OPPORTUNITIES FOR PV ON PUBLIC BUILDINGS IN CYPRUS: CASE STUDY PROPOSED DESIGN FOR PAPHOS CITY HALL

by

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Abstract

The increasing demands for energy and the high dependence on fossil fuels impose high risks to humanity, due to the natural resource depletion and the obvious climate change. The transition towards renewable sustainable sources of energy is continuously attracting attention around the world.

There is a growing interest towards the direction of stimulation of renewable technologies, with photovoltaics constituting a key technology especially in countries with high solar radiation such as Cyprus.

Using the proposed design for Paphos City Hall with a PV installation on the roof of the building, as a case study, this project examines the viability of grid-connected systems in the building sector. The following parameters were considered in order to determine whether the installation of a PV system in Paphos can be viable.

First of all, the energy consumption of the building is calculated. TAS software is used to define cooling and heating loads. The energy concerning lighting and small power is also calculated.

The annual output energy of the photovoltaic system has been modeled using Retscreen software. The embodied energy, the installation cost and the annual savings of the system were calculated in order for the carbon and economic payback periods of the system to be determined.

The analysis showed that the economic payback period of the system is 17.5 years, which is shorter than its lifetime. It is worth noting that the payback period reduces to 7 years, if grants are included. The carbon payback period was estimated to 6.3 years.

A sensitivity analysis on the effect of various factors affecting the viability of the PV installation was carried out. The economic payback period reduces as the capital cost of the photovoltaic installation decreases. The payback period is also reduced, as the electricity rates increase. The project concludes by defining the benefits of the exploitation of PV technology in Cyprus. The analysis makes evidence that PV technology must become the cornerstone of the design philosophy in Cyprus. The application of a relative Merton Rule in Cyprus is regarded as a major step towards this implementation.

AKNOWLEDGMENTS

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I would also like to thank my family for making it possible for me to complete this Masters degree and for their continuous support.

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1. Introduction

"I have learned that beyond death and taxes there is at least one absolutely indisputable fact: not only does human-caused global warming exist, but it is also growing more and more dangerous, and at a pace that has now made it a planetary emergency".

Al Gore. An Inconvenient Truth (Turrent, 2007)

Figure 1: A symbolic representation of global warming. (The Viewspaper, 2008)

It is more than obvious that global warming caused by human activity is one of the biggest challenges the world is facing today. Greenhouse gases from human activity are tipping the planet into a period of rapid and destructive climate change.

1.1 Global warming and carbon dioxide emissions

Global warming is the increase in the average temperature of the Earth's near-surface air and oceans. The predicted effects of global warming are catastrophic and according to McMullan (2007) are likely to be the following:

- Melting of polar ice, causing rise in sea levels and disappearance of land.
- Increase in severity of storms and flooding
- Change in rainfall patterns, forming new desserts
- Changes in ocean currents, causing changes in local climates
- Changes in patterns of snowfall and ice sheets

The earth's global mean surface temperature rose by 0.6ºC during the last century and it is predicted to rise by 1.4 to 5.8ºC by the end of the twenty-first century (Boyle, 2004). It is generally accepted that the rapid increase in global temperature, experienced during the latter part of the twentieth century is due to the increase in anthropogenic greenhouse gas concentrations.

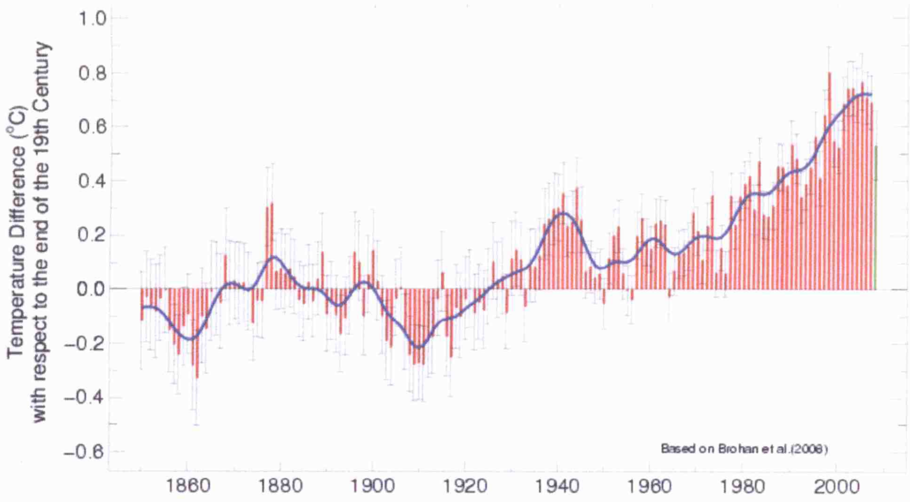


Figure 2: Global near-surface temperatures 1850 -2006 (Metoffice, 2005)

Greenhouse gases control the Earth's temperature, according to the greenhouse effect. The greenhouse effect is a natural phenomenon; essential for keeping the surface of the Earth warm. The Earth's surface behaves like glass in a greenhouse, retaining a certain proportion of the heat received from the sun.

Short-wave solar radiation passes relatively unimpeded to the Earth's surface. The long-wave radiation, produced by the warm surface of the Earth, is partially absorbed and re-emitted downwards by greenhouse gases in the atmosphere. In this way there is a balance between the heat absorbed and given off by the Earth. Without the greenhouse effect it is estimated that the Earth's surface temperature would be approximately 33ºC cooler. (Beggs, 2002)

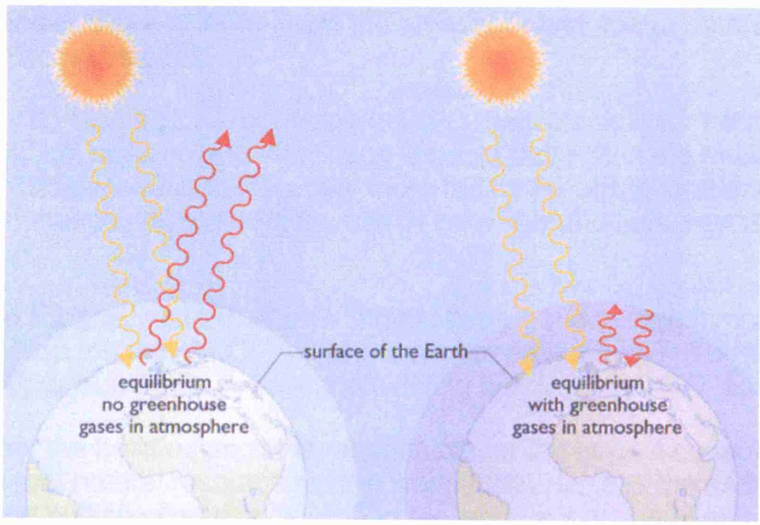


Figure 3: The Greenhouse effect (Boyle, 2004)

The main naturally occurring greenhouse gases in the Earth's surface are water vapour and CO_2. In the last two centuries, there has been a substantial rise in the atmospheric concentration of CO_2. The discovery of large and readily extractable reserves of gas and oil, the increased industrialization and the increasing energy demand lead to an increase of CO_2 levels. It has been estimated that global CO_2 emissions will reach approximately 9.8 billion tonnes per annum by 2020 (70% above 1990 levels). In the industrialized countries, it is predicted that CO_2 emissions will increase from a 1990 level of 2.9 billion tonnes to 3.9 billion tonnes in 2020. (Beggs, 2002)

In 1990, emissions from the developed countries were approximately twice as much as those of the developing world. However, it is predicted that CO_2 emissions in the developing countries will surpass those of the industrialized countries by 2010.

A rapid growth of CO_2 emissions is predicted in the developing Asian countries due to the high rates of economic growth and the heavy dependence on coal. China and India alone is predicted to account for the majority of the worldwide increase in coal consumption by 2020. (Beggs, 2002)

1.2 Building sector-energy consumption

Building sector is regarded as the largest energy consuming and greenhouse gas emitting sector. The energy required to operate residential, commercial and industrial buildings along with the embodied energy of industry-produced building materials (i.e. carpet, tile, glass and concrete) accounts for 30-40% of the total CO_2 emissions.

According to a report, released by the United Nations Environmental Program (UNEP, 2007), the building sector worldwide could deliver emission reductions of 1.8 billion tonnes of CO2, regarding to some conservative estimates. A more aggressive energy efficiency policy might deliver over 2 billion tonnes or close to three times the amount scheduled to be reduced under the Kyoto Protocol.

The energy consumed by an average building in its life time for heating, cooling, lighting, cooking and ventilation is much more than the energy required for its construction. Typically more than 80% of the total energy consumption takes place during the use of buildings and less than 20% during construction.

Concerning Europe, more than one-fifth of present energy consumption and up to 45 million tonnes of CO_2 per year could be saved by 2010 by applying more ambitious standards to new and existing buildings. (UNEP, 2007)

To conclude, the building sector is responsible for the largest consumption of fossil fuels and natural resources in the world today. Unless the architecture, planning and building community around the world act now and act decisively, emerging economies will follow current design and building practices, leading to disastrous global consequences.

1.3 Merton Rule

In order to reduce energy consumed by the building sector, in October 2003, Merton became the first local authority in the UK to include a policy in its Unitary Development Plan that requires new non-residential developments to generate at least 10% of their energy needs from renewable energy equipment such as solar panels and wind turbines.

The first project to comply with the target was 4500m^2 in size and comprised of ten light industrial units. Through the installation of ten small wind turbines and 9kWp of photovoltaics, the predicted CO_2 emissions were cut by 10%. (The Merton Rule, 2006)

The policy has caught the imagination of many boroughs across the UK which follow Merton's example and adopt similar policies of their own, creating a huge demand for renewable energy equipment.

Merton has played the key role in persuading the UK Government to include in 2004, an addition in its national planning policy guidance (PPS22), confirming the legality of these policies and encouraging other boroughs to emulate them.

The actual policy reads (The Merton Rule, 2006): "All new non-residential developments above a threshold of 1,000 m^2 will be expected to incorporate renewable energy production equipment to provide at least 10% of predicted energy requirements".

However, Merton Rule is regarded as a far less efficient way of cutting carbon than by investing in the actual energy efficiency of buildings, according to the British Property Federation (BPF). The BPF (2007) stresses that: "Developers must focus on real solutions and not simply on achieving unrealistic targets hoisted upon developers".

Nevertheless, Merton Rule is regarded as a significant step towards the mitigation of global warming, probably an example to be followed by other governments around the world. Cyprus, although a small country, contributes significantly to the rapid increase of CO_2 emissions. To that end, solutions have to be found in order to reduce the CO_2 emissions coming from the island. Energy consumption and the potential of the exploitation of renewable solar energy in Cyprus are going to be examined in the following chapter.

2. Energy use and the renewable energy potential in Cyprus

The European Union (EU) is working to reduce the effects of climate change and establish a common energy policy. Cyprus, as a member of the EU, has to introduce renewable energy sources as part of its energy production system. Solar energy, wind energy and biomass are the three most favourable forms of Renewable Energy Sources (RES) in Cyprus. This chapter examines and analyzes the currently primary energy sources in Cyprus, the currently established policies in terms of RES and Cyprus renewable energy potential, regarding solar energy.

2.1 Energy consumption in Cyprus

Cyprus is completely dependent on imported hydrocarbon fuels for its energy supply. 91% of the energy production in Cyprus depends on oil products while the remaining 9% is covered by imports of coal (4.5%) and by solar energy (4.5%). Cyprus has no natural oil resources and relies entirely on imported fuels for its energy demands. Syria and Russia are the major oil suppliers. It is important to mention that 62% of the country's export earnings are used to pay for the country's oil import. (Koroneos et al, 2005)

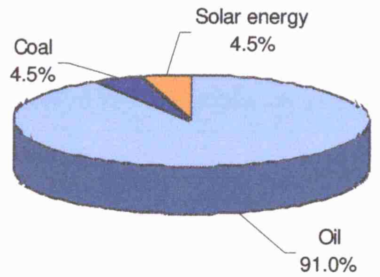


Figure 4: Cyprus Primary energy sources. (Koroneos et al, 2005)

Cyprus has enjoyed sustained economic growth in the last three decades (averaging 5.8% and 3.1% per year over the last 30 and 10 years respectively). Tourist income and the development of financial services is the main responsible for this economic growth. (Zachariadis and Pashourtidou, 2007)

Due to the economic growth and the fact that energy conservation was not a priority for authorities and citizens, the total final energy consumption rose by about 4.5% per year in the period between 1975 and 2004. Electricity consumption increased even faster (by 7.1 % and 5.5% annually in the last 30 and 10 years respectively). According to the European Statistical Service (Eurostat, 2006), the amount of energy consumed per unit of gross domestic product (GDP) is higher than of any other Mediterranean EU country.

