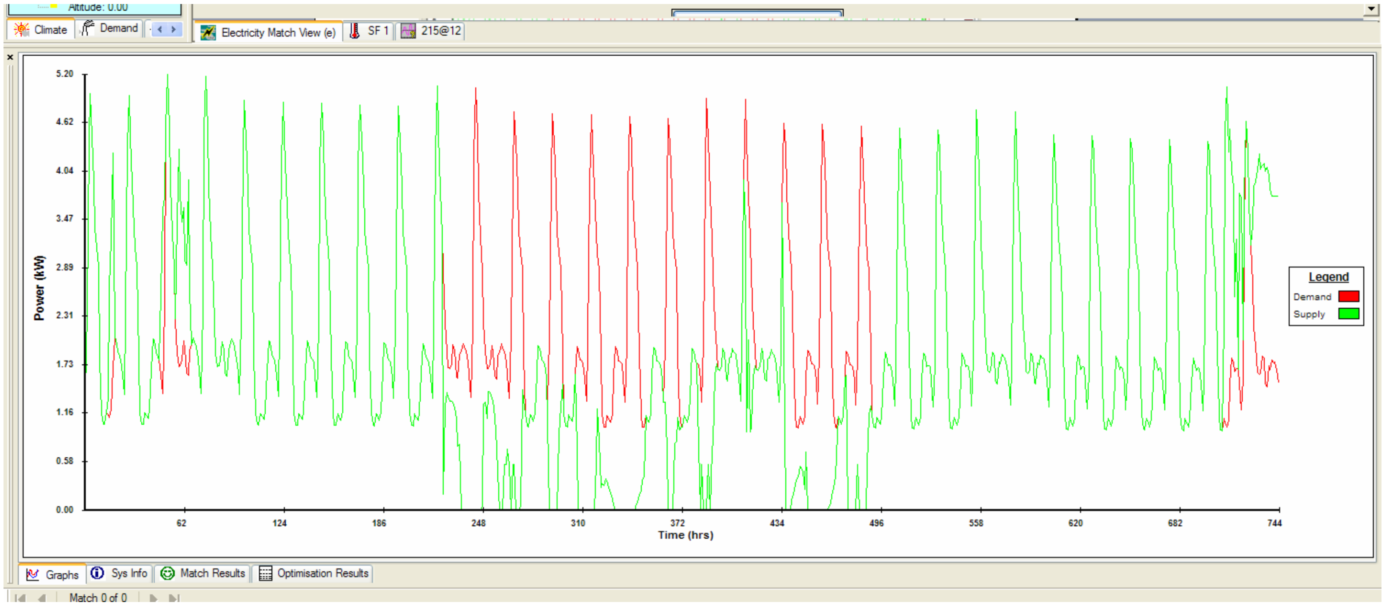


Diagram 13: Graphical match of demands-supplies in January for Glasgow

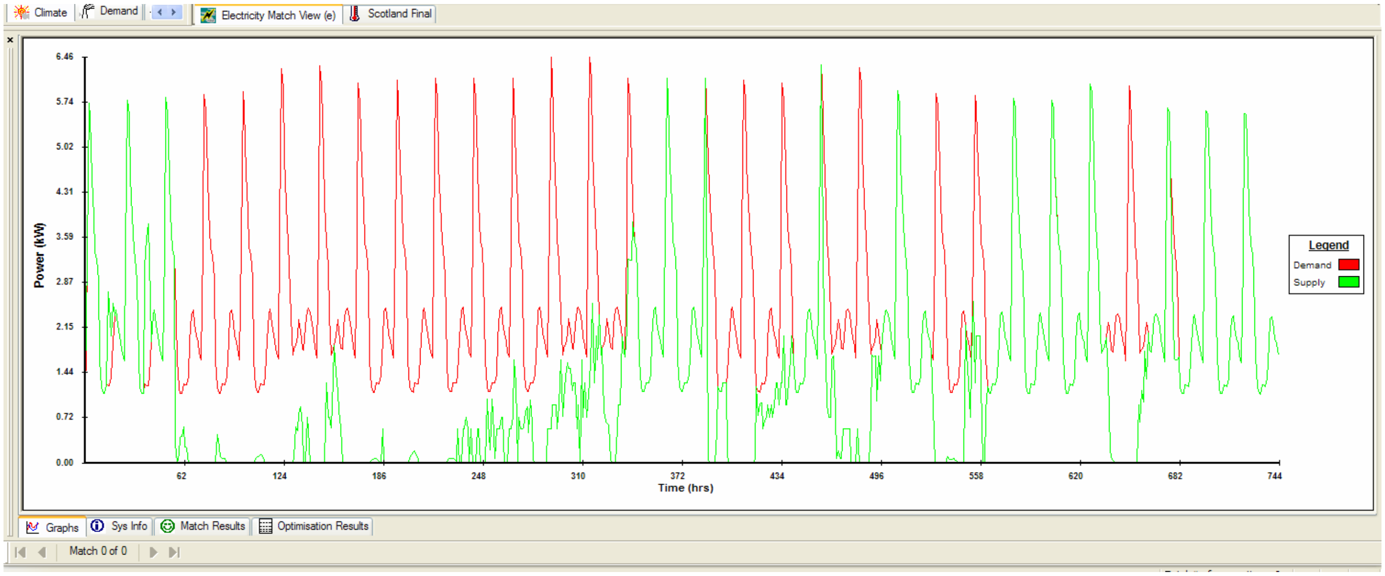


Diagram 14: Graphical match of demands-supplies in March for Glasgow

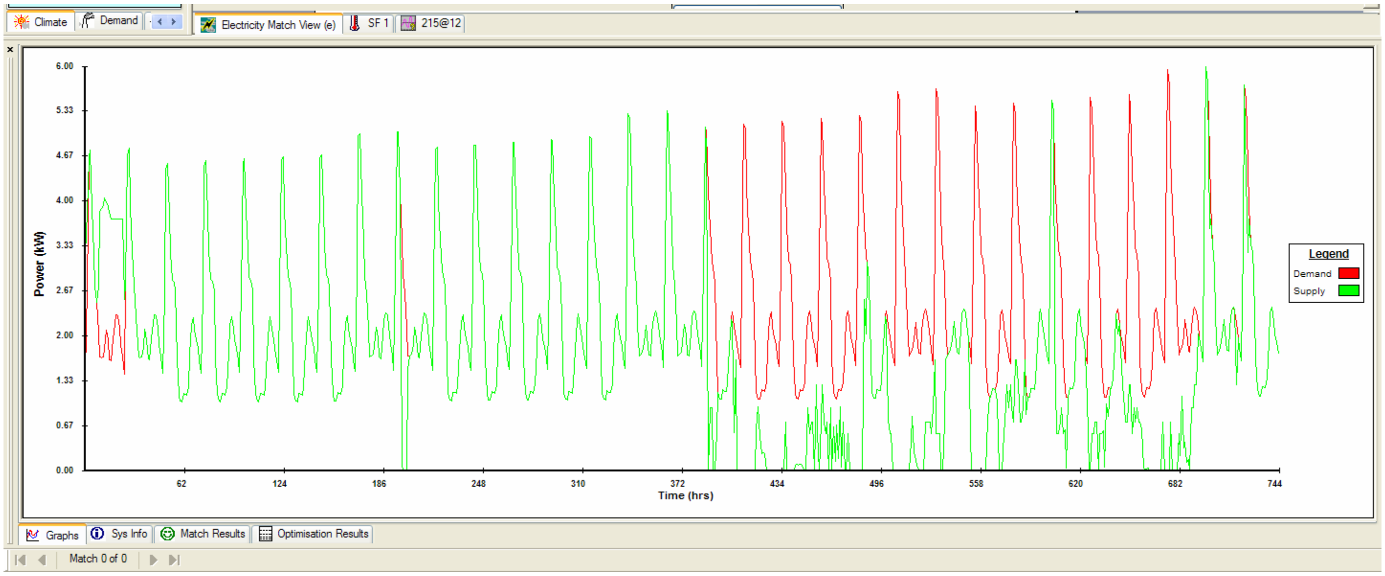


Diagram 15: Graphical match of demands-supplies in December for Glasgow

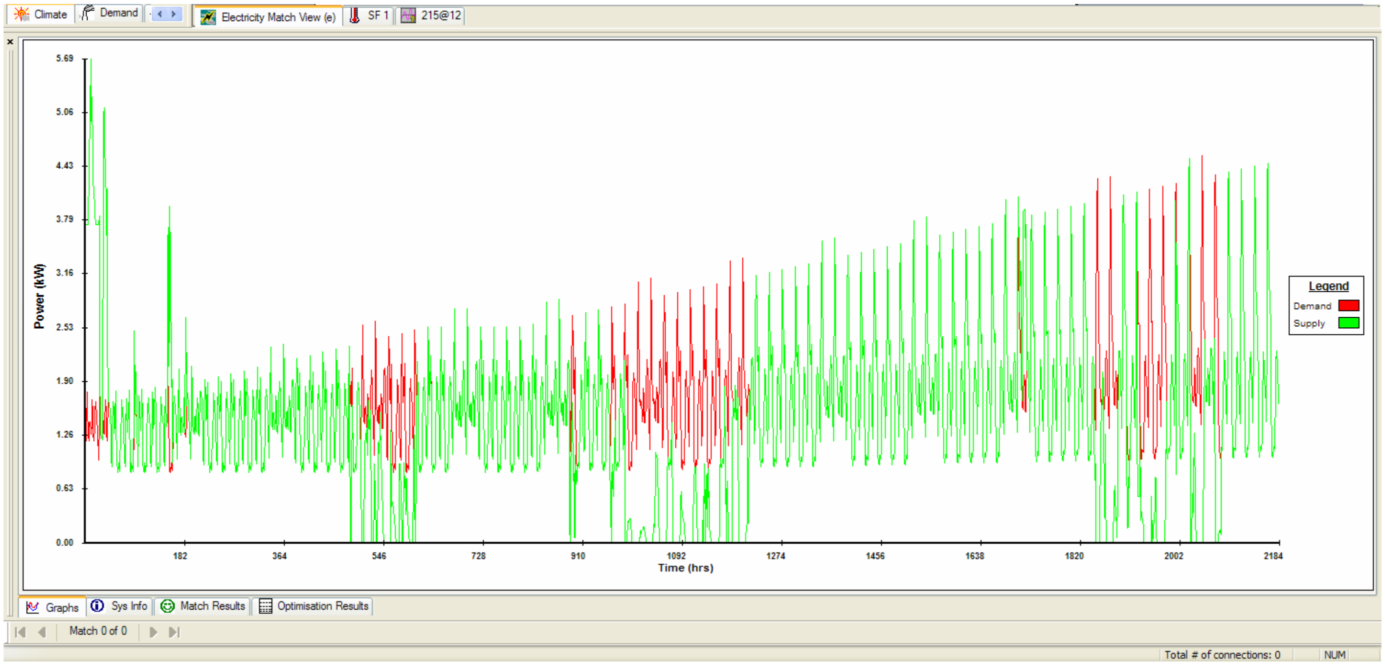


Diagram 16: Graphical match of demands-supplies in September, in October and in November for Glasgow

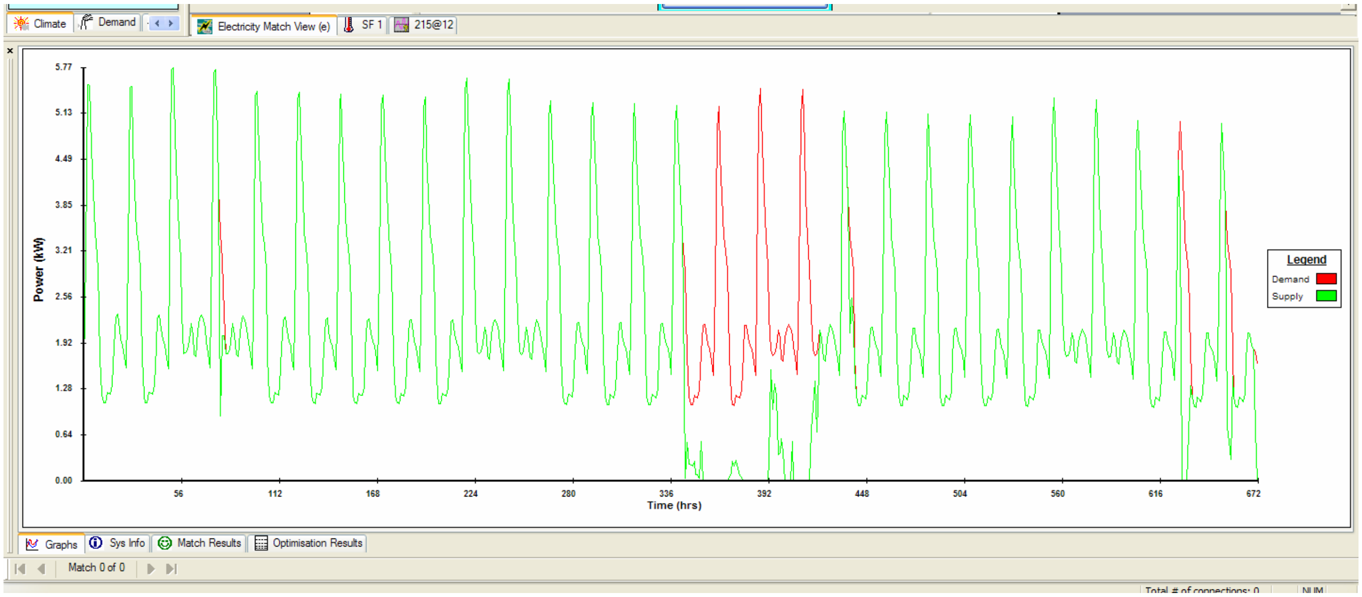


Diagram 17: Graphical match of demands-supplies in February for Glasgow

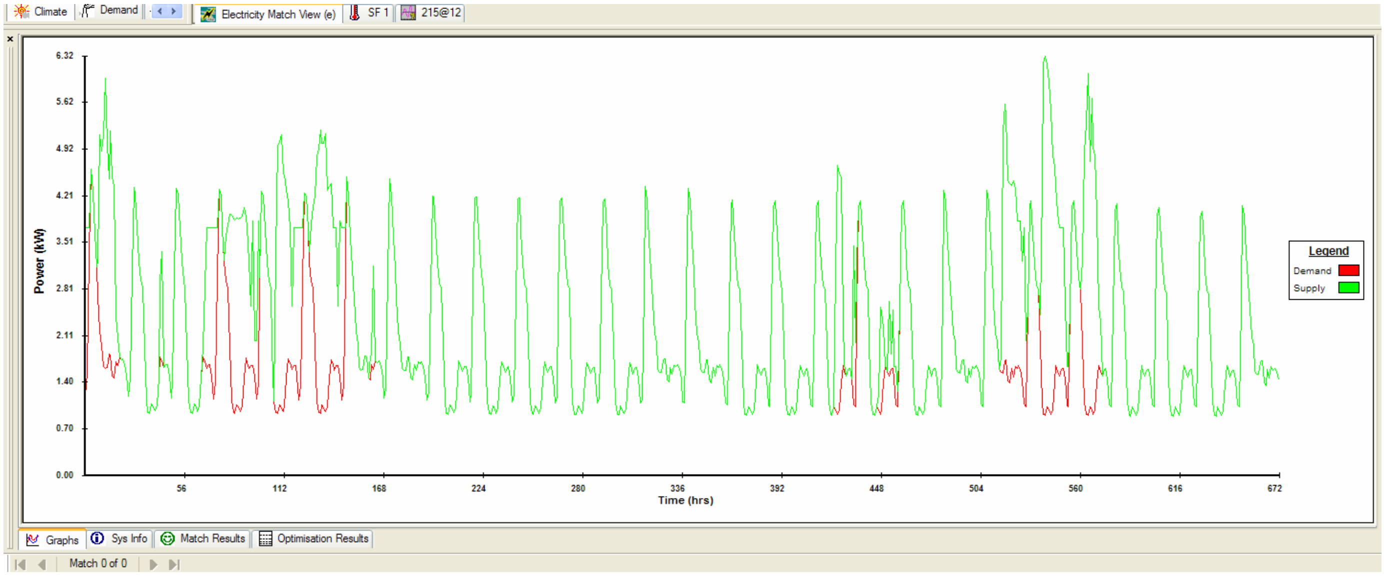


Diagram 18: Graphical match of demands-supplies in April for Glasgow

The parameter which makes the use of photovoltaic panels in Glasgow's climate not so efficient is the few sunny days during the year. Observing the diagrams below, one can see the big difference in sunny days which Glasgow has in comparison with Heraklion Crete. Thus the use of photovoltaic panels in a large scale for the Crete climate is essential for the best performance of the system.

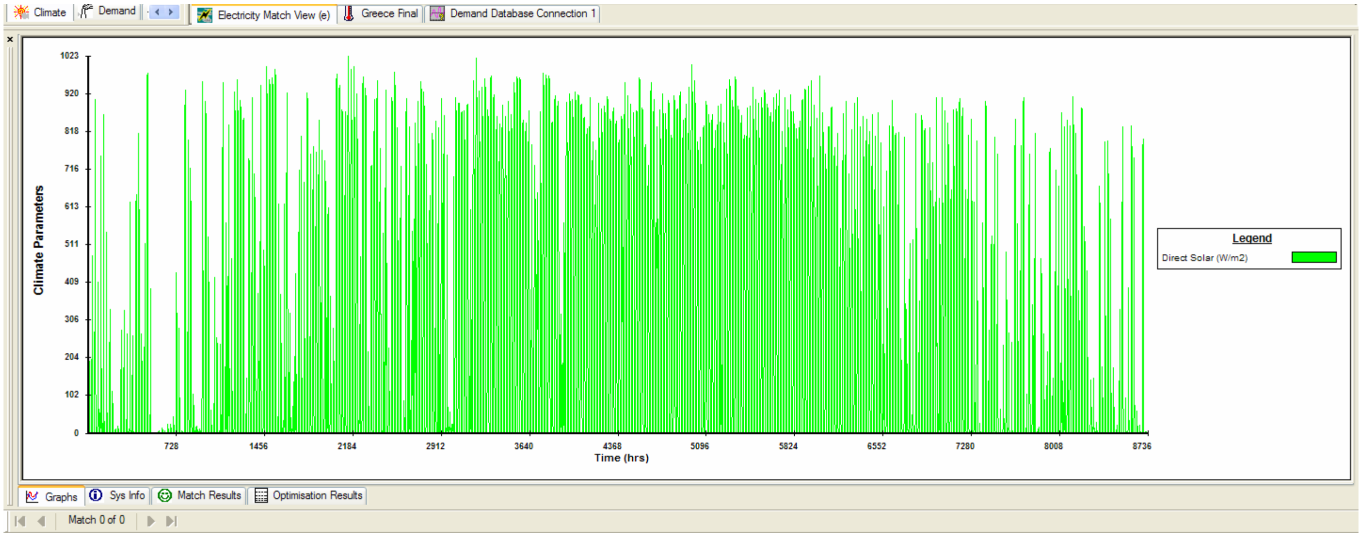


Diagram 19: Graphical distribution of the Direct Solar Radiation, in Heraklion of Crete

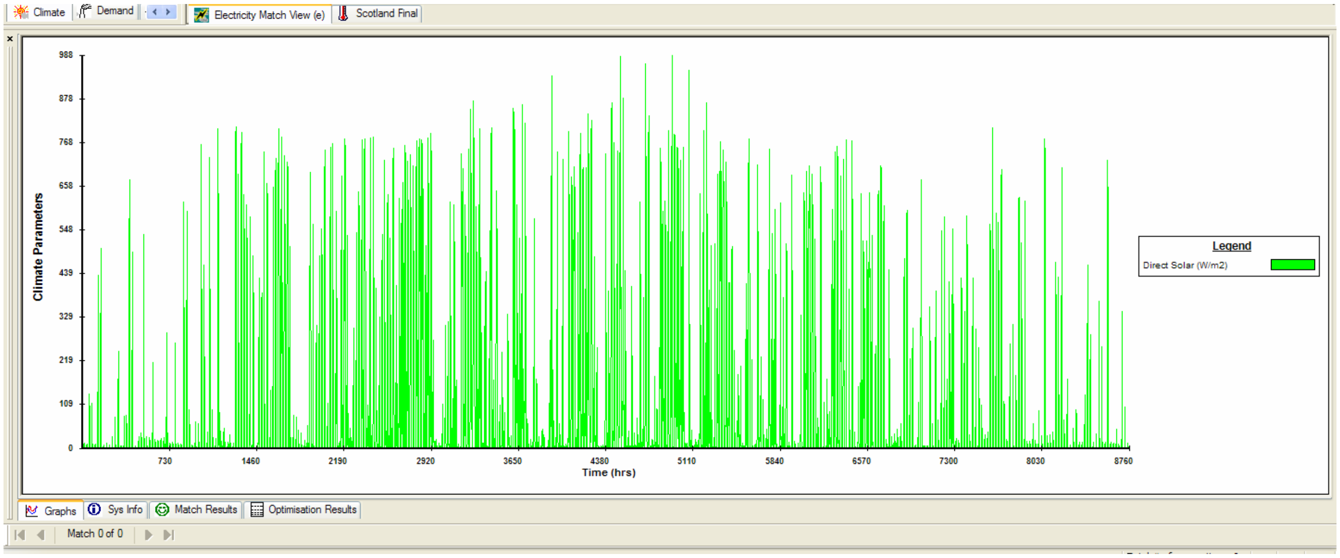


Diagram 20: Graphical distribution of the Direct Solar Radiation, in Glasgow

The optimum tilt angle which was preferred for the photovoltaic panels in Heraklion Crete was 60 degrees. This angle gives a higher efficiency of the operation of the panel during the whole year. This happens because in the winter, as it can be observed in the above diagram, there are many sunshine days and with this tilt angle the solar beams are more vertical to the surface of the panel. Hence the operation of the panels is more efficient during the winter. During the summer period when the power of sun is really high photovoltaic panels in any case operate very well.

During the winter period there is not much direct sun so a tilt angle of about 50 degrees was preferred in order to achieve the best performance and the highest possible efficiency, for the whole year.

Both countries are in the North hemisphere so the orientation of the photovoltaic panels should be south. After many different combinations that took place, the optimum direction for the photovoltaic panels was chosen for each country. Thus for Heraklion the optimum orientation is Southwest 30 degrees from South and for Glasgow Southeast 30 degrees from South. Of course there is no big difference from the absolute South orientation but this is the best direction if the maximum performance from the photovoltaic panels is to be achieved.

Because of the high humidity levels especially in Glasgow the power of the solar radiations beams which reach the Glasgow's surface is reduced. As a result the performance is worse and the efficiency of the photovoltaic panels is reduced. By contrast Heraklion Crete, having a lower level of humidity, although being an island, provides better conditions for the performance of the installed photovoltaic devices.

The number of ducted wind turbines which were used for these analyses are different in each case as well. From the following diagrams it can be observed that the wind potential for both sites is moderately high, a fraction higher in Heraklion of Crete, so this makes the use of the ducted turbines very feasible for both sites.

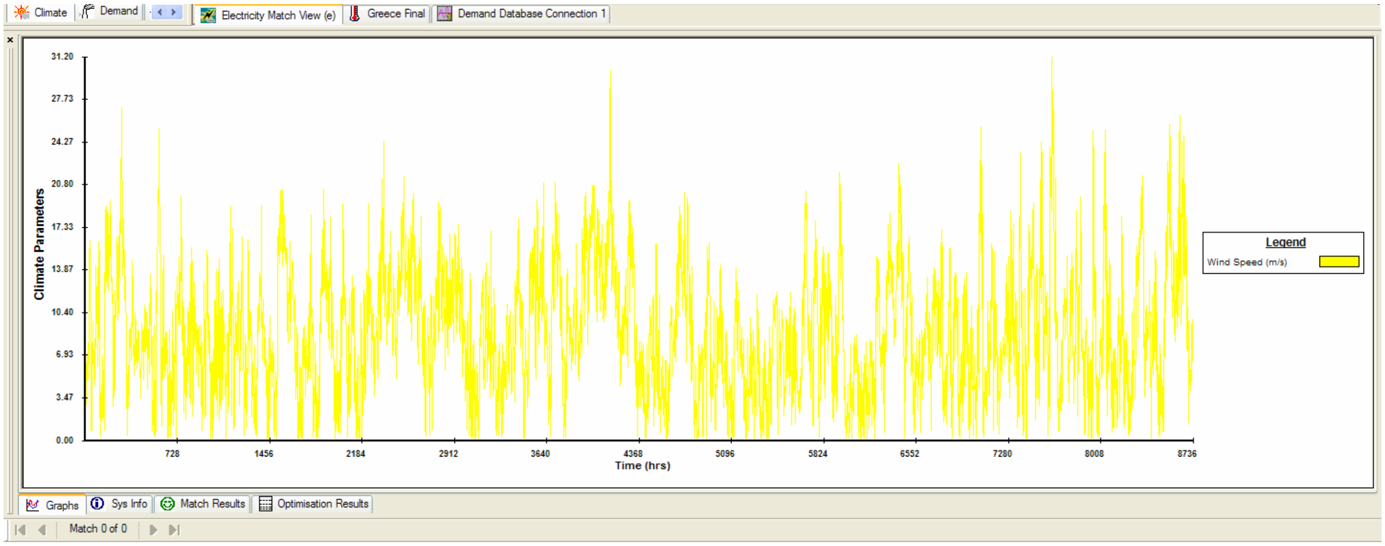


Diagram 21: Graphical Distribution of the Wind Speed, in Heraklion of Crete.

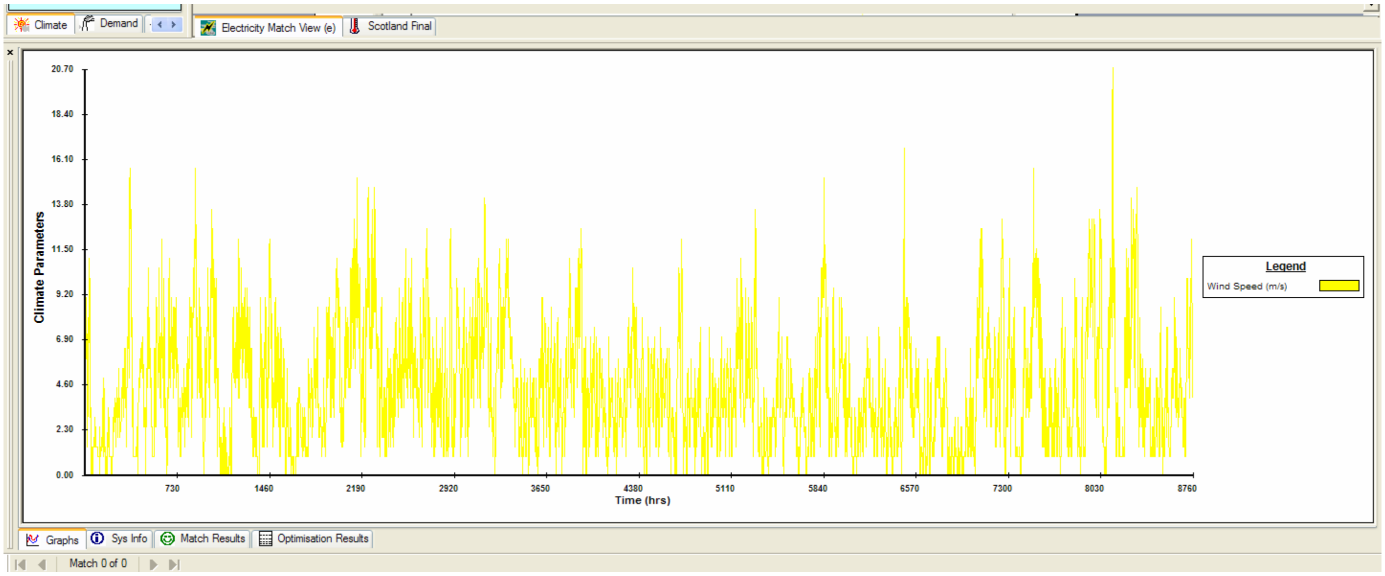


Diagram 22: Graphical Distribution of the Wind Speed, in Glasgow.

Specifically for the energy demands of the Greek building 8 ducted wind turbines were used while for the British one 15 turbines were used. It has to be mentioned that for each building, the appropriate number of ducted wind turbines should be used so as to achieve the highest match rate possible. The use of more wind turbines than needed would render the system inefficient.

The use of ducted wind turbines have to be larger in Glasgow in order to meet the demands of the building, for the reason that the solar radiation is very limited. On the contrary, as far as the Greek building is concerned, there is a more reliable energy production from both photovoltaic panels and ducted turbines because the high rates of the wind speed and solar radiation. Hence, it can be realized that the sun makes a big difference in the performance of both systems.

Finally the auxiliary devices which were used were batteries with a 215 Ah capacity operation at 12 volts and deep discharge level of 70%. This type of battery is used in order to achieve the maximum performance for both systems. From the battery performance graph, which covers a year’s period, it can be observed that during the days that energy sources provide limited energy potential, batteries are being discharged, while the opposite happens when there is availability in the energy sources.

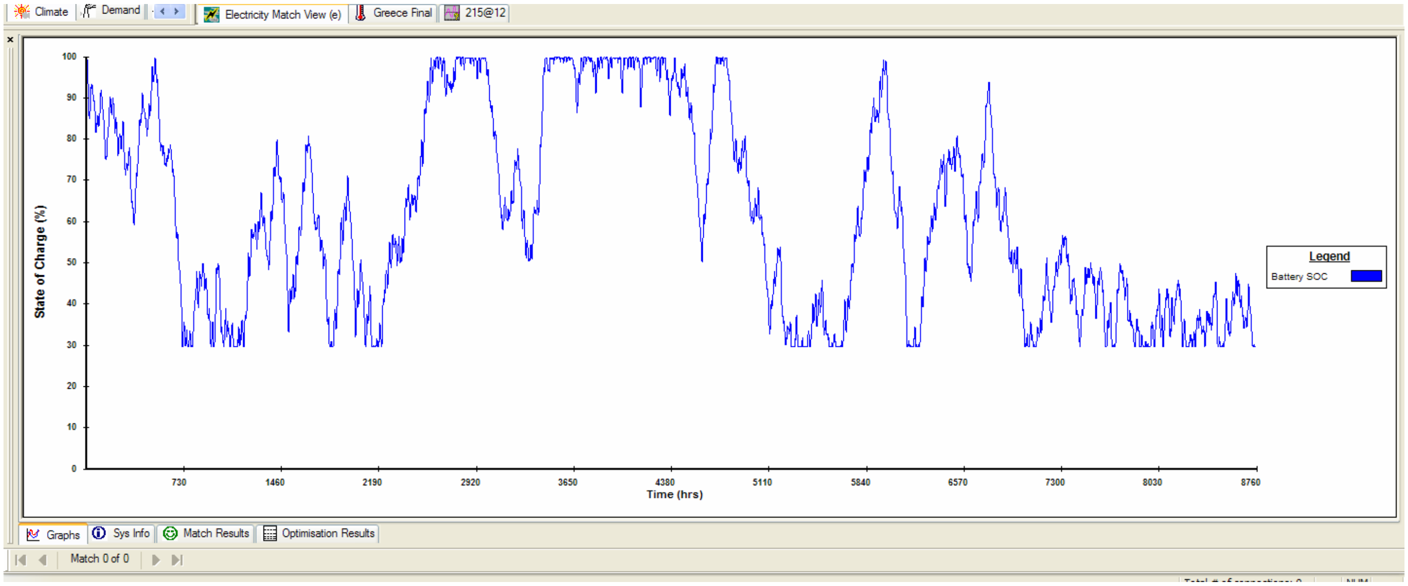


Diagram 23: Yearly Battery Performance in Greece

For Greece, as it can be seen on the above diagram, during the winter period batteries are charged and discharged quite often due to the variations in the power of energy sources. Moreover, during the summer period, when direct solar radiation is available in large quantities, the batteries have a more stable operation and are usually fully charged. The opposite of course happens during the winter period where the energy supplies from the renewable systems are lower due to the lack of energy sources.

In order to make this analysis more interesting some critical points were chosen on the yearly performance battery graph, which are illustrated in the troughs. These troughs are observed during the first and the last months of summer. In addition, from the diagrams below it can be observed that prior to a trough the supply of natural energy is indeed quite high and the fluctuations are low showing a low battery usage. On those days when natural energy is low, fallback onto battery supply is necessary leading to battery discharge as it can be seen from the large troughs in the graph.

As it can be seen, there is a remarkable decrease in the state of the charging of the batteries during August, September and May. And this is due to the wide use of air-conditioners and the high demands of the building for those months.

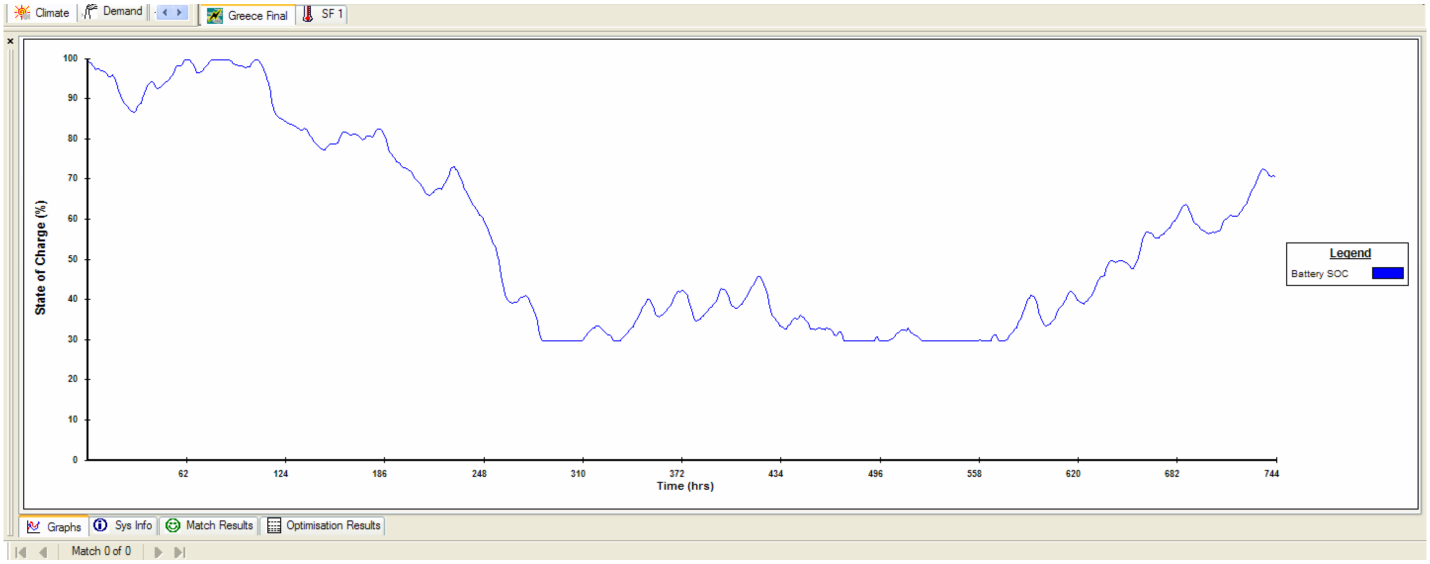


Diagram 24: Battery Performance in August

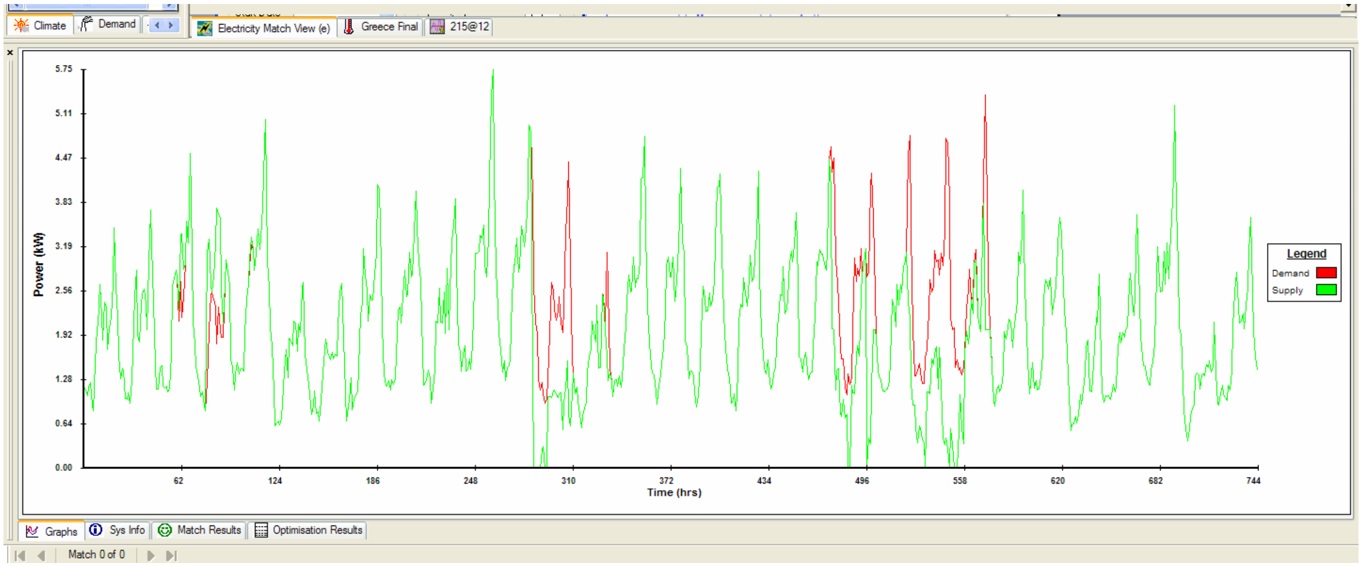


Diagram 25: Diagram of Supplies-Demands in August

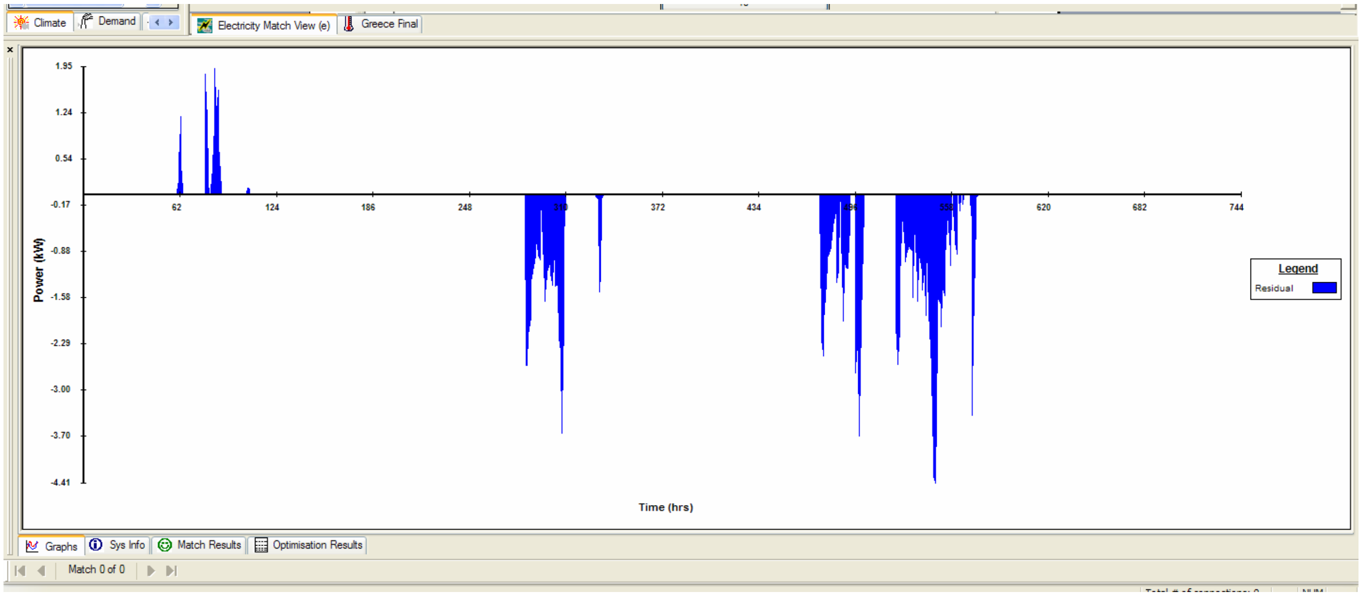


Diagram 26: Residual Power Graph in August

The above diagrams during August are observed, where some demand peaks are shown and which the system is not able to cover. Especially in the residual graph of the battery the lack of energy during those days is illustrated. Of course after the middle of August, batteries start recharging again and this is due to the large amount of energy supplies which the hybrid system produces. As it was mentioned in the last paragraph of the previous section, the high demands of the building which cannot be covered from the hybrid system, because of the wide use of air-conditioners, are going to be covered from the electricity of the national grid.