2.2 Electricity consumption by sector

With regard to fuel shares, electricity is the fastest growing part of the picture, gaining share continuously over all other fuels. The consumption of electricity by the residential and services sector has been rising steadily and in 2004 accounted for about 80% of total electricity use. It is expected that the share of these two sectors will continue to rise in the future, since GDP and household income continue to grow. (Zachariadis and Pashourtidou, 2006)

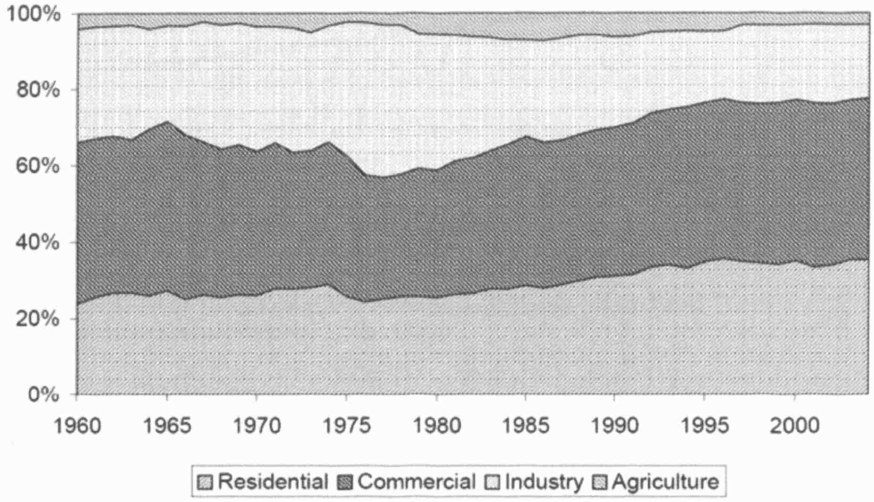


Figure 5: Evolution of electricity consumption by sector in Cyprus, 1960-2004 (CYSTAT, 2005)

2.2.1 Building sector

Building sector is by far the constant leader, concerning electricity consumption in Cyprus. The use of electricity for space heating, water heating, cooking and air conditioning has been remarkable. As it was mentioned, Cyprus government pays unpredictable amounts for the country's oil import, thus the need for energy independence is becoming more and more urgent. Furthermore, the environmental implications of burning fossil fuels contribute to this urgent need.

2.3 Environmental implications of burning fossil fuels in Cyprus

According to a compiled statistics, performed by the Meteorological Service of Cyprus (1996), during the last century there has been a total increase of 0.5°C in temperature on the island and 12% decrease in rainfall for the whole of Cyprus; periods of extreme water shortage are more common.

According to a National Observatory of Athens' report (2001), concerning the reduction of greenhouse emission, electricity production is responsible for the 44% of CO2 total emission. It is therefore apparent that an increase in the share of RES in the electricity sector is a necessary step towards the mitigation of climate change. (Koroneos et al, 2005)

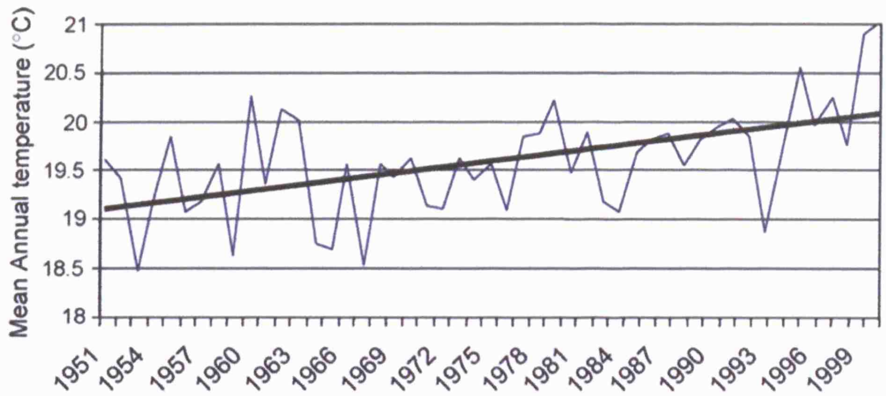


Figure 6: Mean annual temperature change in Nicosia (1951-1999). (Meteorological service of Cyprus, 1996)

2.4 Currently established policies in Cyprus

The first formulation of Renewable Energy and Energy Conservation Action Plan was completed in 1985 and revised in 1998. The aforementioned action included the first energy support Scheme for the sectors of manufacturing industry, hotels and agriculture.

In 2000, the Applied Energy Centre and the Cyprus Institute of Energy were established. Furthermore, during the last decade, the Electricity Authority of Cyprus (EAC) agreed to purchase electricity generated from renewable energy sources. Moreover, the independent authority of Transmission System Operator (TSO) was set. Procedures concerning the licensing and the interconnection of wind and photovoltaic installations to the national grid have been specified and an Action Plan for the years 2002-2010 for renewable energy sources (RES) was formulated.

Moreover, the legislative framework for the promotion of RES and conservation of energy was established in 2003. Cyprus Energy Regulatory Authority (CERA) was instituted in 2004 and new support schemes have been initiated in the same year.

Cyprus ratified the United Nations Framework Convention on Climate Change (UNFCCC) as a non-Annex I party, on 15th October 1997 and on the same basis subsequently ratified the Kyoto Protocol on 16th July 1999. Cyprus has no emissions limitation commitments under the Kyoto Protocol. (Papastavros, 2007)

However, as an EU member, Cyprus had agreed in March 2007 on binding targets to increase the share of renewable energy. By 2020, renewable energy should account for 20% of the EU's final energy consumption (compared to a value of 8.5% reported in 2005). In order to achieve this goal, each Member State needs to increase its production and the use of renewable energy in electricity, heating and cooling and transport. Cyprus target is to increase the use of RES to 13% by 2020, compared to a 2.9% reported in 2005.

According to the European Comission (2007), RES policy in Cyprus consists of the following components:

- The New Grant Schemes, meant a tax of 0.22€ct/kWh on every category of electricity consumption. The income generated by this tax was used for the promotion of RES.
- The New Enhanced Grant Scheme was implemented in January 2006. Financial incentives (30-55% of investments) in the form of government grants and feed-in tariffs are part of this scheme.
- Operation state aid for supporting electricity produced by biomass has been suggested and forwarded to the Commission for approval.

2.5 Cyprus renewable energy potential

2.5.1 General

Renewable energy sources, derived mainly from the power of the sun's radiation, are the most ancient and modern forms of energy used by human being. According to Twidell and Weir (1986) renewable energy is '*the energy obtained from the continuous or repetitive currents of energy recurring in the natural environment*'. Sorensen (2000) defines renewable energies as '*energy flows which are replenished at the same rate as they are used*'. Solar energy and photovoltaics are going to be examined in details in this project.

2.5.2 Solar energy basics

Solar energy is the radiant energy of the sun that can be converted into other forms of energy such as heat or electricity. The amount of solar radiation available outside the Earth's upper atmosphere is approximately 1.35 kW/m^2. Approximately one third of the incident radiation is reflected by the atmosphere and the rest is either absorbed by the atmosphere or reradiated towards space and towards the Earth.

The amount of solar radiation at the Earth's surface depends on the orientation and the tilt of the Earth's axis. It varies seasonally, diurnaly and according to the location. In July, the solar radiation on a horizontal surface in nothern Europe is between 4.5-5 kWh/m^2 per day, while in southern Europe, July solar radiation levels are higher, between 6 and 7.5 kWh/ m^2 per day. Moreover, in winter, the amount of solar radiation is lower. In January, on average in nothern Europe is only one tenth of its July value, around 0.5 kWh/ m^2, while in southern Europe is 1.5-2 kWh/ m^2 per day. (Boyle,2004)

Solar energy can be used either passively or actively, in order to harness the incident solar radiation and transform it to other useful forms of energy. Passive solar refers to the harnessing of the sun's energy to heat, cool, ventilate and illumintate buildings without the use of mechanical equipment. In such buildings the emphasis is on the envelope; as a consequense passive solar buildings have compelex facades, with external shading, opening windows and light shelves. (Beggs, 2002)

Active solar systems include solar thermal collectors which can provide hot water or space heating and photovoltaic systems, which generate electricity. Electricity production from photovoltaics will be studied in detail for this project.

2.5.3 Solar energy in Cyprus

Cyprus is often called the 'sun island' due to the amount of sunshine received all year round. The climatic conditions of Cyprus are predominately very sunny, with daily average solar radiation of about 5.4 kWh/m^2 on a horizontal surface. According to statistical analysis, all parts of Cyprus enjoy a very sunny climate. (Kalorgirou, 2001)

Cyprus is one of the leading countries in the world in the use and construction of solar water heating systems. As it is stated by Koroneos et al (2005) the estimated area of flat plate solar collectors that are in working order is 560,000 m^2, which corresponds to approximately 0.86 m^2 per inhabitant. It is estimated that the number of solar water heaters installed in Cyprus exceeds 190,000 units.

As it is illustrated in figure 7, in Cyprus, a solar collector belongs to the house just as a chimney belongs to a house in the UK. Solar water collectors have been produced locally since 1960. The industry of solar water collectors expanded very quickly and according to Kalogirou (2001) it reaches an annual production of about 30,000 m^2.

Figure 7: In Cyprus a solar collector belongs to the house as just a chimney belongs to a house in the UK – every child knows that (ESTIF, 2007)

According to figure 8 (ESTIF, 2006), Cyprus with more than 530 kW_{th} per 1000 capita is the distant leader, concerning solar thermal capacity in operation per capita. This figure relates the capacities built in the past and deemed to be still in operation, (assuming a life-time of 20 years for systems installed after 1989) to the size of the population.

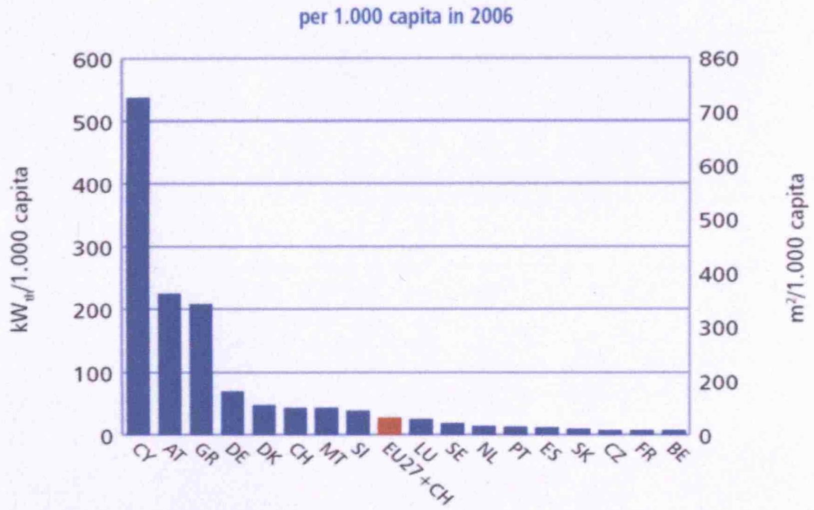


Figure 8: Solar thermal capacity in operation per 1000 capita in 2006 (ESTIF, 2007)

However, solar energy is used exclusively for domestic hot water needs, in terms of solar heaters. The use of photovoltaic solar energy by the public in Cyprus is still in its infancy. Koroneos et al (2005) mentioned that: “Although costs have fallen dramatically with a 25% cost decrease over the past 5 years, as far as photovoltaics are concerned, solar electricity is barely met on the island”.