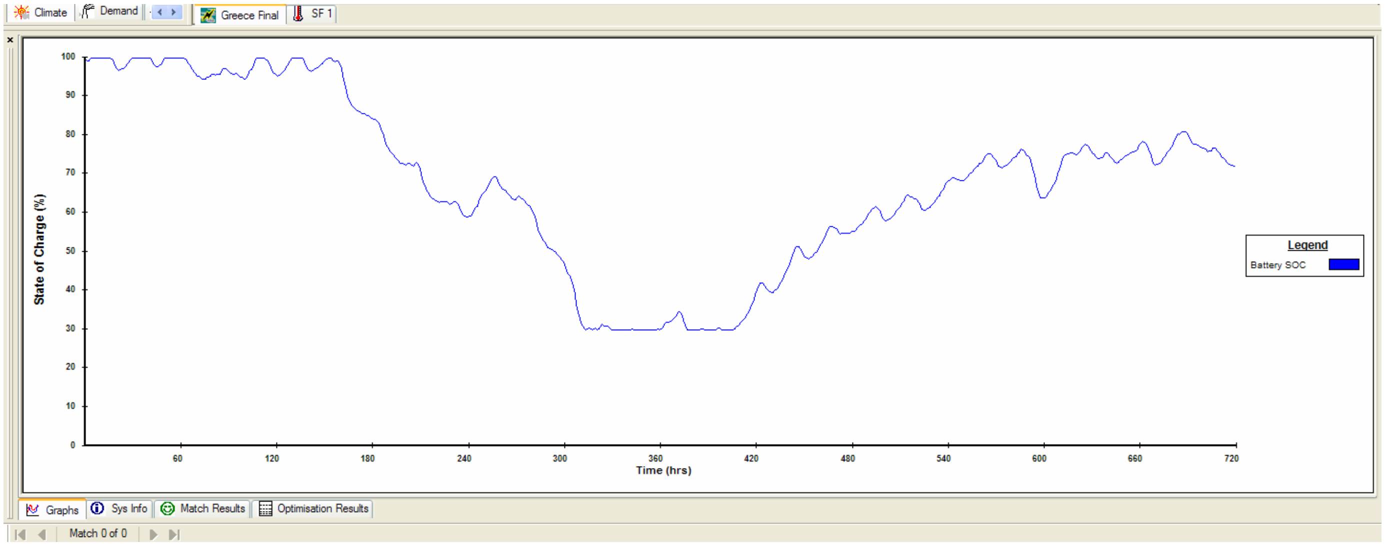


Diagram 27: Battery Performance in September

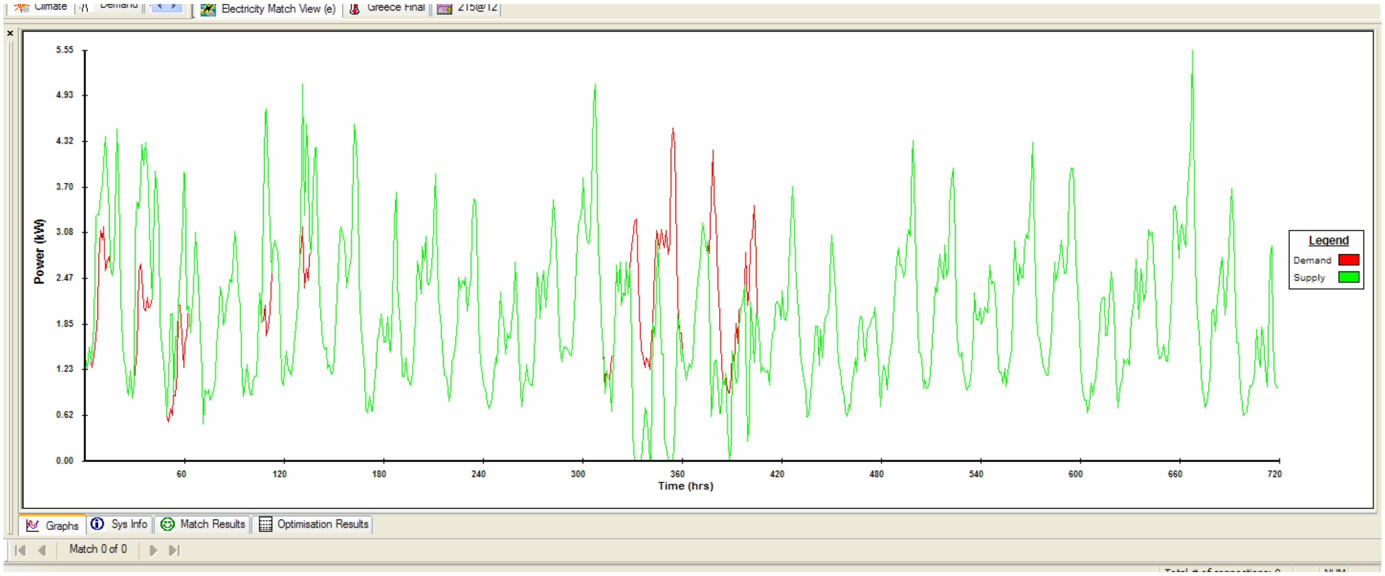


Diagram 28: Diagram of Supplies-Demands in September

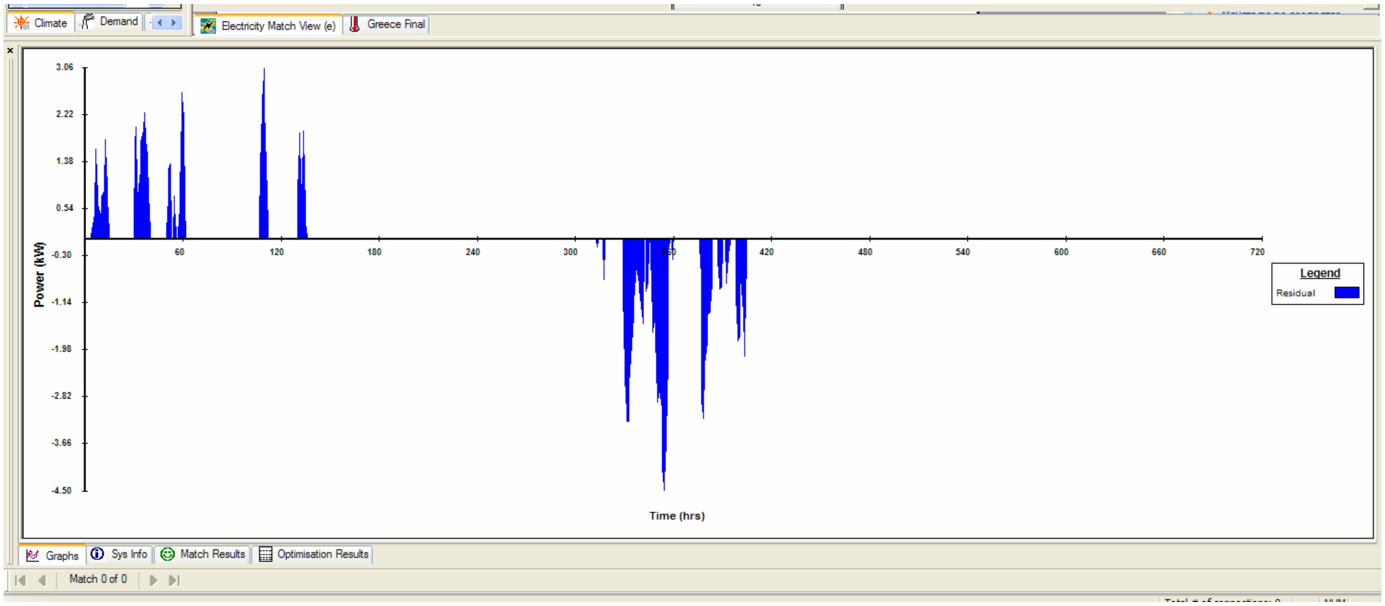


Diagram 29: Residual Power Graph in September

From the above diagrams, it can be observed that during September there is a significant lowering in the energy state of the battery and this is because of the high demands of this month, mostly due to the public's use of air conditioners.

Moreover, as it can be seen, demands can be covered efficiently from the energy supplies of the hybrid system during that period, except for a small period of about 2 days in the middle of September, where there is a lack of energy and residual power, as it can be observed from the residual graph of that month. Of course in the end of September the batteries start to recharge again because of the large amount of supplies which the hybrid system produces.

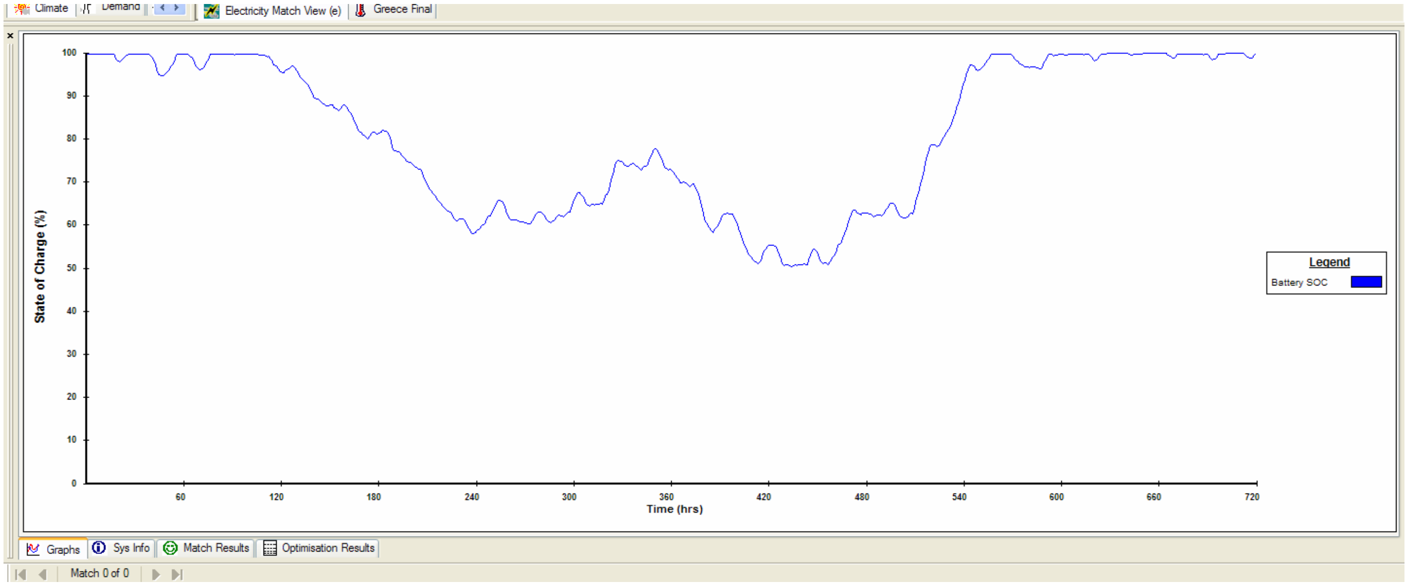


Diagram 30: Battery Performance in May

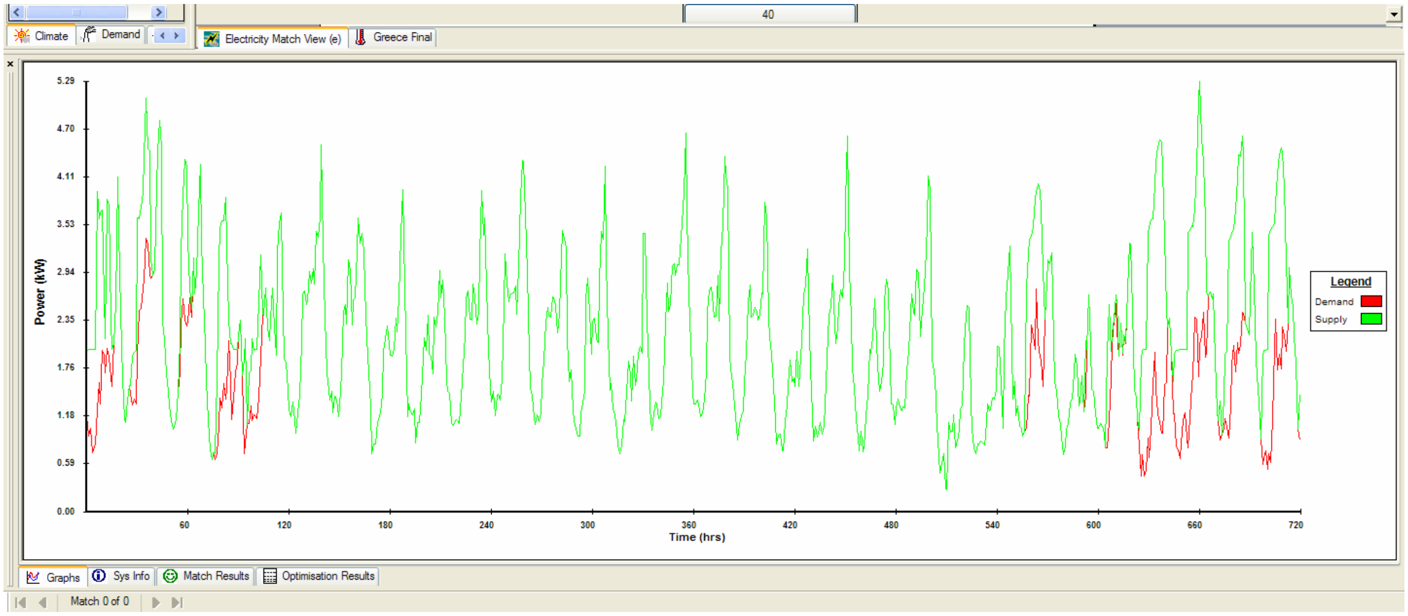


Diagram 31: Diagram of Supplies-Demands in May

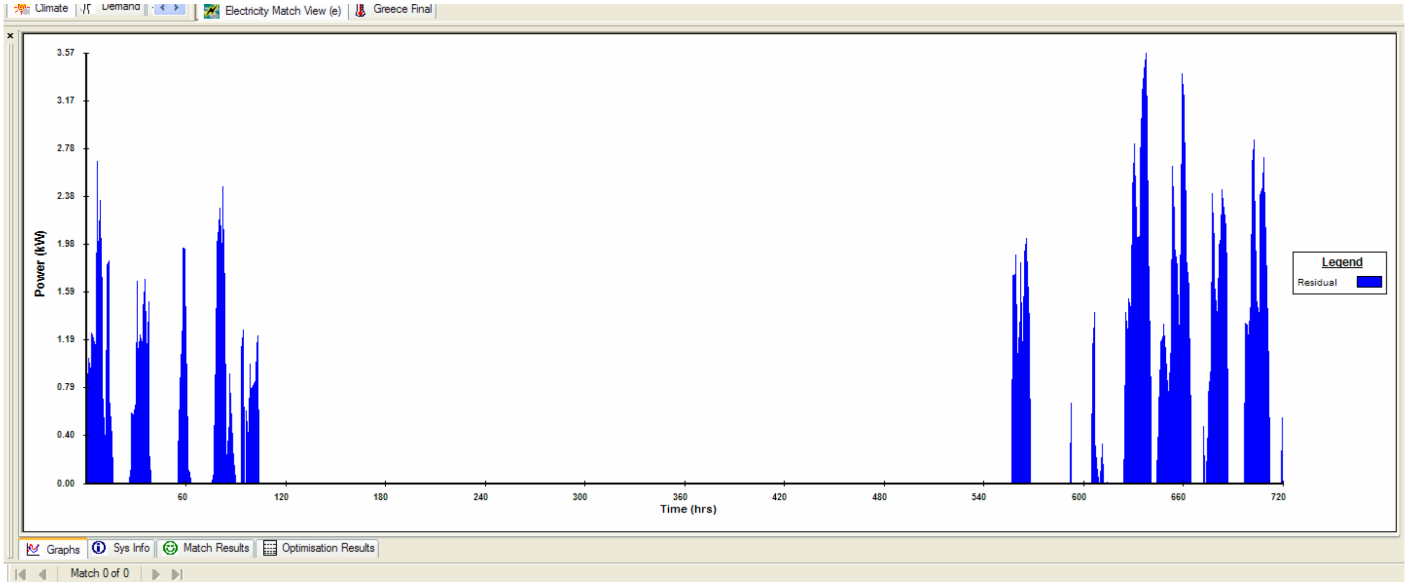


Diagram 32: Residual Power Graph in May

Finally, during May, as it can be seen from the above diagrams, a very good match between supplies and demands is achieved and this is due to the very good performance of the system and especially of the batteries, which provide an excellent support to that system.

Again, like in August, during the last days of May, there is a large production of energy from the renewable systems, which overcompensates the energy needs of the building, and the batteries are being recharged. Furthermore looking at the residual graph it can be seen that the hybrid system can cover totally the energy demands and can store quite large quantities of energy into the batteries as well, in order to use them another day where the climatic conditions may not be ideal.

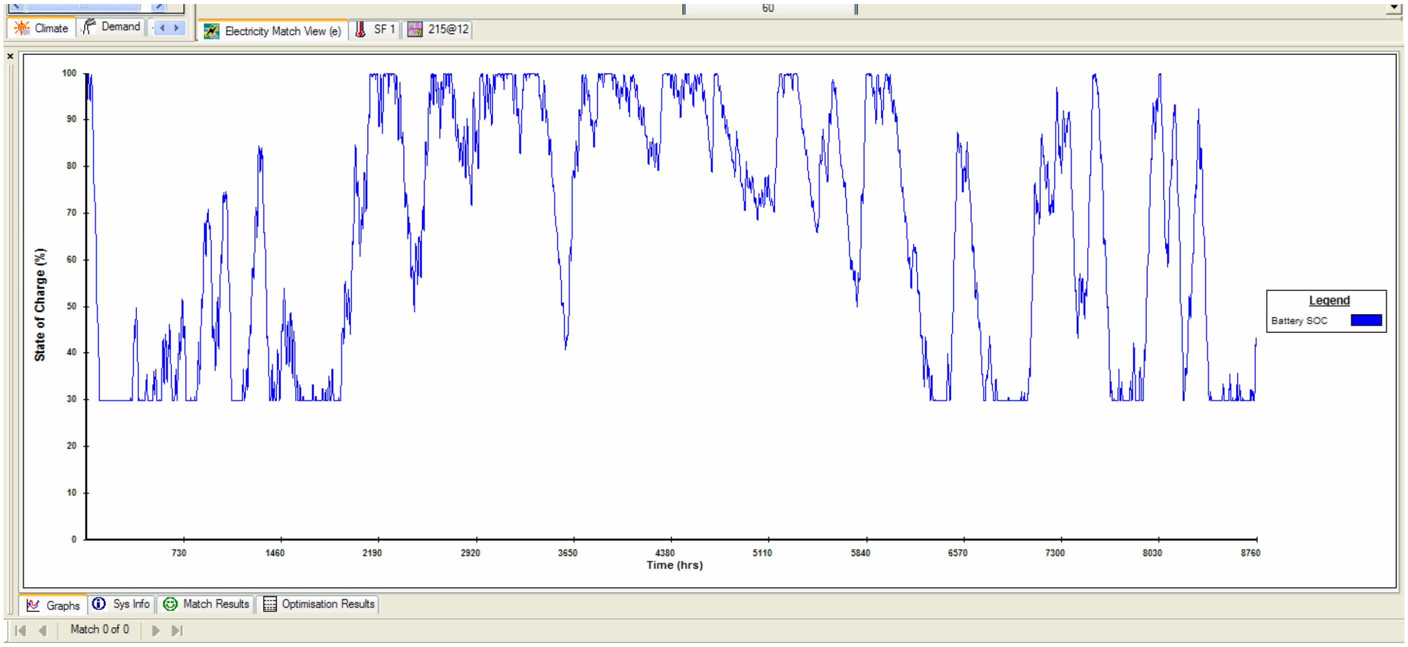


Diagram 33: Yearly Battery Performance in Glasgow

For Glasgow, it can be observed from the above diagram, that during the 6 month period between April and October, when the demands are limited, the batteries' performance is very high and remain fully charged. In contrast, during the other 6 months the state of charge of the batteries is very poor, because during that period there is an increased demand for energy and the system is unable to cover it properly.

Again in order to make this analysis more interesting some critical troughs on the yearly performance battery graphs were chosen. These troughs are illustrated in the middle of April and during the last days of May and August. Again, from the following diagrams it can be observed that prior to a trough, the supply of natural energy is indeed quite high and the fluctuations are low showing a low battery usage. On those days when natural energy is low, fallback onto battery supply is necessary leading to battery discharge as it can be seen from the large troughs in the graph.

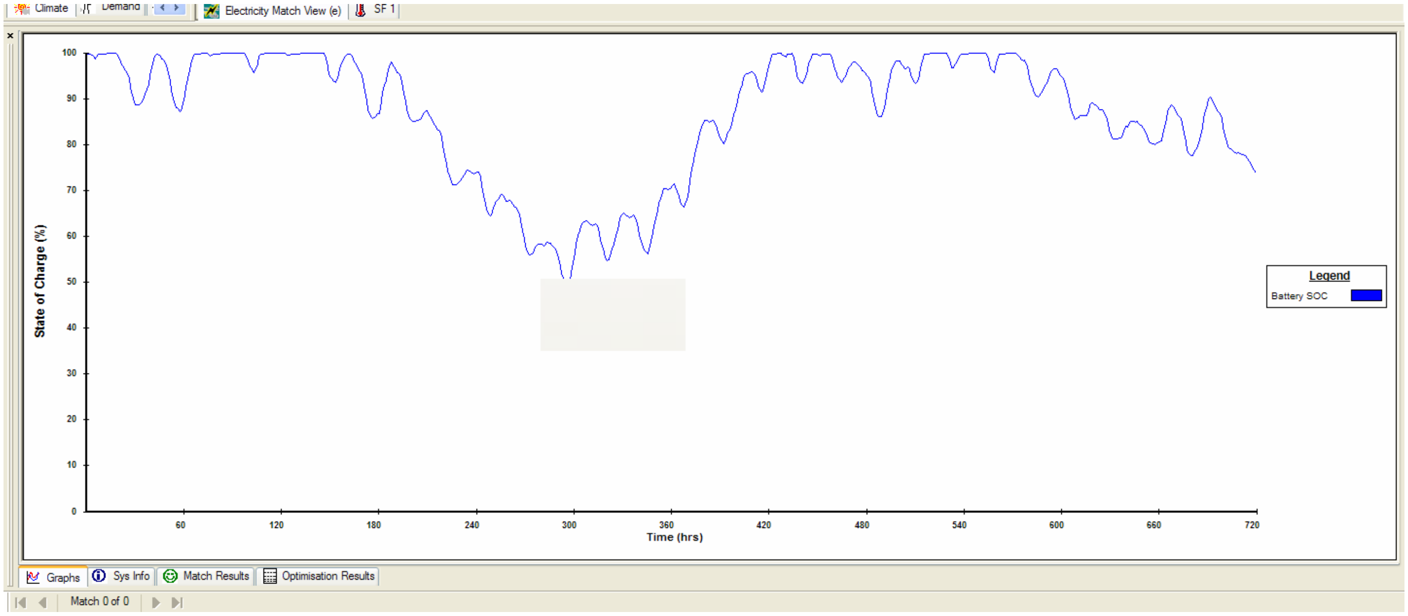


Diagram 34: Battery Performance in April

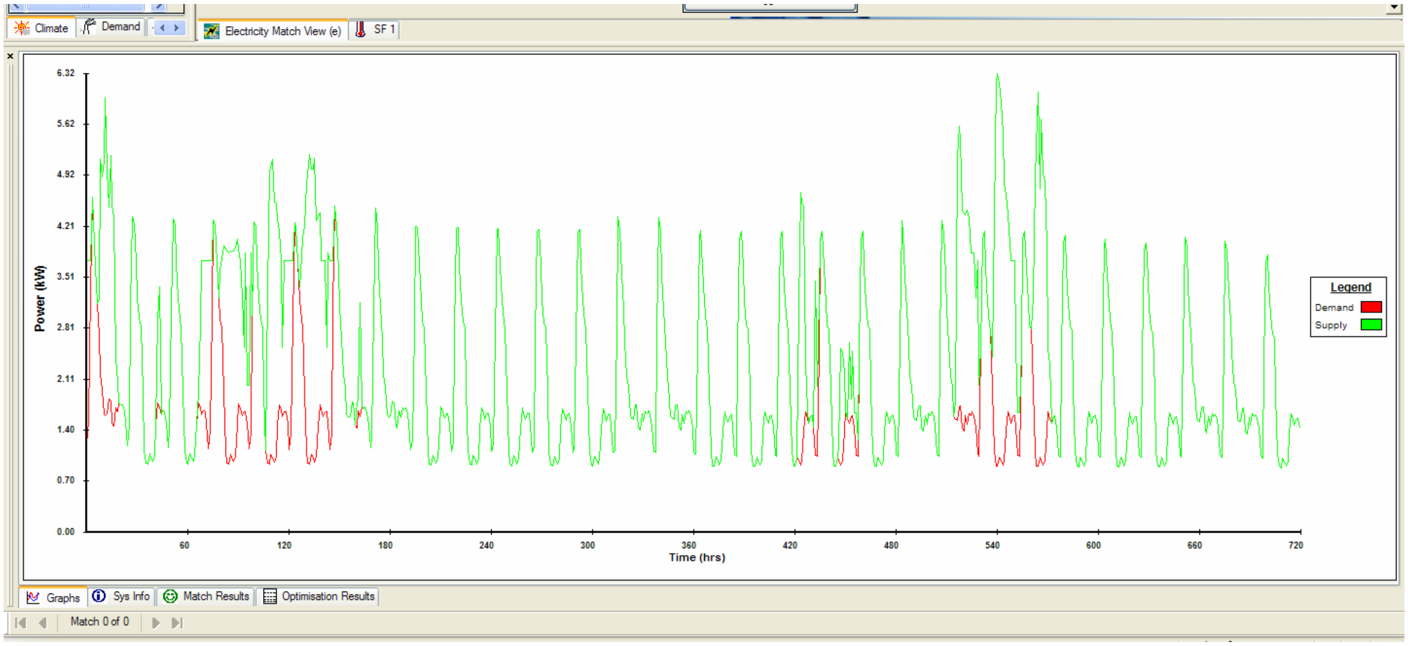


Diagram 35: Diagram of Supplies-Demands in April

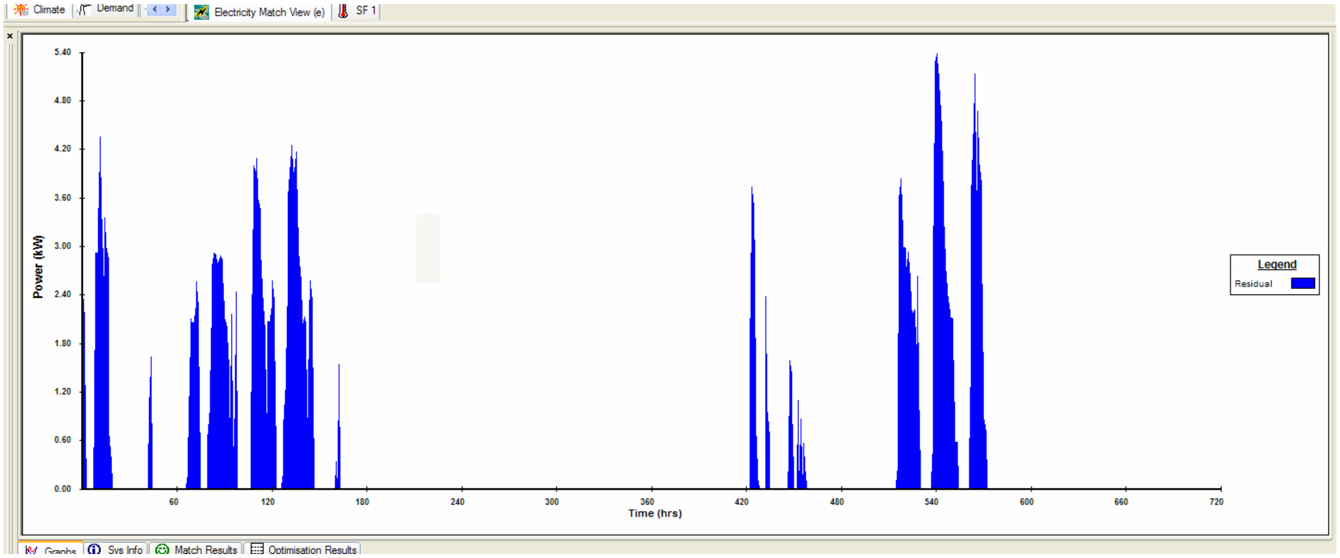


Diagram 36: Residual Power Graph in April

From the above diagrams, one can observe a remarkable system performance during April, because even though the demands are high, the system can cover them totally and its performance is close to being perfect. This is ought to the very good climatic conditions during that month. But as it was mentioned in the previous section this does not mean that for every April the weather conditions will be the same excellent.

Many quantities of residual energy are stored in order to increase the performance of the system in those days without natural energy support and the state of the batteries is really effective in order to improve the match between the supplies and the demands.

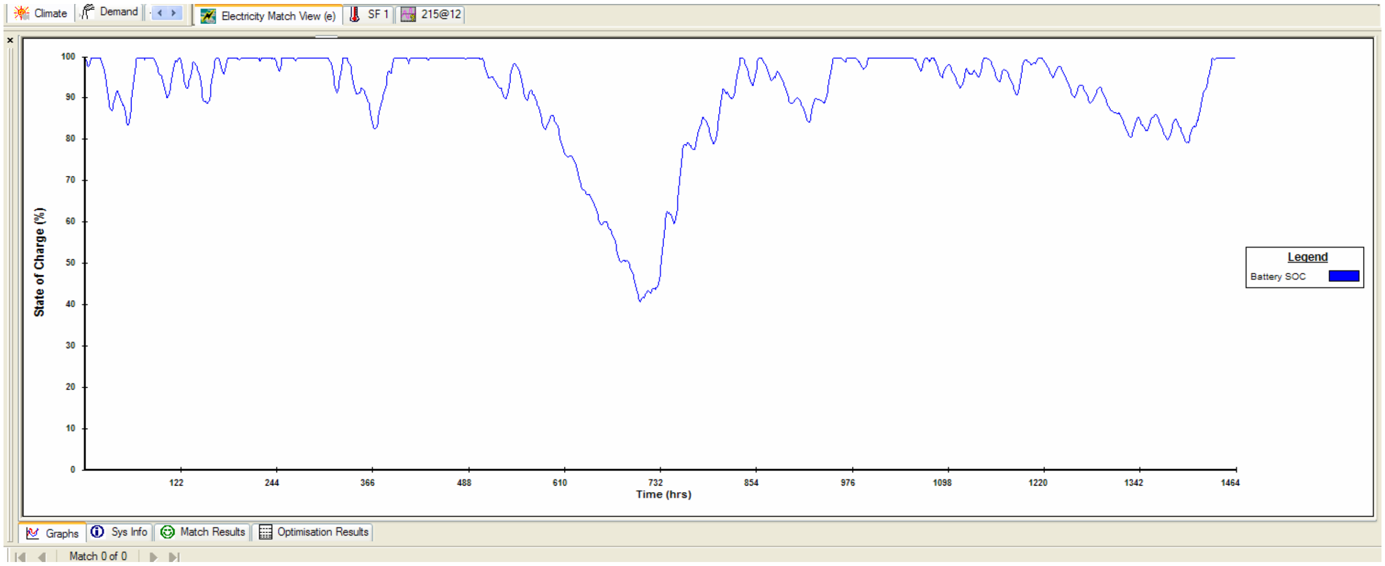


Diagram 37: Battery Performance in May-June

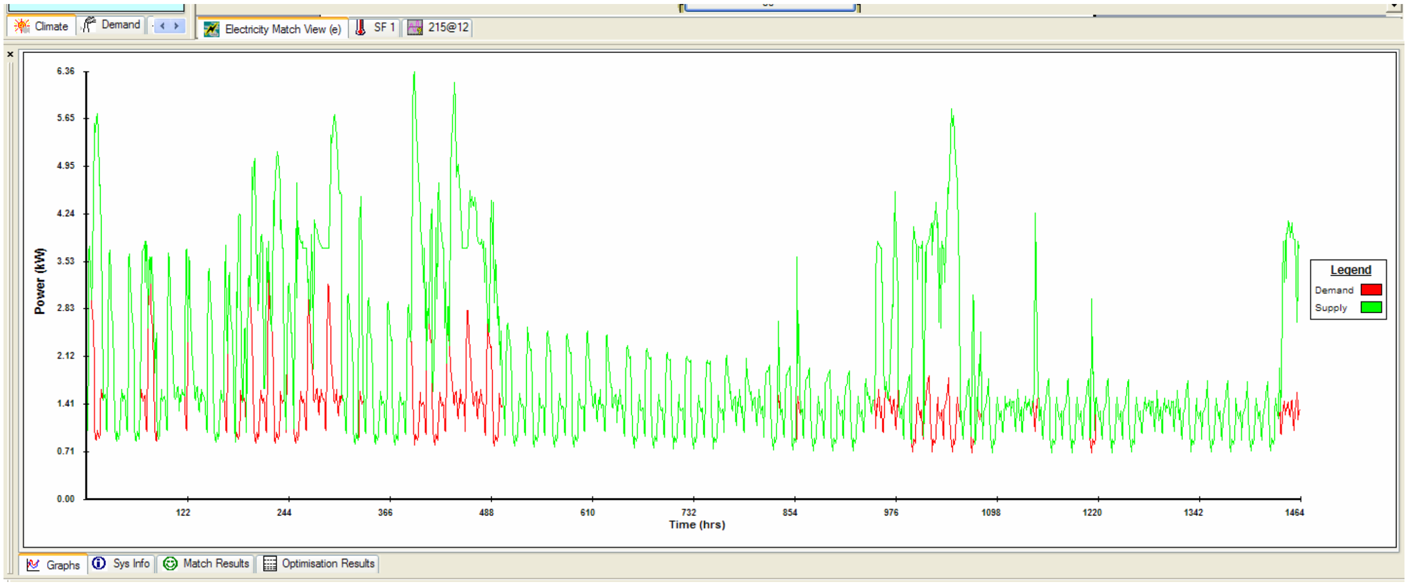


Diagram 38: Diagram of Supplies-Demands in May-June

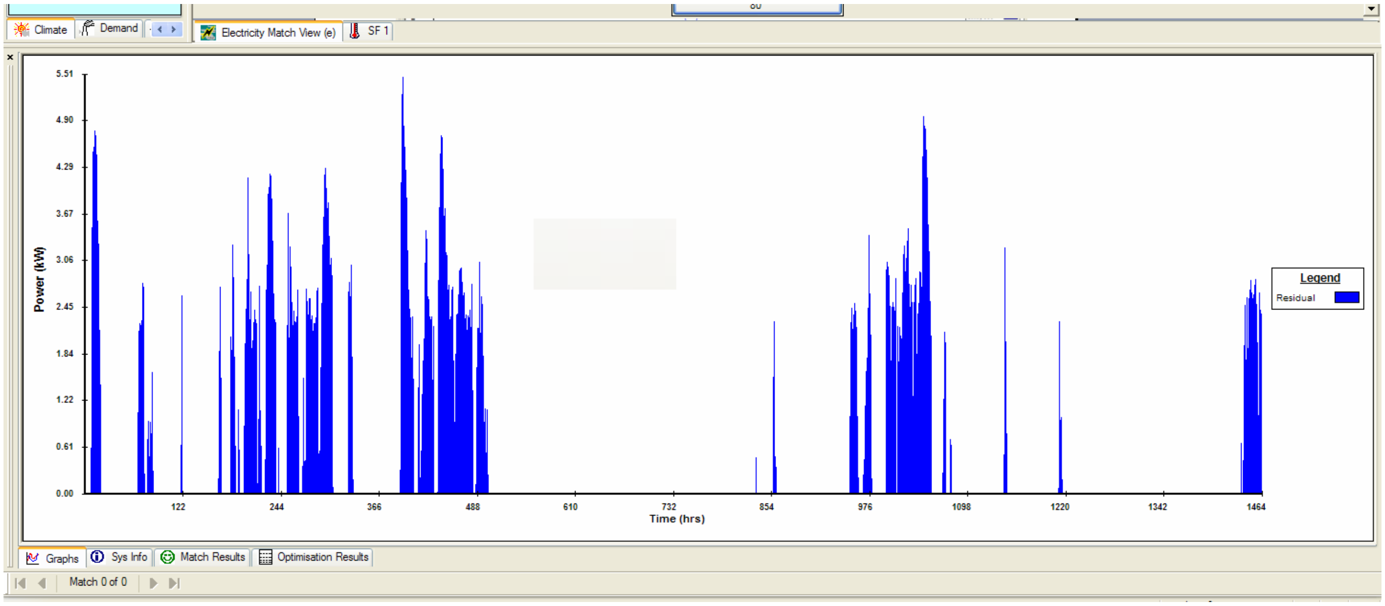


Diagram 39: Residual Power Graph in May-June

In May-June a very good match of the energy demands with the supplies and a very good performance of the batteries are observed. As it can be seen in the above three graphs during the first days of those months the batteries are being charged, then they supply that energy for approximately a week. What occurs is illustrated by this trough on the battery performance graph. They are recharged again and residual power is stored in the batteries.

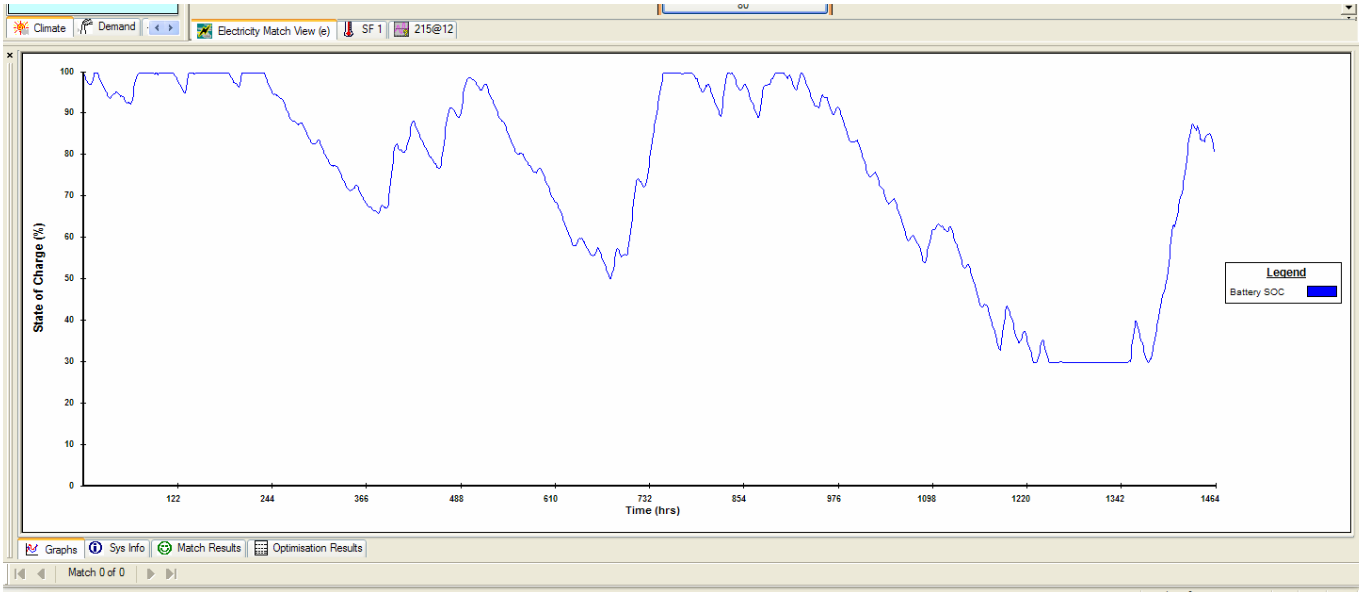


Diagram 40: Battery Performance in August-September

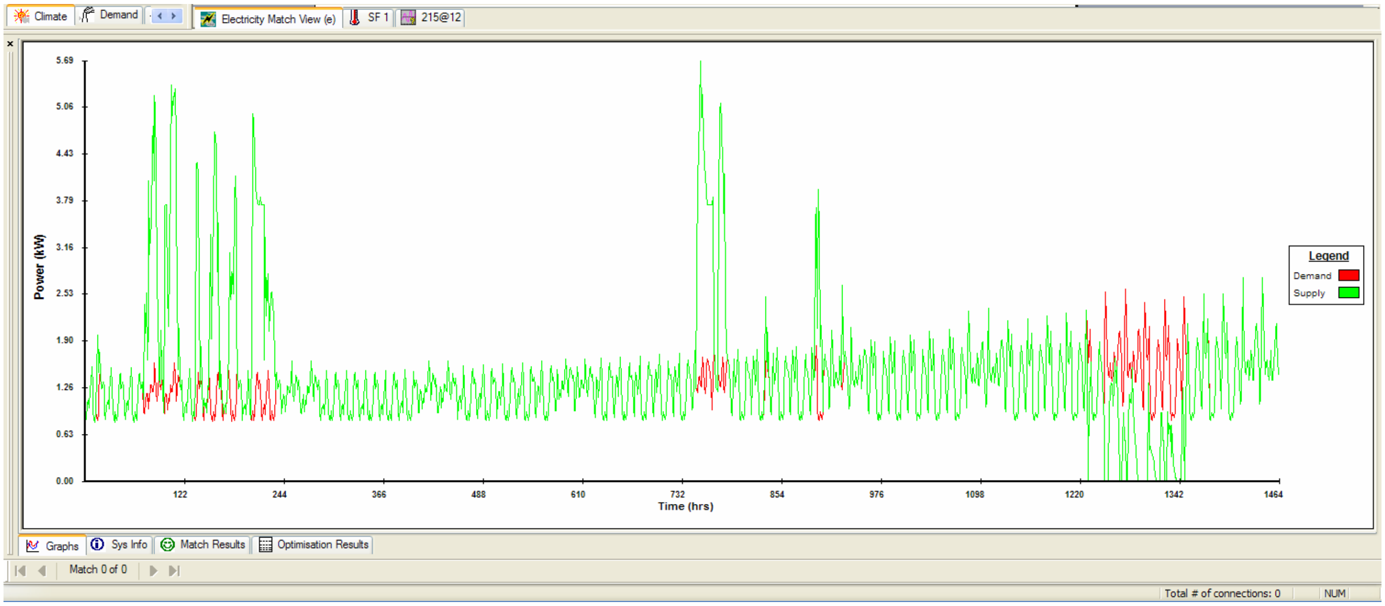


Diagram 41: Diagram of Supplies-Demands in August-September

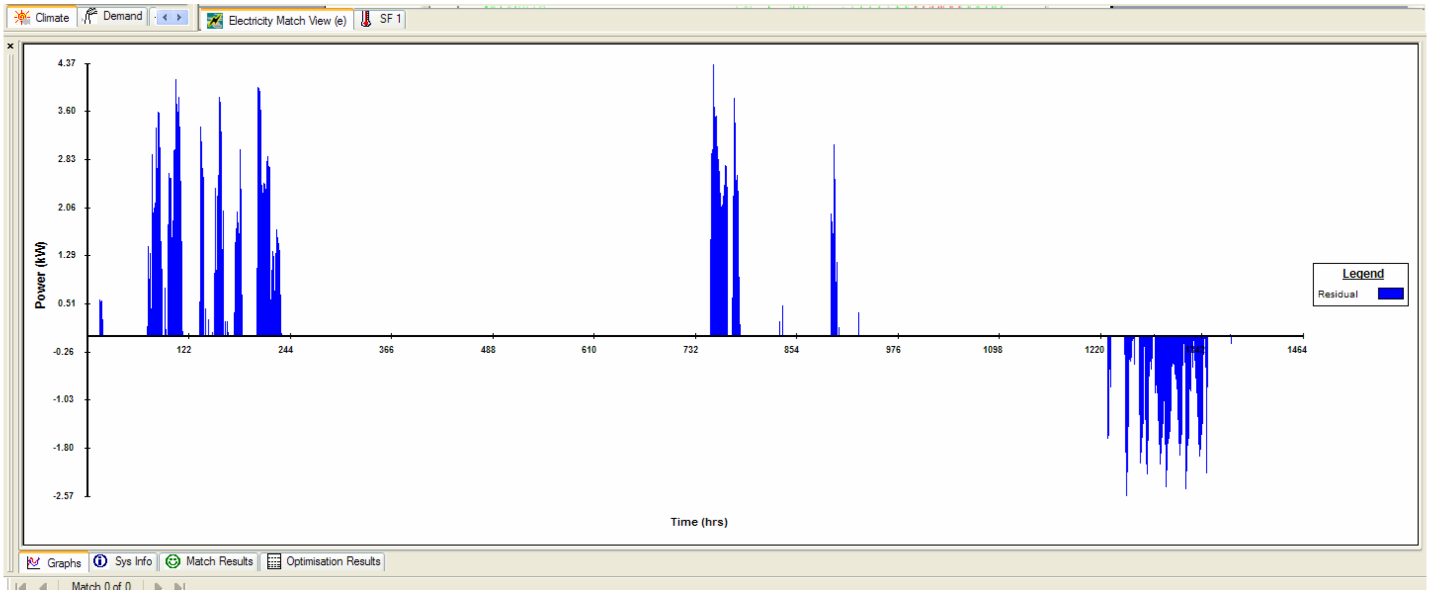


Diagram 42: Residual Power Graph in August-September

During August there is an excellent performance of the system and a consequential full coverage of the demands required for that month. The fluctuations in the state of battery graph represent their very good performance which is a result of the stored energy and illustrate the full coverage of the demands during the days without natural energy support.

In contrast, in September there is the worst performance of the system and demand peaks can be seen during the final days. Furthermore the system for those 5 days is not performing properly and residual power is needed.

Moreover, as more batteries are used in the system so is the match rate of the system increasing. However, a maximum number of batteries, appropriate for each situation, should be used, since the use of more batteries than needed would be costly and would not offer any further to the system operation. This can be observed better by the tables below where the improving match rate and the correlation coefficient for each system are shown. The best match rate possible, after many combinations and the use of different number of batteries, is finally stabilized around 70% for Glasgow and 86% for Crete at which point the maximum performance of the system is achieved. This match rate was achieved using 70 batteries for Crete and 80 batteries for Glasgow. Thus, the use of more batteries would not improve the match rate of the system so their use would only be an additional cost.

<u>Heraklion Crete</u>

Aux Supply Number	*Total Demand*	*Total Supply*	*Total Aux Supply*	*Match Rate (%)*	*Inequality Coefficient*	*Correlation Coefficient*	*Shared Area*
Batteries 40	17.53 MWh	16.61 MWh	614.60 kWh	83.48	0.17	0.71	16188.28

Aux Supply Number e	*Total Demand*	*Total Supply*	*Total Aux Supply*	*Match Rate (%)*	*Inequality Coefficient*	*Correlation Coefficient*	*Shared Area*
Batteries 50	17.53 MWh	16.61 MWh	755.33 kWh	84.56	0.15	0.74	16421.71

Aux Supply Number	*Total Demand*	*Total Supply*	*Total Aux Supply*	*Match Rate (%)*	*Inequality Coefficient*	*Correlation Coefficient*	*Shared Area*
Batteries 60	17.53 MWh	16.61 MWh	867.98 kWh	85.26	0.15	0.76	16576.03

Aux Supply Number	*Total Demand*	*Total Supply*	*Total Aux Supply*	*Match Rate (%)*	*Inequality Coefficient*	*Correlation Coefficient*	*Shared Area*
Batteries 70	17.53 MWh	16.61 MWh	949.83 kWh	85.96	0.14	0.78	16685.97

Table 6: Different performance of the batteries by number in Heraklion Crete

Glasgow

Aux Supply Number	*Total Demand*	*Total Supply*	*Total Aux Supply*	*Match Rate (%)*	*Inequality Coefficient*	*Correlation Coefficient*	*Shared Area*
Batteries 50	16.00 MWh	13.98 MWh	506.57 kWh	68.27	0.32	0.31	12531.31

Aux Supply Number	*Total Demand*	*Total Supply*	*Total Aux Supply*	*Match Rate (%)*	*Inequality Coefficient*	*Correlation Coefficient*	*Shared Area*
Batteries 60	16.00 MWh	13.98 MWh	635.88 kWh	69.30	0.31	0.34	12794.25

Aux Supply Number	*Total Demand*	*Total Supply*	*Total Aux Supply*	*Match Rate (%)*	*Inequality Coefficient*	*Correlation Coefficient*	*Shared Area*
Batteries 70	16.00 MWh	13.98 MWh	747.33 kWh	69.92	0.30	0.35	12980.02

Aux Supply Number	*Total Demand*	*Total Supply*	*Total Aux Supply*	*Match Rate (%)*	*Inequality Coefficient*	*Correlation Coefficient*	*Shared Area*
Batteries 80	16.00 MWh	13.98 MWh	825.65 kWh	70.45	0.30	0.37	13087.36

Table 7: Different performance of the batteries by number in Glasgow

The type of battery which is used for the needs of this analysis was the 215Ah@12 Volt as already mentioned previously. This type of batteries was used in order to achieve the best match rate possible. However, under real circumstances, the system can operate the same efficiently having a lower percentage of match rate. So in real situations, it is not necessary to use this type of battery because it is very expensive but it can be substituted by another less expensive but with similar quality (i.e.145Ah@12) without the performance of the system being reduced significantly. This can be better identified by observing the tables below that refer to different cases.

It can be seen that there is no significant difference in match rate from one case to the other. For each region the appropriate number of batteries is going to be used in order to achieve the best performance of the system. Thus, as it was mentioned previously Heraklion is going to use 70 batteries and Glasgow 80 for all the cases below. Moreover it should be clarified that this type of hybrid system which was used, operates only in 12 volts because the PV which was used operates in 12 Volts as it was illustrated previously in I-V curve. That's why in the tables below different types of batteries which operate in 12 volts are used.

Heraklion Crete

Battery Type	***Total Demand***	***Total Supply***	***Total Aux Supply***	***Match Rate (%)***	***Inequality Coefficient***	***Correlation Coefficient***	***Shared Area***
215@12	17.53 MWh	16.61 MWh	949.83 kWh	85.96	0.14	0.78	16685.97

Battery Type	***Total Demand***	***Total Supply***	***Total Aux Supply***	***Match Rate (%)***	***Inequality Coefficient***	***Correlation Coefficient***	***Shared Area***
120@12	17.53 MWh	16.61 MWh	537.81 kWh	83.24	0.17	0.70	16118.19

Battery Type	***Total Demand***	***Total Supply***	***Total Aux Supply***	***Match Rate (%)***	***Inequality Coefficient***	***Correlation Coefficient***	***Shared Area***
130@12	17.53 MWh	16.61 MWh	574.10 kWh	83.60	0.16	0.71	16190.92

Battery Type	***Total Demand***	***Total Supply***	***Total Aux Supply***	***Match Rate (%)***	***Inequality Coefficient***	***Correlation Coefficient***	***Shared Area***
145@12	17.53 MWh	16.61 MWh	587.56 kWh	83.99	0.16	0.72	16264.47

Table 8: Different performance of the batteries by type in Heraklion Crete

Glasgow

Battery Type	Total Demand	Total Supply	Total Aux Supply	Match Rate (%)	Inequality Coefficient	Correlation Coefficient	Shared Area
215@12	16.00 MWh	13.98 MWh	kWh	70.45	0.30	0.37	13087.36

Battery Type	Total Demand	Total Supply	Total Aux Supply	Match Rate (%)	Inequality Coefficient	Correlation Coefficient	Shared Area
120@12	16.00 MWh	13.98 MWh	366.90 kWh	67.68	0.32	0.29	12358.09

Battery Type	Total Demand	Total Supply	Total Aux Supply	Match Rate (%)	Inequality Coefficient	Correlation Coefficient	Shared Area
130@12	16.00 MWh	13.98 MWh	413.37 kWh	68.07	0.32	0.30	12453.76

Battery Type	Total Demand	Total Supply	Total Aux Supply	Match Rate (%)	Inequality Coefficient	Correlation Coefficient	Shared Area
145@12	16.00 MWh	13.98 MWh	432.27 kWh	68.61	0.31	0.32	12567.59

Table 9: Different performance of the batteries by type in Glasgow

Another interesting observation is the performance of the Greek system without the use of the batteries. Its match rate reaches 70% while the total performance for the British system does not go beyond 71%. This is very interesting and again the important point is that the climatic conditions, especially the sun, have a direct effect on the improvement and maximization of the performance of a hybrid system. This is paramount.

This means that theoretically the installation of a hybrid system in Greece without the use of batteries would reduce the cost of the system and would be a more preferable solution. However, a system without the use of batteries cannot be viable in real situations, because the lack of natural energy sources even for a moment during the day, would cause the system to fail, not being able to provide electricity for the building. Thus the energy storage pack for the hybrid system is always necessary.

6.4 Conclusions-Recommendations of Merit Analysis

In hindsight of this analysis and of the thorough evaluations of the results, it can be concluded with the utmost confidence that an autonomous building is a realistic idea. Although, from an economic point of view, as it will be shown in chapter 7, the installation and use of a hybrid system is not economically viable for Greece and for the UK as well.

In this project the buildings which were used were typical ones for both countries. This means that the total area for each building was about 120 square meters and the roof of a building of this kind usually covers an area of about 75 square meters.

For the Greek analysis the amount of the photovoltaic panels which were used were 40. Using simple calculations it is easy to establish that an installation of them on the roof is feasible. This is because the area of a single photovoltaic module is only 0.8712 m^2, so the total area they can cover is approximately 35 m^2. This area which is covered by the base of one ducted turbine is around 1 square meter so the total of 8 would be able to cover an area of no more than 10 m^2. Thus the total area which the photovoltaic panels and the ducted wind turbines can cover is approximately 45 m^2. This means that there is plenty of space for the installation of the specific Greek hybrid system. Its performance can cover approximately all the energy demands of the building and in that way it can convert it in a functionally autonomous building.

In the same way for the British analysis the amount of the photovoltaic panels which were used was 26 and the number of the ducted turbines was 15. The total area which both energy systems photovoltaic panels and ducted wind turbines can cover is approximately 40 m^2. This again shows that there is plenty of space on the roof of the building for the installation of the specific British hybrid system.

For the Greek climate the performance of the hybrid system is very good and the energy demands can be covered to a large extent. On the contrary, for British climates a hybrid system may not be so effective, however this solution should not be discarded. And this is because while sunlight is limited in winter months, the wind potential in the greater area of Glasgow is high, as it was analytically presented in chapter 5 and depicted in graph 6 below.

A simple recommendation is that in Greece the use of photovoltaic panels has to be widely spread in urban and in rural areas as well. Moreover it is quite remarkable that a country with so much solar potential does not support in a desirable extent this kind of technology and until now it has not applied it around all the main city centres, as it has already been analysed in paragraph 5.1. The use of these energy systems will help in reducing the electricity costs from fossil fuels and it will contribute in the construction of much more autonomous buildings. At present, this solar energy is exploited by the use of other solar systems such as solar water heaters, which are quite widespread all over the country for domestic needs. Even though the first energy power source in Greece is the sun, one cannot disregard the fact that Greece has also high wind energy potential, especially on the islands. Thus the combination of these two energy sources can improve the performance of the building a lot, can make it electrically autonomous and can convert it in a sustainable building.

On the other hand for the British climate the use of a hybrid system does not sound such a good idea and especially for the North parts of the country and Scotland. The reason of course is the limited sunshine during the year but again one cannot disregard the fact that this country has a high wind potential, especially in Scotland. Thus if we would like the idea of an autonomous building in Scotland to be realised and the building to be energy independent from fossil fuels, we must invest primarily in wind technologies, as it has already been mentioned in paragraph 5.2 and 5.2.2.

Finally serious actions have to take place in order not to be restricted in the installation of small scale renewable systems for the cities but to extend further to the installation and the construction of large wind and solar farms. Of course during the last years there has been a remarkable increase in the installation of wind and solar farms as well as a development in the installed small scale renewable energy systems for domestic use in both UK and Greece as it has already been thoroughly analysed in paragraphs 5.1 and 5.2. However, more must be done if we want to meet the obligations of the white paper in 2010, mentioned in paragraph 2.5, for the orthological use of the energy.

For this reason, for Greece more solar farms have to be constructed because, as it has been mentioned in chapter 5, today there are few of them around the Greek territory and much more wind farms have to be constructed as well. For UK because the solar radiation does not help a lot technicians and scientists have to concentrate on the continuous development of wind farms. Of course this is not again the best option for the country because there is not so much reliability in the wind resource as it will be analyzed in the next section 6.5.

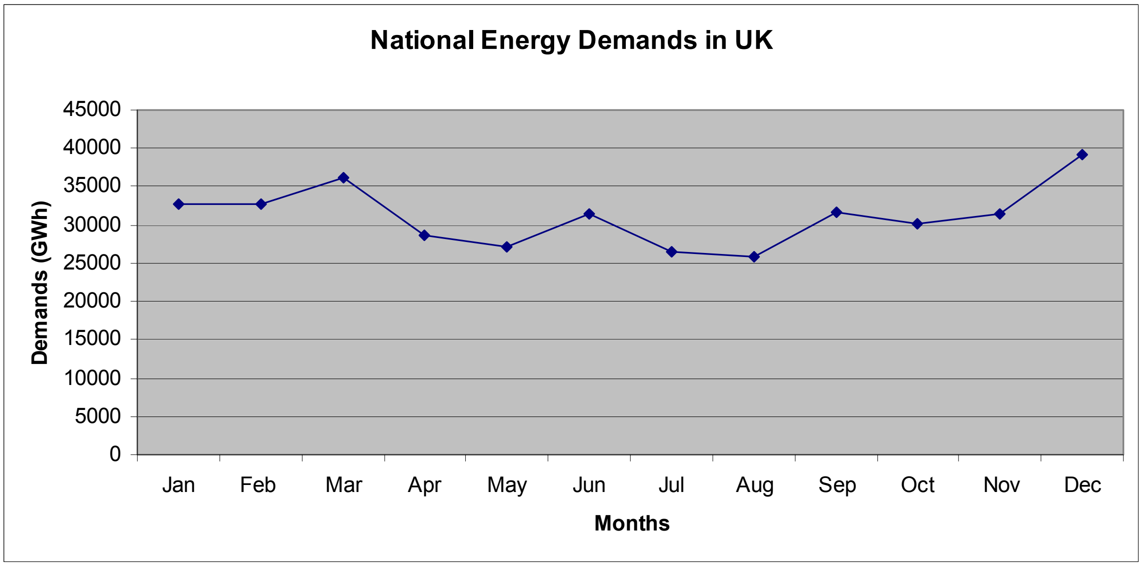
6.5 National Demands for UK-Greece

As it can be observed from diagrams below, the national demands for the UK are quite low during the summer period and high enough during the winter period, which seems very rational. Moreover, the solar radiation significantly increases, reaching the highest value in April and then it slowly decreases, reaching the lowest value in December. In contrast, wind speed has a more stable performance during the whole year as it can be seen from the wind speed graph, although this is not as reliable as it seems to be as it will be further analyzed in a following paragraph.

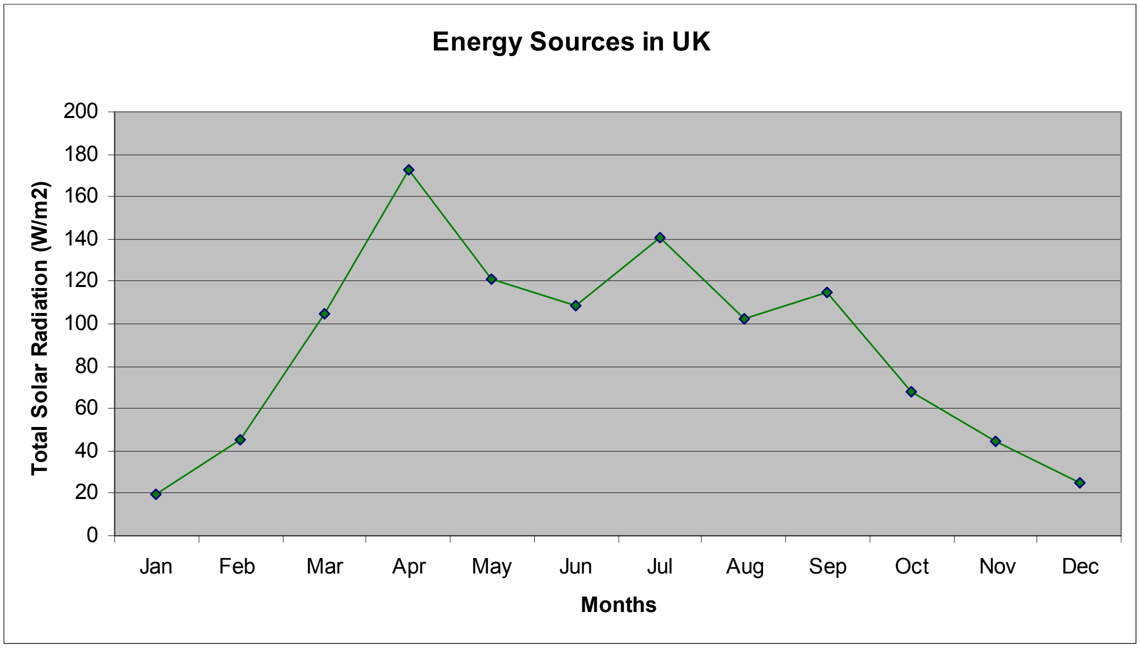
Specifically during April, when the energy demands of the building are quite low, the highest peak of both solar radiation and wind speed are observed. However, this is far from being the best condition as the ideal would be that the high peaks of the energy sources would take place during the months with the highest energy demands of the building, in order for a hybrid system to be able to cover them properly.

In addition, the wind speed remains in rather high levels all through the year as it is illustrated by the wind speed diagram below. With this wind speed, the energy needs which are low during the summer period can be sufficiently covered. In winter the things are different and wind speed cannot be so reliable in order to improve the performance of the hybrid system. The main reason for this is that the highest wind speed values are observed during April and March where the energy demands are rather low and during January, February, November and December where the energy demands reach peak values; a stability of the wind speed is observed at around 5 m/sec with a tendency to reduce. Except that, the value is not as high as it was expected, resulting to the reduction of the performance of the hybrid system. Thus, it can be realized that the wind is not as reliable as it was expected to be, especially during the critical months of the winter period, where the energy demands are very high.

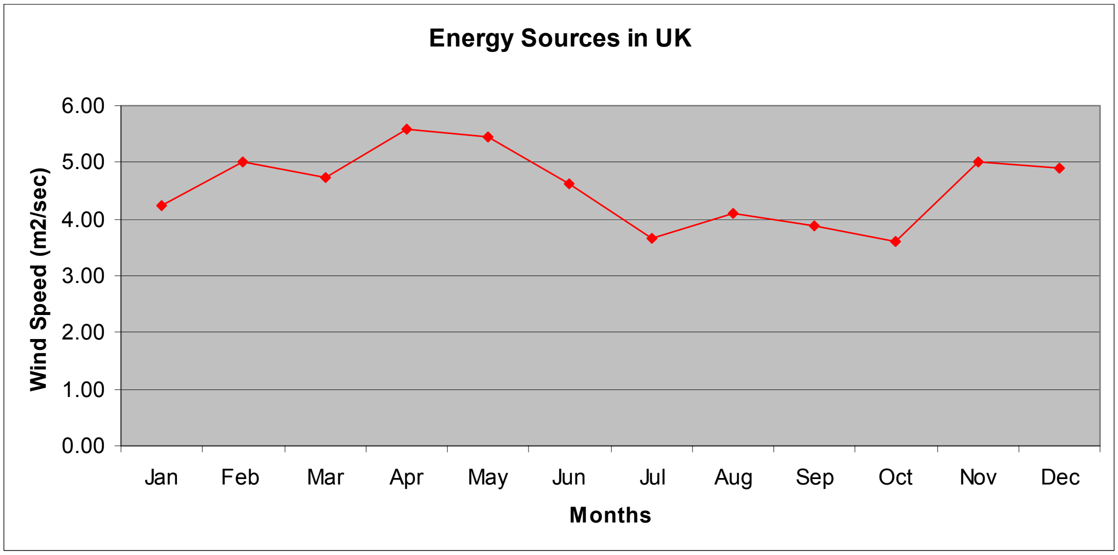
On the other hand, neither can solar radiation be considered a reliable source. This is something which is reasonable for the UK climatic standards and the energy which can be provided is too limited throughout the whole year as it can be clearly seen from the graph below.



Graph 4: National energy demands for a year's period in UK



Graph 5: Total solar radiation for a year's period in UK

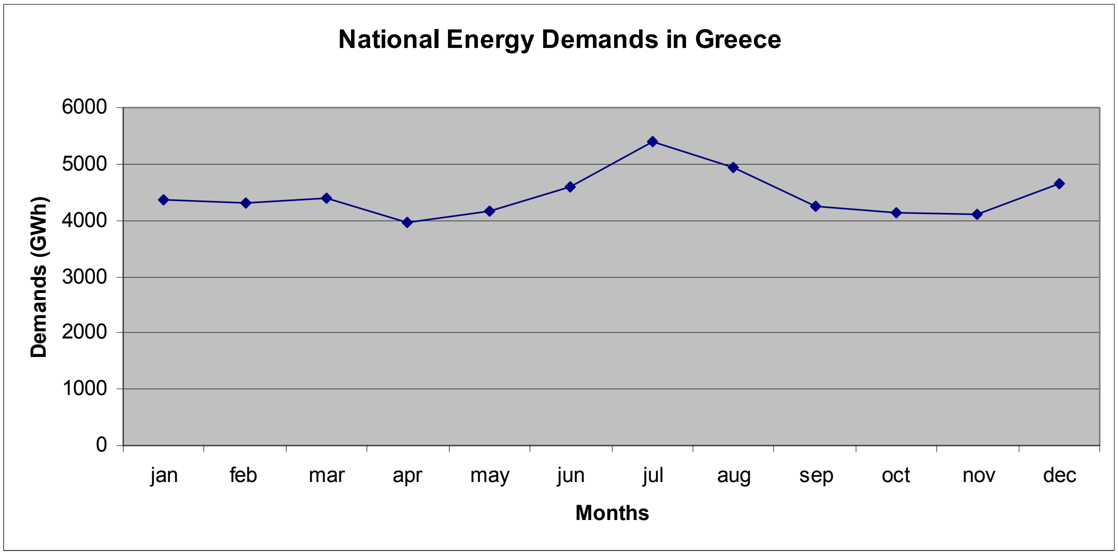


Graph 6: Wind speed for a year's period in UK

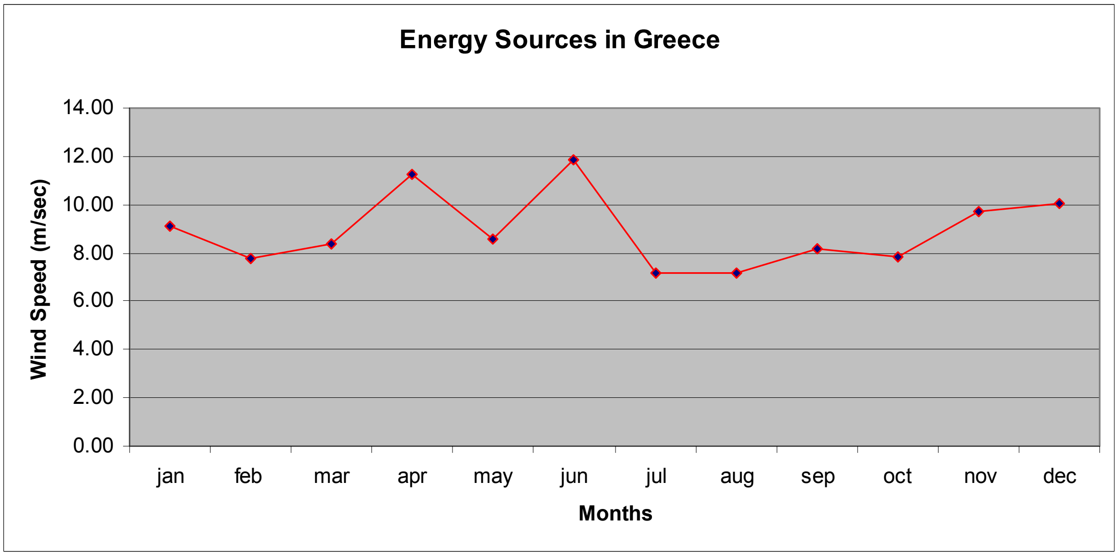
In contrast to the UK case, in Greece the energy sources are more reliable and they can cover to a larger extent the energy needs of a building during the whole year. This can be clearly observed from the diagrams below, where there is a very good performance of the energy sources and a very good match is achieved with the energy demands of a building during this year's period.

For the summer period, where the energy demands are very high, high levels of the solar radiation are observed as well. Especially for June where the highest demand is observed the solar radiation is at its maximum point. This, as it can be realized, will increase the performance of the system and will make the system much more competitive, corresponding to the high energy demands of the building during that month.

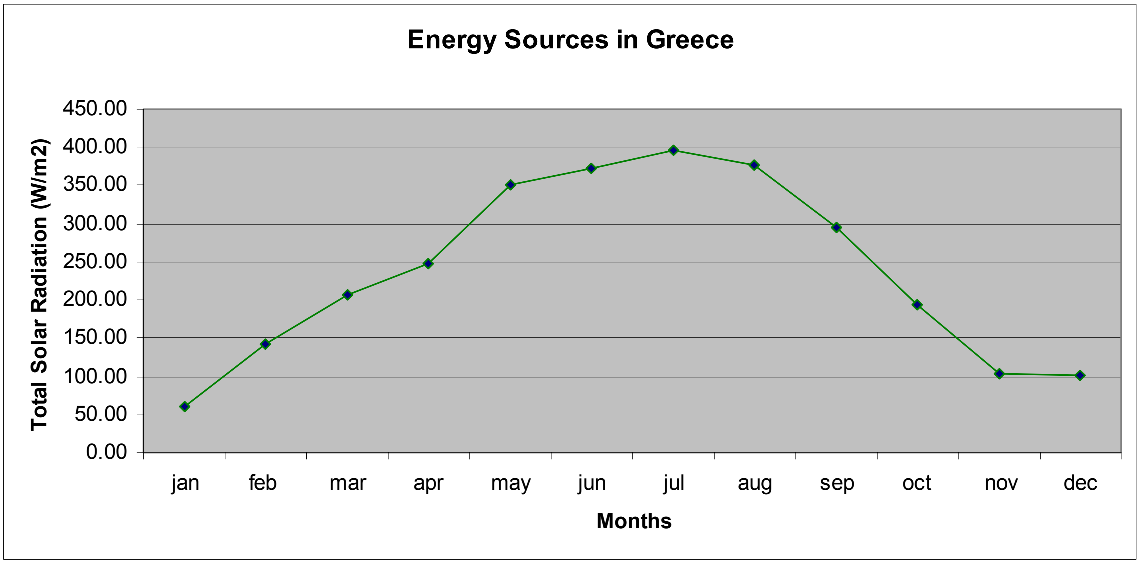
Moreover during the winter period, when the solar radiation is not so strong and effective, the wind energy substitutes the solar energy, as it can be observed from the wind speed diagram below. In that way the performance of the system can become competitive again in order to cover the energy demands of the building.



Graph 7: National energy demands for a year's period in Greece



Graph 8: Wind speed for a year's period in Greece



Graph 9: Total solar radiation for a year's period in Greece

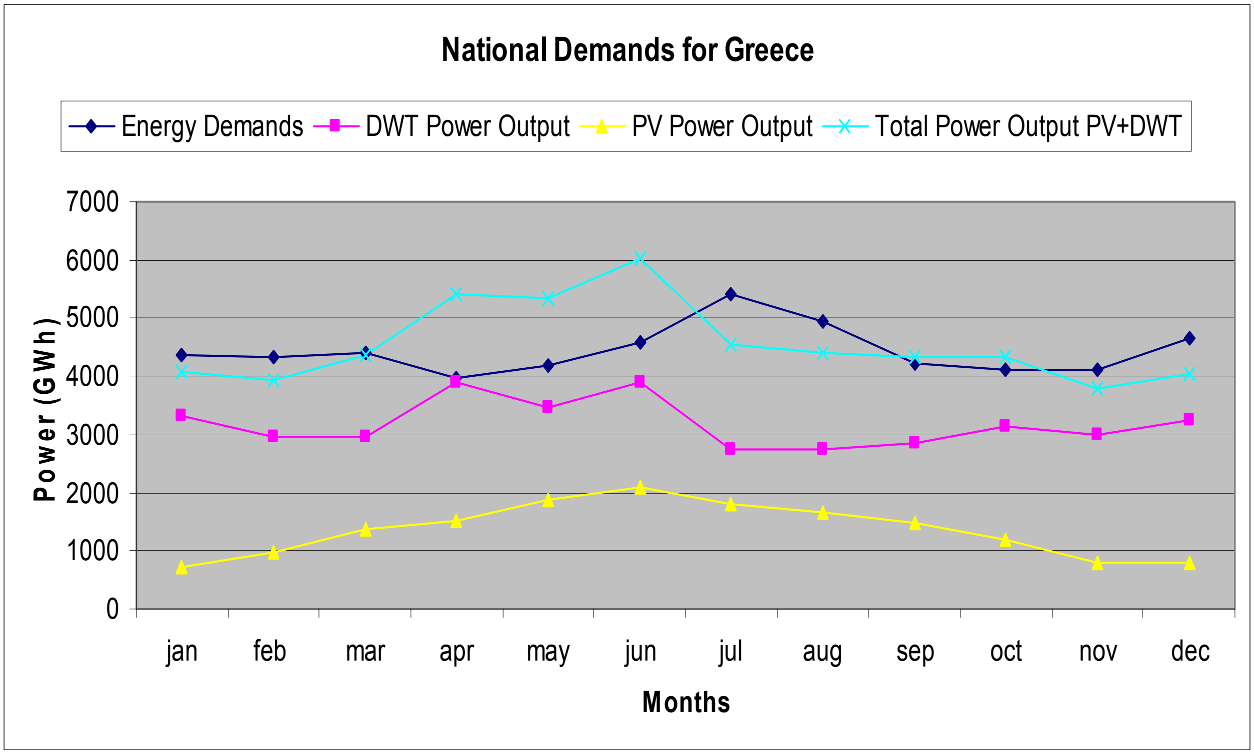
An effort took place in order to estimate approximately how many numbers of photovoltaic panels and wind turbines are required in order to cover the national energy demands for each country. A number of different combinations were used in order to decide which is the best one that could cover most effectively the energy demands for each country separately.

For Greece 150.000 photovoltaic panels and 25.000 ducted wind turbines were used while for UK 300.000 photovoltaic panels and 500.000 ducted wind turbines were used. This big difference in the number of the renewable systems is due to two reasons. Firstly, due to the different rates in the number of the total population and, secondly, due to the different capacity levels in energy sources for each country separately.

Moreover, the UK energy demand is almost 8 times higher than the Greek demand which is very reasonable for a country of 70 million people instead of Greece which has only 10 million people. In addition, for the Greek case it was decided to use more photovoltaic panels instead of ducted wind turbines because as it was mentioned previously the solar energy is in very high levels during the whole year. This has helped the total supply to increase especially during the summer months when the energy needs for electricity, mostly from the air-conditioning, are very high and the wind energy is not very effective.