Nevertheless, as mentioned new grants and feed-in tariffs are promoting photovoltaic technology; it is predicted that photovoltaic technology is going to be one of the most promising technologies on the island. Photovoltaic technology, cells and systems, as well as the photovoltaic market worldwide and in Cyprus are examined analytically in the next chapter.

3. Photovoltaics

3.1 General

Solar energy plays an ever-increasing role affecting the construction, form and the appearance of buildings. One of the main active solar technologies is photovoltaic systems.

Photovoltaic systems produce clean, reliable energy, without consuming fossil fuels and can be used in a wide variety of applications. Research into photovoltaic technology began over one hundred years ago. The first non laboratory use of photovoltaic technology was to power a telephone repeater station on rural Georgia in the late 1950s.

Today, photovoltaic systems are applied worldwide in communications, refrigeration for health care, crop irrigation, water purification, lighting, environmental monitoring, marine and air navigation, utility power and other residential and commercial applications. (Solar Energy International, 2004)

3.2 Photovoltaic technology

Solar cell is the basic element of a photovoltaic module. The solar cell absorbs sunlight and converts it directly into electricity.

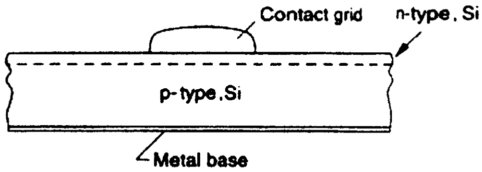


Figure 9: Section of a silicon solar cell (Sick and Erge, 1996)

A photovoltaic cell consists of a junction between two thin layers of dissimilar semi conducting materials; 'p'(positive)-type semiconductors and 'n' (negative)-type semiconductors. The p-type semiconductor layer has a surplus of positive charge carriers while the n-type semiconductor layer a surplus of negative charge carriers. Between these two layers a so called p-n junction is created.

In order to produce power, the PV cell must generate voltage as well as the current provided by the flow of electrons. The voltage is provided by the internal electric field set up at the p-n junction. A single silicon PV cell produces a voltage of about 0.5 V at a current of up to around 3A (a peak power of about 1.5W). (Boyle, 2004)

3.3 Types of photovoltaic cells

The main types of photovoltaic cells are the following:

3.3.1 Monocrystalline silicon cells

The majority of solar cells, until fairly recently, were made of extremely pure monocrystalline silicon (silicon with a single continuous crystal lattice structure). The overall process of monocrystalline silicon solar cell and module production is illustrated in figure 10. In relation to the other types of photovovoltaic cells, they have a high efficiency, but a higher cost due to the expensive production process.

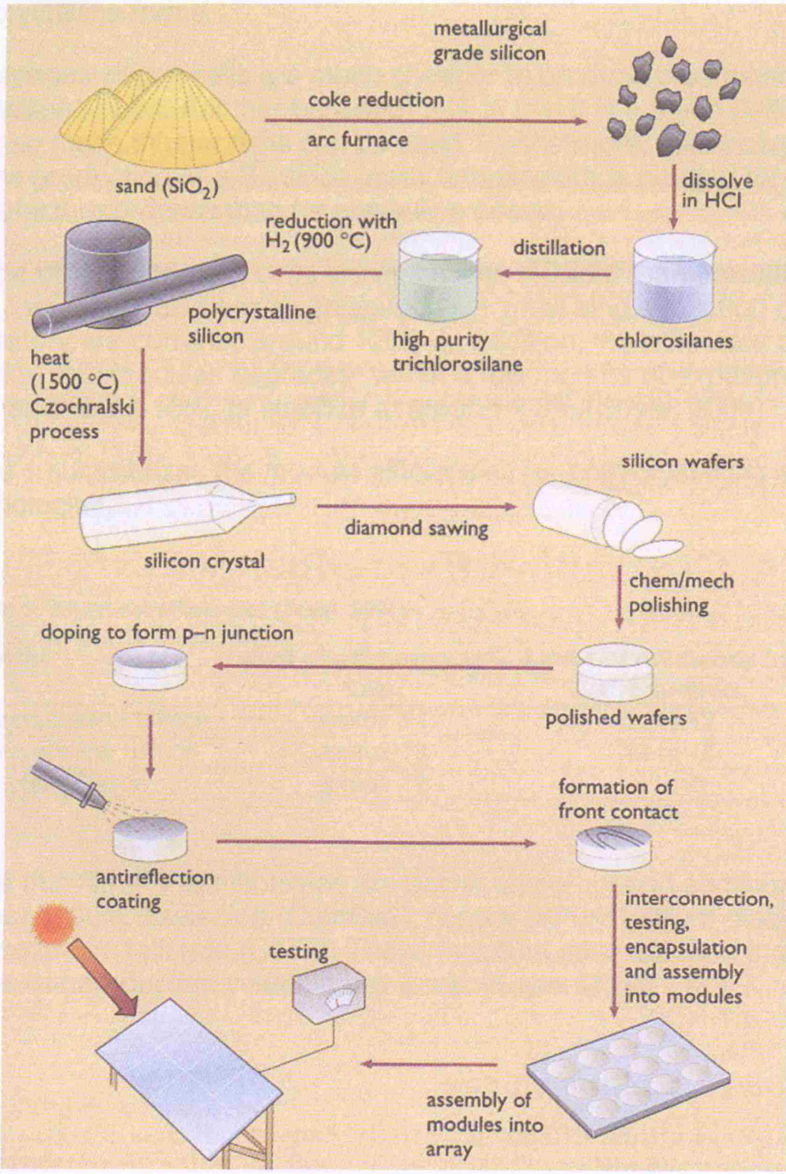


Figure 10: The overall process of monocrystalline silicon solar cell and module production. (Boyle, 2004)

3.3.2 Polycrystalline silicon cells

Polycrystalline silicon cells consist of small grains of monocrystalline silicon. Polycrystalline PV cells are easier and cheaper to manufacture than monocrystalline cells. However, they tend to be less efficient. But recent improvements have enabled commercially available polycrystalline PV cells to reach efficiencies over 14%.

3.3.3 Thin film PV

Thin film PVs are made of very thin films of silicon (amorphous silicon or a-Si). In this type of photovoltaic cells the silicon atoms are much less ordered than the crystalline forms.

Amorphous silicon cells are much cheaper to produce than those made of crystalline silicon. Another benefit of a-Si is that it is a much better absorber of light; so much thinner films can be used. Furthermore, less energy is required for the production of a-Si, since lower temperature is needed for the manufacture process than for crystalline silicon.

On the other hand, a-Si cells are much less efficient than crystalline silicon cells (maximum efficiencies achieved with small single-junction cells in the laboratory are currently around 12%). In addition, the efficiency of many single junction a-Si modules degrades, within a few months of exposure to sunlight, from an initial 6-10%, to stabilize at around 4-8%.(Boyle, 2004)

Table 1 summarizes the module efficiencies for both crystalline and thin film technologies.

Table 1: Silicon cell efficiencies (Boyle, 2004)

Material	Level of efficiency in% Lab	Level of efficiency in% Production
Monocrystalline Silicon	approx 24	14 to 17
Polycrystalline Silicon	approx 18	13 to 15
Amorphus Silicon	approx 12	6 to10

Other thin film PV technologies are based on compound semiconductors; copper indium diselenide (CuInSe2), copper indium gallium diselenide (CIGS) and cadmium telluride (CdTe). These modules have reached the production stage, but production volumes are small. (Boyle, 2004)

3.4 Types of photovoltaic systems

The cells which are low voltage are joined in series or in parallel in any number and combination. Thus, PV systems have the potential to be realized in a great range of power. Different amounts of energy can be achieved; from milliwatt systems in watches or calculators to megawatt systems for central power production.

There are two basically different photovoltaic systems: grid connected and stand-alone or remote systems.

3.4.1 Grid connected systems

Photovoltaic systems are connected to the public grid, which serves as an ideal storage component and ensures system's reliability. An inverter is required for the transformation of the PV-generated DC electricity to the grid AC electricity at the level of the grid voltage.

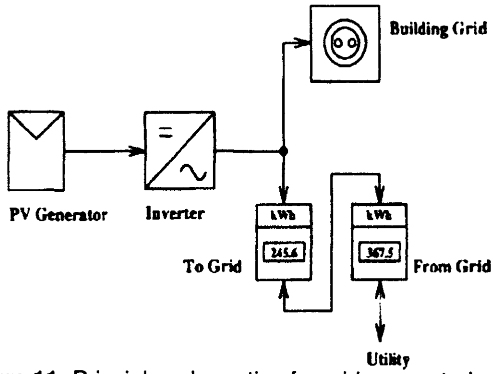


Figure 11: Principle schematic of a grid-connected PV power system (Sick and Erge, 1996)

In these grid-connected PV systems, when the PV power is surplus to current needs, the grid can absorb PV power making it available for use by other customers. At night or on cloudy days, when the output of the PV system is less than the demanding power, the balance of the required power is received from the grid.

3.4.2 Stand-alone systems

Mostly used in remote sites off the electrical grid, especially in locations where the access is possible by air only. The costs for such a system in this case compete against the cost for conventional grid supplies or other possible ways of remote energy supply.

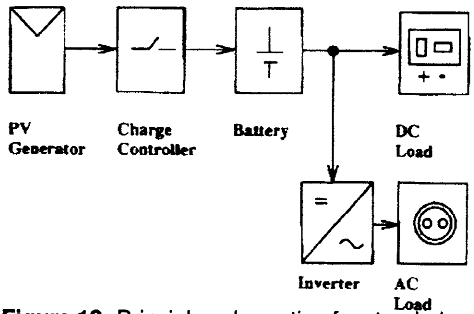


Figure 12: Principle schematic of a stand-alone PV power system (Sick and Erge, 1996)

A storage battery is necessary for this application. This battery serves as a buffer between the fluctuating power generated by the PV cells and the load. In order to ensure continuity of power, even under extreme conditions, a backup generator is often also installed.

A charge controller is responsible for the charge/discharge process, according to the different loads of demand and output power. Excess energy produced by the photovoltaic system during times with no or low loads, charges the battery, while at times with no or too low solar radiation, the loads are met by discharging it. When required, an inverter is used to transform DC to AC electricity. (Sick and Erge, 1996)

3.4.3 Hybrid systems

Hybrid systems do not run the entire load solely of the PV system, but they integrate another power source. The most common approach of a hybrid system incorporates a gas or a diesel powered engine generator, reducing the initial cost. A generator can provide the extra power needed during cloudy weather and when loads are heavier.

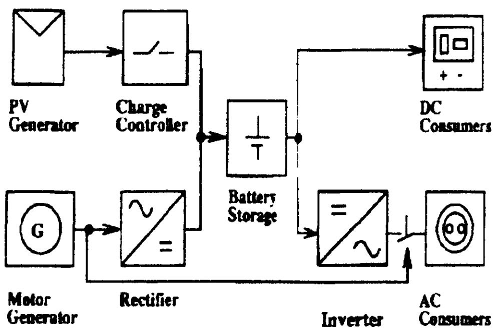


Figure 13: Principle schematic of a hybrid PV power system (Sick and Erge, 1996)

Another hybrid form is a PV system integrated with a wind turbine. In places where wind blows when the weather is cloudy, wind turbines can solve the problem of low power output with a conventional PV system. Furthermore, for even greater reliability and flexibility, a generator can be included in a PV/Wind system. (Solar Energy International, 2004)

3.5 Advantages and Disadvantages of Photovoltaic Technology

Photovoltaic systems offer substantial advantages over conventional power sources. The main advantages of photovoltaic systems according to Solar Energy International (2004) are:

- Reliability: photovoltaic systems have proven their reliability, even in difficult conditions. PV arrays prevent costly power failures in situations where continuous operation is critical.
- Durability: A PV system can produce power for 20 -25 years.
- Low maintenance cost: costs for periodic inspection and occasional maintenance for the PV systems are usually less compared to conventionally fueled systems.
- Reduced sound pollution: photovoltaic systems operate silently and with minimal movement.
- Photovoltaic modularity: PV systems are more cost effective than bulky conventional systems. Modules may be added incrementally to a PV system to increase available power.