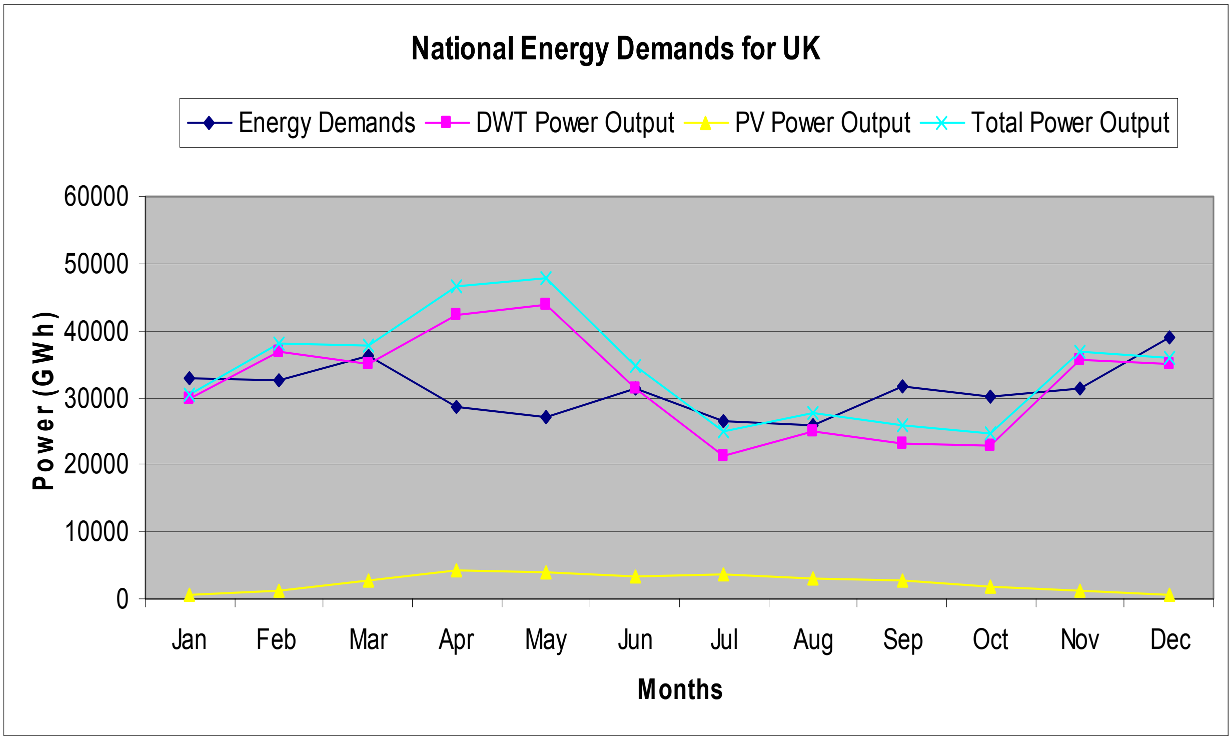
On the contrary, for the UK it was decided to use much more ducted wind turbines because as it can be realized from the previous paragraphs the main energy source throughout the whole year is wind. Thus a large number of turbines were used, while the number of photovoltaic panels used was quite less, both helping the total power output to be increased during the summer period and to meet the country's huge demand.

All these observations can be realized better from the diagrams below. Moreover it can be seen that for Greece the total power output from the renewable systems can meet, to a satisfying extent, the demands during the whole year. Only during April, May and June does supply go beyond demand but this is not too bad because during the summer period the supply has to be quite high, in order to appropriately cover the demands for every year in Greece. In addition a better match between supplies/demands during those months can be achieved, if the operation of the photovoltaic panels is stopped. Thus, the energy demands will be covered only by the use of ducted wind turbines and the match of the supplies/demands will be almost perfect as it can be seen from the below graph.



Graph 10: Matching Demands/Supplies in a national level for Greece

Furthermore for the UK case it can be observed by the following diagram, that the number of small scale renewable systems that were used can be very effective and can meet successfully the total demands during the whole year. Especially during the winter period where the demands are very high there is a very good match. Only during April and May were the supplies a lot higher than the demands. Even in this case the situation is not as bad as one may think because during April the need for energy in the UK is essential even in the spring season as there are still cold days.



Graph 11: Matching Demands/Supplies in a national level for UK

Finally it has to be said that all these scenarios are hypothetical ones and the effort made in order to find out how many small scale renewable systems like the ones which were used for the Merit analysis are required, in order to cover the national energy demands for each country. This on the one hand can provide a general realistic image of the total coverage of the energy needs by the use of renewable systems while on the other hand it will be helpful for the years to come so as to see how each country can cover the energy demands using in a large scale these small scale renewable systems, because the scenario of fossil fuels being exhausted seems more and more likely in the close future.

7 ECONOMIC ANALYSIS

7.1 INTRODUCTION

An economic analysis took place, in order to test if the hybrid system which is going to be used for both places is worth the risk of investing the money on a technology like this one or not.

For both systems the same cost was applied, thus the individual components for the installation of each system were the same and were purchased at the same cost from the same market. This was the case in order to achieve a more accurate and reliable economic comparison between the two systems. The cost of these items, which were collected from companies constructing this kind of modules, is the real cost for these kinds of renewable technologies. The purchase cost of these items is a retailing cost, instead of a wholesale cost which would be the normal cost for this multi-complex system. As a result of that, additional costs for the installation (such as labour) are not included, as they would bias the total costs upwards.

Moreover, two different cases were chosen to be analyzed as it will be depicted in tables 11 and 16 below. The first case for each system focuses on the usage of the maximum number of batteries while the second case refers to the usage of the minimum number of batteries for each system.

Furthermore it is assumed that the operation of this system is going to last for 25 years and the average annual operating cost, is chosen to be 2% of the initial cost of the system, for each case separately. The interest rate (i) of the present value equation was defined to be 3.5% for Greece because the inflation rate is around 3% and 5.25% for UK according to the Financial Times for the year 2007. The batteries which are used will be replaced during the lifecycle of the system, which is 25 years, because the batteries life cycle cannot exceed 15 years of operation. That’s why the cost of the batteries for this economic analysis was doubled. The price for a single battery is £50 while for the economic analysis of the systems the price reached £100. Finally a subsidy from the government of each country is assumed to reach 40% of the total cost of installation.

7.2 METHODOLOGY

The methodology which was used for this analysis is as it follows. Firstly the initial installation cost was calculated by adding the individual cost of the items which were used for each system and for each case. The initial installation cost includes the purchase price of the complete system (including charge controller, wiring, battery storage equipment, etc.). Then the initial installation cost was multiplied with the percentage rate that is subsidized by the government for each country respectively. In this way, the total installation cost for each case and system was calculated, as it can be seen from the table below.

Items	***Cost per Item (£)***
PV panel	325
Base PV	38
DWT	650
Batteries	100
Inverter	2385
Other Equipment	1100

Table 10: Costs of the items

	Hybrid System for Greece	***Cost of the Items (£)***
	40 Panels	13000
	40 Bases	1520
	8 DWT	5200
Case 1	70 Batteries	7000
Case 2	30 Batteries	3000
	1 Inverter	2385
	Other Equipment	1100
Case 1	***Initial Installation Cost***	***£30205***
Case 2	***Initial Installation Cost***	***£26205***
	Government Support Subsidies	***40%***
Case 1	***Total Installation Cost of the System***	***£18123***
Case 2	***Total Installation Cost of the System***	***£15723***

Table 11: Installation Costs for Greek Hybrid System

The total cost per kWh had to be estimated for Greece and then converted into pounds, in order to have the same currency and make the calculations easier. Moreover, the value of the kWh for each year has to be converted into its respective present value for each of the next 25 years, which is the estimated lifetime of the system. Besides, an assumption was made that for each five years the price per kWh will be increasing for both countries at around 5%, in comparison to the last value which the kWh had. This can be observed better from the table below.

Greece	Cost per kWh in Pounds(£)	Years
	0.047	Present Value
	0.050	Value after 5 years
	0.052	Value after 10 years
	0.055	Value after 15 years
	0.057	Value after 20 years-Until 25 years

Table 12: Cost per kWh for the next 25 years for Greece

An effort took place in order to estimate the total present value for the hybrid system and for the national electricity company for both cases in both countries. This was done with the primary goal being the comparison of these presents values, the careful evaluation of them, and finally the derivation of useful conclusions. The result of this comparison will indicate if the system is worth being installed or not.

Moreover for Greece the value of interest (i) was chosen to be 0.035. The supplies for the Greek system, as it has already been mentioned, were 16,610 kWh. In addition, the operating costs of the system include maintenance and service cost. A rule of thumb is estimated for annual operating expenses around 2% of the initial system cost.

Using all these values, the inflows of the system for that period were calculated. Basically, the energy supplies of the system for each year were multiplied with the cost per kWh for the following 25 years, with the aim to calculate the inflows of the system. Then the profit was calculated by subtracting the inflows from the outflows, with the latter being the operating costs of the system. This was done for both cases. The final step was to convert the profit of all these years to their present value. This was made using the following formula solved for K_o.

$$K_n = K_0 * (1+i)^n$$

Where: K_n is the future value at period n

K_0 is the initial value

i is the market interest 0.035

n is the number of periods

Greek Hybrid System

Years	***i* (interest)**	***Supplies from the System(kWh)***	***Cost per kWh (£) for the next 25 years***
1	0.035	16610	0.047
2	0.035	16610	0.047
3	0.035	16610	0.047
4	0.035	16610	0.047
5	0.035	16610	0.047
6	0.035	16610	0.050
7	0.035	16610	0.050
8	0.035	16610	0.050
9	0.035	16610	0.050
10	0.035	16610	0.050
11	0.035	16610	0.052
12	0.035	16610	0.052
13	0.035	16610	0.052
14	0.035	16610	0.052
15	0.035	16610	0.052
16	0.035	16610	0.055
17	0.035	16610	0.055
18	0.035	16610	0.055
19	0.035	16610	0.055
20	0.035	16610	0.055
21	0.035	16610	0.057
22	0.035	16610	0.057
23	0.035	16610	0.057
24	0.035	16610	0.057
25	0.035	16610	0.057

Maintenance Cost 1 (2% Initial Cost)	***Maintenance Cost 2 (2% Initial Cost)***
604.1	524.1
604.1	524.1
604.1	524.1
604.1	524.1
604.1	524.1
604.1	524.1
604.1	524.1
604.1	524.1
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604.1	524.1
604.1	524.1
604.1	524.1
604.1	524.1
604.1	524.1
604.1	524.1

Inflows	***Profit 1***	***Profit 2***	***Present Value 1 (£)***	***Present Value 2 (£)***
785.608	171.033	251.033	165.250	243.544
775.133	171.033	251.033	159.661	234.342
775.133	171.033	251.033	154.262	226.418
775.133	171.033	251.033	149.046	218.761
775.133	171.033	251.033	144.005	211.363
830.500	226.400	306.400	184.177	249.257
830.500	226.400	306.400	177.948	240.828
830.500	226.400	306.400	171.931	232.684
830.500	226.400	306.400	166.117	224.815
830.500	226.400	306.400	160.499	217.213
864.169	260.069	340.069	178.133	232.929
864.169	260.069	340.069	172.109	225.052
864.169	260.069	340.069	166.289	217.441
864.169	260.069	340.069	160.666	210.088
864.169	260.069	340.069	155.233	202.984
909.061	304.961	384.961	175.873	222.009
909.061	304.961	384.961	169.925	214.502
909.061	304.961	384.961	164.179	207.248
909.061	304.961	384.961	158.627	200.240
909.061	304.961	384.961	153.263	193.468
953.953	349.853	429.853	169.878	208.724
953.953	349.853	429.853	164.134	201.666
953.953	349.853	429.853	158.583	194.846
953.953	349.853	429.853	153.220	188.257
953.953	349.853	429.853	148.039	181.891
			4081.048	***5399.569***

Table 13: Calculation of the present values of profits for both cases in Greece

Using the same concept as previously, the cost of the electricity provided by the national electricity grid company of each country was calculated.

For Greece as it can be seen from the tables below the demands of the building which was used for the needs of this analysis were 17,530 kWh as they were estimated in a previous section, and multiplied with the cost per kWh for the following 25 years. The result of this process was the calculation of the outflows for the energy consumption of the building, assuming that only electricity from the grid will be used for this 25-year period. Then the outflows were converted to their present values using again the same formula.

Of course in this case, where the building is wholly supplied with electricity from the grid, there is an opportunity cost, which has to be taken into consideration for the accuracy of this analysis. This opportunity cost, is the total installation cost of the hybrid system which was calculated in table 11 plus the additional cost from the amount of electricity which cannot be covered from the system and is provided from the grid as it can be seen from table 15. The demands of the building are 17530 kWh per year and the system can cover effectively 16610, so this additional amount of electricity thus 920 kWh which is going to be needed and is taken from the national grid was calculated and added to the opportunity cost. Then this opportunity cost has to be subtracted from the final present value of the outflows. In that way the net present value turns up and this analytical economic process ends.

Before the evaluation of the results a brief discussion about the Scottish analysis is going to be made as well.

Greek National Electricity Company

Years	**Cost per kW**	**Demands of the Building**	**Outflows**	**Present Value (£)**
1	0.047	17530	823.91	790.403
2	0.047	17530	823.91	763.674
3	0.047	17530	823.91	737.849
4	0.047	17530	823.91	712.898
5	0.047	17530	823.91	688.790

6	0.049	17530	858.97	703.526
7	0.049	17530	858.97	679.735
8	0.049	17530	858.97	656.749
9	0.049	17530	858.97	634.540
10	0.049	17530	858.97	613.082
11	0.051	17530	894.03	616.364
12	0.051	17530	894.03	595.521
13	0.051	17530	894.03	575.383
14	0.051	17530	894.03	555.925
15	0.051	17530	894.03	537.126
16	0.054	17530	946.62	545.921
17	0.054	17530	946.62	527.460
18	0.054	17530	946.62	509.623
19	0.054	17530	946.62	492.390
20	0.054	17530	946.62	475.739
21	0.057	17530	999.21	482.350
22	0.057	17530	999.21	466.039
23	0.057	17530	999.21	450.279
24	0.057	17530	999.21	435.052
25	0.057	17530	999.21	420.340
				Sum: 14666.760

Table 14: Calculation of the present values of the outflows from the electricity grid in Greece

Years	***Cost per kW***	***Demands of the Building cannot cover the system***	***Outflows***	***Present Value (£)***
1	0.047	920	43.24	41.481
2	0.047	920	43.24	40.079
3	0.047	920	43.24	38.723
4	0.047	920	43.24	37.414
5	0.047	920	43.24	36.149
6	0.049	920	45.08	36.922
7	0.049	920	45.08	35.674
8	0.049	920	45.08	34.467
9	0.049	920	45.08	33.302
10	0.049	920	45.08	32.175
11	0.051	920	46.92	32.348
12	0.051	920	46.92	31.254
13	0.051	920	46.92	30.197
14	0.051	920	46.92	29.176
15	0.051	920	46.92	28.189
16	0.054	920	49,68	28.651
17	0.054	920	49,68	27.682
18	0.054	920	49,68	26.746
19	0.054	920	49,68	25.841
20	0.054	920	49,68	24.967
21	0.057	920	52.44	25.314

22	0.057	920	52.44	24.458
23	0.057	920	52.44	23.631
24	0.057	920	52.44	22.832
25	0.057	920	52.44	22.060
				769.733

Table 15: Calculation of the present values of the additional amount of electricity which is going to be needed

Opportunity Cost Case 1 (£)	***Opportunity Cost Case 2 (£)***	***Net Present Value Case 1***	***Net Present Value Case 2***
18123	***15723***		
769.7	**769.7**		
18892.7	**16492.7**	**-4226**	**-1826**

Table 16: Calculation of the net present values of the outflows from the electricity grid in Greece

Again like in the Greek scenario, the initial installation cost was calculated by adding the individual costs of the items which were used for each system and for each case. Then the initial installation cost was multiplied with the percentage rate that is subsidized by the government. The result was the estimation of the total installation cost for each case and for each system separately, as it can be seen from the table below.

	Hybrid System for Scotland	***Cost of the Items (£)***
	26 Panels	8450
	26 Bases	988
	15 DWT	9750
Case 1	80 Batteries	8000
Case 2	40 Batteries	4000
	1 Inverter	2385
	Other Equipment	1100
Case 1	***Initial Installation Cost***	***£30673***
Case 2	***Initial Installation Cost***	***£26673***
	Government Support Subsidies	***40%***
Case 1	***Total Installation Cost of the System***	***£18403.8***
Case 2	***Total Installation Cost of the System***	***£16003.8***

Table 17: Installation Costs for Scottish Hybrid System

Again, as it can be observed from the table below, the total cost per kWh for the following 25 years which is the estimated lifetime of the system, had to be calculated for Scotland. In addition, the value of the kWh for each year has to be converted into its respective present value for each of the next 25 years, which is the estimated lifetime of the system. For this reason, again like in the Greek case, the same assumption was made that for each five years the price per kWh will be increasing at around 5% in comparison to the last value which the kWh had.

Scotland	Cost per kWh in Pounds(£)	Years
	0.080	Present Value
	0.084	Value after 5 years
	0.088	Value after 10 years
	0.093	Value after 15 years
	0.097	Value after 20 years-Until 25 years

Table 18: Cost per kWh for the next 25 years for Scotland

Again the same effort took place in order to estimate the total present value for the hybrid system and for the national electricity company for both cases, for Scotland. This was made with the primary goal of comparing these present values and drawing useful conclusions. The result of that comparison will indicate if the system is worth or not being installed in Scotland.

Moreover for Scotland the value of interest (i) was chosen to be 0.0525. The supplies for the Scottish system, as it has already been mentioned in a previous section, were 13,980 kWh. In addition, the operating costs of the system include maintenance and service cost and are estimated at about 2% of the initial system cost.

Using again all these values, the inflows of the system for that period were calculated. Then the profit was calculated by the subtraction of the outflows from the inflows. The outflows were the operating costs of the system. Then the profits were converted to their present values using again the following formula where i in this case is estimated to be 0.04.

$$K_n = K_0 * (1+i)^n$$

Scottish Hybrid System

Years	***i* (interest)**	**Supplies from the System(kWh)**	**Cost per kWh (£) for the next 25 years**
1	0.0525	13980	0.080
2	0.0525	13980	0.080
3	0.0525	13980	0.080
4	0.0525	13980	0.080
5	0.0525	13980	0.080
6	0.0525	13980	0.084
7	0.0525	13980	0.084
8	0.0525	13980	0.084
9	0.0525	13980	0.084
10	0.0525	13980	0.084
11	0.0525	13980	0.088
12	0.0525	13980	0.088
13	0.0525	13980	0.088
14	0.0525	13980	0.088
15	0.0525	13980	0.088
16	0.0525	13980	0.093
17	0.0525	13980	0.093
18	0.0525	13980	0.093
19	0.0525	13980	0.093
20	0.0525	13980	0.093
21	0.0525	13980	0.097
22	0.0525	13980	0.097
23	0.0525	13980	0.097
24	0.0525	13980	0.097
25	0.0525	13980	0.097

Maintenance Cost 1 (2% Initial Cost)	***Maintenance Cost 2 (2% Initial Cost)***
613.46	533.46
613.46	533.46
613.46	533.46
613.46	533.46
613.46	533.46
613.46	533.46
613.46	533.46
613.46	533.46
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613.46	533.46
613.46	533.46
613.46	533.46
613.46	533.46
613.46	533.46
613.46	533.46

Inflows	*Profit 1*	*Profit 2*	*Present Value 1 (£)*	*Present Value 2 (£)*
1118.4	504.94	584.94	479.753	555.762
1118.4	504.94	584.94	455.822	528.040
1118.4	504.94	584.94	433.085	501.701
1118.4	504.94	584.94	411.482	476.676
1118.4	504.94	584.94	390.957	452.898
1174.32	560.86	640.86	412.593	471.444
1174.32	560.86	640.86	392.012	447.928
1174.32	560.86	640.86	372.458	425.585
1174.32	560.86	640.86	353.880	404.356
1174.32	560.86	640.86	336.228	384.187
1230.24	616.78	696.78	351.307	396.874
1230.24	616.78	696.78	333.784	377.077
1230.24	616.78	696.78	317.134	358.268
1230.24	616.78	696.78	301.315	340.397
1230.24	616.78	696.78	286.285	323.418
1300.14	686.68	766.68	302.831	338.112
1300.14	686.68	766.68	287.726	321.246
1300.14	686.68	766.68	273.374	305.222
1300.14	686.68	766.68	259.737	289.997
1300.14	686.68	766.68	246.781	275.532
1356.06	742.6	822.6	253.566	280.882
1356.06	742.6	822.6	240.918	266.872
1356.06	742.6	822.6	228.900	253.560
1356.06	742.6	822.6	217.483	240.912
1356.06	742.6	822.6	206.634	228.895
			8146.046	***9245.844***

Table 19: Calculation of the present values of the profits for both cases in Scotland

For Scotland, as it can be seen from the tables below the demands of the building which is used for this analysis were 16,000 kWh, as they were estimated previously, and are multiplied with the cost per kWh for the following 25 years. The result of this process was the calculation of the outflows which stem from the energy consumption of the building, if it is assumed again that it uses electricity only from the grid for that period of the 25 years. Then the outflows were converted to their present values using again the same formula.

Of course also in this case, where the building is entirely supplied with electricity from the grid, there is an opportunity cost, which has to be taken into consideration for the accuracy of this analysis as before. This opportunity cost, is the total installation cost of the hybrid system which was calculated in table 17 plus the additional cost from the amount of electricity which cannot be covered from the system and is provided from the grid as it can be seen from the table 21. The demands of the building are 16000 kWh per year and the system can cover effectively 13980 kWh, so this additional amount of electricity 2020 kWh which is going to be needed and is taken from the national grid was calculated and added to the opportunity cost. Then this opportunity cost has to be subtracted from the final present value of the outflows. In that way the net present value turns up and this analytical economic process ends.

Scottish National Electricity Company

Years	Cost per KW	Demands of the Building	Outflows	Present Value (£)
1	0.080	16000	1280	1236.715
2	0.080	16000	1280	1194.894
3	0.080	16000	1280	1154.487
4	0.080	16000	1280	1115.446
5	0.080	16000	1280	1077.726
6	0.084	16000	1344	1093.345
7	0.084	16000	1344	1056.372
8	0.084	16000	1344	1020.649
9	0.084	16000	1344	986.134
10	0.084	16000	1344	952.787
11	0.088	16000	1408	964.404
12	0.088	16000	1408	931.791
13	0.088	16000	1408	900.281
14	0.088	16000	1408	869.837
15	0.088	16000	1408	840.422
16	0.093	16000	1488	858.138

17	0.093	16000	1488	829.119
18	0.093	16000	1488	801.081
19	0.093	16000	1488	773.992
20	0.093	16000	1488	747.818
21	0.097	16000	1552	753.606
22	0.097	16000	1552	728.122
23	0.097	16000	1552	703.499
24	0.097	16000	1552	679.709
25	0.097	16000	1552	656.724
				22927.098

Table 20: Calculation of the present values of the outflows from the electricity grid in Scotland

Years	***Cost per kW***	***Demands of the Building cannot cover the system***	***Outflows***	***Present Value (£)***
1	0.080	2020	161.6	156.135
2	0.080	2020	161.6	150.855
3	0.080	2020	161.6	145.754
4	0.080	2020	161.6	140.825
5	0.080	2020	161.6	136.063
6	0.084	2020	169.68	138.035
7	0.084	2020	169.68	133.367
8	0.084	2020	169.68	128.857
9	0.084	2020	169.68	124.499
10	0.084	2020	169.68	120.289
11	0.088	2020	177.76	121.756
12	0.088	2020	177.76	117.639
13	0.088	2020	177.76	113.660
14	0.088	2020	177.76	109.817
15	0.088	2020	177.76	106.103
16	0.093	2020	187.86	108.340
17	0.093	2020	187.86	104.676
18	0.093	2020	187.86	101.137
19	0.093	2020	187.86	97.716
20	0.093	2020	187.86	94.412
21	0.097	2020	195.94	95.143
22	0.097	2020	195.94	91.925
23	0.097	2020	195.94	88.817
24	0.097	2020	195.94	85.813
25	0.097	2020	195.94	82.911
				2894.546

Table 21: Calculation of the present values of the additional amount of electricity which is going to be needed

Opportunity Cost Case 1 (£)	Opportunity Cost Case 2 (£)	Net Present Value Case 1	Net Present Value Case 2
18403.8	16003.8		
2894.5	2894.5		
21298.3	18898.3	383.9	2783.9

Table 22: Calculation of the net present values of the outflows from the electricity grid in Scotland

7.3 CONCLUSIONS-RECOMMENDATIONS

As it can be observed from the previous tables, both of the systems are not economically feasible and sustainable.

First of all for the Greek system, the total installation cost in the first case was £18,123 and in the second case, which was the most attractive and realistic one because the minimum number of batteries were used, the price lowered to £15,723. Moreover the profit from the use of that system, for the following 25 years for the first case is £4,081 while for the second it is £5,400. This means that the money invested in the installation of the specific hybrid system will never be refunded during that period.

Furthermore it can be observed that the outflow costs of the building using only electricity from the grid are £14,667. If from this value the opportunity cost is subtracted, which as it was mentioned before is the total installation cost of the system plus the additional cost from the grid, then the net present value is increased. The net present value for the first case is a negative of 4,226 pounds, which means that if only electricity from the grid is going to be used, £4,226 is going to be saved.

In the second case the situation is looking more optimistic yet not so encouraging for the use of the hybrid system. In this case there is a negative net present value of £1,826 which means that, if only electricity from the grid is going to be used in order to cover the total energy demands of the building, 1,826 pounds is going to be saved. Thus, for Greece, in both cases it can be said that the operation of a hybrid system like that, which would be used under the current circumstances in Crete, could not constitute a sustainable and viable idea. The use of the electricity from the grid in order to cover the electrical demands of the building would be suggested as the best option for the period of the next 25 years.

For Scotland, as it can be seen from the previous tables, the situation is shortly better but again not the desirable one in order to use these kinds of systems for the coverage of the energy needs inside a house. The total installation cost for the first case is £18,043.8 and for the second case which was the most attractive and realistic one because of the minimum number of batteries which were used, is £16,003.8. Moreover the profit from the use of that system, for the following 25 years for the first case is £8,146 while for the second one is £9,245.8. This means that the money which was invested for the installation of the specific hybrid system will not be refunded for both cases again. The gap will be around £9,897.7 for the first case while for the second case will be around £6,106.

Furthermore it can be observed that the outflows of the building using only electricity from the grid are £21,682.2. If from this value the opportunity cost is subtracted, which as it was mentioned before is the total installation cost of the system plus the additional cost from the grid, then net present value is turned up. The net present value for the first case is £383.9 which means that if only electricity from the grid is going to be used, in order to cover the total demands of the building for the next 25 years, an additional amount of money of around £400 is going to be needed. For the second case the things are better for the hybrid system because the additional amount of money which is going to be needed is £2783.9.

As far as the system is concerned, in the case of Scotland, it would not be an economic advantage to use the hybrid system for domestic use for the 25 year period but the electricity from the national grid as in Greek case as well. This would induce a deficit of a total amount of about £9,513.7 in the case where the maximum number of batteries is used. That is calculated as it follows £9,897.6 - £383.9 = £9,513.7. This means that if the hybrid system is going to be used instead of the national grid for the 25 years period the additional cost would be around 9,500 pounds more than if only electricity from the national grid were used. But even in the second case, where the minimum number of batteries is used and that would seem quite more attractive for the investors, the difference between the cost of using the electricity from the grid and that of a hybrid system is minor so once again the national grid would be more preferable because it is a more reliable source of energy than that of nature. That is, if the net present value of £2,783.9 is subtracted from the economic difference between profit value of the inflows and installation cost which was calculated £6,106.046 a profit of a total amount of money of about £3320 is estimated. This again, can be calculated as it follows £6,106 - £2,783.8 = £3322.2. This means that if the hybrid system is going to be used instead of the national grid for the 25 years period an additional cost of 3320 pounds would be saved than if only electricity from the national grid were used.

7.4 FUTURE SCENARIO

Thus, from all the aforementioned, it can now be better understood that for both countries, a hybrid system like the one which was used for the analysis, cannot cover relatively effectively the energy demands of a building in a totally realistic situation from an economic point of view. An important element which differentiates from an economic point of view Greece from Scotland is the price of kWh which is much higher in the latter. For Greece this means that people have to wait more years in order for the cost of these technologies to be reduced. This will occur when large and effective research investments will take place in that field of renewable technologies. In that way the costs will be reduced and the systems will be more effective and efficient during their performance at a lower cost.

In the case that the cost per kWh of national grid supplies is going to be increased, these kinds of technologies will be more economically attractive for the investors to install small scale renewable systems for the use in domestic sector as well. This can happen only if a significant rise in the prices of the fossil fuels takes place and especially that of the oil. This will be observed over the years to come.

On the other hand for Scotland although the situation is different, the results as they were investigated are the same like in the Greek case. In the Scottish case the use of more wind ducted turbines in order to cover properly the energy demands of a building increase the initial installation cost of the system while the interest rate for UK is much higher than that of Greece at around 5.25%. Thus these two parameters affect in a large extent the economic performance and viability of the hybrid system and make the use of the electricity from the national grid more advantageous for the coverage of the electrical needs in a house. Thus a renewable solution in order to cover the energy needs of a building is not quite a viable idea from every aspect.

That's why nowadays and in the near feature this which can make the installation of a system like the above ones more viable, from an economic point of view for both countries, is the increase of subsidies from the government or the reduction of the inflation in each country or both of the above. So using a simple calculation in the previous economic analysis it was found that for Greece a subsidy of around 70% and the reduction of the inflation of the country to 2.5% can make the installation of a hybrid system economically viable when at the same time a subsidy around 60% for Scotland and the reduction of the inflation of the country by approximately 1% as well can have the same results for the potential investors. This can be better observed from the below table.

Period (years)	***Final Cost in Pounds Case 2***	***Profit(Present value) (£)***	***Additional energy cost from national grid(£)***	***Energy cost National grid(£)***
25	***7861.5***	***6122.44***	***769.73***	***14,666.76***

Table 23: Greek results for subsidy 70% and inflation 2.5%

In this theoretical scenario, the case with the minimum number of batteries was used for both countries because it is the most profitable solution for the installation of the hybrid system.

As it can be seen, for the Greek case the amount of subsidy of 70% reduce a lot the installation cost of the system and can make it economically viable. The profit from the system is now competitive to the installation cost and this means that the system can cover efficiently the electrical needs of the building for the next 25 years while an amount of £6000 is going to be saved. That is because as it has already been mentioned in the previous tables the cost of the use of electricity from the grid for the next 25 years would be around £15000 which means that the difference from the installation cost plus the additional amount of electricity which the building will need is £14666.76 - £7861.5 - £769.73 = £6035.53. Thus an amount of 6000 pounds is going to be saved for the Greek case and also the building is going to be using only renewable systems producing green power to cover its energy needs.

For the Scottish case the things are similar but even better. This is because in this scenario the increase of the subsidy was less, thus 20%, so now the subsidy from the government is assumed to be 60% and the interest rate is reduced to 4%. The profit from the system is now much more competitive to the installation cost. This means that the system can cover efficiently the electrical needs of the building for the next 25 years while an amount of £8000 is going to be saved. That again can be better understood by the following calculation. The electricity from the grid is going to cost £21,682.2 as it has already been mentioned in order to cover the needs of the building for the next 25 years. So the profit, thus the money which is going to be saved from the use of the hybrid system, in this case also is estimated as follows £21,682.2 - £10,669.2 - £2,894.5 = £8118.5. Thus an amount of 8000 pounds is going to be saved and again the building can be energetically autonomous from the national grid and dependent only upon the renewable systems which are implemented on that.

Period (years)	Final Cost in Pounds Case 2	Profit(Present value) (£)	Additional energy cost from national grid(£)	Energy cost National grid(£)
25	**10669.2**	**10611.1**	**2894.5**	**21682.2**

Table 24: Scottish results for subsidy 60% and interest rate 4%

Thus it can be concluded, that in the case of mass installations of this kind of renewable systems, investors and consumers will be able to achieve better market prices, thus lower installation and maintenance costs. Moreover, mass installations will initiate the development of economies of scale by the companies which produce these systems so they will be able to sell them at a lower price. In addition, each country separately along with the European Union should provide subsidies for research and improvement of these systems so as their production cost could be reduced. Last but not least, a reduction in the borrowing interest rate would make the investment in these renewable systems more profitable.

However, as far as the environmental aspects are concerned, this kind of hybrid systems, and all the similar ones, have to be wide spread in order to cover the energy demands of buildings in a larger extent, and in that way to help reduce the greenhouse gases and the pollution of the environment.

In addition to all these, there is another aspect of effective use of this system in the residential sector. A hybrid system like the one observed, can be used very effectively and efficiently as well, in rural areas, where the connection from the grid is not possible. In this case an installation of a system like this, in these kind of areas usually is an economically viable idea and most of the time a cost saving one. This is instead of a full electric system being installed close to the building. This would demand the establishment of connection wires to the nearest electric sub station. Sometimes this whole process may cost double the money than the initial cost of the system. Of course it always depends on the distance, which the building has from the nearest electrical grid.

8 Overall Conclusion

Although the climatic conditions in Greece are excellent, the economic prospects of the installation of a small renewable system, such as the one used for this project in order to cover the energy needs of the building, do not indicate it as a preferable investment decision. This does not mean that hybrid systems in Greece are not or will never be profitable. It is suggested that for the time being the best practice is patience; to wait until the energy market in Greece develops further and matures in order to be more competitive compared to the European ones. It is anticipated that finally the relative cost of these systems will reduce, making the investment more attractive, especially for their use in an urban environment.

As far as the UK is concerned, the climatic conditions are less attractive and reliable in comparison with the Greek ones, however the energy market in the UK is already very powerful and from an economic point of view the installation of a small renewable system could not be an entirely discarded option but again it cannot yet be considered a realistic and viable energy solution for the domestic sector.

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APPENDIX

"COMBINING WIND AND SOLAR ENERGY TO MEET DEMANDS IN THE BUILT ENVIRONMENT"
(GLASGOW-HERAKLION CRETE ANALYSIS)

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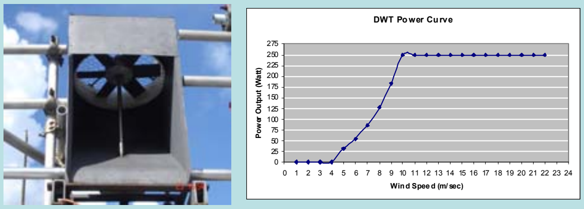
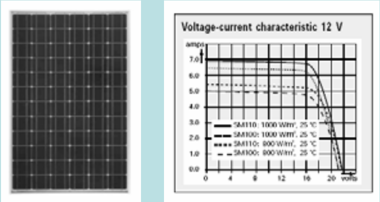
Energy System Research Unit, University of Strathclyde, Glasgow, Scotland, U.K.

This project is based upon the combined use of solar and wind energy, in the hope to discover and determine to what extent the energy produced is capable of satisfying the energy demands of a typical building for Glasgow-Heraklion Crete respectively.

For the analysis a number of PV panels and ducted wind turbines were used.

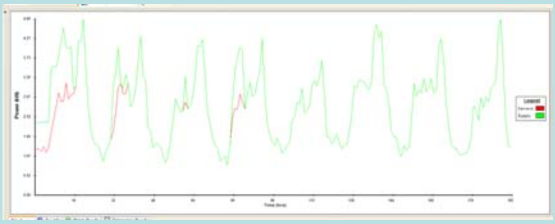


DWT mounted on the roof of James Weir Building and its power curve



Siemens PV Cell SM 110 and its characteristic I-V curve

Heraklion Crete



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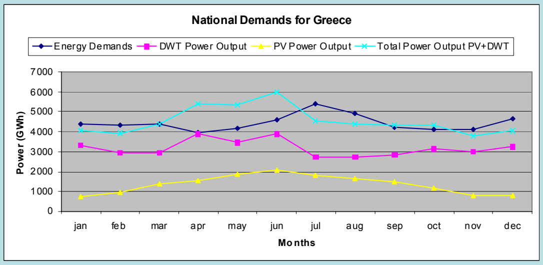


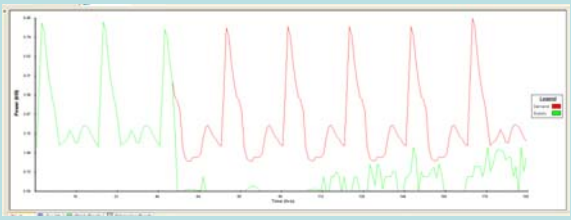
Matching Demands/Supplies in a National level

Economic Analysis Next 25 Years (Present Values)			
	Installation cost including subsidies (£)	Operation profit after 25 years (£)	
Hybrid System	***15723***	***5399.569***	
	Outflows after 25 years (£)	Opportunity Cost (£)	Net Present Value (£)
National Grid	***14666.760***	***16492.733***	***-1825.973***

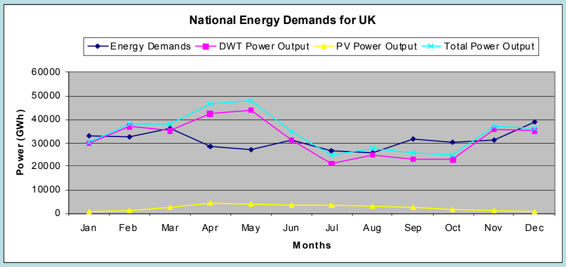
Conclusions

- The climatic conditions are excellent and the performance of the hybrid system is very good and the energy demands can be covered to a large extent
- The national demands by the use of a large number of DWT and PV can be covered very effectively for the whole year.
- The economic prospects for the installation of a small renewable system do not suggest that it is a preferred investment decision.