- Safety: no combustible fuels are required and they are very safe when they are designed and installed properly.
- Independence: many residential PV users cite energy independence from utilities as their primary motivation, for adopting the new technology.
- Electrical grid decentralization: small scale-decentralized power stations reduce the possibility of outages on the electric grid.
- High altitude performance: increased insolation at high altitudes makes using photovoltaics advantageous, since power output is optimized. On the contrary, a diesel generator at higher altitudes must be de-rated because of losses in efficiency and power output.

However, photovoltaic technology has also some disadvantages, concerning the following factors:

- Initial Cost: Initial cost is still high. However, it is expected that photovoltaic systems will become more economically competitive during the next years.
- Variability of available solar radiation: weather affects the power output of any solar-based energy system; variations in climate or site conditions require modifications in system design.
- Energy Storage: the size and the cost of some PV systems are increased by the use of batteries in order for the energy to be stored. This concerns only stand alone systems.
- Education: due to the fact that PV systems present a new and unfamiliar technology, few people understand their value and feasibility. (Solar Energy International, 2004)

3.6 The status and future of the photovoltaic market

The aforementioned disadvantages of PV technology lose their strength, as technology is progressing. Over the last decade the photovoltaic sector has become an important industry in many countries.

According to the European Photovoltaic Energy Platform (2006), the worldwide solar photovoltaic industry reached a consolidated figure of 2.1GW, representing an annual growth of 30%. It is estimated that with adequate support mechanisms such as feed-in tarrifs, a global annual market of 5.6 GW could be reached by the year 2010. PV system cost is expected to decrease further, by at least 5% annually, over the next decades. This will lead to a further increase of the use of photovoltaic technology.

Table 2 illustrates global cell production between 2000 and 2006. An icrease of 41% of global cell production was observed in 2006. The global cell production showed growth acrooss all the geographic regions. Japanese production represents the lowest increase because of the effects of the polysilicon shortage. The production in the rest of the world category is the strongest, illustrating the rapid emergence of the Chinese and Taiwanese companies to serve the PV market.

Table2: Global cell production until 2006 (MW DC) (Maycock, Bradford, 2007)

Country	2000	2001	2002	2003	2004	2005	2006	2006 v 2005
US	75	100.3	120.6	103	138.7	154	201.6	30,90%
Japan	128.6	171.2	251.1	363.9	601.5	833	926.9	11,30%
Europe	49.8	73.9	122.1	200.2	311.8	476.6	678.3	42,3%
Rest of the world	23.4	40.6	53.3	81.3	141.5	322.5	714	121,4%
Total	276.8	386	547.1	748.4	1193.5	1786.1	2520.8	41,1%

Installations of photovoltaic cells and modules grew in line with global production. Table 3 shows that the spread of PV across different markets remained concentrated in the grid-tied and off-grid applications with over 90% of PV installations.

Table3: Global PV cell use by application (Maycock, Bradford, 2007)

Market sector	1996	1998	2000	2002	2004	2005	2006
Consumer products	22	30	40	60	75	80	90
World off-grid rural	23	34	53	85	110	125	140
Communications signal	23	31	40	60	80	90	100
Off-grid commercial	12	20	30	45	55	60	70
Grid connected residential/commercial	7	35	120	270	700	1375	1600
Large (>500kW)	2	2	5	5	20	30	100
Actural (Mw/yr)	89	152	288	525	1040	1550	2200
Actual average module price (US$/W)	4	4	3.5	3.25	3.25	3.5	3.75

Concerning the geographical spread of the modules used in those system-based applications, Germany dominates PV market, with over 56% of the system based modules installed and a growth of 50% over 2005. Countries in the rest of Europe showed extremely high demand growth. The US market grew by 31%, while Japanese market grew by only 10% as the market continued to adjust to the elimination of the government support program in 2005.

Table 4: Global PV module installations (systems only) from 2000-2006 and forecast for 2007. (Maycock, Bradford, 2007)

Country	2000	2001	2002	2003	2004	2005	2006	2007
Germany	44	78	80	170	500	700	1050	1260
Rest of Europe	1	3	10	11	24	60	118	234
Japan	74.4	91	141	201	256	320	350	402.5
Rest of Asia	13	19	43	33	47	55	81	131.9
US	16.8	28.4	49.1	71.7	89.9	108	141.4	259
Row	21	37	77	118	147	139	130	158.8
Total	170.2	256.4	400.1	604.7	1063.9	1382	1870.4	2446.2

It is expected that the PV market will continue to grow and it will become a dominant component of sustainable architecture. New financing models, the discovery of new products to meet new applications, and the decrease in PV prices, will lead to this growth.

3.7 Photovoltaics in Cyprus

Considering the environmental and financial benefits of photovoltaic systems in Cyprus, the need for such a market to be developed becomes almost necessary. As mentioned, the climatic conditions of Cyprus are predominately very sunny, with daily average solar radiation of about 5.4 kWh/m² on a horizontal surface.

Cyprus has already proved its ability to utilize solar energy, as it is one of the leading countries in the world, when it comes to utilizing solar water heater. However, as it was mentioned, the use of photovoltaic solar energy by public in Cyprus is still in its infancy. Photovoltaics have been used by the Cyprus Telecommunication Authority (CYTA) for the telephone kiosks and transmitters. The Cyprus Broadcasting Corporation Authority has also used photovoltaics for transmitters.

Figure 14 illustrates the annual sum of global radiation received by optimally-inclined PV modules in Cyprus. It is obvious that the southwestern parts of Cyprus are the most favorable sites for PV installations.

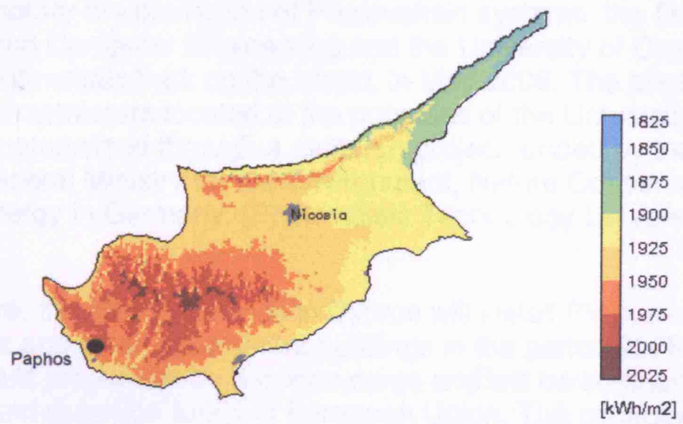


Figure 14: Yearly sum of global radiation received by optimally-inclined PV modules. (European Commission Joint Research System, 2008)

During the last years, photovoltaic technology is becoming more spread and by 2007 the total installed PV power in Cyprus reached a value of 1450 kW, compared to a value of 254 kW reported in 2003.

Table 5: Installed PV power in Cyprus in 2003-2007 (EPIA, 2008)

2003			2004			2005			2006			2007		
Off grid Kw	On-grid Kw	Total Kw	Off grid Kw	On-grid Kw	Total Kw	Off grid Kw	On-grid Kw	Total Kw	Off grid Kw	On-grid Kw	Total Kw	Off grid Kw	On-grid Kw	Total Kw
242	12	254	318	22	340	363	118	481	450	526	976	560	890	1450

As mentioned in a previous paragraph, part of the RES policy concerns grants for the installation of photovoltaic technology. In more details, the EAC (Electricity Authority of Cyprus), in line with the government's energy policy is obliged to buy electricity produced by renewable energy sources in a fixed feed-in tariff; a feed-in tariff of 0.392euro/kWh for household, other entities and organizations not engaged in economic activities and 0.342euro/kWh for enterprises. If an investment grant is taken the tariff is reduced to 0.21€/kWh.

For a photovoltaic installation up to 20kW, investment grants for households, other entities and organizations not engaged in economic activities are limited to a maximum 55% of the eligible costs and maximum grant is 16.5k€ with a fixed-in tariff to 0.21€/kWh. For enterprises, the grant is 40% of eligible costs and the maximum amount of the grant is 12k€. (Cyprus Institute of Energy, 2008)

In an attempt for the promotion of Photovoltaic systems, the Department of Electrical and Computer Engineering and the University of Cyprus completed the first Photovoltaic Park on the island, in May 2006. The photovoltaic park, a research infrastructure located at the premises of the University of Cyprus, has been materialized through a research project funded by the BMU, the German Federal Ministry for the Environment, Nature Conservation and Nuclear Energy in Germany. (Photovoltaic Technology University of Cyprus, 2007)

Furthermore, the Energy Service in Cyprus will install PV systems in schools, army bases and other government buildings in the period 2008-2009. The budget of this project will be 5 million euros and will be co-financed with the structural and cohesion funds of European Union. The capacity of the systems that would be installed is expected to be 1.5MWh each year.

Moreover, as it was released in 'Politis' newspaper (2008), a new scheme which is promoted by the council of ministers, concerns PV installations up to 100kW and a new feed-in tariff of 0.44€ (compared to value of 0.392euro/kWh) for household, other entities and organizations not engaged in economic activities and 0.342euro/kWh for enterprises. If an investment grant is taken the tariff is 0.239€/kWh (compared to a value of 0.21€/kWh)

More and more people in Cyprus start to realize the benefits of photovoltaic systems. The continuous rise of oil prices and the promotion of grants and feed-in tariffs by the government are encouraging people to invest in photovoltaic technology.

The installation of a PV system on the roof of a public building, connected to the grid is going to be studied. The aim is to explore if such a system is economically viable and to detect its environmental benefits. A sensitivity analysis of the factors affecting the economic viability of photovoltaic system is then carried out.

4. Methodology of study

This study is divided in three principal sections. Initially calculations concerning the energy demand of the building have been carried out. Then the proposed photovoltaic installation has been analyzed and finally a sensitivity analysis of the factors affecting the economic viability of the proposed photovoltaic system has been carried out.

First of all, the energy required for the operation of the building is appreciated. Therefore, cooling and heating demands of the building have been calculated, using TAS (Thermal Analysis Software). Also, the electric demand for lighting and small power has been calculated.

Having determined the energy demand of the building, a photovoltaic system is proposed in order to cover the 10% of the energy demand of the building. Retscreen software is used to calculate the output energy of the system, as well as the PV system greenhouse gas emission reduction. The simple economic payback period of the system and the economic payback period with NPC are then calculated. The energy payback period of the system is then estimated, using data from previous studies, concerning the embodied energy of photovoltaic modules.

Finally, various factors considered to influence the economic viability of the photovoltaic system have been analyzed. The effect of the financial grants, climate change, capital cost and future electricity prices on the economic payback period of the system is examined.

5. Specific case study

5.1 Proposed Design for Paphos City Hall

The theoretical research concerning the application of photovoltaic technology on the island makes evidence that the creation of a strong photovoltaic market in Cyprus must be one of the major steps towards the mitigation of global warming. In order to understand the importance of photovoltaic technology in the building sector, the proposed design for Paphos City Hall is examined.

5.1.1 Paphos, Cyprus

The town o f Paphos is a coastal city in the southwest of Cyprus. Paphos has a population of about 67,432 (end of 2004). It is divided into two major quarters: Ktima, on the sea terrace, the main residential district, and Kato Paphos, by the sea which is built around the medieval port and contains most of the luxury hotels and the entertainment infrastructure of the city.(Wikepedia, 2008)

5.1.2 Description of the building

The city hall of Paphos to be examined, was the participation of the 'Kannavos' architectural office in the Pancyprian Architectural Competition, announced in January 2008. The plot which is is situated in the centre of Paphos faces the orthodox chuch of Pantanassa on the north and a green public zone on the west. The surrounding plots are constructed with low buildings so the particular building is not shaded by surrounding buildings or obstacles, making it particulary suitable for photovoltaic installation.

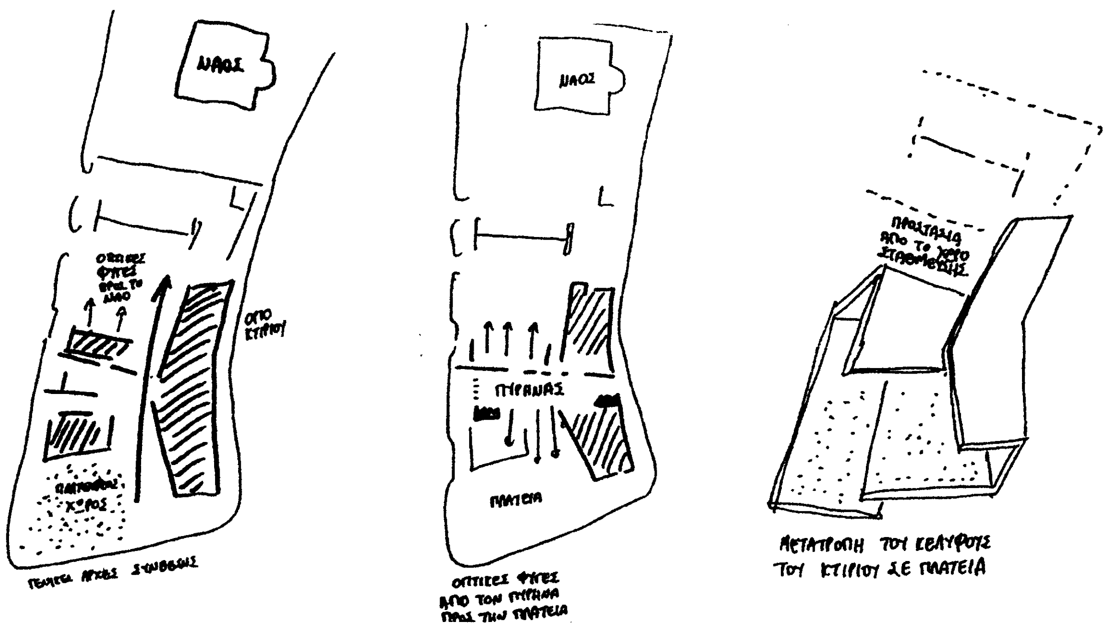


Figure 15: First sketches of the building ('Kannavos' architectural office)

The basic aim of this project was the creation of a 'friendly' building which would welcome the citizens to the centre of the cultural and social events of the city of Paphos. The shell of the building itself unfolds and it is transformed to a plaza which represents a harmonic journey from the urban envinronment to the heart of the building.

The building is organised in four levels (basement – parking, ground, first and second floor) and it consits mainly of offices. However, a lecture theatre for 140 people, seminar rooms, a café and an exhibition hall are also contained in the building. The whole building is organised around a central core which it is the main circular space of the building.

The spaces concerning the cultural activities of the city hall (lecture theatre, exhibition spaces, library) are situated on the ground floor. The café is also situated on the ground floor and serves not only the people that work there on weekdays, but also residents of the surrounding area during the week (including weekends).

The first floor accomodates the offices of the Technical Service and the sector of Public Hygienic and Cleaning, while the second floor accomodates the offices of the Management and Financial sector. The offices concernig the mayor and the officers of the city hall are situated at the front part of the building, above the plaza of the city hall. More details, considering the building plans can be found in Appendix I

Concerning the opening hours of the building, all offices wiil operate from 7:30 to 2:30 in weekdays. The café will operate from 7:30-10:00 everyday. The lecture theatre will be open twice a week,10:00-13:00 and 16:00-19:00, while the entrance-exhibition hall will be open every day from 7:30-19:30.

Figure 16: A 3d representation of the proposed building (Kannavos architectural office)

Figure 17: 3d views of the interior space (exhibition and circulation space) (Kannavos architectural office)

5.1.3 Building materials

In the proposed building, the skeleton will be constructed of reinforced concrete with the maximum distances between the columns being 7.5m. Some surfaces of the building will be fare-face concrete, where the appropriate chemical materials will ensure the right waterproof level. External walls will be made of two layers of bricks with insulation in-between them.

The shell of the lecture theatre will be a metallic construction, covered with aluminium sheets. All the glazing parts of the building will be double glazed. Louvres are positioned in particular spaces for sun protection. The floors are coverd with grey granite ceramics.

5.1.4 Photovoltaic roof

What is important about this building is the potential of photovoltaic installation on the roof. According to the drawings, photovoltaic panels are positioned on the roof, in order to promote the use of innovative and clean energy production technologies. The fact that it is a public building strengthens the need to become a flagship building, promoting sustainability and renewable energy.

Figure 18: Proposed PV installation on the roof (Kannavos architectural office)

5.2 TAS

The construction of the model in TAS Manager was based on the drawings, designed by the architectural office. Nevertheless, the model was kept simple, omitting certain architectural details that would not affect the thermal behavior of the building. Concerning the simulation process, spaces with approximate the same internal conditions were grouped in zones, in order to be analyzed.

5.2.1 Construction elements

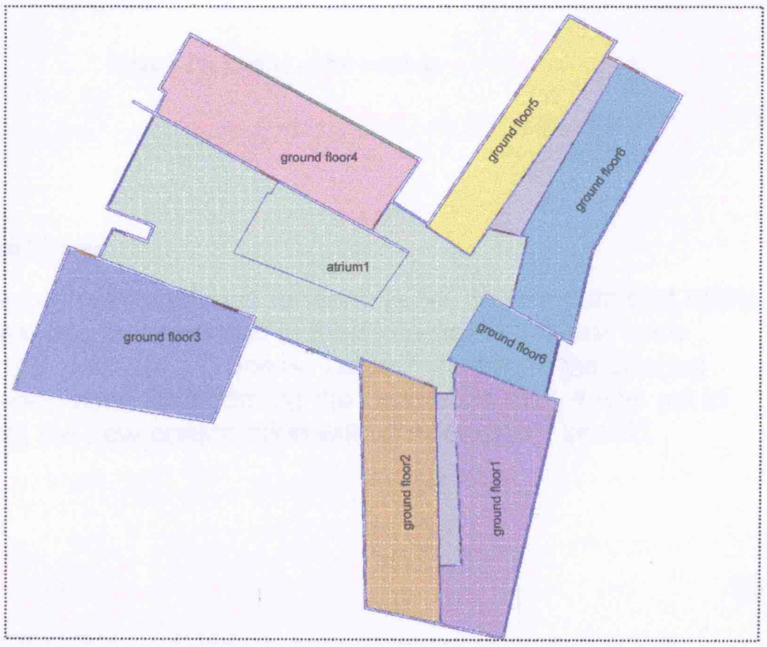
The various construction elements (table 6) were created in TAS, by combining certain materials that were taken from the existing material database of the software. The materials were constructed in order to represent in the best possible way the proposed materials of the building.

Table 6: Main construction elements

Element	Materials/Layers	Thickness (mm)	U-value
External walls	Plaster	20	0.45
	Brick	120	
	Cavity	50	
	Brick	120	
	Plaster	20	
Internal walls	Plaster	20	1.95
	Brrick	150	
	Plaster	20	
Ground floor	Tile	5	0.28
	Concrete screed	50	
	Concrete	125	
	Aggregate	75	
	Solid	1000	
Raised floor	Tile	30	0.67
	Void	80	
	Sceed	150	
	Concrete	250	
	Plaster	20	
Roof	Tile	20	0.48
	EPS	50	
	lightweight Concret	100	
	Asphault	19	
	Concrete	250	
Metallic Construction	Metal cladding wall and roof		0.37
Windonw pane	Glass	4	2.86
	Cavity	12	
	Glass	4	

5.2.2 Zoning

Spaces with approximate the same internal conditions were grouped in zones in order to be analyzed. Figure 19 illustrates the various zones of the building.



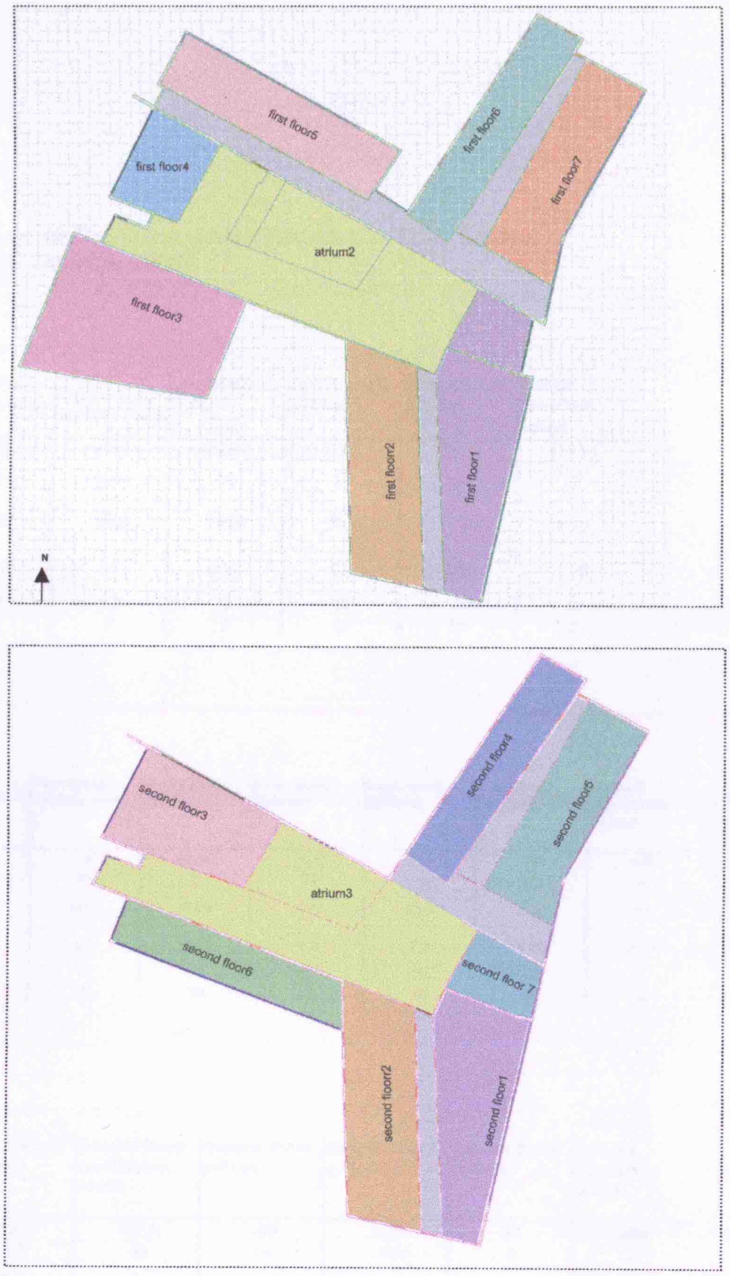


Figure 19: Zoning of the building

5.2.3 Internal Conditions

In order to define the internal conditions for each zone, certain data that relate to the different spaces' occupancies and to their internal conditions were defined and used to the simulation process. Table 7 illustrates the internal heat gains used for each zone. Concerning the ventilation rate, it was set to 0.3ach, assuming that the new construction will be adequately sealed.