Glasgow



Match Supply/Demands 07/01/01-14/01/01



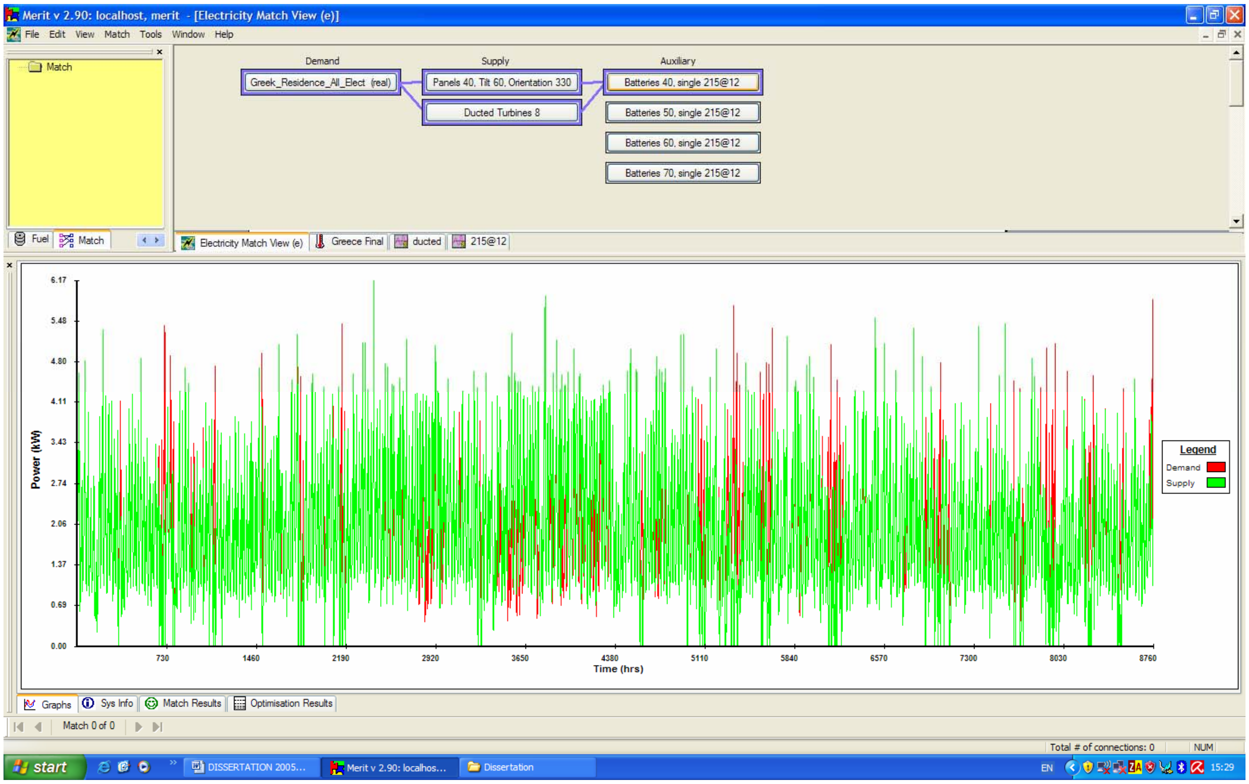
Matching Demands/Supplies in a National level

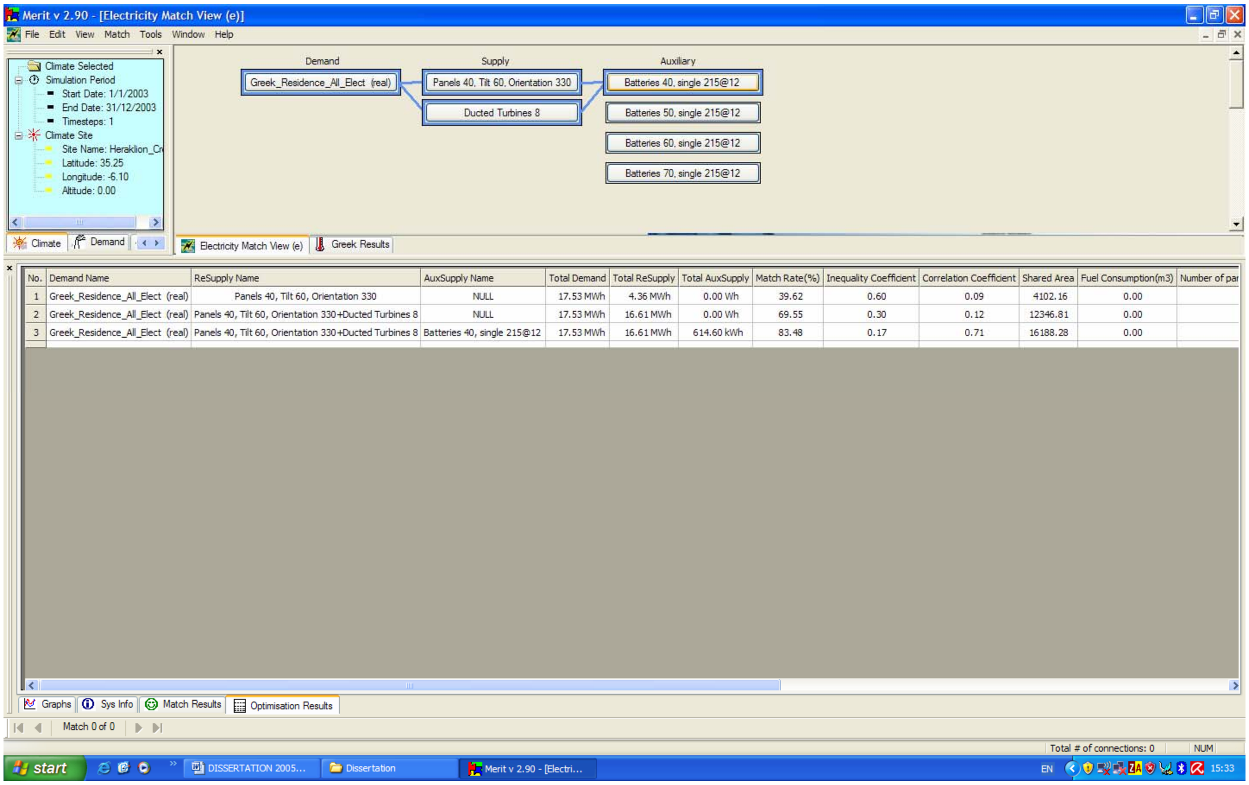
Economic Analysis Next 25 Years (Present Values)			
	Installation cost including subsidies (£)	Operation profit after 25 years (£)	
Hybrid System	***16003.8***	***9245.844***	
	Outflows after 25 years (£)	Opportunity Cost (£)	Net Present Value (£)
National Grid	***21682.202***	***18898.346***	***2783.856***

Conclusions

- The climatic conditions are less attractive and reliable in comparison to the Greek ones but the energy demands can be covered in a reasonable extent
- The national demands by the use of a large number of DWT and PV can be covered quite effectively for the whole year.
- From an economic point of view the installation of a small renewable system is quite an attractive idea for the investments but again the profit derived from the use of the system instead of the grid cannot be considered as a viable idea

Merit Analysis Heraklion Crete





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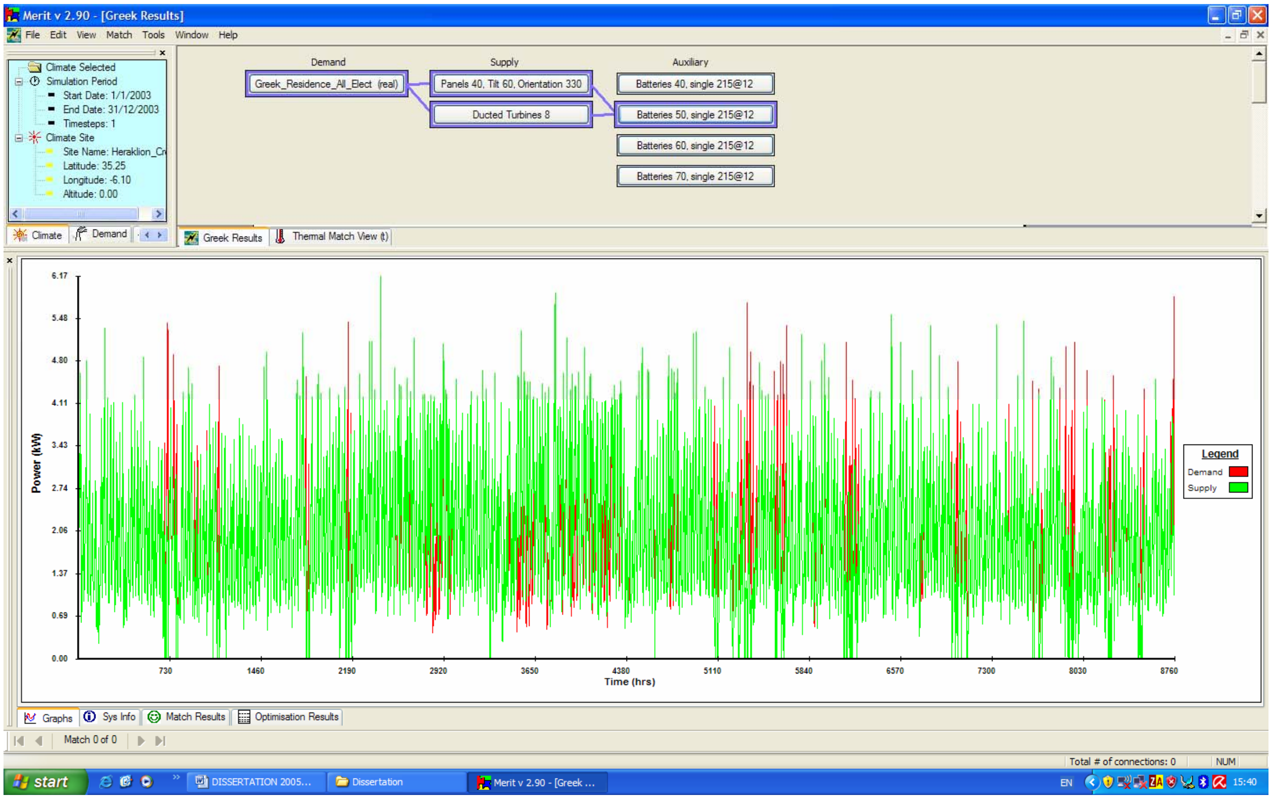
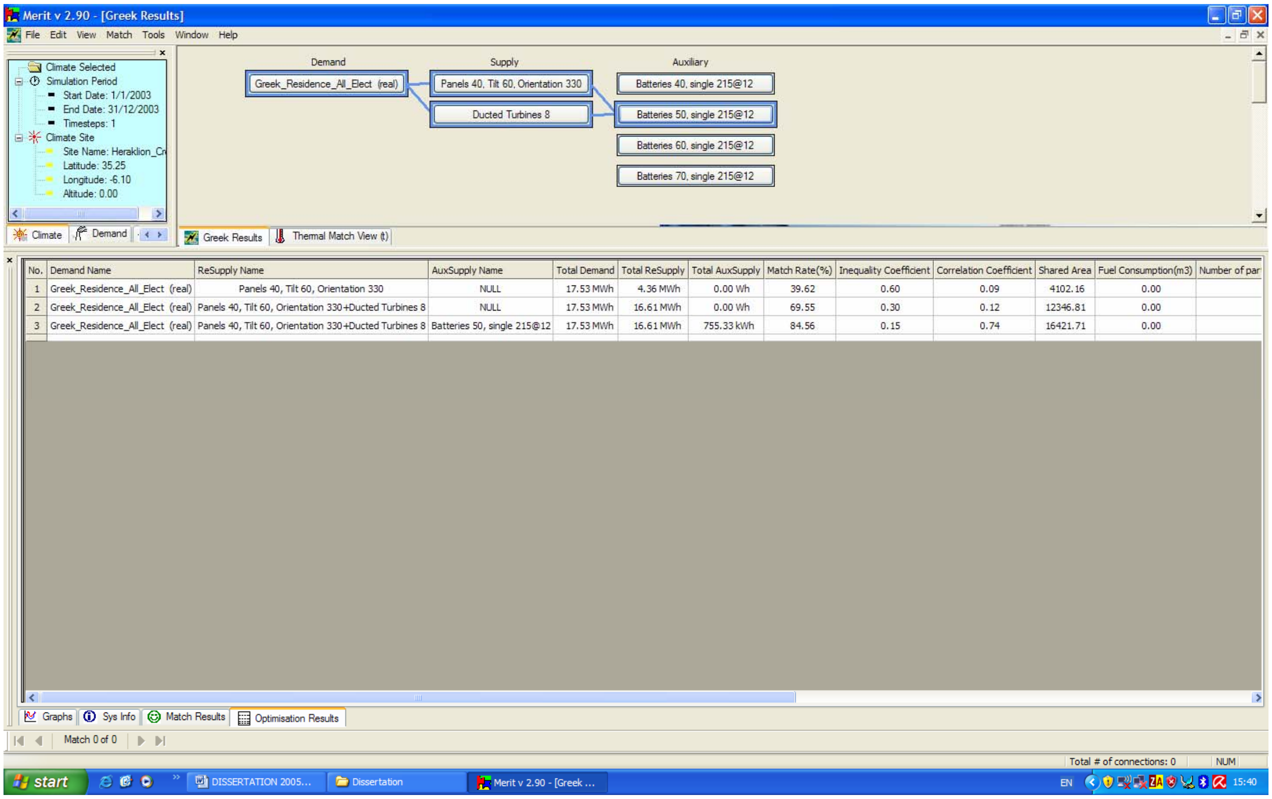
  - End Date: 31/12/2003
  - Timesteps: 1
- Climate Site
  - Site Name: Heraklion_Cr
  - Latitude: 35.25
  - Longitude: -6.10
  - Altitude: 0.00

No.	Demand Name	ReSupply Name	AuxSupply Name	Total Demand	Total ReSupply	Total AuxSupply	Match Rate(%)	Inequality Coefficient	Correlation Coefficient	Shared Area	Fuel Consumption(m3)	Number of par
1	Greek_Residence_All_Elect (real)	Panels 40, Tilt 60, Orientation 330	NULL	17.53 MWh	4.36 MWh	0.00 Wh	39.62	0.60	0.09	4102.16	0.00	
2	Greek_Residence_All_Elect (real)	Panels 40, Tilt 60, Orientation 330+Ducted Turbines 8	NULL	17.53 MWh	16.61 MWh	0.00 Wh	69.55	0.30	0.12	12346.81	0.00	
3	Greek_Residence_All_Elect (real)	Panels 40, Tilt 60, Orientation 330+Ducted Turbines 8	Batteries 40, single 215@12	17.53 MWh	16.61 MWh	614.60 kWh	83.48	0.17	0.71	16188.28	0.00	

Graphical match and results of the Supplies/Demands-8 Turbines, 40 PV, 40 Batteries single 215@12



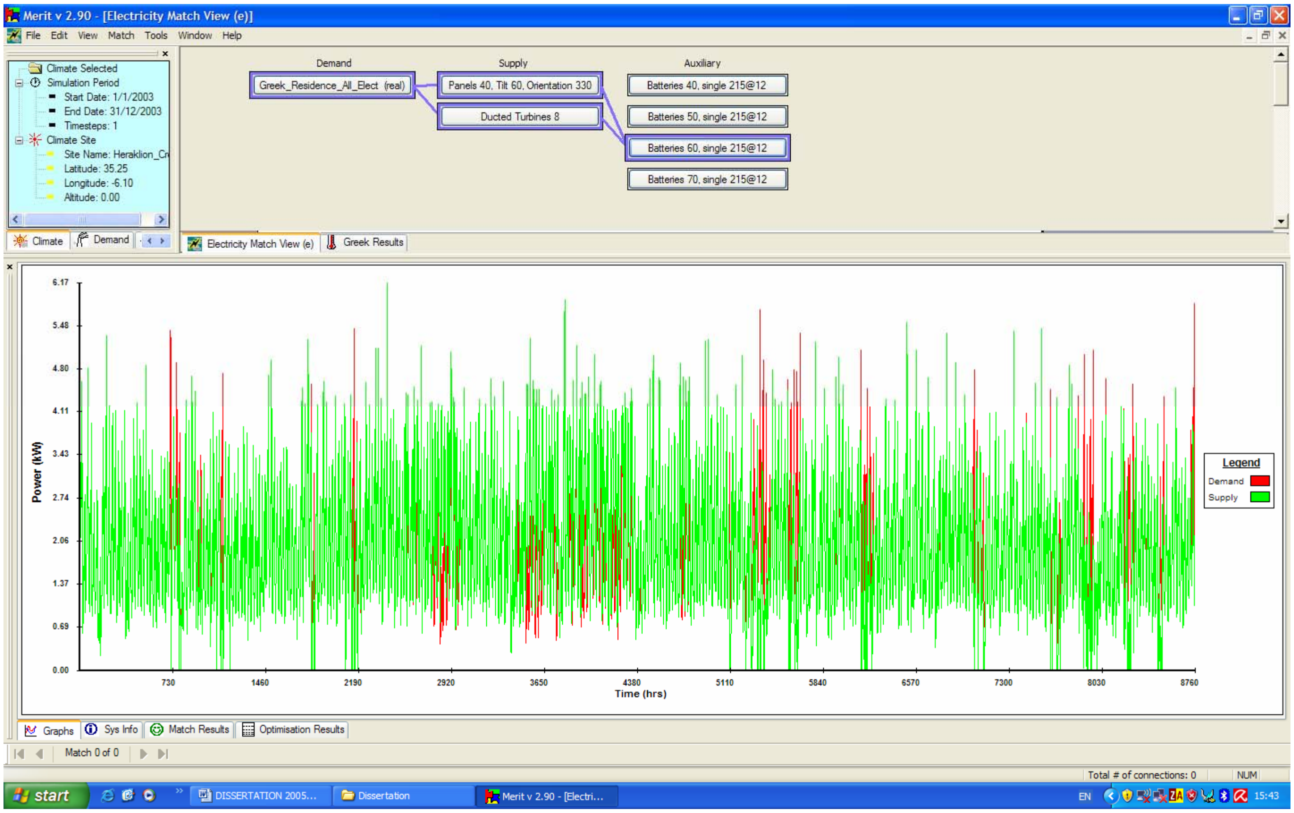
Climate Selected
Simulation Period
Start Date: 1/1/2003
End Date: 31/12/2003
Timesteps: 1
Climate Site
Site Name: Heraklion_Cr
Latitude: 35.25
Longitude: -6.10
Altitude: 0.00

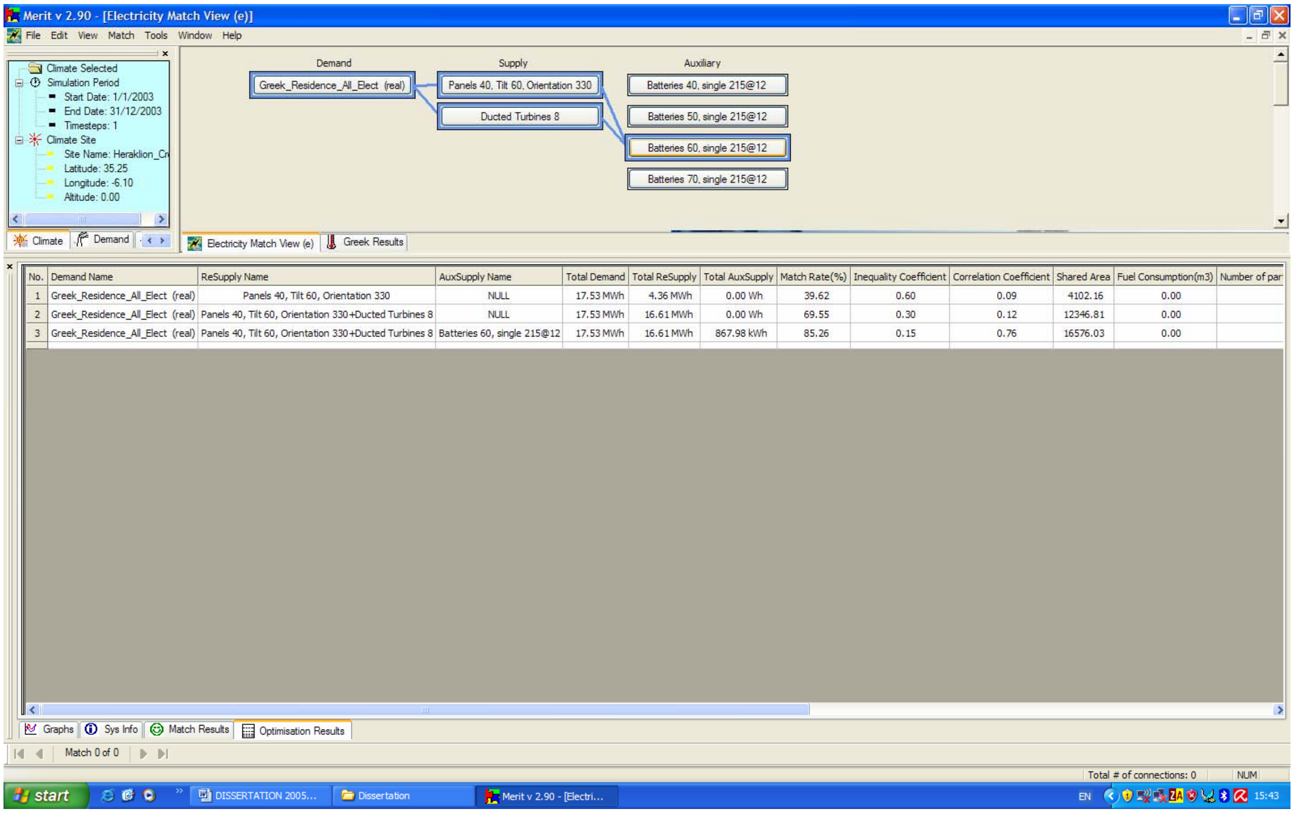


Climate Selected
Simulation Period
Start Date: 1/1/2003
End Date: 31/12/2003
Timesteps: 1
Climate Site
Site Name: Heraklion_Cr
Latitude: 35.25
Longitude: -6.10
Altitude: 0.00

No.	Demand Name	ReSupply Name	AuxSupply Name	Total Demand	Total ReSupply	Total AuxSupply	Match Rate(%)	Inequality Coefficient	Correlation Coefficient	Shared Area	Fuel Consumption(m3)	Number of par
1	Greek_Residence_All_Elect (real)	Panels 40, Tilt 60, Orientation 330	NULL	17.53 MWh	4.36 MWh	0.00 Wh	39.62	0.60	0.09	4102.16	0.00	
2	Greek_Residence_All_Elect (real)	Panels 40, Tilt 60, Orientation 330+Ducted Turbines 8	NULL	17.53 MWh	16.61 MWh	0.00 Wh	69.55	0.30	0.12	12346.81	0.00	
3	Greek_Residence_All_Elect (real)	Panels 40, Tilt 60, Orientation 330+Ducted Turbines 8	Batteries 50, single 215@12	17.53 MWh	16.61 MWh	755.33 kWh	84.56	0.15	0.74	16421.71	0.00	

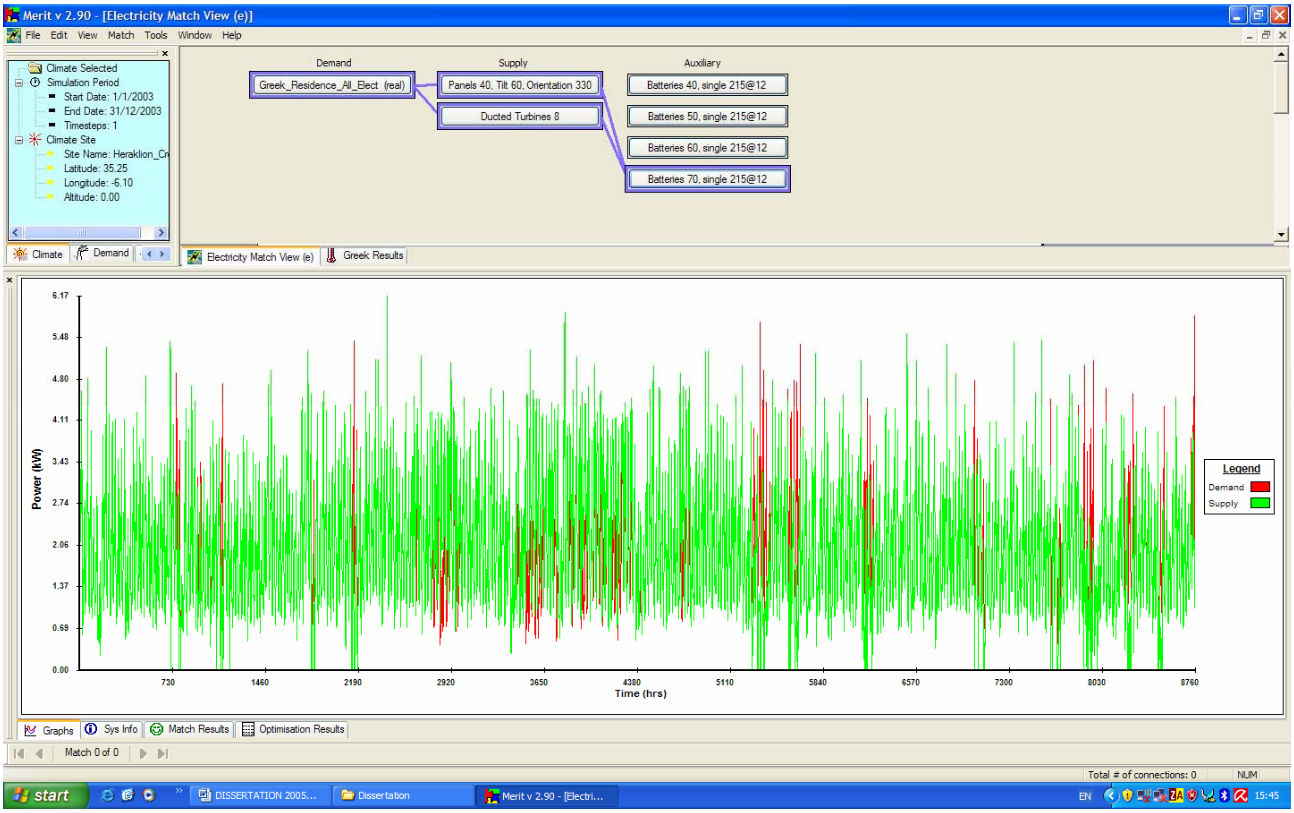
Graphical match and results of the Supplies/Demands-8 Turbines, 40 PV, 50 Batteries single 215@12



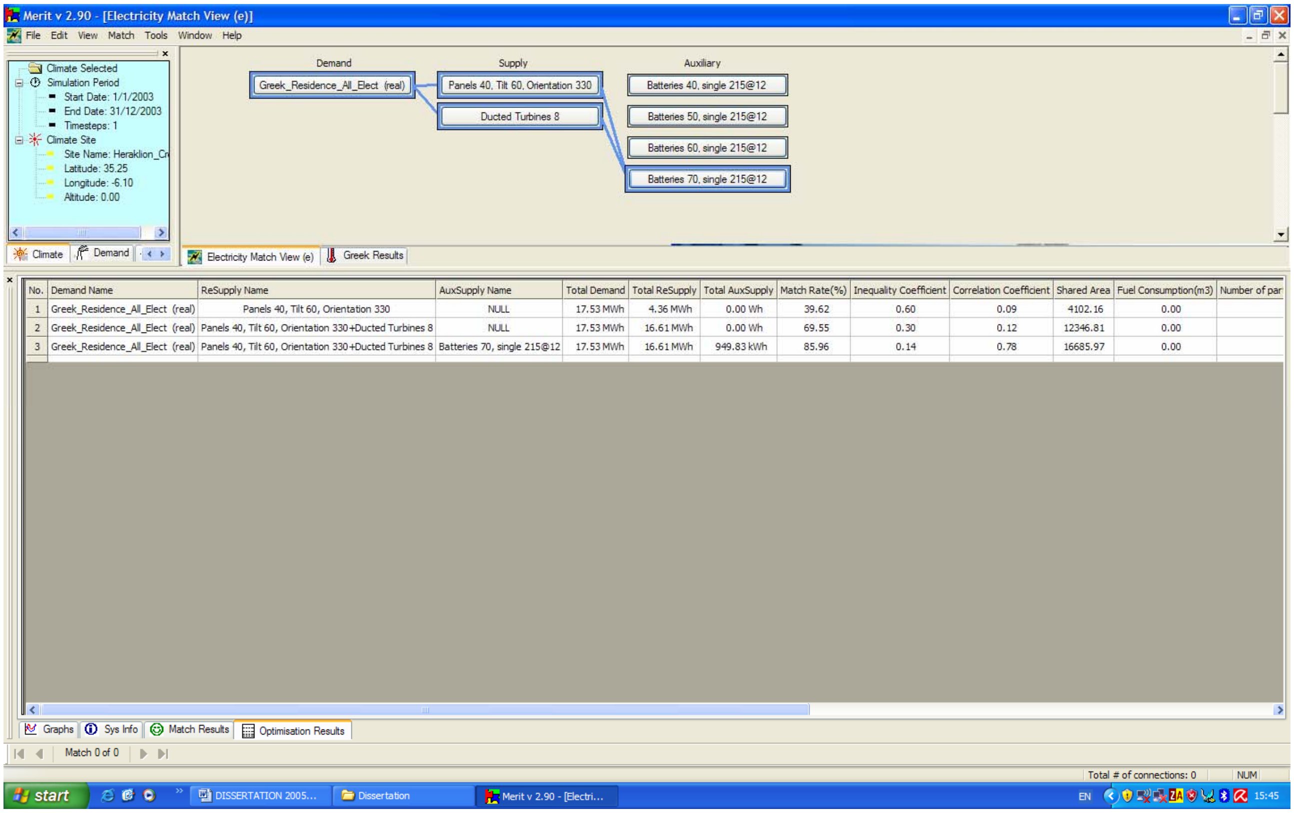


No.	Demand Name	ReSupply Name	AuxSupply Name	Total Demand	Total ReSupply	Total AuxSupply	Match Rate(%)	Inequality Coefficient	Correlation Coefficient	Shared Area	Fuel Consumption(m3)	Number of par
1	Greek_Residence_All_Elect (real)	Panels 40, Tilt 60, Orientation 330	NULL	17.53 MWh	4.36 MWh	0.00 Wh	39.62	0.60	0.09	4102.16	0.00	
2	Greek_Residence_All_Elect (real)	Panels 40, Tilt 60, Orientation 330+Ducted Turbines 8	NULL	17.53 MWh	16.61 MWh	0.00 Wh	69.55	0.30	0.12	12346.81	0.00	
3	Greek_Residence_All_Elect (real)	Panels 40, Tilt 60, Orientation 330+Ducted Turbines 8	Batteries 60, single 215@12	17.53 MWh	16.61 MWh	867.98 kWh	85.26	0.15	0.76	16576.03	0.00	

Graphical match and results of the Supplies/Demands-8 Turbines, 40 PV, 60 Batteries single 215@12

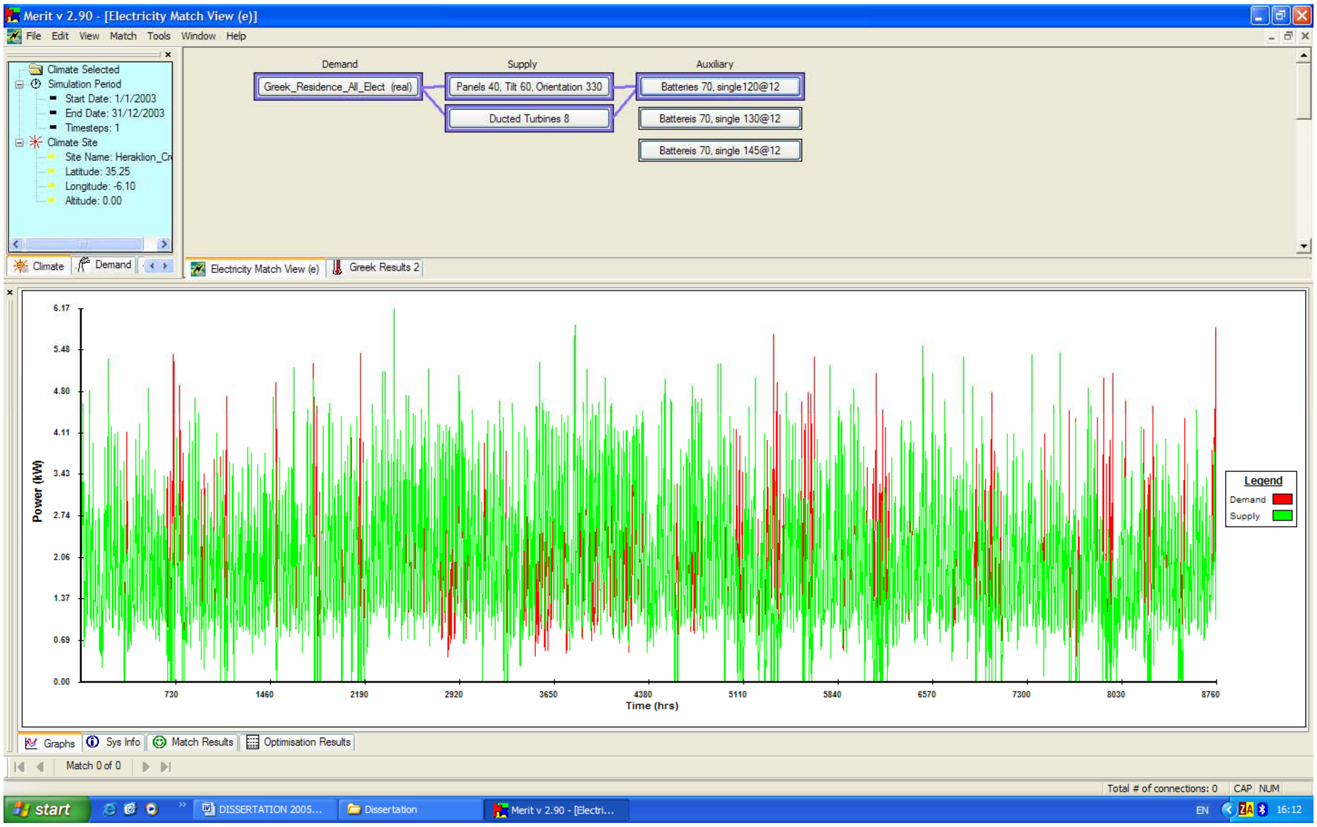


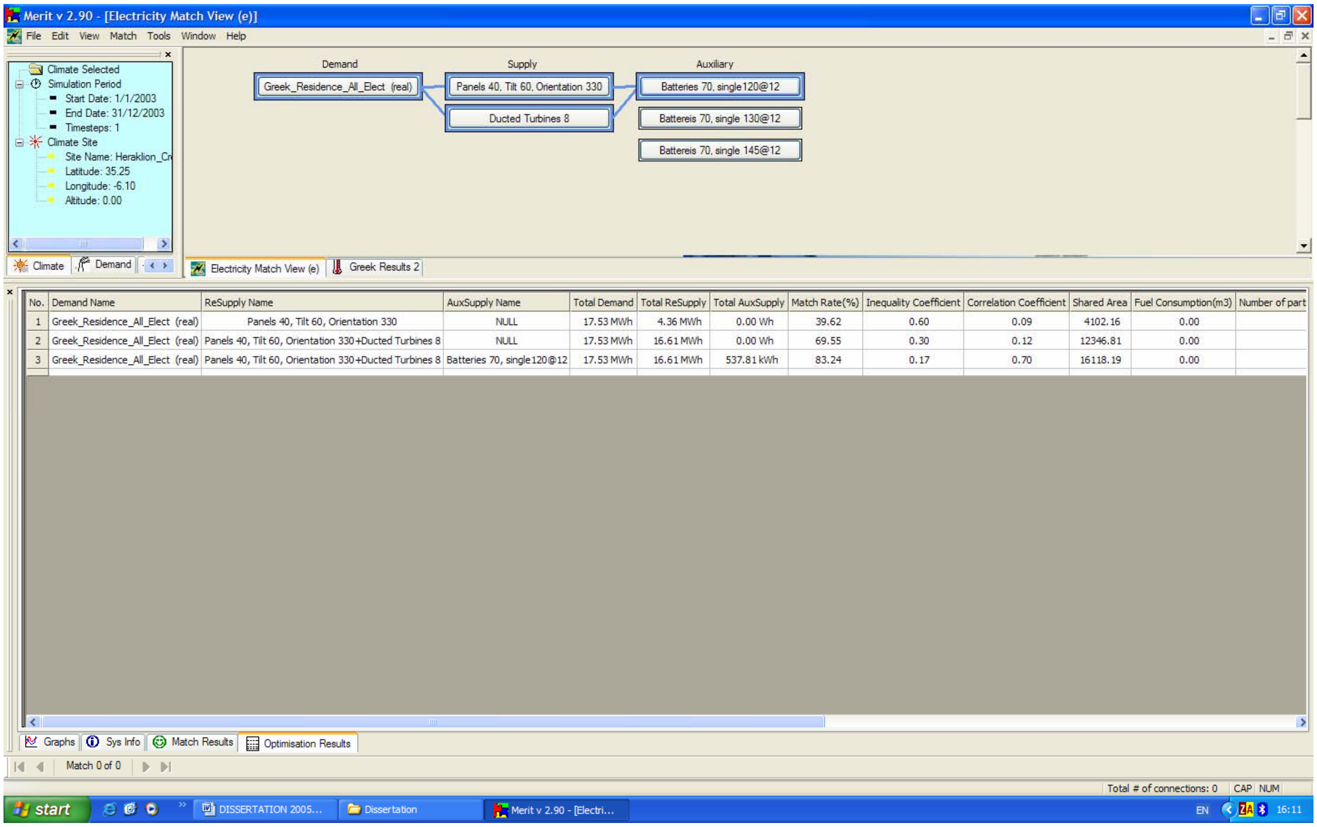
Climate Selected
Simulation Period
Start Date: 1/1/2003
End Date: 31/12/2003
Timesteps: 1
Climate Site
Site Name: Heraklion_Cr
Latitude: 35.25
Longitude: -6.10
Altitude: 0.00



No.	Demand Name	ReSupply Name	AuxSupply Name	Total Demand	Total ReSupply	Total AuxSupply	Match Rate(%)	Inequality Coefficient	Correlation Coefficient	Shared Area	Fuel Consumption(m3)	Number of par
1	Greek_Residence_All_Elect (real)	Panels 40, Tilt 60, Orientation 330	NULL	17.53 MWh	4.36 MWh	0.00 Wh	39.62	0.60	0.09	4102.16	0.00	
2	Greek_Residence_All_Elect (real)	Panels 40, Tilt 60, Orientation 330+Ducted Turbines 8	NULL	17.53 MWh	16.61 MWh	0.00 Wh	69.55	0.30	0.12	12346.81	0.00	
3	Greek_Residence_All_Elect (real)	Panels 40, Tilt 60, Orientation 330+Ducted Turbines 8	Batteries 70, single 215@12	17.53 MWh	16.61 MWh	949.83 kWh	85.96	0.14	0.78	16685.97	0.00	