Table 7: Internal Conditions

The internal conditions were defined according to the values illustrated in Table 6.3 and 6.4 in CIBSE Guide A (Source: CIBSE Guide A, 2006)

INTERNAL HEAT GAINS (W/m^2) - Ground floor

Rooms/Zones	Ground floor1 (wc, offices)	Ground floor2 (seminar room library)	Ground floor3 (seminar room)	Ground floor4 (cafe)	Ground floor5 (offices)	Ground floor6 (offices)	Atrium1 (exhibition space)
Area (m^2)	121.37	134.82	140	162.67	100	203.5	434.24
Average occupancy	14	52	200	50	22	55	30
Occupancy Sensible gains (W/m^2)	8.07	25.07	45.5	19.98	15.4	17.93	5.15
Occupancy Latent gains (W/m^2)	5.17	11.57	21	9.22	9.9	9.21	3.75
Lighting Gain (W/m^2)	8	12	12	12	12	12	8
Equipment Gain (W/m^2)	2	5	5	5	15	15	2

INTERNAL HEAT GAINS (W/m^2) - First floor

Rooms/Zones	First floor1 (wc, conference room)	First floor2 (offices)	First floor3 seminar room	First floor4 (offices)	First floor5 (offices)	First floor6 (offices)	First floor7 (offices)	Atrium2 (circulation space)
Area (m^2)	153.16	139.81	140	61.46	119.38	100	135	349
Average occupancy	16	12	200	6	13	16	13	4
Occupancy Sensible gains (W/m^2)	8.98	6.01	45.5	6.83	7.62	11.2	6.74	0.8
Occupancy Latent gains (W/m^2)	4.28	3.86	21	4.39	4.9	7.2	4.33	0.57
Lighting Gain(W/m^2)	8	12	12	12	12	12	12	8
Equipment Gain(W/m^2)	2	15	5	15	15	15	15	2

INTERNAL HEAT GAINS (W/m^2) - Second floor

Rooms/Zones	Second floor1 (wc, offices)	Second floor2 (offices)	Second floor3 (conference room)	Second floor4 (offices)	Second floor5 (offices)	Second floor6 (offices)	Atrium3 (circulation space)
Area (m^2)	123	139.81	127.8	100	135	93	293
Average occupancy	13	14	40	14	14	9	3
Occupancy Sensible gains (W/m^2)	7.4	7.01	17.8	13.3	7.26	6.77	0.75
Occupancy Latent gains (W/m^2)	4.76	4.51	8.21	8.55	4.67	4.35	0.52
Lighting Gain (W/m^2)	8	12	10	12	12	12	8
Equipment Gain(W/m^2)	2	15	5	15	15	15	2

5.2.4 Openings-Ventilation strategy

The air movement through the building is controlled by the various openings of the building and the way these operate. A single and cross ventilation strategy is used to ventilate the various zones of the building. Windows start to open when the internal temperature reaches 23°C and are totally closed when the internal temperature reaches 27 °C. In terms of the simulation process the windows have been considered to open automatically. However, this type of control can be manually overridden by the occupants.

Louvers are positioned, in order to protect from the sun, during high solar radiation, in particular positions on the south façade, according to the drawings.

5.2.5 Simulations

1st simulation

Table 8 illustrates the average, maximum and minimum temperature presented in the various zones. Furthermore, it demonstrates the frequencies of temperature occurrence, in relation with the target temperature that resulted with the first simulation. Regarding the target temperature, it was defined according to the following formulae (De Dear, R., Branger, G.S., 2001), known as the adaptive comfort standard.

Upper 80% acceptable limit (°C) = 0.31* (outdoor air temperature) + 21.3
Lower 80% acceptable limit (°C) = 0.31* (outdoor air temperature) + 14.3

Table 8: Temperatures appeared in the various zones

Zone	function	average temp (Celcius)	max temp. (Celcius)	min temp. (Celcius)	frequencies of temperature 20.22<t<27.22 (%)	frequencies of temperature t>27.22 (%)	frequencies of temperature t<20.22 (%)
Ground floor 1	wc, offices	25.22	38.3	19.16	73.85	23.96	2.19
Ground floor 2	offices	26.1	45.04	19.46	72.48	26.20	1.32
Atrium1	entrance exhibition	23.85	35.44	16.64	69.52	16.55	13.93
Ground floor 3	seminar room	26.91	48.04	15.97	39.65	46.75	13.60
Ground floor 4	kafe	24.78	42.52	17.04	72.23	18.12	9.65
Ground floor 5	offices	24.9	43.11	16.438	59.95	23.63	16.42
Ground floor 6	offices	24.59	40.73	17.58	65.45	21.11	13.44
First floor 1	wc, offices	25.22	40.47	18	67.32	24.92	7.76
First floor 2	offices	26.19	46.43	18.02	67.99	27.27	4.74
Atrium 2	circulation space	24.07	36.12	16.38	65.05	21.04	13.91
First floor 3	seminar room	27.11	47.90	15.87	38.63	47.80	13.57
First floor 4	offices	22.57	36.88	13.11	51.64	16.50	31.86
First floor 5	offices	24.68	43.16	14.14	51.94	25.75	22.31
First floor 6	offices	25.24	46.29	15.16	55.95	25.19	18.86
First floor 7	offices	25.19	43.11	16.75	60.39	25.29	14.32
Second floor 1	wc, offices	25.04	42.76	15.6	62.61	24.93	12.46
Second floor 2	offices	26.1	48.56	15.46	64.19	26.62	9.19
Atrium3	circulation space	24.34	37.93	16.13	61.03	23.21	15.76
Second floor 3	offices	23.13	41.77	11.75	50.51	19.59	29.90
Second floor 4	offices	25.33	48.74	13.33	54.12	25.56	20.32
Second floor 5	offices	25.05	46	14.44	57.11	25.38	17.51
Second floor 6	offices	21.53	38.77	8.86	42.56	16.18	41.26
Second floor 7	archive	24.98	39.98	15.54	53.54	28.62	17.84

The analysis showed that the temperatures in most of the zones are more than 50% in the target temperatures. The zone with the worst results is the ground floor3 and first floor3 zone. This fact was more than prospective, since the volume concerning these zones does not have any openings. As defined by the natural ventilation strategy, the air movement throughout the building is controlled by specific openings and the way these operate. The aforementioned space has no openings. Furthermore a lot of people are gathered in this space (as it functions as a seminar room). The volume can not be naturally ventilated and thus is overheated.

2nd simulation

In order to improve the results, the seminar room was reconstructed with openings on the second floor.

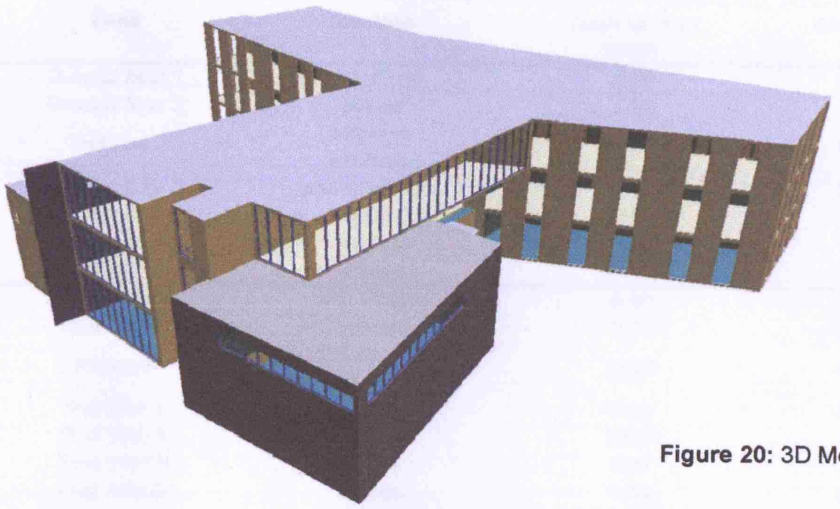


Figure 20: 3D Model in TAS

Table 9: Temperatures appeared in the various zones (2nd simulation)

Zone	function	average temp (Celcius)	max temp. (Celcius)	min temp. (Celcius)	frequencies of temperature 20.22<t<27.22 (%)	frequencies of temperature t>27.22 (%)	frequencies of temperature t<20.22 (%)
Ground floor 1	wc, offices	25.22	38.3	19.15	73.85	23.96	2.19
Ground floor 2	offices	26.1	45.03	19.46	72.48	26.20	1.32
Atrium1	entrance exhibition	23.83	35.43	16.62	69.43	16.53	14.04
Ground floor 3	seminar room	23.57	45.88	15.72	69.8	14.04	16.16
Ground floor 4	kafe	24.77	42.51	17.05	72.23	18.12	9.65
Ground floor 5	offices	24.89	43.11	16.38	58.95	23.63	17.42
Ground floor 6	offices	24.58	40.72	17.58	65.45	21.10	13.45
First floor 1	wc, offices	25.22	40.46	18	67.35	24.92	7.73
First floor 2	offices	26.19	46.41	18.01	67.96	27.27	4.77
Atrium 2	circulation space	24.05	36.07	16.36	64.09	20.94	14.97
First floor 3	seminar room	23.76	45.90	15.6	66.78	16.38	16.84
First floor 4	offices	22.56	36.88	13.1	51.67	16.40	31.93
First floor 5	offices	24.67	43.15	14.13	51.96	25.72	22.32
First floor 6	offices	25.24	46.28	15.15	55.96	25.19	18.85
First floor 7	offices	25.19	43.1	16.75	60.38	25.29	14.33
Second floor 1	wc, offices	25.04	42.76	15.6	62.6	24.93	12.47
Second floor 2	offices	26.1	48.56	15.45	64.19	26.62	9.19
Atrium3	circulation space	24.33	37.91	16.11	60.96	23.18	15.86
Second floor 3	offices	23.12	41.76	11.74	50.53	19.55	29.92
Second floor 4	offices	25.33	48.74	13.32	54.1	25.56	20.34
Second floor 5	offices	25.05	45.99	14.43	57.12	25.37	17.51
Second floor 6	offices	21.44	38.65	8.81	42.58	15.78	41.64
Second floor 7	archive	24.87	39.97	15.53	53.54	28.60	17.86

According to table 9, the second simulation showed that just by introducing windows in the seminar room, there is a great increase in the percentage of the temperatures within the target range. The rest zones appeared to have about the same temperatures, since the seminar room is quiet independent from the rest spaces.

At this part of the analysis, the heating and cooling loads of the simulated spaces were calculated. More particularly, table 10 shows the heating and cooling loads for each zone. The total heating and cooling load is estimated to be 869 kWh and 104,284 kWh respectively.

Table 10: Heating and Cooling Loads per zone (2nd simulation)

Zone	function	heating load (KWh)	cooling load (KWh)
Ground floor 1	wc, offices	0.00	2222.79
Ground floor 2	offices	0.00	4634.54
atrium1	entrance exhibition	115.17	9154.18
Ground floor 3	seminar room	0.00	2966.67
Ground floor 4	kafe	0.00	11119.11
Ground floor 5	offices	0.00	3168.27
Ground floor 6	offices	0.00	4717.82
First floor 1	wc, offices	0.00	3138.35
First floor 2	offices	0.00	4917.55
Atrium 2	circulation spaces	45.27	4824.69
first floor 3	seminar room	0.00	3248.96
First floor 4	offices	32.96	840.73
First floor 5	offices	5.07	3015.50
First floor 6	offices	0.00	3654.64
First floor 7	offices	0.00	3138.74
Second floor 1	wc, offices	18.89	2220.23
Second floor 2	offices	0.71	4752.00
Atrium3	circulation spaces	199.87	2417.95
Second floor 3	offices	46.12	2053.11
Second floor 4	offices	6.61	3658.48
Second floor 5	offices	1.68	3715.88
Second floor 6	offices	383.35	20005.09
Second floor 7	archive	13.29	699.39
		Total heating load (kwh)	868.99
		Total cooling load (kwh)	104284.67

The total heating and cooling load for each month of the year is illustrated in table 11 and figures 21 and 22. As it can be seen, the highest cooling loads occur in July and August, whereas during winter there are no cooling loads. Apparently this has to do with the external temperatures that as expected are very high during summer. As it was expected the cooling load is considerably higher than the heating load, since outside temperature reaches 37.8°C. Furthermore, the significant low value required for heating is due to the fact that the ventilation rate was set to 0.3 ach and most of the spaces are operating between 07:30 to 14:30 in weekdays.

Table 11: Heating and Cooling Loads per month

	Heating loads (kWh)	Cooling loads (kWh)
jan	465.43	0
feb	191.29	1.5
mar	54.24	206.11
ap	0	1015
may	0	4655.87
june	0	13258.24
july	0	21538.7
aug	0	23087.72
sept	0	13799.73
octob	0	7136.62
nov	1.09	32.69
dec	156.94	2.41

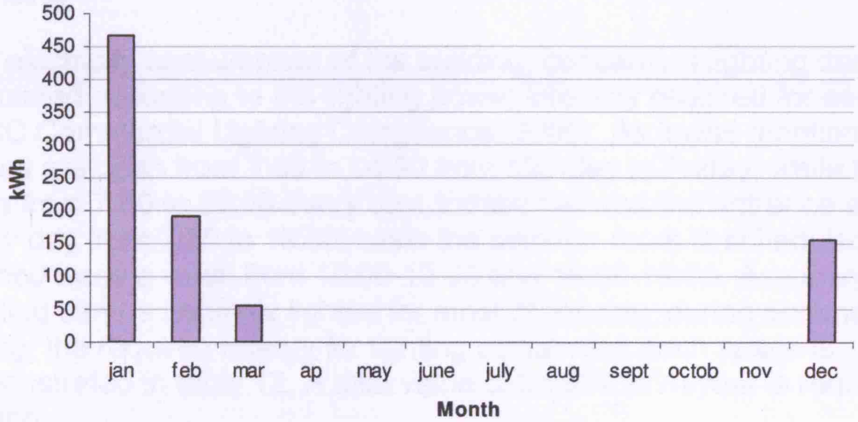


Figure 21: Total monthly heating loads of simulated spaces

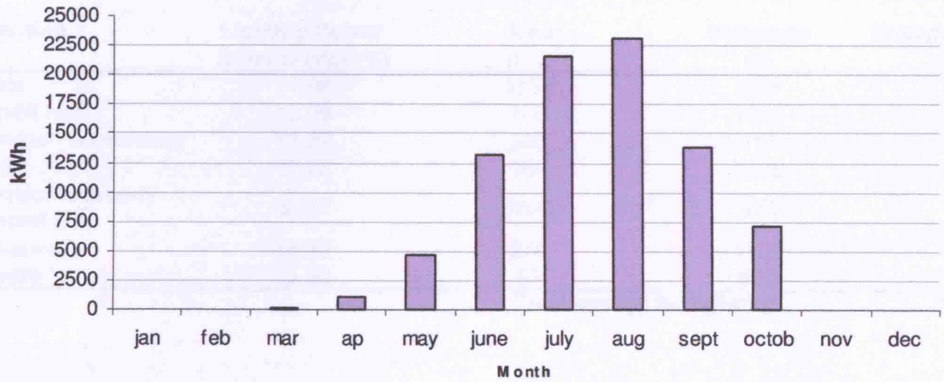


Figure 22: Total monthly cooling loads of simulated spaces

5.3 Electric demand of the building

The electric demand of the building is calculated in order for the photovoltaic system to be examined.

5.3.1Cooling demands

An air conditioning system is going to be installed to cover the cooling loads for the proposed building. Heating loads are neglected due to their low value. Cooling loads have been calculated, using TAS software at a value of 104,284 kWh/year. In order to estimate the electricity consumed for cooling, this value is divided by the coefficient of performance of the air conditioning system. Assuming that an air conditioner which consumes1 kW, removes heat from the interior of a building at a rate of 2 kW, the electricity consumed for cooling is 52,142 kWh/year.

5.3.2 Lighting and small power

Lighting

The electricity consumption of the building, concerning lighting demand is calculated according to the lighting power intensity required for each space (IECC Commercial Lighting Compliance, 2006). As it was mentioned, the offices are open from 7:30 to 14:30 from Monday to Friday, while the café is open from 7:30 to 22:00 every day. Exhibit hall and the entrance are open every day from 7:30 to 19:30, while the seminar room is scheduled to be opened twice a week from 10:00-13:00 and 16:00-19:00. Assuming that the building can be naturally lighted for most of the day, during summer and spring, the required energy for lighting concerning each space is demonstrated in table 12. A total value of 34,534 kWh/year is required for lighting.

Table 12: Energy demand for lighting

Function	**Lighting Power Density** (W/m^2)	**Area** m^2	**Schedule** (h)	**Energy Consumption** kWh/year
office	11.84	1554	520	9568.22
Exhibit hall	13.99	100	1300	1819.16
Seminar/ conference	15.07	333	312	1565.71
Café	17.22	180	2190	6789.24
Corridor/restroom/ support area	9.69	1894	520	9541.36
Entrance	13.99	240	1300	4365.98
Library	18.30	93	520	884.95
		Total energy for lighting		**34534.62**

Small power
Concerning the energy demand for small power, offices have typical equipment: computers, printers-faxes and a large copier shared for all offices. The lecture theatre is equipped with a projector, a DVD player and a television, while the two other small seminar rooms with a projector. The café is equipped with 2 refrigerators, 3 toasters and 3 coffee makers. Table 13 illustrates the energy consumed by the various equipments. A total of 47,289 kWh/year is required for small power.

Table 13: Energy demand for small power

Small Power	Wattage (W)	Schedule (h)	Energy Consumption kWh/year	Number	Total Energy consumption kWh/year
pc	150	1820	273	86	23478
printer laser	50	1820	26	20	520
copier-large	1500	260	390	1	390
projector	600	780	468	3	1404
dvd player	30	156	4.68	1	4.68
tv	200	156	31.2	1	31.2
refrigerator	475	8760	4161	2	8322
toaster over	1000	1825	1825	3	5475
coffe maker	1400	1825	2555	3	7665
			Total energy for small power		**47289.88**

The total annual building electricity consumption is estimated to be 133,966kWh/yr or 32 kWh/m². During the year 2007, the Electricity Authority of Cyprus sold electricity produced by oil at an average value of 0.198 €/kWh. Assuming that the oil price remains constant at this value, the cost concerning the electricity consumption of the building is estimated to 26,525 €/year.

5.3.3 Electric demands in similar buildings in Paphos and region

A small research about the electric demands concerning similar buildings in Paphos and in Cyprus was completed. The results are illustrated in table14. As it can be observed, the electricity consumption varies between 50 kWh/m² and 60kWh/m². The proposed building is estimated to consume 32kWh/m². This difference is due to the fact that the cooling load of the building was quiet low. Furthermore, the case studies are not recently constructed buildings, thus no environmental issues (high insulation value, economic light bulbs) were considered during the design process.

Table 14: Electric demands in similar building in Cyprus (Data were gathered concerning the information given by the director of each building, according to the electricity bills)

Building	Area m²	Electricity consumption kWh/m²
Paphos District Walfare Office	700	58.33
City Hall of Strovolos	9722	69.35
City Hall of Anglantzia	600	50.51

5.4. *The PV System*

5.4.1 Description of the proposed PV system

The proposed photovoltaic system is grid connected and will be installed on the roof of the building. In this case study, a grid-connected PV generation system offers several advantages over a stand-alone system. Some of the advantages of the proposed photovoltaic system are: savings on wiring costs - due to the capability of using existing wiring in the building- , no need for storage batteries to be used as the grid backups the system and the possibility of selling surplus electricity.

A space of around 535 m^2 is available on the roof for this installation. The proposed panels are of polycrystalline silicon with an aluminum frame and 12.7% efficiency. 425 panels are used for a system of 68kW total installed power. The photovoltaic system also includes inverters to convert the generated electricity from DC to AC and the required cabling and support construction for the PV arrays. The estimated lifetime of the system is around 25 years. The output energy, the greenhouse gas emission reduction and the payback period of the proposed PV system are going to be examined in this chapter.

5.4.2 PV system output calculation

In order to calculate the PV system's output, RETScreen International Clean Energy Project Analysis Software was used. This software offers the possibility to evaluate the energy production for various types of renewable energy and energy efficient technologies worldwide. Weather files for various places in the world are included in the software.

Concerning the PV installation, solar radiation is one of the most important factors affecting the output of the system. Figure 23, illustrates the daily solar radiation per month in Paphos, according to the weather data of the software. As it is demonstrated, during the summer months the solar radiation is higher, reaching a value of 7.5 KWh/m^2 compared to the winter months (with the lower value reported in December at 3.8 kWh/m^2).

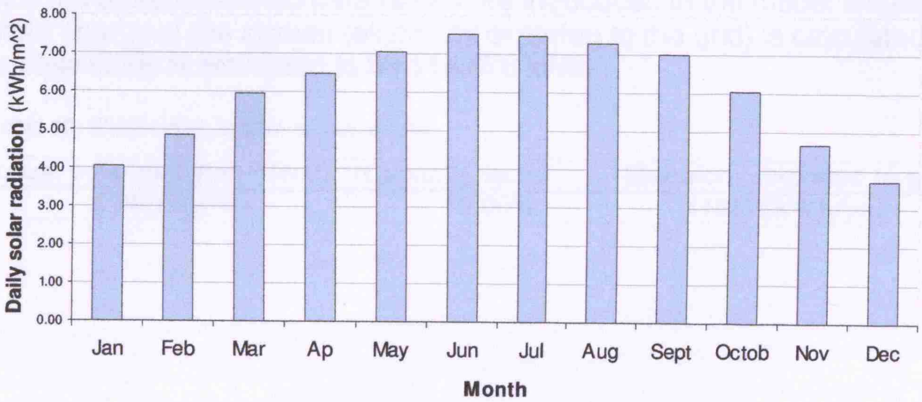


Figure 23: Daily solar radiation per month in Paphos

Certain parameters concerning the installation of the PV system were introduced in the calculation sheets, in order to calculate the PV system's output energy, as it is illustrated in table15. The complete calculation model sheets are presented in Appendix II.

Table 15: Parameters entered in RETScreen International Software

Start Sheet		
Project Information		
Project type	Power	
Technology	Photovoltaic	
Grid-type	Central-grid	
Site reference conditions		
Climate data location	Paphos	
Energy Model sheet		
Resource assessment		
Slope	30° (optimum angle for yearly operation)	
Azimuth	0°	
Photovoltaic (By specifying the product from a given product database and the number of units. The rest information is given by the manufacturer)		
Type	poly-Si	
Power capacity	68kW	
Manufacturer	BP Solar	
Moderl	poly-Si-BP 3160	
Efficiency	12.70%	
Nominal operating cell temperature	45℃	
Temperature coefficient	0.40%	
Solar collector area	535m²	
Miscellaneous losses	5%	425 units
Inverter		
Efiiciency	90% (maximum)	
Miscellaneous losses	0%	

Once the aforementioned parameters are introduced in the model sheets, the output energy of the system (electricity exported to the grid) is calculated. For the case study is estimated to be 118,676 kWh.

Table 16: Photovoltaic system output results

Annual solar radiation (tilted)	Capacity factor	Electricity exported to grid
2.2MWh/m²	19.90%	**118676kWh/year**

5.4.3 PV system greenhouse gas emission reduction analysis

Emission analysis spreadsheet, included in the RETScreen International Clean Energy Project Analysis Software is used to perform the greenhouse gas emission reduction analysis. The software calculates the annual greenhouse gas emission reduction for a clean energy technology, (PV in this particular study) compared to a conventional technology base case.

Results are presented in terms of the tonnes of carbon dioxide per year that would be equivalent to the emission reduction, regardless to the actual gases that compose the emissions. In order to achieve this, methane and nitrous oxide emissions are converted to the equivalent carbon dioxide emissions in terms of their global warming potential. (Retscreen Software, 2008)

RETScreen compares energy produced by PVs to a baseline; emissions emitted from an electricity system. The emission analysis spreadsheet offers the possibility to select the country where the PVs are going to be installed and thus the GHG emission factor in t_{co2}/MWh is defined for the base case system.

Fuel types for the electricity production and transmission and distribution losses between the plant and the end user were also defined. Electricity production in Cyprus is totally based on oil sources. According to the Electricity Authority of Cyprus (EAC), transmission and distribution losses are estimated to be 5%.

In the proposed photovoltaic system, GHG emission factor is set to 0%, assuming that PVs do not produce any GHG emissions. A value for the GHG credits transaction fee is also needed in order for the results to be produced. The Electricity Authority of Cyprus (EAC) is collecting a small tax (0.22 €/KWh, about 2.5%) on electrical consumption. The net GHG emission reduction is then calculated equal to 92.8 t_{co2}. The complete calculation model sheets are presented in Appendix II.

Table 17: GHG emission reduction results

Base case GHG emission factor	Proposed case GHG emiision factor	Net annual GHG emission reduction
0.758 tco2/MWh	0.00 tco2/MWh	92.8 tco2/year

5.4.4 Economic Payback period

Simple Payback period

Economic payback period is defined as the length of time it will take to earn back the money invested in a project. Therefore, in order to calculate the economic payback period of the PV system, both the annual financial savings that the system returns and the total cost of the photovoltaic system must be defined.

The **total capital cost** of the photovoltaic system is estimated to approximately 390,600€, including VAT, as it is illustrated in table 18.