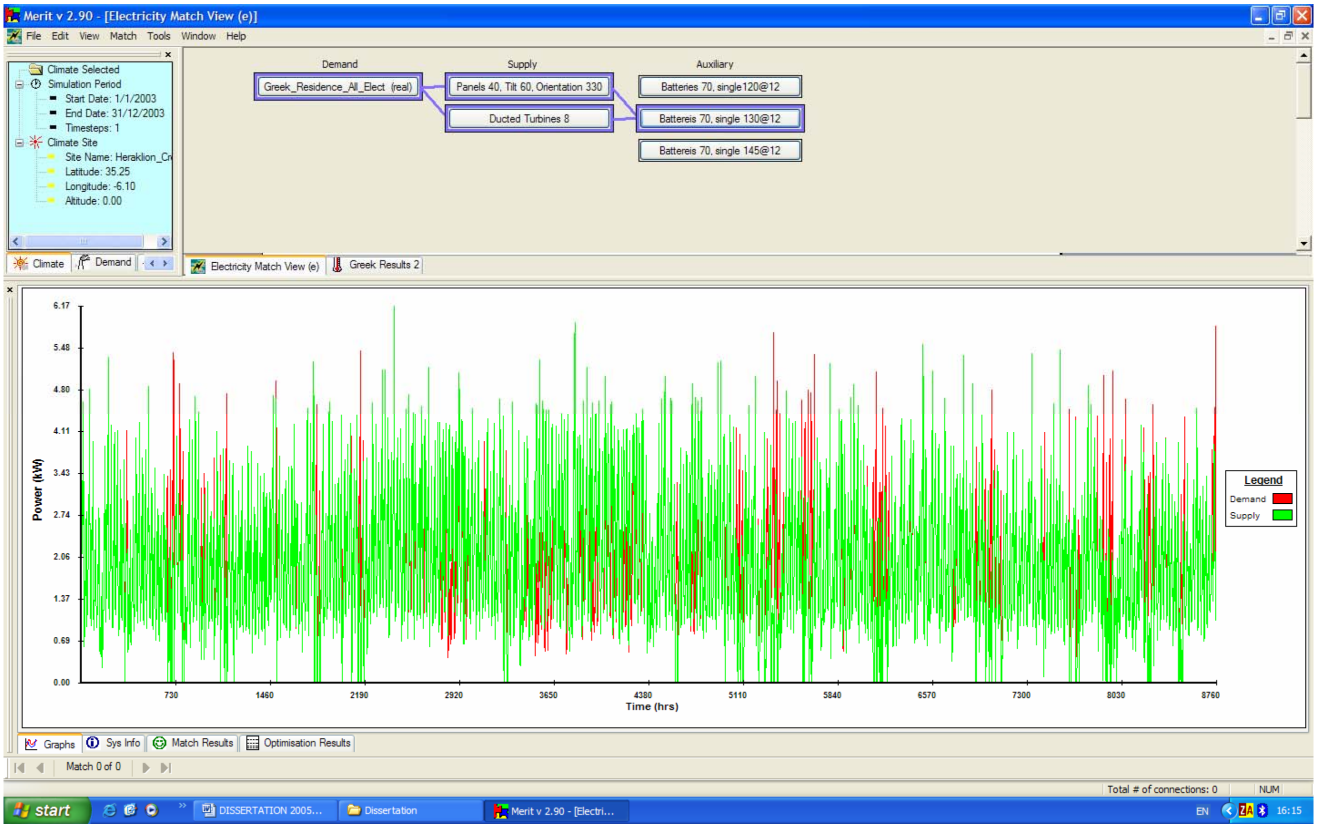
Graphical match and results of the Supplies/Demands-8 Turbines, 40 PV, 70 Batteries single 215@12



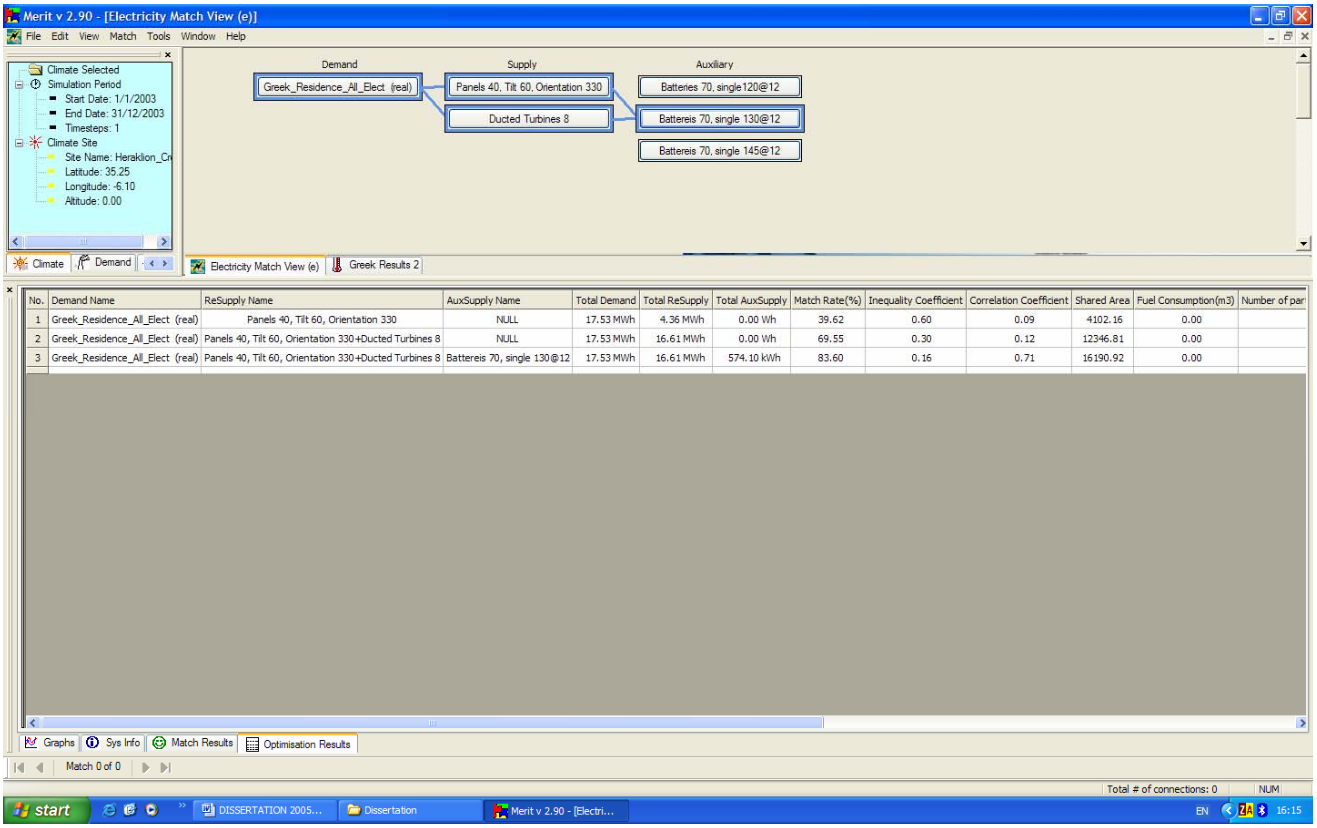


No.	Demand Name	ReSupply Name	AuxSupply Name	Total Demand	Total ReSupply	Total AuxSupply	Match Rate(%)	Inequality Coefficient	Correlation Coefficient	Shared Area	Fuel Consumption(m3)	Number of part
1	Greek_Residence_All_Elect (real)	Panels 40, Tilt 60, Orientation 330	NULL	17.53 MWh	4.36 MWh	0.00 Wh	39.62	0.60	0.09	4102.16	0.00	
2	Greek_Residence_All_Elect (real)	Panels 40, Tilt 60, Orientation 330+Ducted Turbines 8	NULL	17.53 MWh	16.61 MWh	0.00 Wh	69.55	0.30	0.12	12346.81	0.00	
3	Greek_Residence_All_Elect (real)	Panels 40, Tilt 60, Orientation 330+Ducted Turbines 8	Batteries 70, single120@12	17.53 MWh	16.61 MWh	537.81 kWh	83.24	0.17	0.70	16118.19	0.00	

Graphical match and results of the Supplies/Demands-8 Turbines, 40 PV, 70 Batteries single 120@12



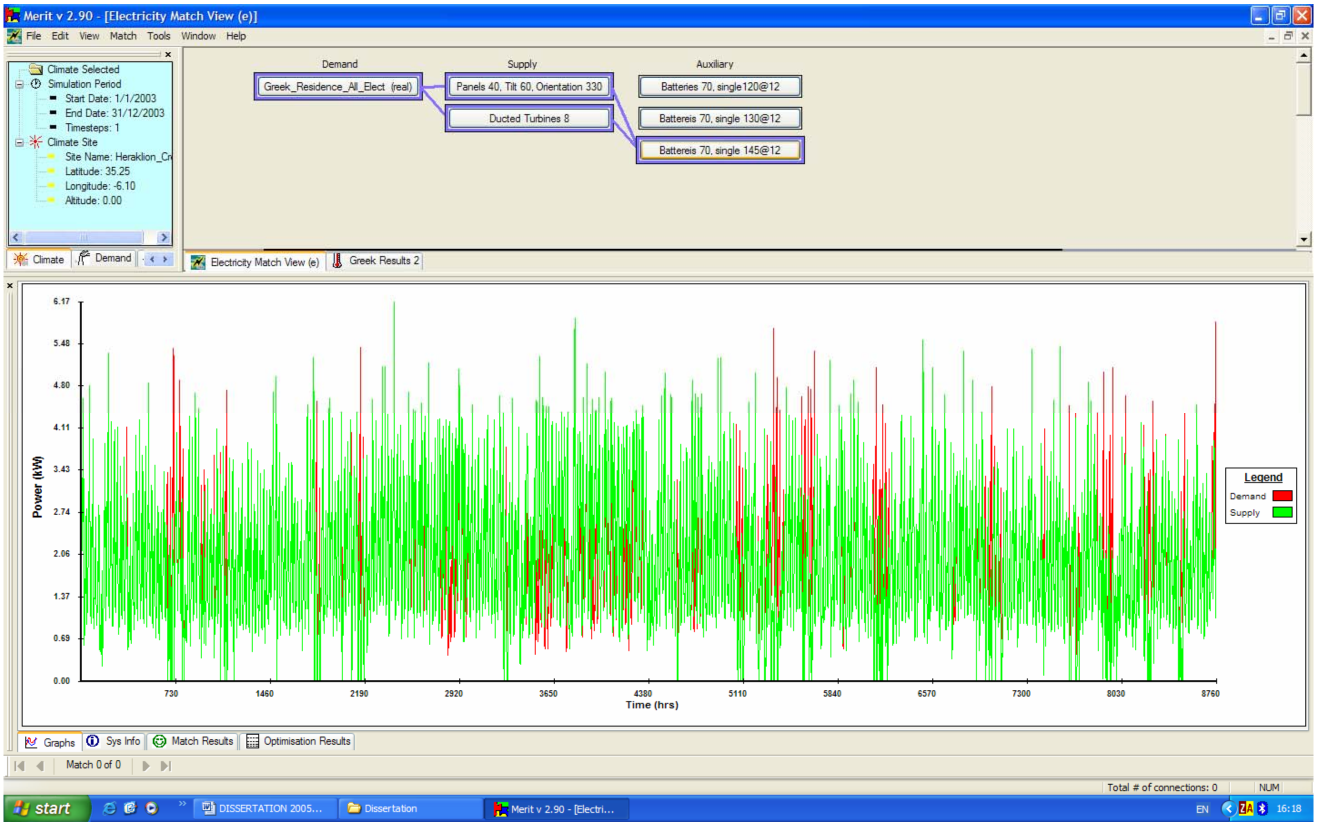
Start Date: 1/1/2003
End Date: 31/12/2003
Timesteps: 1
Site Name: Heraklion_Cr
Latitude: 35.25
Longitude: -6.10
Altitude: 0.00



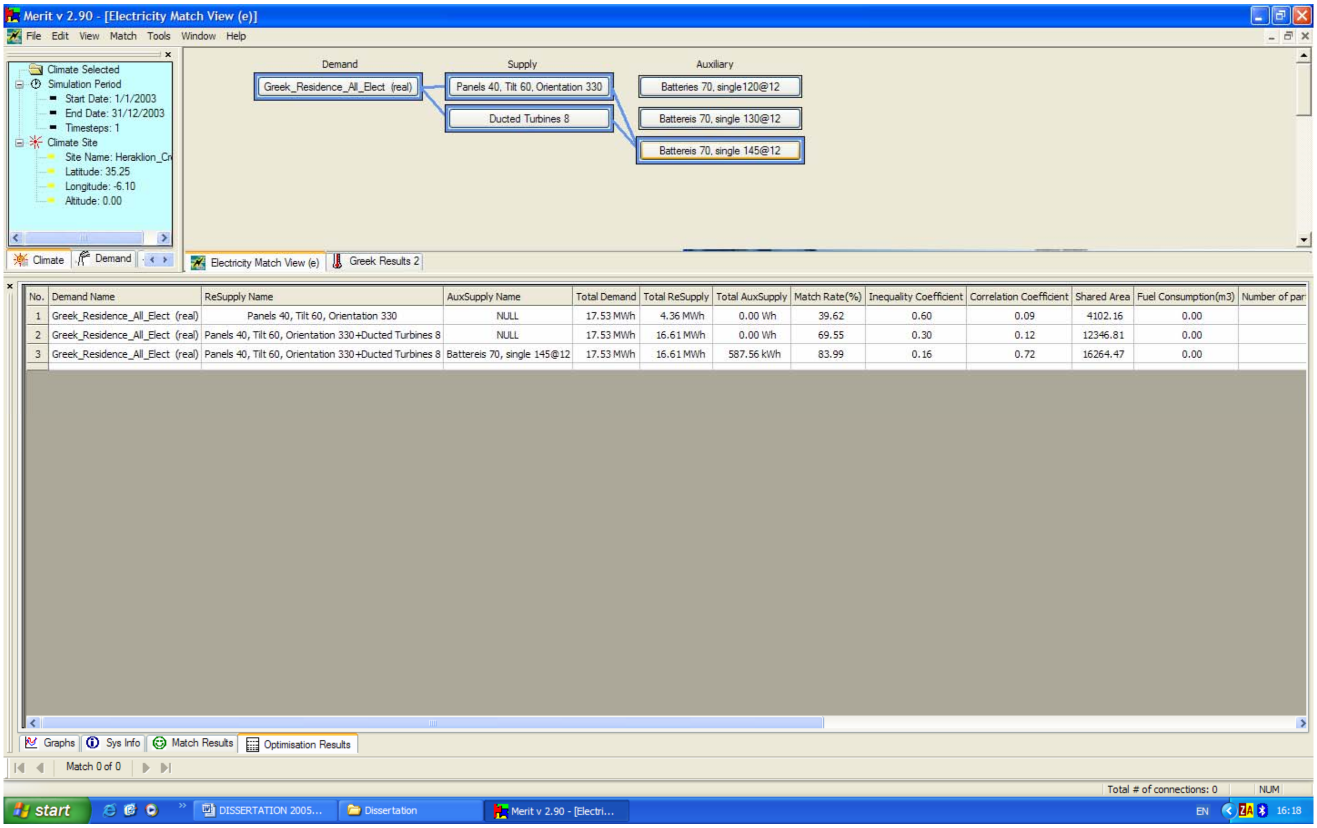
Start Date: 1/1/2003
End Date: 31/12/2003
Timesteps: 1
Site Name: Heraklion_Cr
Latitude: 35.25
Longitude: -6.10
Altitude: 0.00

No.	Demand Name	ReSupply Name	AuxSupply Name	Total Demand	Total ReSupply	Total AuxSupply	Match Rate(%)	Inequality Coefficient	Correlation Coefficient	Shared Area	Fuel Consumption(m3)	Number of par
1	Greek_Residence_All_Elect (real)	Panels 40, Tilt 60, Orientation 330	NULL	17.53 MWh	4.36 MWh	0.00 Wh	39.62	0.60	0.09	4102.16	0.00	
2	Greek_Residence_All_Elect (real)	Panels 40, Tilt 60, Orientation 330+Ducted Turbines 8	NULL	17.53 MWh	16.61 MWh	0.00 Wh	69.55	0.30	0.12	12346.81	0.00	
3	Greek_Residence_All_Elect (real)	Panels 40, Tilt 60, Orientation 330+Ducted Turbines 8	Battereis 70, single 130@12	17.53 MWh	16.61 MWh	574.10 kWh	83.60	0.16	0.71	16190.92	0.00	

Graphical match and results of the Supplies/Demands-8 Turbines, 40 PV, 70 Batteries single 130@12



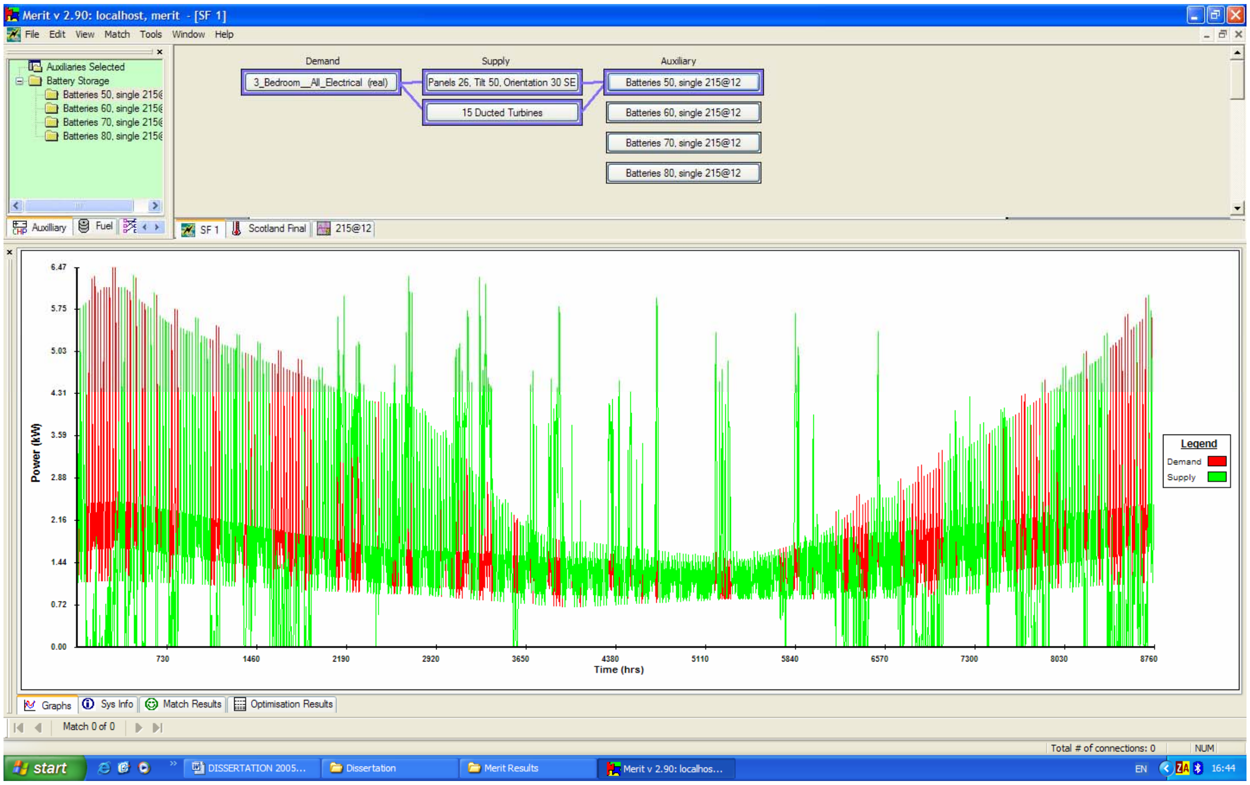
Climate Selected
Simulation Period
Start Date: 1/1/2003
End Date: 31/12/2003
Timesteps: 1
Climate Site
Site Name: Heraklion_Cr
Latitude: 35.25
Longitude: -6.10
Altitude: 0.00

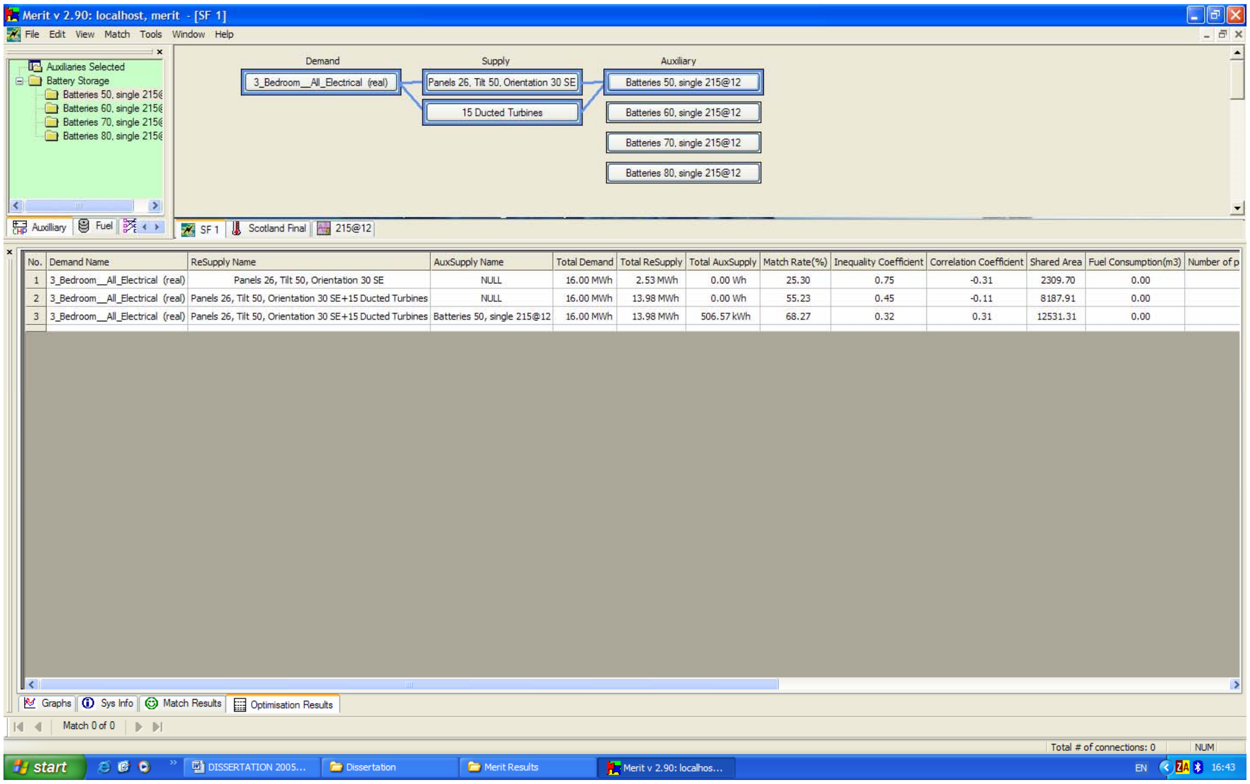


No.	Demand Name	ReSupply Name	AuxSupply Name	Total Demand	Total ReSupply	Total AuxSupply	Match Rate(%)	Inequality Coefficient	Correlation Coefficient	Shared Area	Fuel Consumption(m3)	Number of par
1	Greek_Residence_All_Elect (real)	Panels 40, Tilt 60, Orientation 330	NULL	17.53 MWh	4.36 MWh	0.00 Wh	39.62	0.60	0.09	4102.16	0.00	
2	Greek_Residence_All_Elect (real)	Panels 40, Tilt 60, Orientation 330+Ducted Turbines 8	NULL	17.53 MWh	16.61 MWh	0.00 Wh	69.55	0.30	0.12	12346.81	0.00	
3	Greek_Residence_All_Elect (real)	Panels 40, Tilt 60, Orientation 330+Ducted Turbines 8	Battereis 70, single 145@12	17.53 MWh	16.61 MWh	587.56 kWh	83.99	0.16	0.72	16264.47	0.00	

Graphical match and results of the Supplies/Demands-8 Turbines, 40 PV, 70 Batteries single 145@12

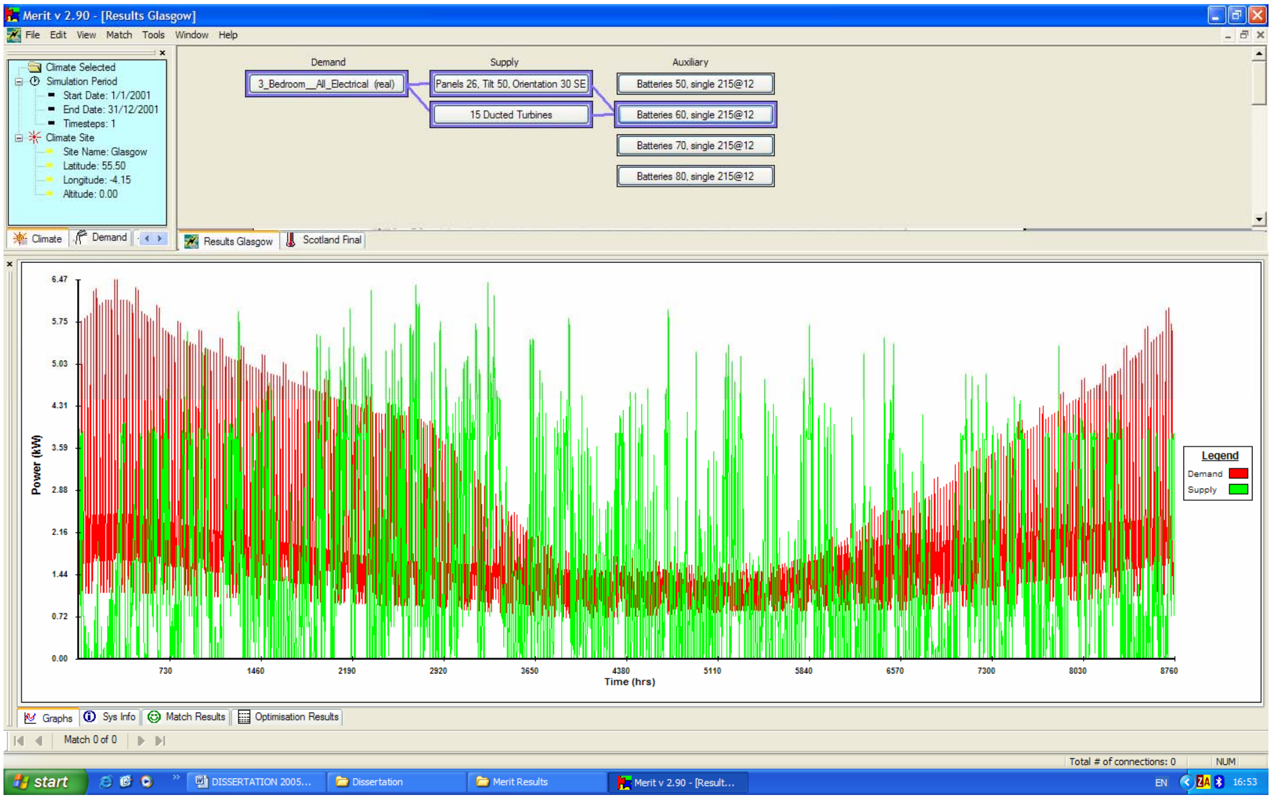
Merit Analysis Glasgow



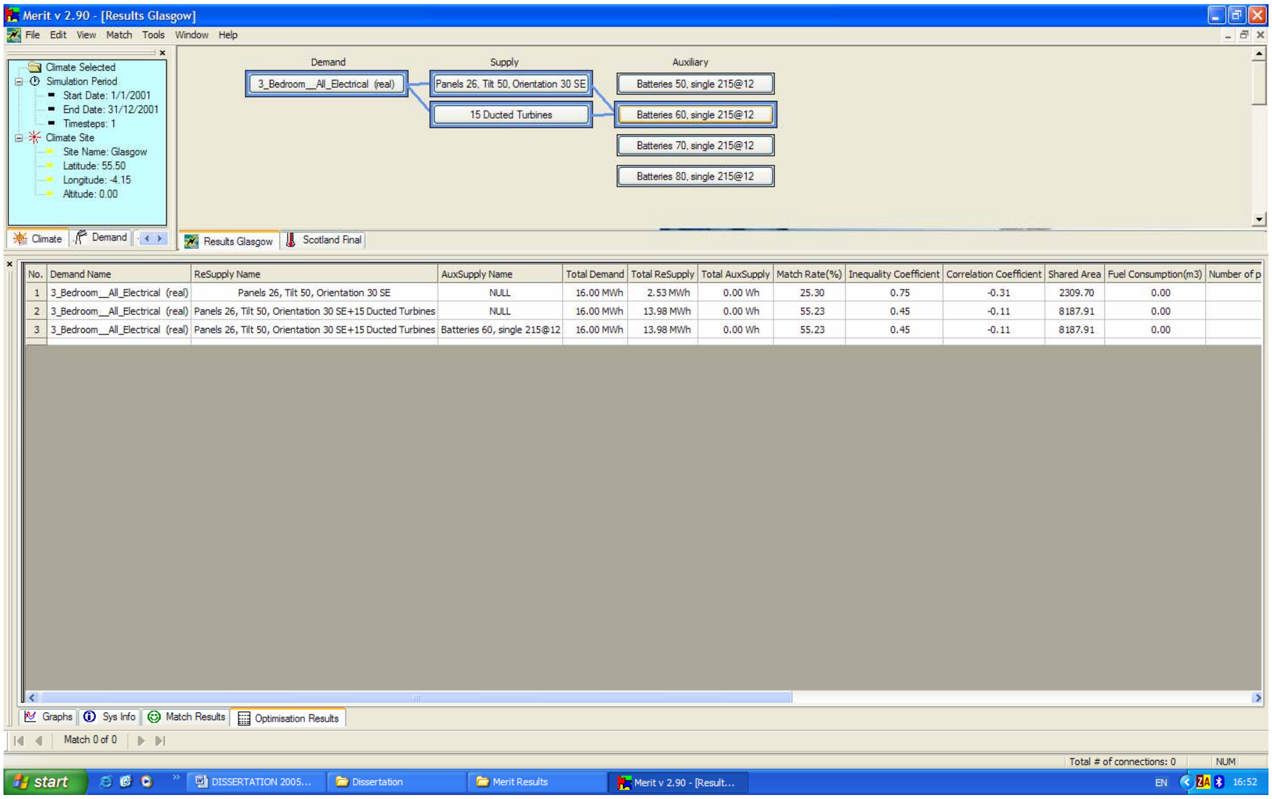


No.	Demand Name	ReSupply Name	AuxSupply Name	Total Demand	Total ReSupply	Total AuxSupply	Match Rate(%)	Inequality Coefficient	Correlation Coefficient	Shared Area	Fuel Consumption(m3)	Number of p
1	3_Bedroom__All_Electrical (real)	Panels 26, Tilt 50, Orientation 30 SE	NULL	16.00 MWh	2.53 MWh	0.00 Wh	25.30	0.75	-0.31	2309.70	0.00	
2	3_Bedroom__All_Electrical (real)	Panels 26, Tilt 50, Orientation 30 SE+15 Ducted Turbines	NULL	16.00 MWh	13.98 MWh	0.00 Wh	55.23	0.45	-0.11	8187.91	0.00	
3	3_Bedroom__All_Electrical (real)	Panels 26, Tilt 50, Orientation 30 SE+15 Ducted Turbines	Batteries 50, single 215@12	16.00 MWh	13.98 MWh	506.57 kWh	68.27	0.32	0.31	12531.31	0.00	

Graphical match and results of the Supplies/Demands-15 Turbines, 26 PV, 50 Batteries single 215@12



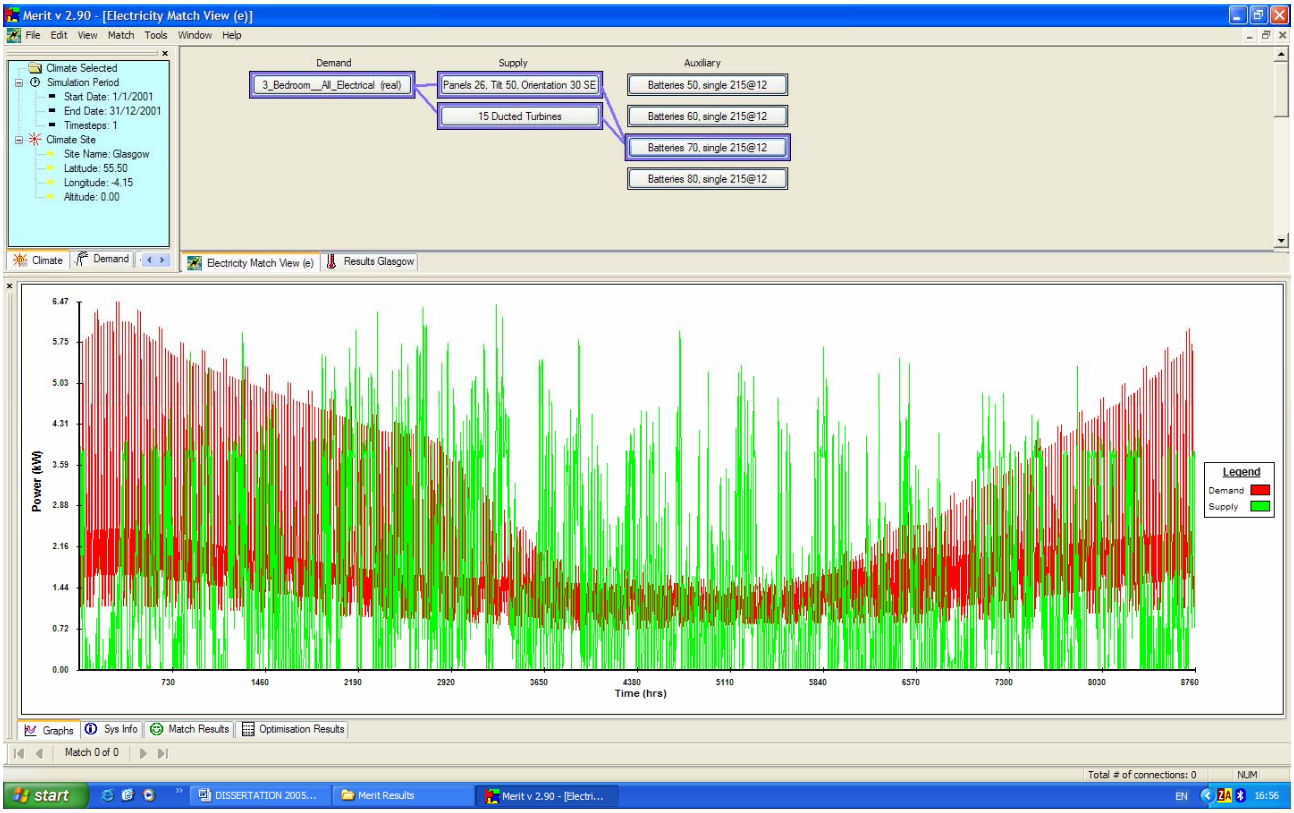
Climate Selected
Simulation Period
Start Date: 1/1/2001
End Date: 31/12/2001
Timesteps: 1
Climate Site
Site Name: Glasgow
Latitude: 55.50
Longitude: -4.15
Altitude: 0.00



Climate Selected
Simulation Period
Start Date: 1/1/2001
End Date: 31/12/2001
Timesteps: 1
Climate Site
Site Name: Glasgow
Latitude: 55.50
Longitude: -4.15
Altitude: 0.00

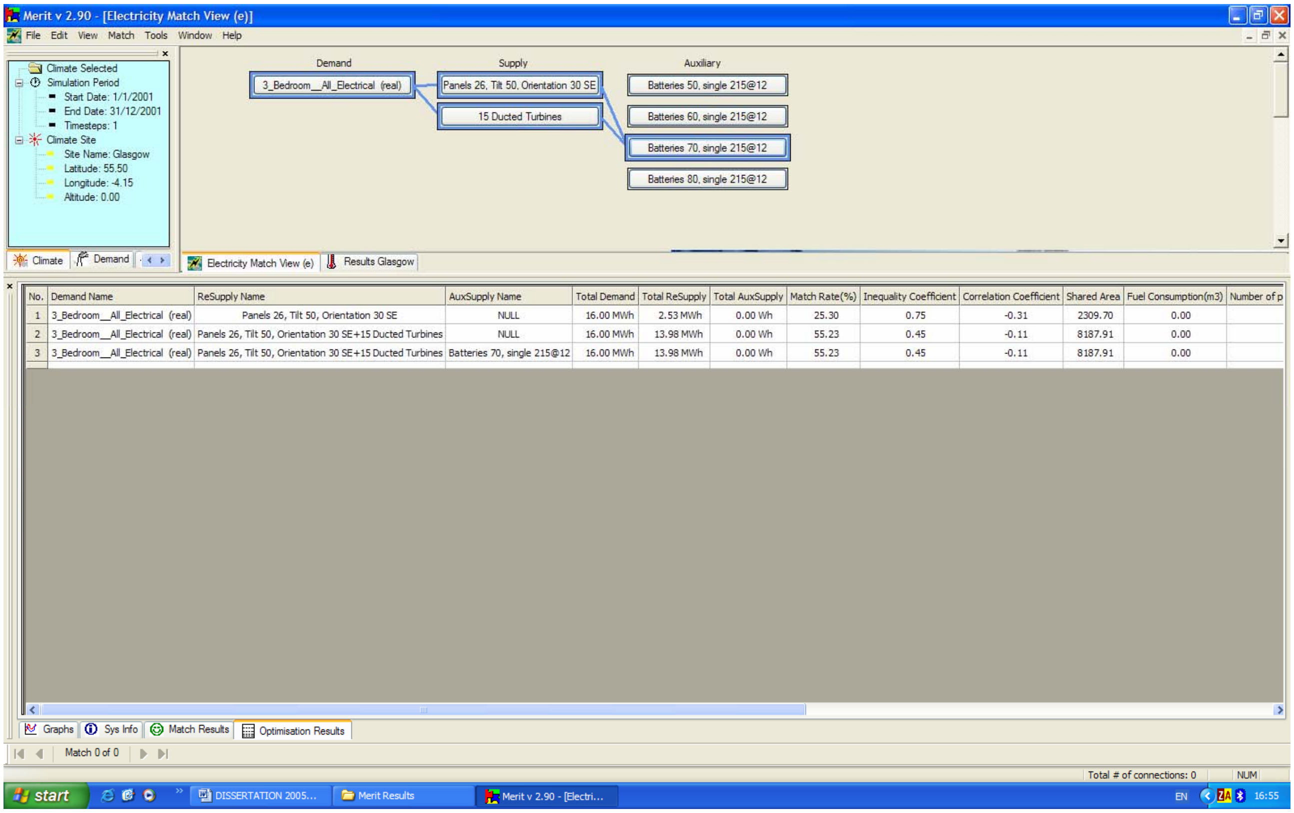
No.	Demand Name	ReSupply Name	AuxSupply Name	Total Demand	Total ReSupply	Total AuxSupply	Match Rate(%)	Inequality Coefficient	Correlation Coefficient	Shared Area	Fuel Consumption(m3)	Number of p
1	3_Bedroom__All_Electrical (real)	Panels 26, Tilt 50, Orientation 30 SE	NULL	16.00 MWh	2.53 MWh	0.00 Wh	25.30	0.75	-0.31	2309.70	0.00	
2	3_Bedroom__All_Electrical (real)	Panels 26, Tilt 50, Orientation 30 SE+15 Ducted Turbines	NULL	16.00 MWh	13.98 MWh	0.00 Wh	55.23	0.45	-0.11	8187.91	0.00	
3	3_Bedroom__All_Electrical (real)	Panels 26, Tilt 50, Orientation 30 SE+15 Ducted Turbines	Batteries 60, single 215@12	16.00 MWh	13.98 MWh	0.00 Wh	55.23	0.45	-0.11	8187.91	0.00	

Graphical match and results of the Supplies/Demands-15 Turbines, 26 PV, 60 Batteries single 215@12



Climate Selected
Simulation Period
- Start Date: 1/1/2001
- End Date: 31/12/2001
- Timesteps: 1

Climate Site
- Site Name: Glasgow
- Latitude: 55.50
- Longitude: -4.15
- Altitude: 0.00

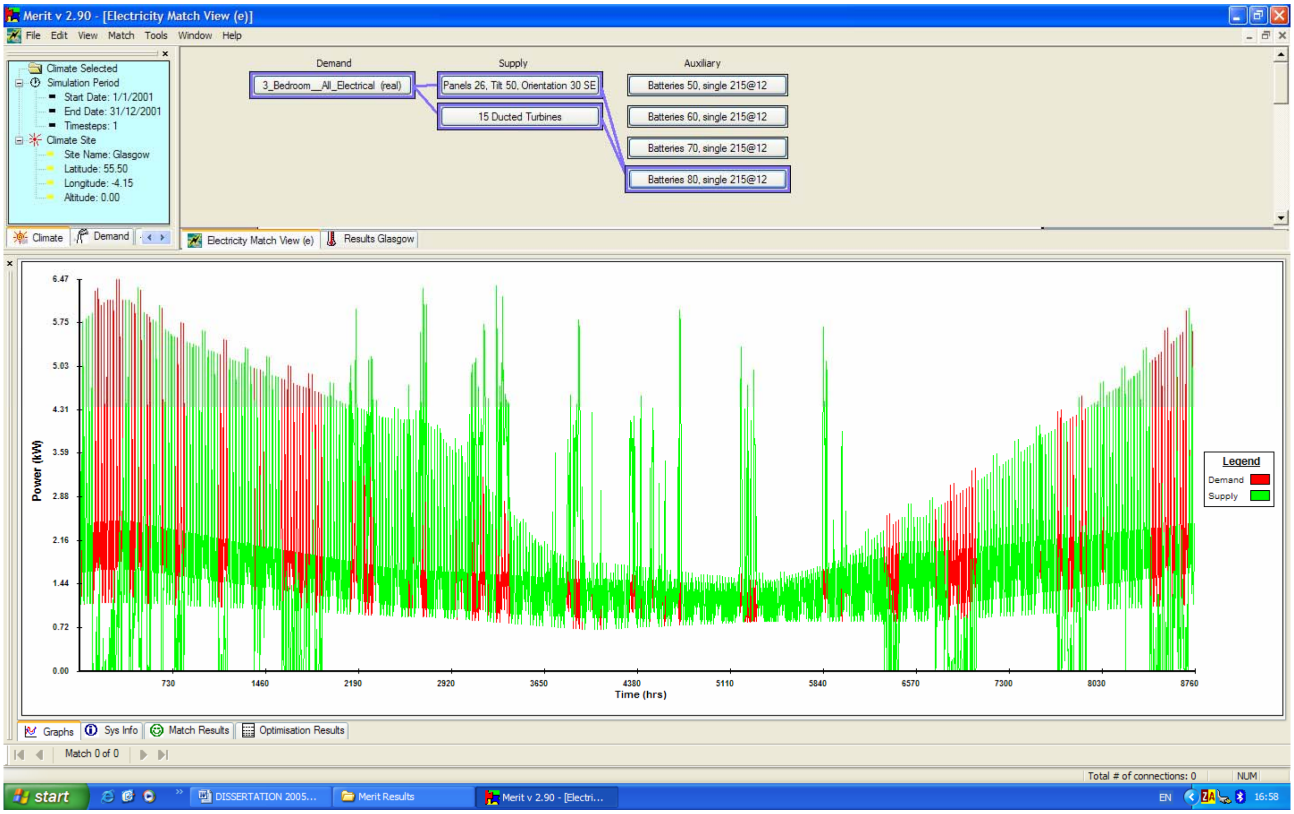


Climate Selected
Simulation Period
- Start Date: 1/1/2001
- End Date: 31/12/2001
- Timesteps: 1

Climate Site
- Site Name: Glasgow
- Latitude: 55.50
- Longitude: -4.15
- Altitude: 0.00

No.	Demand Name	ReSupply Name	AuxSupply Name	Total Demand	Total ReSupply	Total AuxSupply	Match Rate(%)	Inequality Coefficient	Correlation Coefficient	Shared Area	Fuel Consumption(m3)	Number of p
1	3_Bedroom__All_Electrical (real)	Panels 26, Tilt 50, Orientation 30 SE	NULL	16.00 MWh	2.53 MWh	0.00 Wh	25.30	0.75	-0.31	2309.70	0.00	
2	3_Bedroom__All_Electrical (real)	Panels 26, Tilt 50, Orientation 30 SE+15 Ducted Turbines	NULL	16.00 MWh	13.98 MWh	0.00 Wh	55.23	0.45	-0.11	8187.91	0.00	
3	3_Bedroom__All_Electrical (real)	Panels 26, Tilt 50, Orientation 30 SE+15 Ducted Turbines	Batteries 70, single 215@12	16.00 MWh	13.98 MWh	0.00 Wh	55.23	0.45	-0.11	8187.91	0.00	

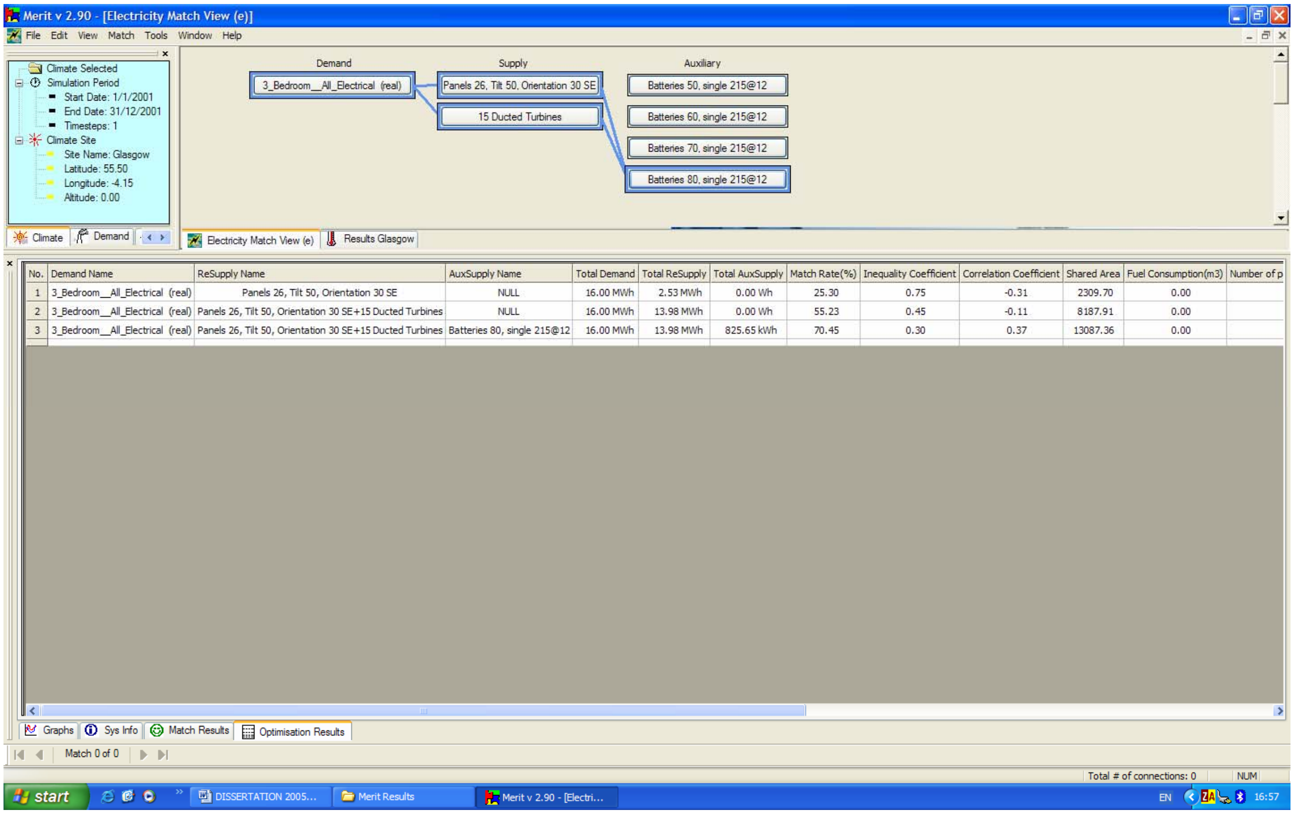
Graphical match and results of the Supplies/Demands-15 Turbines, 26 PV, 70 Batteries single 215@12



Climate Selected
Simulation Period
- Start Date: 1/1/2001
- End Date: 31/12/2001
- Timesteps: 1

Climate Site
- Site Name: Glasgow
- Latitude: 55.50
- Longitude: -4.15
- Altitude: 0.00

Demand	Supply	Auxiliary
3_Bedroom__All_Electrical (real)	Panels 26, Tilt 50, Orientation 30 SE	Batteries 50, single 215@12
	15 Ducted Turbines	Batteries 60, single 215@12
		Batteries 70, single 215@12
		Batteries 80, single 215@12



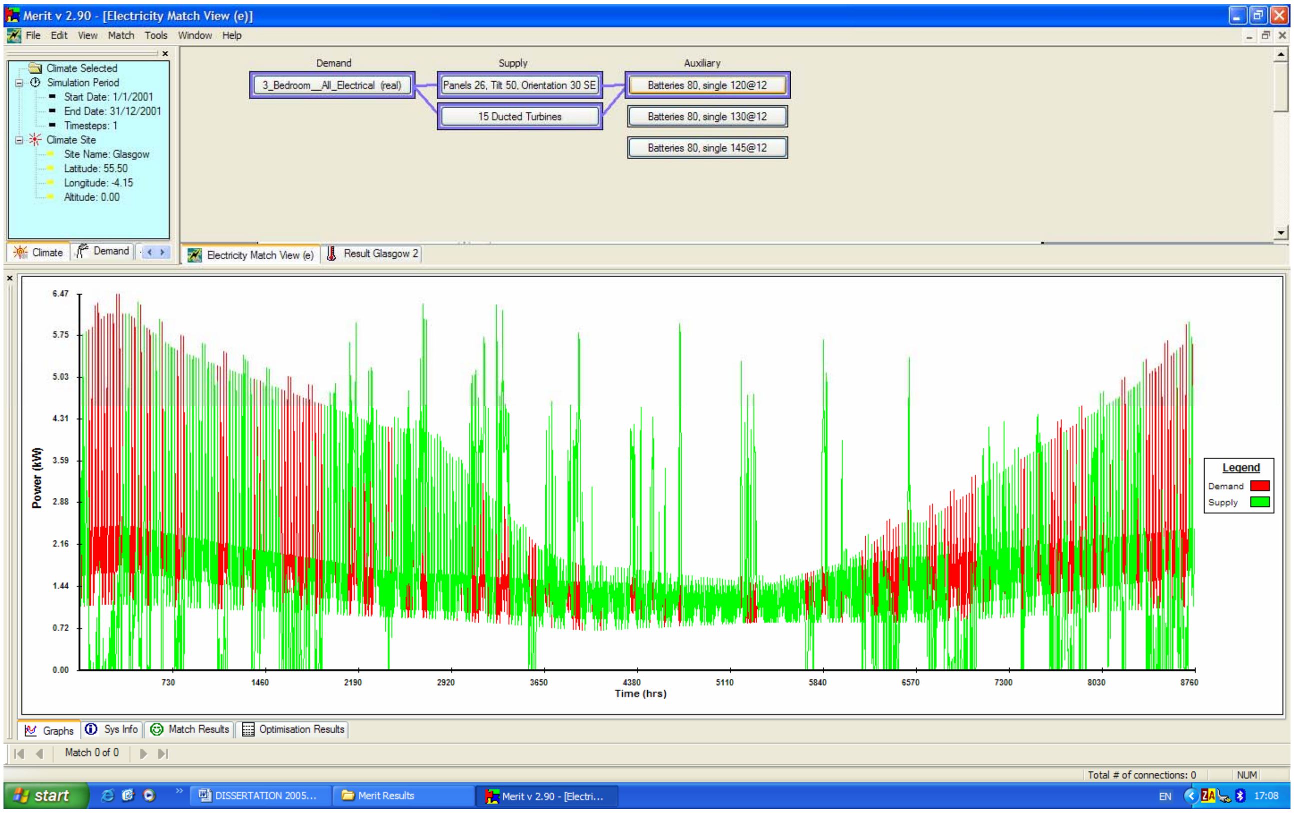
Climate Selected
Simulation Period
- Start Date: 1/1/2001
- End Date: 31/12/2001
- Timesteps: 1

Climate Site
- Site Name: Glasgow
- Latitude: 55.50
- Longitude: -4.15
- Altitude: 0.00

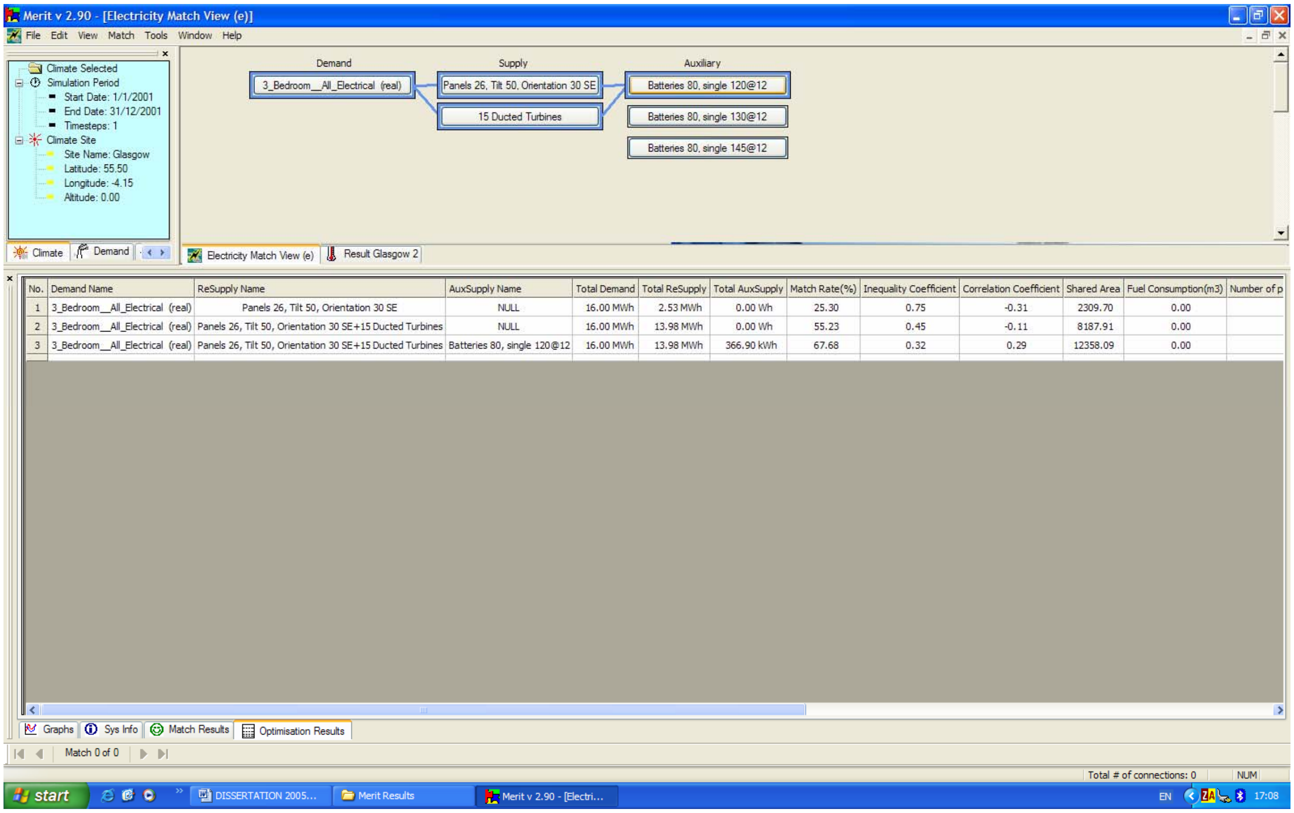
Demand	Supply	Auxiliary
3_Bedroom__All_Electrical (real)	Panels 26, Tilt 50, Orientation 30 SE	Batteries 50, single 215@12
	15 Ducted Turbines	Batteries 60, single 215@12
		Batteries 70, single 215@12
		Batteries 80, single 215@12

No.	Demand Name	ReSupply Name	AuxSupply Name	Total Demand	Total ReSupply	Total AuxSupply	Match Rate(%)	Inequality Coefficient	Correlation Coefficient	Shared Area	Fuel Consumption(m3)	Number of p
1	3_Bedroom__All_Electrical (real)	Panels 26, Tilt 50, Orientation 30 SE	NULL	16.00 MWh	2.53 MWh	0.00 Wh	25.30	0.75	-0.31	2309.70	0.00	
2	3_Bedroom__All_Electrical (real)	Panels 26, Tilt 50, Orientation 30 SE+15 Ducted Turbines	NULL	16.00 MWh	13.98 MWh	0.00 Wh	55.23	0.45	-0.11	8187.91	0.00	
3	3_Bedroom__All_Electrical (real)	Panels 26, Tilt 50, Orientation 30 SE+15 Ducted Turbines	Batteries 80, single 215@12	16.00 MWh	13.98 MWh	825.65 kWh	70.45	0.30	0.37	13087.36	0.00	

Graphical match and results of the Supplies/Demands-15 Turbines, 26 PV, 80 Batteries single 215@12



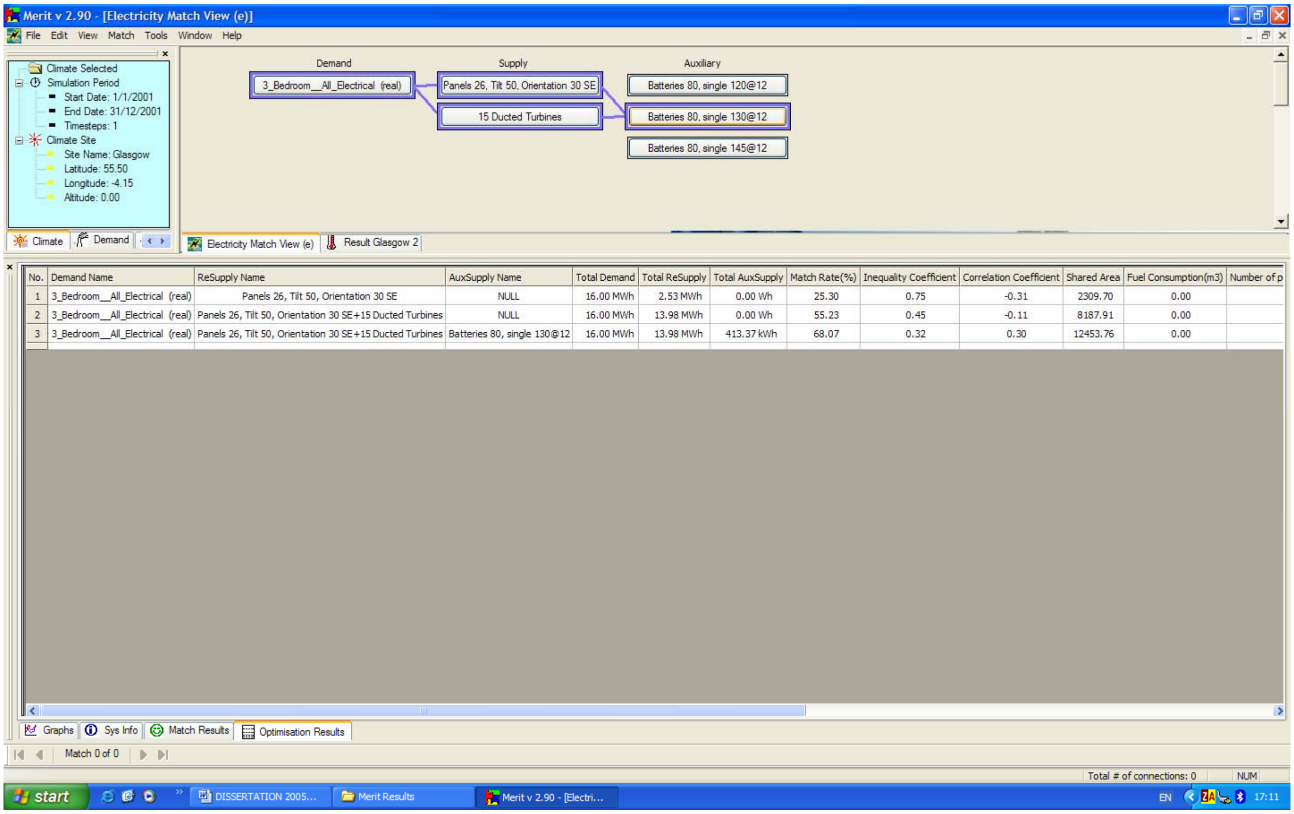
Start Date: 1/1/2001
End Date: 31/12/2001
Timesteps: 1
Site Name: Glasgow
Latitude: 55.50
Longitude: -4.15
Altitude: 0.00



Start Date: 1/1/2001
End Date: 31/12/2001
Timesteps: 1
Site Name: Glasgow
Latitude: 55.50
Longitude: -4.15
Altitude: 0.00

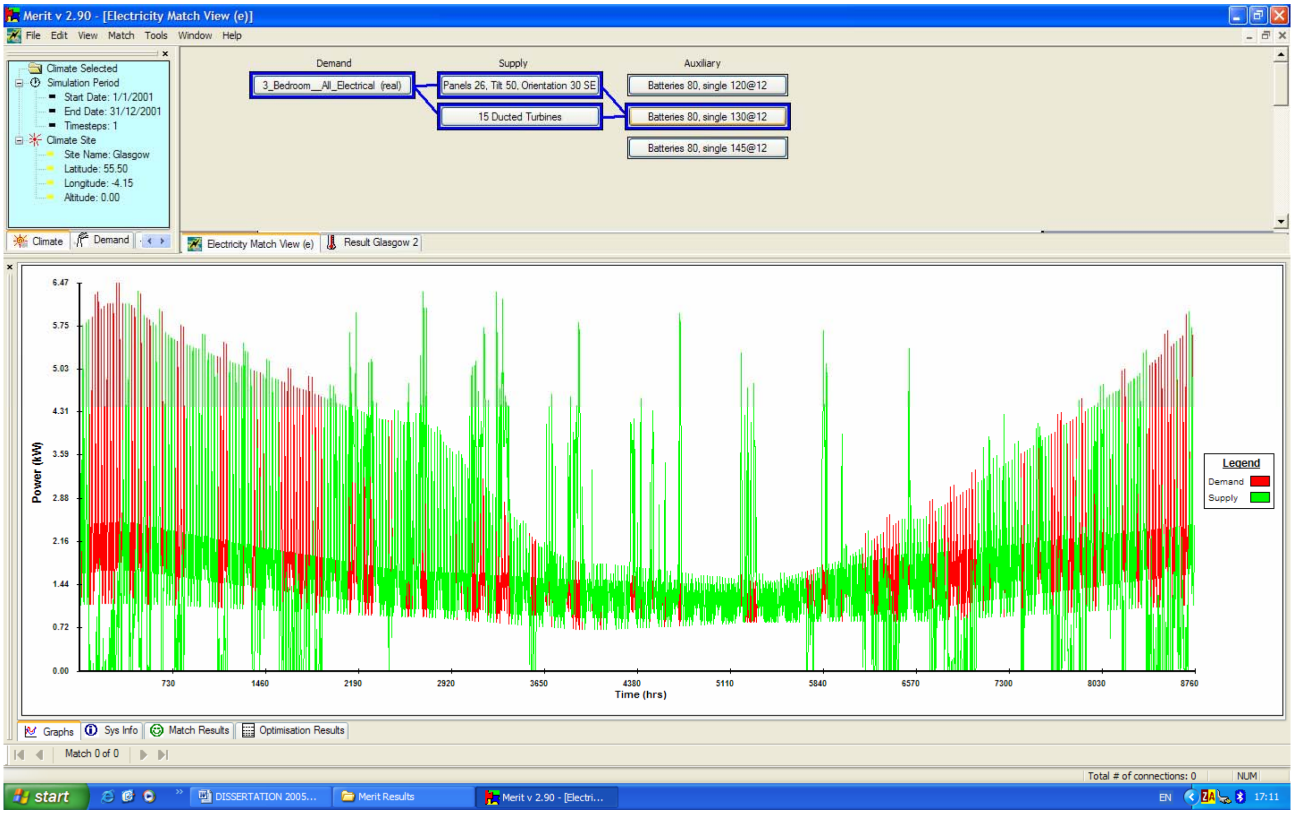
No.	Demand Name	ReSupply Name	AuxSupply Name	Total Demand	Total ReSupply	Total AuxSupply	Match Rate(%)	Inequality Coefficient	Correlation Coefficient	Shared Area	Fuel Consumption(m3)	Number of p
1	3_Bedroom__All_Electrical (real)	Panels 26, Tilt 50, Orientation 30 SE	NULL	16.00 MWh	2.53 MWh	0.00 Wh	25.30	0.75	-0.31	2309.70	0.00	
2	3_Bedroom__All_Electrical (real)	Panels 26, Tilt 50, Orientation 30 SE+15 Ducted Turbines	NULL	16.00 MWh	13.98 MWh	0.00 Wh	55.23	0.45	-0.11	8187.91	0.00	
3	3_Bedroom__All_Electrical (real)	Panels 26, Tilt 50, Orientation 30 SE+15 Ducted Turbines	Batteries 80, single 120@12	16.00 MWh	13.98 MWh	366.90 kWh	67.68	0.32	0.29	12358.09	0.00	

Graphical match and results of the Supplies/Demands-15 Turbines, 26 PV, 80 Batteries single 120@12



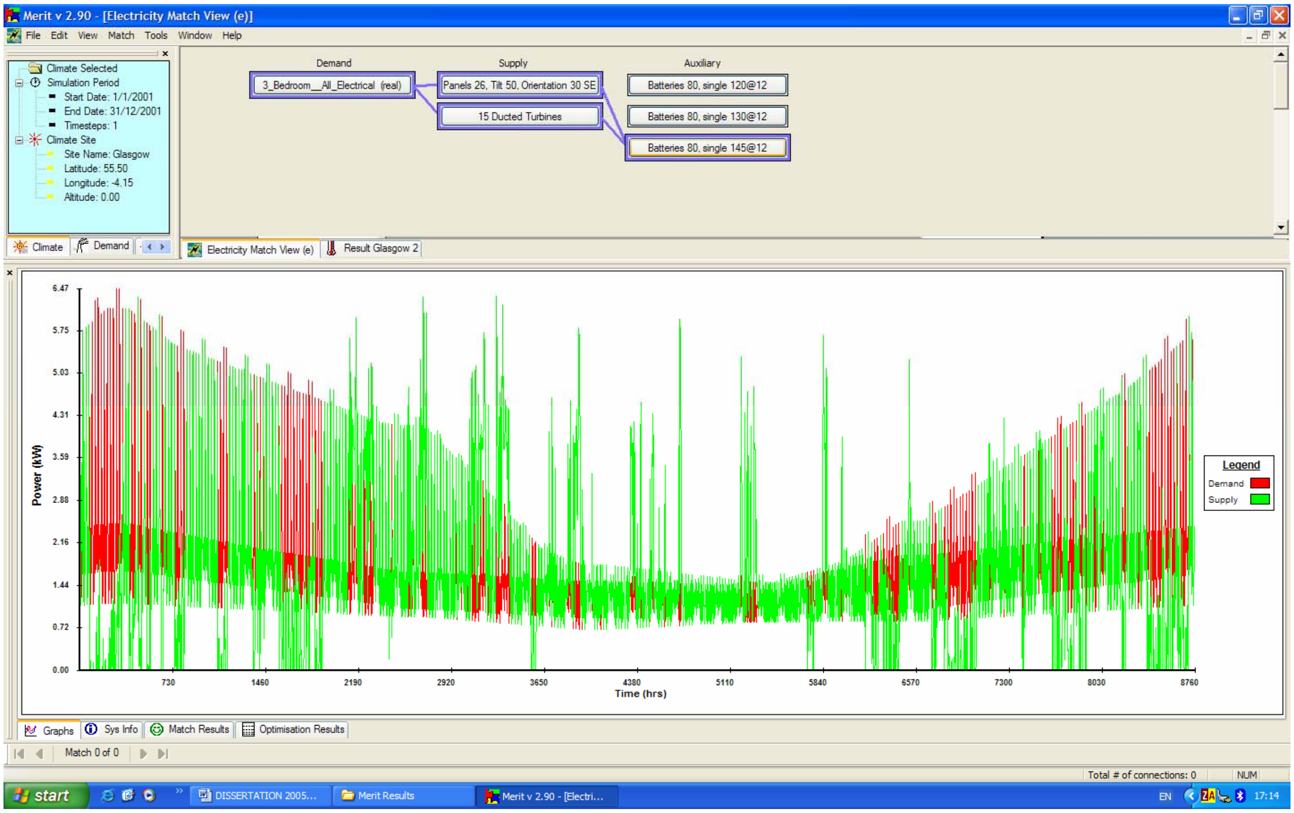
Climate Selected
Simulation Period
Start Date: 1/1/2001
End Date: 31/12/2001
Timesteps: 1
Climate Site
Site Name: Glasgow
Latitude: 55.50
Longitude: -4.15
Altitude: 0.00

No.	Demand Name	ReSupply Name	AuxSupply Name	Total Demand	Total ReSupply	Total AuxSupply	Match Rate(%)	Inequality Coefficient	Correlation Coefficient	Shared Area	Fuel Consumption(m3)	Number of p
1	3_Bedroom__All_Electrical (real)	Panels 26, Tilt 50, Orientation 30 SE	NULL	16.00 MWh	2.53 MWh	0.00 Wh	25.30	0.75	-0.31	2309.70	0.00	
2	3_Bedroom__All_Electrical (real)	Panels 26, Tilt 50, Orientation 30 SE+15 Ducted Turbines	NULL	16.00 MWh	13.98 MWh	0.00 Wh	55.23	0.45	-0.11	8187.91	0.00	
3	3_Bedroom__All_Electrical (real)	Panels 26, Tilt 50, Orientation 30 SE+15 Ducted Turbines	Batteries 80, single 130@12	16.00 MWh	13.98 MWh	413.37 kWh	68.07	0.32	0.30	12453.76	0.00	



Climate Selected
Simulation Period
Start Date: 1/1/2001
End Date: 31/12/2001
Timesteps: 1
Climate Site
Site Name: Glasgow
Latitude: 55.50
Longitude: -4.15
Altitude: 0.00

Graphical match and results of the Supplies/Demands-15 Turbines, 26 PV, 80 Batteries single 130@12

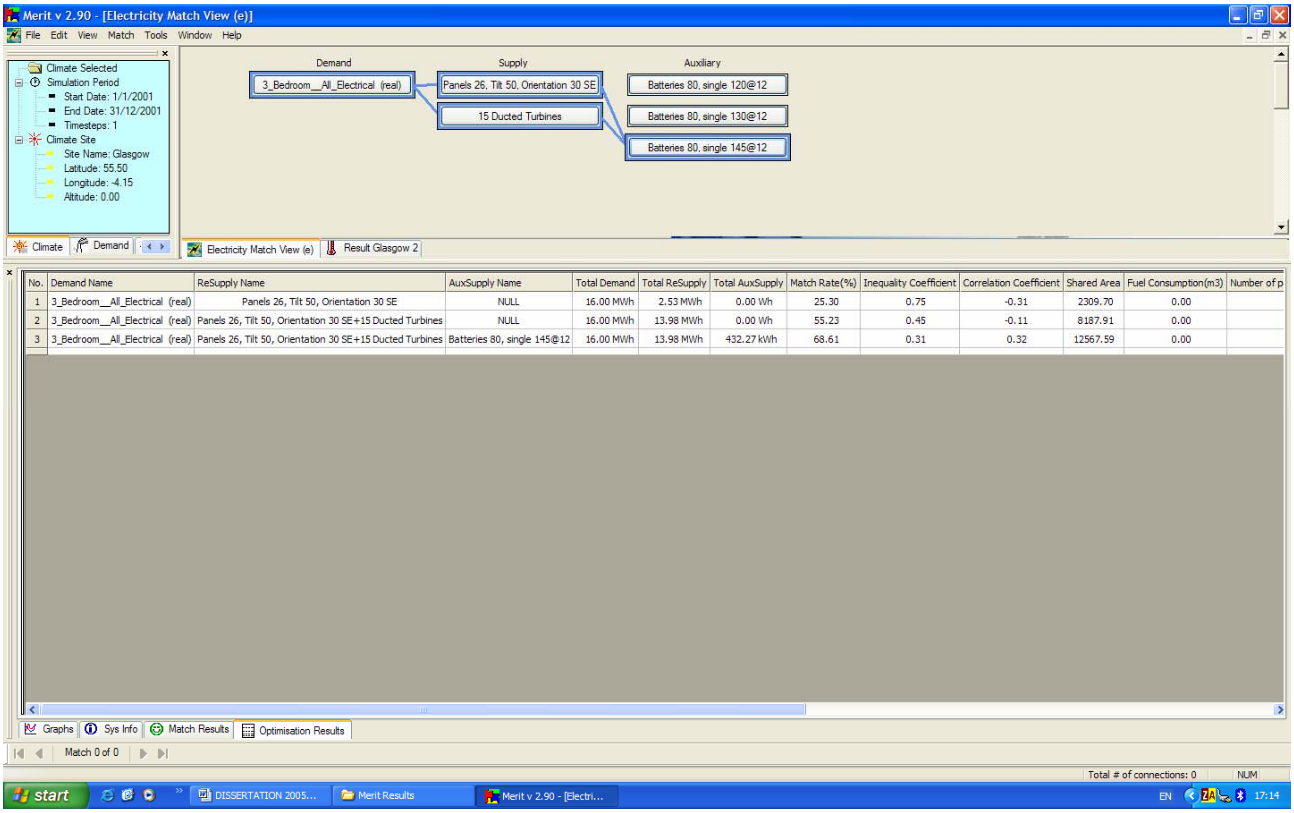


Climate Selected
Simulation Period
Start Date: 1/1/2001
End Date: 31/12/2001
Timesteps: 1
Climate Site
Site Name: Glasgow
Latitude: 55.50
Longitude: -4.15
Altitude: 0.00

Demand: 3_Bedroom__All_Electrical (real)

Supply: Panels 26, Tilt 50, Orientation 30 SE; 15 Ducted Turbines

Auxiliary: Batteries 80, single 120@12; Batteries 80, single 130@12; Batteries 80, single 145@12



No.	Demand Name	ReSupply Name	AuxSupply Name	Total Demand	Total ReSupply	Total AuxSupply	Match Rate(%)	Inequality Coefficient	Correlation Coefficient	Shared Area	Fuel Consumption(m3)	Number of p
1	3_Bedroom__All_Electrical (real)	Panels 26, Tilt 50, Orientation 30 SE	NULL	16.00 MWh	2.53 MWh	0.00 Wh	25.30	0.75	-0.31	2309.70	0.00	
2	3_Bedroom__All_Electrical (real)	Panels 26, Tilt 50, Orientation 30 SE+15 Ducted Turbines	NULL	16.00 MWh	13.98 MWh	0.00 Wh	55.23	0.45	-0.11	8187.91	0.00	
3	3_Bedroom__All_Electrical (real)	Panels 26, Tilt 50, Orientation 30 SE+15 Ducted Turbines	Batteries 80, single 145@12	16.00 MWh	13.98 MWh	432.27 kWh	68.61	0.31	0.32	12567.59	0.00	

Graphical match and results of the Supplies/Demands-15 Turbines, 26 PV, 80 Batteries single 145@12

National Demands

Greece	***Energy Demands (GWh)***	***Direct Solar (W/m^2)***	***Wind Speed (m/sec)***	***PV Output (KWh)***	***DWT Output (KWh)***
Jan	4363	60.86	9.14	4.88	133.1
Feb	4319	142.47	7.74	6.45	117.99
Mar	4385	206.51	8.41	9.21	118.78
Apr	3970	247.43	11.28	10.21	155.4
May	4168	351.09	8.60	12.41	139.23
Jun	4581	372.09	11.89	14.05	156.2
Jul	5397	395.20	7.19	12.09	109.89
Aug	4941	375.75	7.17	11.01	110.2
Sep	4236	294.57	8.17	9.91	113.92
Oct	4120	193.04	7.86	7.9	126.21
Nov	4107	103.92	9.71	5.37	119.48
Dec	4638	102.16	10.06	5.28	129.32

DWT (Number)	***PV (Number)***	***DWT Output (GWh)***	***PV Output (GWh)***	***Total Power (GWh)***
25000	150000	3327.5	732	4059.5
25000	150000	2949.75	967.5	3917.25
25000	150000	2969.5	1381.5	4351
25000	150000	3885	1531.5	5416.5
25000	150000	3480.75	1861.5	5342.25
25000	150000	3905	2107.5	6012.5
25000	150000	2747.25	1813.5	4560.75
25000	150000	2755	1651.5	4406.5
25000	150000	2848	1486.5	4334.5
25000	150000	3155.25	1185	4340.25
25000	150000	2987	805.5	3792.5
25000	150000	3233	792	4025

Theoretical number of wind turbines and PV panels which can cover effectively the National demands for Greece

UK	***Energy Demands(GWh)***	***Direct Solar (W/ m^2)***	***Wind Speed (m/sec)***	***PV Output(KWh)***	***DWT Output(KWh)***
Jan	32833	19.67	4.23	2.11	59.4
Feb	32648	45.56	5.02	4.44	73.77
Mar	36128	104.43	4.74	8.65	70.24
Apr	28542	172.30	5.60	14.08	84.51
May	27125	121.14	5.45	13.26	87.48
Jun	31402	108.55	4.63	11.22	62.64
Jul	26585	140.43	3.65	12.04	42.56
Aug	25944	102.27	4.10	9.87	49.77
Sep	31678	114.53	3.87	9.14	45.99
Oct	30107	68.01	3.61	6.23	45.5
Nov	31362	44.18	5.00	3.94	71.34
Dec	39108	25.15	4.91	2.31	70.25

DWT (Number)	***PV (Number)***	***DWT Output (GWh)***	***PV Output (GWh)***	***Total Power (GWh)***
500000	300000	29700	633	30333
500000	300000	36885	1332	38217
500000	300000	35120	2595	37715
500000	300000	42255	4224	46479
500000	300000	43740	3978	47718
500000	300000	31320	3366	34686
500000	300000	21280	3612	24892
500000	300000	24885	2961	27846
500000	300000	22995	2742	25737
500000	300000	22750	1869	24619
500000	300000	35670	1182	36852
500000	300000	35125	693	35818

Theoretical number of wind turbines and PV panels which can cover effectively the National demands for Glasgow

Wind Power Measurements

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LabVIEW Measurement
Writer_Version                      0.92
Reader_Version                         1
Separator               Tab
Multi_Headings          No
X_Columns               One
Time_Pref               Absolute
Operator                Student
Date                          07/08/2006
Time                             43:04.5
***End_of_Header***

Channels                               3
Samples                                1               1                 1
Date                          07/08/2006      07/08/2006        07/08/2006
Time                             43:04.5         43:04.5           43:04.5
X_Dimension             Time              Time            Time
X0                              0.00E+00        0.00E+00          0.00E+00
Delta_X                                1               1                 1
***End_of_Header***
X_Value Time (seconds)    Direction       Wind Velocity       Power Output
                     0        279.316406        5.566406                 0
                 8.922        276.679687        3.076172                 0
                18.922        255.761719        5.126953                 0
                28.922        200.214844        7.617187                 0
                38.922        238.710937        8.349609          0.004883
                48.922        254.003906        7.763672                 0
                58.922         243.28125       12.597656                 0
                68.922        244.160156       12.304687          0.014648
                78.922        244.160156       11.132812          0.004883
                88.922        224.648437        9.228516          0.004883
                98.922         212.34375       12.011719           0.03418
               108.922            213.75       15.234375           0.27832
               118.922        229.394531       17.431641          1.162109
               128.922          210.9375       12.304687          1.118164
               138.922         215.15625       10.986328           1.12793
               148.922        283.007812        3.808594          0.004883
               158.922         277.03125        4.833984                 0
               168.922        296.894531        11.71875                 0
               178.922        285.996094       12.451172                 0
               188.922        271.582031        9.667969                 0
               198.922        294.960937       13.769531          0.004883
               208.922        298.300781       11.425781                 0

             86188.922        243.105469        6.591797          0.004883
             86198.922        226.933594       10.839844                 0
             86208.922        250.488281       13.183594          0.078125
```

86218.922	229.21875	14.355469	0.063477
86228.922	235.722656	9.960937	0.053711
86238.922	251.894531	15.087891	0
86248.922	241.171875	10.400391	0
86258.922	243.808594	16.113281	0
86268.922	267.539062	16.552734	0
86278.922	210.410156	13.183594	0.004883
86288.922	260.507812	13.769531	0
86298.922	257.695312	17.285156	0.014648
86308.922	249.960937	11.865234	0
86318.922	244.6875	11.572266	0
86328.922	227.636719	13.916016	0.185547
86338.922	215.683594	13.037109	0.81543
86348.922	216.914062	10.986328	1.015625
86358.922	224.121094	9.960937	0.161133
86368.922	224.121094	12.451172	0.458984
86378.922	223.59375	11.132812	0.141602
86388.922	239.941406	12.744141	0.161133
86398.922	251.542969	13.330078	0.009766

153648.9	270.5273	17.13867	0
153658.9	269.4727	18.01758	0.004883
153668.9	253.3008	12.1582	0
153678.9	278.4375	13.33008	0.004883
153688.9	263.6719	12.1582	0
153698.9	266.1328	13.33008	0
153708.9	244.8633	14.64844	0
153718.9	250.6641	11.71875	0.004883
153728.9	269.1211	10.25391	0.004883
153738.9	296.0156	9.960937	0
153748.9	261.5625	8.496094	0
153758.9	215.332	8.642578	0
153768.9	239.5898	14.35547	0
153778.9	275.9766	8.496094	0.004883
153788.9	270.3516	10.69336	0
153798.9	279.668	11.13281	0
153808.9	289.6875	11.13281	0.009766
153818.9	284.2383	9.521484	0.004883
153828.9	269.8242	11.71875	0
153838.9	271.2305	13.47656	0.004883
153848.9	268.0664	13.47656	0.004883
153858.9	249.7852	16.40625	0
153868.9	236.25	13.03711	0
153878.9	241.1719	10.69336	0.009766
153888.9	278.9648	9.521484	0.004883
153898.9	260.332	17.13867	0
153908.9	249.6094	18.60352	0
153918.9	219.0234	8.642578	0
153928.9	239.5898	11.71875	0
153938.9	248.3789	17.43164	0.004883
153948.9	248.9063	16.40625	0
153958.9	257.168	21.38672	0
153968.9	246.7969	14.35547	0
153978.9	253.3008	20.50781	0
153988.9	253.4766	15.9668	0
153998.9	233.7891	13.33008	0

154008.9	233.6133	19.48242	0
154018.9	257.6953	14.79492	0.151367
154028.9	253.8281	13.18359	0
154038.9	254.707	15.38086	0
154048.9	263.1445	11.57227	0.004883
154058.9	266.1328	7.177734	0.004883

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199666.4	91	3.4	0.009766
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199686.4	151	2.1	0
199696.4	66	2.8	0.009766
199706.4	108	3.1	0
199716.4	78	1.8	0
199726.4	70	2.8	0
199736.4	88	2.6	0
199746.4	67	1.6	0
199756.4	101	1.3	0
199766.4	116	0.9	0
199776.4	206	1.3	0
199786.4	110	1	0.009766
199796.4	104	1.9	0
199806.4	112	1.3	0
199816.4	114	0.7	0.009766
199826.4	113	0.4	0
199836.4	121	0.9	0
199846.4	326	1	0
199856.4	7	1	0
199866.4	20	0.7	0.009766
199876.4	76	3.2	0
199886.4	49	2.6	0.009766
199896.4	53	0.7	0
199906.4	56	1.3	0
199916.4	182	1.5	0
199926.4	92	3.8	0
199936.4	114	2.8	0
199946.4	79	1.6	0
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199986.4	68	3.2	0
199996.4	59	3.7	0
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200136.4	77	0.4	0
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200156.4	100	1.9	0
200166.4	95	1.2	0
200176.4	29	1.6	0
200186.4	140	1.5	0
200196.4	146	1.3	0
200206.4	40	2.1	0
200216.4	26	2.5	0
200226.4	181	1.9	0
200236.4	182	0.6	0
200246.4	274	1.6	0
200256.4	311	0.7	0
200266.4	342	1.8	0
200276.4	342	0.9	0
200286.4	113	1.2	0
200296.4	330	2.2	0
200306.4	353	2.1	0
200316.4	23	2.9	0
200326.4	56	1	0
200336.4	20	2.9	0
200346.4	69	1.2	0
200356.4	131	0.9	0
200366.4	16	0.3	0.009766
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200386.4	104	3.5	0
200396.4	92	2.3	0
200406.4	89	1.9	0
200416.4	183	2.3	0
200426.4	153	0.1	0
200436.4	181	1	0
200446.4	190	1.9	0
200456.4	94	2.1	0
200466.4	74	4.2	0
200476.4	60	4.5	0
200486.4	69	4.2	0
200496.4	116	2.5	0
200506.4	106	2.1	0
200516.4	65	1.9	0
200526.4	357	1.5	0
200536.4	345	0.7	0
200546.4	342	0.6	0

200556.4	343	1.2	0
200566.4	45	0.9	0
200576.4	42	0.6	0
200586.4	50	1.6	0
200596.4	39	0.7	0
200606.4	210	2.3	0
200616.4	110	0.7	0
200626.4	144	1.2	0
200636.4	143	0.3	0
200646.4	289	1.6	0.009766
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200666.4	306	1	0
200676.4	305	0	0
200686.4	259	1.2	0
200696.4	262	0.7	0
200706.4	325	0.7	0
200716.4	325	0.6	0
200726.4	280	0.9	0
200736.4	280	0.9	0
200746.4	279	0.9	0.009766
200756.4	281	0.9	0
200766.4	280	1	0
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200786.4	101	1	0
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200816.4	105	0.9	0
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200836.4	48	2.2	0
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200856.4	65	2.6	0
200866.4	64	0.4	0
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200886.4	45	2.6	0
200896.4	122	2.6	0
200906.4	39	3.1	0
200916.4	36	2.6	0
200926.4	84	2.3	0
200936.4	137	1	0
200946.4	140	0.1	0
200956.4	137	1	0.009766
200966.4	139	0.6	0
200976.4	130	0.7	0
200986.4	68	2.8	0
200996.4	68	2.9	0.009766
201006.4	287	1.6	0
201016.4	283	1	0
201026.4	319	1.6	0

201036.4	359	0.9	0
201046.4	326	0.4	0
201056.4	193	1	0
201066.4	193	1.2	0
201076.4	193	0.3	0
201086.4	193	0.1	0
201096.4	32	2.2	0
201106.4	52	1.6	0
201116.4	75	4.1	0
201126.4	42	4	0
201136.4	103	3.5	0
201146.4	33	2.3	0
201156.4	350	1.5	0
201166.4	39	2.1	0
201176.4	67	2.3	0
201186.4	93	1	0
201196.4	106	0.3	0
201206.4	76	1.9	0
201216.4	132	2.6	0
201226.4	57	3.5	0
201236.4	62	0.6	0.009766
201246.4	62	4.2	0.014648
201256.4	27	3.5	0
201266.4	50	3.5	0
201276.4	92	2.5	0
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201296.4	68	1.6	0
201306.4	66	2.3	0
201316.4	42	1.9	0
201326.4	23	2.2	0
201336.4	7	1.6	0
201346.4	31	1.8	0
201356.4	77	1.6	0
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201386.4	63	1	0
201396.4	196	1.9	0
201406.4	145	0.6	0
201416.4	221	1.2	0
201426.4	221	0.1	0
201436.4	140	1.6	0
201446.4	301	1.8	0
201456.4	11	0.9	0
201466.4	80	1.5	0
201476.4	91	1.8	0
201486.4	54	1	0
201496.4	75	1.2	0
201506.4	71	1.5	0

201516.4	75	0.6	0.009766
201526.4	67	3.8	0
201536.4	114	2.8	0
201546.4	138	2.2	0
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201566.4	27	1	0
201576.4	34	1.9	0
201586.4	21	0.9	0
201596.4	27	0.6	0
201606.4	68	1.6	0
201616.4	69	1.3	0
201626.4	68	0.7	0
201636.4	243	1.3	0.009766
201646.4	244	0.6	0
201656.4	243	0.6	0
201666.4	244	0.9	0
201676.4	244	0	0

Characteristics Measurements from the Ducted Wind Turbine mounted on the roof of the James Weir Building in the University of Strathclyde

Weather Data of Heraklion Crete

Months	Days	Hours	Temperature (C)	Direct Radiation(W/m2)	Diffuse Radiation(W/m2)	Wind Speed(m/sec)	Wind Direction(Deg)
1	1	1	8.91	0	0	7.122	237.167
1	1	2	8.40	0	0	7.865	227.6
1	1	3	8.14	0	0	7.068	221
1	1	4	8.00	0	0	6.955	222.1
1	1	5	7.83	12	17	6.728	222.7
1	1	6	7.58	16	49	6.112	224.933
1	1	7	7.41	156	144	8.41	234.967
1	1	8	7.40	159	155	7.393	237.8
1	1	9	8.54	12	193	5.055	247.85
1	1	10	11.09	197	294	4.703	248.333
1	1	11	13.49	71	252	3.365	251.6
1	1	12	15.15	12	158	2.997	215.333
1	1	13	14.15	6	64	4.588	219.417
1	1	14	14.37	4	21	6.348	218.6
1	1	15	12.95	0	0	6.357	214.4
1	1	16	13.34	0	0	6.392	219.117
1	1	17	13.60	0	0	7.153	226.917
1	1	18	12.55	0	0	5.625	234.483
1	1	19	10.96	0	0	5.053	231.15
1	1	20	10.57	0	0	6.55	228.567
1	1	21	10.08	0	0	6.72	241.217
1	1	22	9.75	0	0	4.97	246.05
1	1	23	10.37	0	0	5.28	244.933
1	1	24	10.15	0	0	5.098	237.833
1	2	1	9.73	0	0	5.963	242.067
1	2	2	9.30	0	0	7.805	247.383
1	2	3	8.99	0	0	7.183	254.867
1	2	4	9.00	0	0	5.482	243.583
1	2	5	8.31	11	17	5.98	235.017
1	2	6	8.31	16	60	7.33	228.233
1	2	7	8.45	113	144	8.735	235.783
1	2	8	8.24	294	168	10.653	233.133
1	2	9	8.68	484	201	12.54	235.55
1	2	10	9.81	323	196	11.457	241.183
1	2	11	12.15	243	186	6.382	229.1
1	2	12	11.00	250	163	11.475	222.6
1	2	13	10.98	58	120	14.403	218.633
1	2	14	10.76	34	52	15.043	224.167
1	2	15	11.12	0	0	16.313	225.733
1	2	16	11.32	0	0	15.402	223.133
1	2	17	12.79	0	0	14.7	228.467
1	2	18	11.66	0	0	13.305	230.133
1	2	19	11.26	0	0	13.093	231.067
1	2	20	10.82	0	0	12.243	236.8
1	2	21	10.68	0	0	12.103	236.567
1	2	22	10.51	0	0	9.055	245.217

1	2	23	10.24	0	0	6.787	246.433
1	2	24	10.26	0	0	6.132	250.533
1	3	1	9.87	0	0	3.733	275.483
1	3	2	9.77	0	0	2.158	42.233
1	3	3	9.48	0	0	0.938	106.5
1	3	4	8.67	4	8	2.653	181.767
1	3	5	8.25	43	21	2.663	231.15
1	3	6	8.59	198	52	5.835	244.2
1	3	7	8.98	357	106	7.992	239.55
1	3	8	9.12	748	122	4.877	280.383
1	3	9	9.30	906	64	3.408	279.667
1	3	10	10.40	851	85	2.145	277.217
1	3	11	12.37	300	120	0.88	166.367
1	3	12	13.99	424	138	5.808	230.033
1	3	13	13.20	435	132	6.658	231.483
1	3	14	13.33	180	69	6.588	223.817
1	3	15	13.12	37	23	6.512	225.283
1	3	16	12.18	0	0	6.462	225.767
1	3	17	12.15	0	0	8.903	224.467
1	3	18	11.31	0	0	9.748	235.233
1	3	19	10.73	0	0	8.433	233.95
1	3	20	9.88	0	0	6.815	237.133
1	3	21	9.22	0	0	6.393	240.467
1	3	22	8.69	0	0	6.403	240.4
1	3	23	8.51	0	0	7.4	243.15
1	3	24	8.74	0	0	6.232	248.6
1	4	1	9.58	0	0	5.133	241.717
1	4	2	9.97	0	0	6.44	242.5
1	4	3	9.10	0	0	6.358	240.533
1	4	4	8.63	0	0	8.355	240.267
1	4	5	8.45	11	17	8.013	235.3
1	4	6	8.81	15	63	7.49	237.983
1	4	7	8.63	24	131	7.678	238.3
1	4	8	8.41	100	199	5.302	239.317
1	4	9	8.53	277	210	4.56	226.317
1	4	10	9.38	412	208	6.135	213.533
1	4	11	9.99	374	199	7.007	229.233
1	4	12	9.32	130	162	8.148	227.133
1	4	13	9.68	37	118	9.803	225.9
1	4	14	9.73	67	51	11.578	230.05
1	4	15	9.13	22	22	13.058	226.917
1	4	16	9.33	0	0	13.533	227.117
1	4	17	9.40	0	0	14.25	225.55
1	4	18	9.54	0	0	12.327	223.717
1	4	19	10.66	0	0	11.253	222.467
1	4	20	11.14	0	0	11.687	223.717
1	4	21	11.16	0	0	9.602	227.1
1	4	22	10.91	0	0	11.713	229.267
1	4	23	10.78	0	0	10.073	225.017
1	4	24	10.64	0	0	11.77	224.1
1	5	1	10.59	0	0	12.407	224.8
1	5	2	10.55	0	0	12.575	224.567

1	5	3	10.39	0	0	12.018	226.5
1	5	4	10.20	0	0	10.208	227.5
1	5	5	10.30	5	18	8.207	228.717
1	5	6	10.22	114	87	6.072	217.633
1	5	7	10.32	628	79	6.408	203.683
1	5	8	10.14	753	71	6.63	187.067
1	5	9	10.27	580	110	14.102	225.133
1	5	10	11.13	488	167	11.843	215.333
1	5	11	11.61	162	187	10.523	209.95
1	5	12	12.44	112	110	13.337	224.1
1	5	13	11.82	16	61	8.387	197.233
1	5	14	12.05	178	45	10.51	205.45
1	5	15	12.39	10	22	12.315	190.083
1	5	16	12.63	0	0	14.24	192.567
1	5	17	12.87	0	0	16.198	209.717
1	5	18	12.46	0	0	14.913	221.45
1	5	19	12.42	0	0	13.443	217.183
1	5	20	12.32	0	0	10.452	220.283
1	5	21	12.54	0	0	6.368	175.817
1	5	22	12.05	0	0	4.663	149.05
1	5	23	11.52	0	0	5.425	189.1
1	5	24	11.17	0	0	3.478	190.717
1	6	1	10.79	0	0	1.908	153.8
1	6	2	10.02	0	0	3.965	218.35
1	6	3	9.81	0	0	2.73	174.233
1	6	4	9.68	0	0	0.915	155.017
1	6	5	9.22	61	15	0.443	122.433
1	6	6	9.08	524	29	0.443	95.7
1	6	7	8.05	777	41	1.363	42.317
1	6	8	8.45	866	48	2.3	43.8
1	6	9	9.56	806	87	3.577	105.917
1	6	10	11.94	124	205	2.927	117.033
1	6	11	13.80	7	137	3.602	96.283
1	6	12	14.42	11	141	3.213	151.183
1	6	13	15.24	34	102	3.24	135.317
1	6	14	15.46	9	30	4.205	156.133
1	6	15	15.49	2	4	4.615	176.95
1	6	16	15.93	0	0	1.703	156.8
1	6	17	15.57	0	0	2.075	161.483
1	6	18	13.20	0	0	5.118	166.95
1	6	19	9.88	0	0	6.938	217.3
1	6	20	9.81	0	0	4.675	181.933
1	6	21	9.78	0	0	3.132	139.3
1	6	22	8.76	0	0	3.468	172.967
1	6	23	8.14	0	0	3.752	214.267
1	6	24	8.03	0	0	4.497	228.4
1	7	1	7.85	0	0	5.773	233.667
1	7	2	7.58	0	0	5.387	242.867
1	7	3	7.28	0	0	5.36	245.017
1	7	4	8.20	0	0	5.467	246.75
1	7	5	7.93	12	20	5.73	243.233
1	7	6	8.17	160	63	4.522	234.6

1	7	7	9.00	91	86	1.998	276.283
1	7	8	10.11	506	119	3.225	248.767
1	7	9	10.86	546	149	1.333	213.283
1	7	10	10.82	329	147	0.878	237.083
1	7	11	11.77	24	149	6.933	334.767
1	7	12	12.33	58	127	8.863	333.683
1	7	13	10.83	2	26	11.977	344.983
1	7	14	12.16	4	13	13.708	355.483
1	7	15	12.57	5	2	12.227	355.583
1	7	16	12.02	0	0	12.097	179.783
1	7	17	11.69	0	0	12.368	356.9
1	7	18	11.64	0	0	12.402	180.233
1	7	19	11.56	0	0	14.523	2.333
1	7	20	11.16	0	0	16.138	1.533
1	7	21	9.89	0	0	17.863	120.283
1	7	22	10.86	0	0	18.638	120.65
1	7	23	11.50	0	0	19.113	60.883
1	7	24	10.65	0	0	17.51	2.45
1	8	1	11.04	0	0	14.615	2.567
1	8	2	11.70	0	0	15.147	2.233
1	8	3	11.74	0	0	13.272	180.1

7	27	1	22.8029285	0	0	3.572	41.383
7	27	2	21.1756915	0	0	2.808	50.533
7	27	3	20.59332463	284	16	1.63	73.033
7	27	4	20.29600008	549	34	1.012	105.533
7	27	5	19.86780613	771	51	0.895	122.033
7	27	6	19.65457875	876	59	2.378	162.117
7	27	7	21.07803279	951	59	3.825	174.4
7	27	8	23.50610342	978	64	3.787	182.633
7	27	9	25.95330071	988	67	4.607	186.2
7	27	10	27.49113092	994	67	4.455	191.733
7	27	11	27.93961158	1001	62	4.158	195.683
7	27	12	27.23973054	984	60	4.532	209.267
7	27	13	27.87900458	956	55	6.328	214.5
7	27	14	28.99482129	901	49	6.808	212.75
7	27	15	29.21371763	760	42	7.985	218.017
7	27	16	29.62979779	492	27	9.67	218.783
7	27	17	29.26248363	216	12	9.773	217.567
7	27	18	28.663291	0	0	9.827	222.883
7	27	19	27.77326679	0	0	10.885	227.817
7	27	20	26.14620021	0	0	9.322	230.283
7	27	21	25.12519142	0	0	6.837	236.083
7	27	22	23.85943892	0	0	6.253	243.683
7	27	23	23.07831733	0	0	6.45	244.583
7	27	24	22.90670854	0	0	5.597	242.2
7	28	1	22.42649175	0	0	5.102	227.1
7	28	2	21.94275117	0	0	6.78	229.017
7	28	3	21.49046575	206	17	7.77	232.367
7	28	4	20.89323817	494	39	6.533	228.783
7	28	5	20.65564592	728	61	6.36	221.783
7	28	6	20.80621958	830	76	6.83	225.85

7	28	7	20.89731667	893	85	9.248	226.95
7	28	8	23.525537	929	89	9.993	228.317
7	28	9	25.64681017	958	90	10.138	230.267
7	28	10	27.13454192	944	99	10.177	232.667
7	28	11	27.17880708	936	98	8.35	230.6
7	28	12	27.27844858	914	95	9.143	221.883
7	28	13	28.11000288	885	84	12.875	225.633
7	28	14	28.6384335	815	75	11.902	222.15
7	28	15	28.64538254	643	65	12.398	221.133
7	28	16	28.56096763	343	40	13.295	222.233
7	28	17	27.79664663	102	16	13.575	223.717
7	28	18	27.42633775	0	0	14.173	225.867
7	28	19	26.57061333	0	0	14.335	226.167
7	28	20	25.59231154	0	0	13.965	226.3
7	28	21	25.03865646	0	0	13.593	227.2
7	28	22	23.58370458	0	0	8.47	225.883
7	28	23	22.837873	0	0	6.647	224.117
7	28	24	22.69136738	0	0	7.18	221.617
7	29	1	22.63512633	0	0	6.743	218.067
7	29	2	21.64011233	0	0	6.012	217.55
7	29	3	20.75777975	57	19	5.818	219.283
7	29	4	20.32808175	240	58	5.503	216.217
7	29	5	19.68375838	453	114	6.508	223.733
7	29	6	19.68488088	620	143	8.73	225.883
7	29	7	20.50235521	687	169	10.203	230.2
7	29	8	23.00915342	765	170	11.012	228.733
7	29	9	24.89079367	792	174	10.15	234.383
7	29	10	26.530142	793	178	8.917	237.2
7	29	11	26.62342596	789	173	6.822	236.233
7	29	12	26.65052154	753	166	6.937	233.75
7	29	13	27.47106971	690	158	7.215	232.833
7	29	14	28.06784329	612	129	7.493	225.95
7	29	15	28.60169813	453	94	5.803	225.267
7	29	16	28.24666792	223	52	5.653	221.55
7	29	17	27.82944133	61	19	3.683	234.3
7	29	18	27.0952585	0	0	5.12	220.8
7	29	19	25.88212892	0	0	2.797	252.517
7	29	20	24.70915679	0	0	4.89	234.133
7	29	21	24.24968888	0	0	4.452	247.45
7	29	22	23.46924771	0	0	4.488	246.983
7	29	23	22.38179913	0	0	4.115	234.9
7	29	24	21.98144975	0	0	5.488	232.4
7	30	1	21.56362446	0	0	6.107	234.717
7	30	2	20.99151825	0	0	5.348	232.017
7	30	3	20.44245204	72	20	6.51	241.567
7	30	4	20.3373415	273	55	5.83	240.383
7	30	5	19.63643475	502	98	4.907	241.617
7	30	6	19.16949733	643	124	6.29	242.4
7	30	7	20.62629463	729	140	4.947	251.3
7	30	8	23.02906246	756	163	6.122	231.5
7	30	9	25.056679	806	157	8.742	232.5
7	30	10	25.78267858	795	173	3.822	216.517

7	30	11	25.78730679	749	196	3.892	233.267
7	30	12	25.15349442	715	208	6.238	231.633
7	30	13	26.01192038	710	136	5.967	222.85
7	30	14	26.75433454	668	107	5.183	212.883
7	30	15	27.35792575	493	80	3.967	191.2
7	30	16	27.03957263	262	43	2.982	203.067
7	30	17	26.66331667	68	15	5.812	332.233
7	30	18	26.6764165	0	0	8.033	350.367
7	30	19	26.09709842	0	0	8.228	352.367
7	30	20	24.801305	0	0	8.968	353.8
7	30	21	24.10587517	0	0	8.8	349.4
7	30	22	23.64835271	0	0	7.8	354.95
7	30	23	23.08401754	0	0	7.858	297.5
7	30	24	22.71044283	0	0	7.862	354.683
7	31	1	21.83461929	0	0	6.087	356.567
7	31	2	19.81186404	0	0	5.598	238.017
7	31	3	20.10052846	35	14	3.615	288.5
7	31	4	19.13757271	188	49	1.052	282.717
7	31	5	18.90317646	486	94	2.035	270.5
7	31	6	18.94683263	638	119	0.588	166.183
7	31	7	20.28264783	729	130	3.285	9.25
7	31	8	22.68074925	788	135	0.688	14.8
7	31	9	24.26609088	820	135	0.3	269.867
7	31	10	25.27532333	827	136	1.917	234.333
7	31	11	25.5273825	836	127	4.103	248.083
7	31	12	25.27181542	816	120	3.468	242.75
7	31	13	25.80779646	791	101	3.073	230.2
7	31	14	27.34997117	726	81	3.77	228.017
7	31	15	27.79157433	554	62	3.973	213.583
7	31	16	27.71838825	338	33	4.09	217.183
7	31	17	27.294893	95	11	5.185	220.217
7	31	18	27.20844479	0	0	5.258	220.833
7	31	19	26.19604058	0	0	4.73	242.133
7	31	20	24.946975	0	0	4.843	342.233
7	31	21	24.48819604	0	0	4.903	346.967
7	31	22	24.00950871	0	0	4.155	10.6
7	31	23	23.02177629	0	0	3.983	20.167
7	31	24	21.62616838	0	0	3.92	13.25
8	1	1	21.54129838	0	0	4.185	13.317
8	1	2	20.64198804	0	0	3.088	29.65
8	1	3	19.51796508	169	17	3.243	17.917
8	1	4	18.93409333	405	39	2.997	15.717
8	1	5	18.52279279	658	61	0.66	46.683
8	1	6	17.95027804	801	70	1.547	127.817
8	1	7	19.57082054	888	67	0.595	342.983
8	1	8	21.8583275	901	81	1.847	335.367
8	1	9	23.94690338	898	97	2.403	349.05
8	1	10	24.99012017	888	107	4.228	345.283
8	1	11	25.64974183	882	105	4.702	352.4
8	1	12	26.04430617	884	90	2.33	181.017
8	1	13	26.15940013	853	79	0.428	167.55
8	1	14	27.04671263	790	65	2.772	209.617

8	1	15	27.89393067	607	50	5.167	222.033
8	1	16	28.0144705	366	28	6.705	222.367
8	1	17	27.99154429	79	9	5.105	244.283
8	1	18	27.49472592	0	0	3.642	295.933
8	1	19	26.31570817	0	0	3.708	322.083
8	1	20	25.13731046	0	0	0.795	312.85
8	1	21	24.723571	0	0	1.948	324.95
8	1	22	23.95632663	0	0	2.778	319.017
8	1	23	23.40784633	0	0	3.273	292.8
8	1	24	22.24547533	0	0	0.39	290.133
8	2	1	21.19356671	0	0	0.405	239.217
8	2	2	20.61326988	0	0	0.308	133.117
8	2	3	19.79016888	171	18	1.2	83.767
8	2	4	19.87640008	397	43	0.348	127.033
8	2	5	19.14045538	657	67	4.21	287.167
8	2	6	19.04356646	796	77	5.198	337.1
8	2	7	20.67655896	860	86	5.613	345.417
8	2	8	23.0771855	865	108	7.573	337.617
8	2	9	25.74399004	859	126	8.107	342.583
8	2	10	27.23549192	830	146	8.635	346.15
8	2	11	27.30816967	839	135	10.293	349.05
8	2	12	26.89808104	842	116	11.438	353.4
8	2	13	26.96026608	790	108	10.682	238.183
8	2	14	27.77592225	675	100	10.232	356.083
8	2	15	28.51923171	498	73	10.63	298.067
8	2	16	28.81731875	266	36	10.772	239.083
8	2	17	28.34459758	89	13	11.582	60.167
8	2	18	27.99151421	0	0	10.912	179.517
8	2	19	26.62359288	0	0	10.73	355.983
8	2	20	25.65813608	0	0	10.85	297.1
8	2	21	25.32939283	0	0	11.04	298.25
8	2	22	24.97527592	0	0	12.755	358.467
8	2	23	24.34121292	0	0	14.15	3.1
8	2	24	24.16095992	0	0	12.313	3.35
8	3	1	24.01101242	0	0	10.923	10.567
8	3	2	23.75750625	0	0	8.632	16.317
8	3	3	23.77870846	108	18	11.103	3.233
8	3	4	23.44119929	306	50	12.96	60.817
8	3	5	22.98244454	561	90	11.458	2.617
8	3	6	22.74955054	712	112	9.423	62.867
8	3	7	23.59755546	807	122	12.153	121.35
8	3	8	24.76904871	835	138	8.39	2.75
8	3	9	25.51519046	865	140	7.985	75.4
8	3	10	26.19291467	862	146	6.82	25.317
8	3	11	26.41609121	865	138	5.633	33.817
8	3	12	27.02791108	824	138	8.077	39.417
8	3	13	27.4597815	780	124	9.697	22.133
8	3	14	28.10083217	695	107	10.658	20.8
8	3	15	28.59835679	489	80	10.515	66.083
8	3	16	28.76972363	234	40	11.212	242.467
8	3	17	28.52167213	51	13	10.367	126.783
8	3	18	28.01943913	0	0	12.253	120.4

8	3	19	27.38071875	0	0	12.32	180.333
8	3	20	26.21721358	0	0	11.067	1.733
8	3	21	25.60946279	0	0	11.398	239.517
8	3	22	25.02802421	0	0	11.698	1.983
8	3	23	24.704505	0	0	11.587	121.083
8	3	24	24.99786521	0	0	9.9	298.9
8	4	1	24.39350588	0	0	9.423	3.55
8	4	2	23.36070183	0	0	7.875	8.033
8	4	3	21.87619988	155	20	7.637	20.317
8	4	4	21.27130821	366	52	8.3	17.567
8	4	5	20.41209921	566	93	8.213	21.167
8	4	6	20.18914767	677	123	6.798	40.5
8	4	7	20.723858	758	143	7.765	23.517
8	4	8	22.75076446	789	160	8.063	23.65
8	4	9	25.00681125	820	166	6.49	42.383
8	4	10	26.14427958	823	169	6.125	53
8	4	11	26.43393679	803	171	6.213	28.533
8	4	12	26.70068771	757	174	6.862	45.4
8	4	13	27.19023283	688	161	8.123	21.533
8	4	14	28.27536133	581	135	8.187	20.867
8	4	15	28.28749104	378	98	7.912	25.133
8	4	16	27.66469571	134	46	7.5	15.967
8	4	17	27.39622379	31	13	8.202	186.583
8	4	18	27.04051225	0	0	9.267	180.65
8	4	19	26.32558463	0	0	8.858	180.4
8	4	20	25.07683488	0	0	9.057	120.017
8	4	21	24.48023088	0	0	8.627	349.283
8	4	22	24.11679892	0	0	6.952	346.667
8	4	23	23.270493	0	0	5.072	340.533
8	4	24	22.77976604	0	0	6.26	340.333
8	5	1	21.86484754	0	0	6.057	339.4
8	5	2	21.57891504	0	0	5.848	341.533
8	5	3	21.19152879	212	15	5.58	341.267
8	5	4	20.91486983	460	36	6.66	337.983

12	28	7	15.70541638	6	60	16.5	19.317
12	28	8	15.72207575	5	111	17.977	123.933
12	28	9	15.78579758	7	115	15.842	183.683
12	28	10	16.07756754	6	135	13.467	16.083
12	28	11	16.253233	5	120	16.083	17.867
12	28	12	16.46085117	5	59	14.722	69.133
12	28	13	16.53553608	6	36	15.017	15.617
12	28	14	16.78397413	3	10	15.115	20.5
12	28	15	17.55381808	0	0	15.442	18.233
12	28	16	16.71849121	0	0	15.853	18.967
12	28	17	16.21278742	0	0	13.47	16.65
12	28	18	16.08281942	0	0	14.953	18.083
12	28	19	16.35090771	0	0	14.592	17.45
12	28	20	15.22602571	0	0	15.247	6.7
12	28	21	15.45137929	0	0	18.282	1.233
12	28	22	15.38097092	0	0	15.302	3.983
12	28	23	14.92775604	0	0	11.165	18.017

12	28	24	14.58379329	0	0	10.987	15.433
12	29	1	13.98025713	0	0	8.767	29.317
12	29	2	13.51847338	0	0	8.892	25.433
12	29	3	13.35182029	0	0	7.59	34.133
12	29	4	13.57310533	0	0	7.327	24.567
12	29	5	13.59544463	41	20	7.612	14.45
12	29	6	13.91421108	379	44	10.973	6.9
12	29	7	13.80345108	581	70	10.785	7.3
12	29	8	14.14736096	725	82	8.762	6.5
12	29	9	14.85075967	771	88	10.732	3.067
12	29	10	14.33355996	799	87	8.247	62.433
12	29	11	14.239666	722	88	9.8	61.35
12	29	12	15.05217354	736	72	9.562	3.45
12	29	13	16.20027283	581	57	7.127	178.983
12	29	14	13.01563979	299	32	4.815	121.383
12	29	15	15.22008471	0	0	3.052	294.75
12	29	16	14.62693946	0	0	1.515	185.133
12	29	17	13.79315279	0	0	4.13	213.8
12	29	18	13.4140315	0	0	7.017	224.517
12	29	19	11.97498492	0	0	5.615	236.05
12	29	20	11.30319075	0	0	6.153	231.317
12	29	21	10.43403292	0	0	6.58	237.483
12	29	22	10.19137579	0	0	5.94	247.217
12	29	23	9.851266208	0	0	4.842	260.167
12	29	24	8.933639083	0	0	4.638	261.85
12	30	1	8.439254208	0	0	5.035	256.083
12	30	2	8.816014958	0	0	5.743	250.9
12	30	3	9.800698125	0	0	4.053	247.633
12	30	4	8.990541417	0	0	5.665	247.617
12	30	5	9.636162417	6	20	4.53	241.317
12	30	6	9.740146708	4	34	4.797	240.45
12	30	7	10.27142746	4	39	5.695	238.433
12	30	8	12.64006358	4	44	5.778	241.983
12	30	9	14.041288	6	77	5.125	241.917
12	30	10	14.90344704	6	81	5.337	247.433
12	30	11	15.57854138	6	85	4.877	244.667
12	30	12	15.66567842	4	58	6.227	240.533
12	30	13	14.56075729	2	22	7.458	235.383
12	30	14	16.66584471	5	14	7.177	231.383
12	30	15	14.79311367	0	0	7.71	224.333
12	30	16	14.25989196	0	0	9.14	223.017
12	30	17	13.17411758	0	0	9.947	224.667
12	30	18	13.06800283	0	0	9.08	225.867
12	30	19	12.4069775	0	0	7.483	233.033
12	30	20	12.32350646	0	0	7.215	231.067
12	30	21	11.79145821	0	0	7.152	235.733
12	30	22	12.18382596	0	0	7.51	237.3
12	30	23	12.84509225	0	0	6.483	237.583
12	30	24	12.84169058	0	0	6.773	232.583
12	31	1	11.54074396	0	0	7.093	234.6
12	31	2	11.18207692	0	0	8.618	240.283
12	31	3	10.93161879	0	0	10.262	246.967

12	31	4	10.68993408	0	0	10.462	245.817
12	31	5	11.01624579	24	25	10.488	247.367
12	31	6	10.80907583	32	73	10.802	248.033
12	31	7	11.10040113	40	128	10.318	248.4
12	31	8	11.00647921	10	109	9.703	252.017
12	31	9	10.93871767	222	189	9.54	249.25
12	31	10	11.50644442	438	182	8.675	244.6
12	31	11	11.82941579	194	251	8.61	243.283
12	31	12	12.80127461	33	168	8.055	236.717
12	31	13	13.04796863	18	82	7.102	229.967
12	31	14	13.519958	6	31	10.432	229.983
12	31	15	13.53578171	0	0	11.4	231.4
12	31	16	13.67628208	0	0	10.487	233.65
12	31	17	13.46552117	0	0	9.945	237.1
12	31	18	12.6547115	0	0	8.868	234.983
12	31	19	11.68304921	0	0	7.767	230.133
12	31	20	10.64220229	0	0	8.035	228.667
12	31	21	10.37522075	0	0	7.208	235.067
12	31	22	10.33402404	0	0	5.897	240.033
12	31	23	9.7197515	0	0	6.027	246.067
12	31	24	8.912406792	0	0	7.042	245.717

Economic Analysis

				CASE 1	***CASE 2***							
	PV panel	Base PV	DWT	Batteries	Batteries	Inverter	Other Equipment(Charge Controler, Power system Battery Pack, Wires etc)					
Cost per Item	325	38	650	100	100	2385	1100					
Greece	40 Panels	40 Bases	8 DWT	70 Batteries	30 Batteries	1 Inverter	Other Equipment	Installation Cost Case 1	Installation Cost Case 2	Subsidies	***Final Cost in Pounds Case 1***	***Final Cost in Pounds Case 2***
	13000	1520	5200	7000	3000	2385	1100	30205	26205	0.4	***18123***	***15723***
Scotland	26 Panels	26 Bases	15 DWT	80 Batteries	40 Batteries	1 Inverter	Other Equipment	Installation Cost Case 1	Installation Cost Case 2	Subsidies	***Final Cost in Pounds Case 1***	***Final Cost in Pounds Case 2***
	8450	988	9750	8000	4000	2385	1100	30673	26673	0.4	***18403.8***	***16003.8***

Greece	Cost per KWh in Pounds(£)	Years	Hours
	0.047	Present Value	43800
	0.050	Value after 5 years	43800
	0.052	Value after 10 years	43800
	0.055	Value after 15 years	43800
	0.057	Value after 20 years-Until 25 years	43800
Scotland	Cost per KWh in Pounds(£)	Years	Hours
	0.080	Present Value	43800
	0.084	Value after 5 years	43800
	0.088	Value after 10 years	43800
	0.093	Value after 15 years	43800
	0.097	Value after 20 years-Until 25 years	43800