Table 18: PV installation estimated breakdown costs (Advice from the director of 'Solar Technologies', a company undertaking PV installations in Paphos)

Equipment	**Quantity**	**Cost (€)**	Total cost(€)
1.PV panels	425	800	340000
2. Inverter	7	3500	24500
3. Profile support			14300
4. Electical accessories (junction box-plastic pipe cables for PVs - isolator - fused)			2900
5. Complete study			300
6. Installation & Connection to the grid			8600
TOTAL COST			**390600**

Assuming that the photovoltaic system will cover 10% of the total 133,967 kWh/yr consumed (26,525€), then 13,397 kWh (2,652€) have to be covered by the photovoltaic system.

The output energy of the photovoltaic system is equal to 118,676 kWh/year. The energy generated is more than the 10% (13,397 kWh) consumed. Therefore, the surplus 105,279 kWh is sold back to the grid at a value of 0.198 €/KWh (feed-in tariffs). The **annual savings** are in total 23,497 €/KWh.

The simple economic payback period is given by the following formula

P=C/S, where P: simple payback period (yrs)

C: capital cost (€)

S: annual savings (€)

As it is illustrated in table 19, the simple payback time is calculated to be 16.6 years, without any grants taken into account.

Table 19: Simple payback period of the PV system

Capital cost	Annual savings	Simple payback period
390,600 €	23,497 €	16.6 years

Simple Payback period with Net Present Cost

The net present cost (NPC) of a system is the worth of the financial investment and it is defined by the initial capita cost plus the discounted annual running cost (fuel and maintenance costs) over the lifetime of the system.

$$NPC = C + R\sum_{t=1}^{t=n}\frac{(1+f)^t}{(1+i)^t}$$

C: Capital Cost of measure (€)

R: Annual Running Cost (€)

f: Average rate of increase of fuel prices (%)

i: Discount rate(%)

n: lifetime of measure (years)

For a 25 year lifetime of the PV system, the annual running costs are estimated at a value of 2,110 €, assuming that the inverters will be replaced every ten years and that the electrical inspection of the installation will cost at about 150€/yr. Taking f equal to 0 and assuming a social discount rate of 10%, the net present cost of the system is calculated to be 409,750. Therefore the payback period with NPC is slightly increased to 17.5 years, when the net present cost is considered.

Table 20: Simple payback period with NPC

Capital cost	Annual running cost	Lifetime	Social discount rate	NPC	Simple Payback with NPC
390,600 €	2,110 €	25 years	10%	409750	17.5 years

5.4.5 Energy Payback period

Energy payback period can be defined as the time necessary for a photovoltaic panel to generate the energy equivalent to that used to produce it. The energy payback period of a photovoltaic panel is therefore determined by two parameters: how it is produced and how it is implemented. The energy required to produce the product (known as the embodied energy) refers to the energy required to source the materials, transport them and manufacture them. (Knapp and Jester, 2001)

Literature review

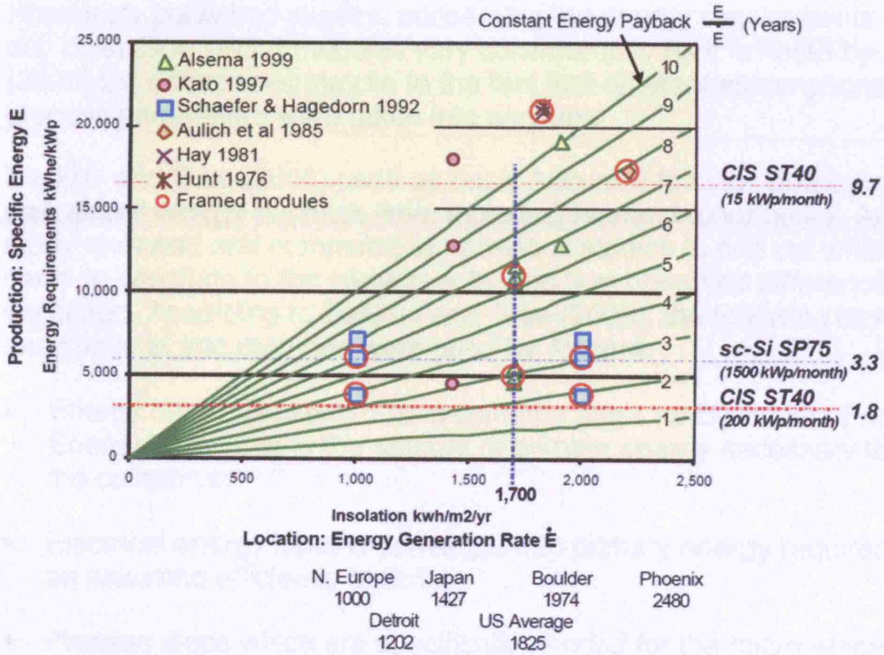


Figure 24: Specific Energy and Energy Generation Rate relationship to energy payback time (Knapp and Jester, 2001)

Figure 24 illustrates several reported results for various technologies, system types and locations. The first research in this area was published by Hunt who estimated the payback time for just the cell (2" diameter with yields around 18%) to 11.6 years. Hay calculated the payback time to 11.4 years and pushed early into investigating other technologies such as ribbon silicon, a-Si and CdS:CuS as they looked more favorable at the time.

One of the key contributors to the energy payback field is E. Alsema. He estimated for a current sc-Si technology modules the payback time ranging from a low of 2.9 to a high of 6.5 years (at 1700 kWh/ m^2). He also expands the discussion for possible future paths for solar silicon production comparing it to thin film estimates for energy payback.

Palz and Zibetta, including process energy only, arrived at an understandably favourable payback time of less than two years for polycrystalline or monocrystalline modules.

Keoleian and Lewis focus on the payback time of amorphous silicon, providing some good data but they seem to overstate the 2-7 year payback time. Aulish provides useful data for raw materials use and alternate silicon production and wafering process, as well as potential module designs, estimating payback time of 8 years for the then-current technology. (Knapp and Jester, 2001)

Calculation of energy payback time

Previously published studies, concerning the energy requirements of present day crystalline silicon modules vary considerably. As it is noted by Alsema (2000) the differences may lie to the fact that different assumptions for process parameters were taken into account.

Bankier and Gale (2006) used as basis Alsema's findings and estimated their own actual energy payback time, including human labour factor. Alsema's study reviewed and compared ten previous studies to find out which data seem to conclude to the same results and how observed differences may be explained. According to Bankier and Gale (2006), the following key assumptions and methods were used by Alsema:

- Energy data is presented on a common basis as Equivalent Primary Energy Units, that is the amount of primary energy necessary to produce the component
- Electrical energy input is converted into primary energy requirements with an assumed efficiency of 35%
- Process steps which are specifically needed for the micro-electronics wafers are disregarded
- Lower estimates for process energy consumption are used with the argument that lower quality requirements may lead to reduced energy consumption
- Mc-Si, sc-Si and thin film modules are assumed to have efficiencies of 13, 14 and 7 percent respectively
- The systems are assumed to receive an irradiation of 1700 $kWh/m^2/yr$ and have a performance ratio of 0.75.

However, as it is noted by Bankier and Gale (2006), Alsema's findings haven't accounted the human labour factor. Human labour associated with the construction and operation of the PV plant is regarded as negligible, since it would be spread over thousands of PV module. Nevertheless, the labour for installation of each system would be significant, thus it is included in Bankier's and Gale's (2006) calculations. Embodied energy of human service contributions was calculated using the national fuel share per person and it was found to be 967MJ (rounded to 1000MJ) per worker per day. It was estimated that one tradesman would require one whole working day to install a typical roof-mounted system. Table 21 illustrates the embodied energy per module according to Alsema and the embodied energy per module as it was adjusted by Bankier and Gale.

Table 21: Embodied energy of a module according to Alsema and Bankier and Gale (Bankier and Gale, 2006)

Module Type	Alsema: **Energy Requirement module only** (MJ/m^2)	Alsema: **Energy Requirement module with frame (Al), supports and inverter** (MJ/m^2)	Bankier and Gale: **Energy Requirement module with frame (Al), supports inverter and human labour** (MJ/m^2)
mc-Si	4200	5400	6400
Sc-Si	5700	6900	7900
Thin film	1200	2400	3400

Based on these results the embodied energy for the proposed photovoltaic installation is estimated to be 802,500 kWh.

Table 22: Embodied energy for the proposed PV system

Estimated embodied energy for Poly -Si cells according to Bankier and Gale	Total module area	Total cell embodied energy
5400MJ/m²	535m²	2,889,00MJ or 802,500kWh

The energy payback time of the photovoltaic system can now be calculated using the following formula:

P=Ee/Es, where P: energy payback time (years)

Ee: embodied energy of this system (kWh)

Es: annual energy savings of the system (kWh/year)

A payback period of 6.7 years was found for the specific PV system. As it is obvious the payback period is shorter than the system's lifetime, thus the photovoltaic system saves more energy though its operation than that consumed during its manufacture.

Table 23: Energy payback period

Embodied energy of the system	Annual energy savings of the system	Energy payback period
802,500 kWh	118,676 kWh	6.7years

The following table summarizes the basic parameters of the Photovoltaic installation. After having calculated the various parameters concerning the photovoltaic panels' installation, a discussion and sensitivity analysis is considered necessary. Thus, the following chapter discusses and analyses the effect of various factors concerning the payback period of the photovoltaic system.

Table 24: Summary Table of the Photovoltaic installation

Summary of results	
Type of system	Grid connected, roof system
Type of cells	polycrystallince cells
Total installed power	68kWp
Annual energy output	118,676kWh/yr
Electric consumption of the building	133, 966kWh/yr
10% consumption of the building	13, 396kWh/yr
Annual Co2 savings	92.9tCO2/yr
Embodied energy	802,500kWh
Capital cost	390,600 €
Net present Cost	409,750 €
Annual financial savings	23,497 €
Annual runninc costs	2,110 €
Energy Payback Period	6.7 years
Simple Economic Payback with NPC	17.5 years

6. Discussion and sensitivity analysis

In the previous chapter, various parameters concerning the photovoltaic installation on the roof were calculated. In order to investigate the viability of this system, various factors that seem to influence the economic payback period are examined in this chapter.

6.1 Discussion

The carbon payback period for the photovoltaic system was found to be 6.7 years, lying within the expected range of payback period calculated by Bankier and Gale (2006). However, Alsema (2000) predicts that energy payback periods will decrease to approximately 2 years by 2010, and even below by 2020, based on technological advances.

The economic payback period with NPC was calculated to be 17.5 years. This value can be considered as a long payback period for a system lifetime of around 25 years. However, it is important to mention that grants were not included in the calculations. Various sensitivity factors, influencing the economic payback period of the photovoltaic installation are examined in the next chapter. The factors considered in the sensitivity analysis include:

- Financial grants
- Climate change
- Capital cost
- Future electricity prices

6.2 Sensitivity analysis

6.2.1 Financial grants

According to the currently grant scheme, grants do not concern photovoltaic installations over 20kW. However, as it was mentioned the new grant scheme, promoted by the council of ministers, concerns PVs installation up to 100kW and a new feed-in tariff of 0.44€ for household, other entities and organizations not engaged in economic activities.

If an investment grant (max 55%) is taken the tariff is 0.239€/kWh. It is predicted that this new Grant scheme will be accepted and implemented during 2008. As it is illustrated in table 25, it is obvious that grants make an investment on PVs much more profitable. Payback time is now reduced to 7 years.

Table 25: Payback period with NPC for two different scenarios: **1st** -excluding grants but with feed-in tariff of 0.44€, **2nd** – including a 55% investment grant and a feed-in tariff of 0.239€

Net Present Capital cost (€)	Price of electricity sold to the grid (€)	Grant (%)	Annual savings (€)	Simple payback period with NPC years
409750	0.198	0%	23497	17.5
409750	0.44	0%	48974	8.4
194920	0.239	55%	27814	7.0

6.2.2 Climate change

As it was mentioned during the last century, there has been a total increase of 0.5°C in temperature on the island, due to global warming. It is predicted that the temperature will increase further, and solar radiation will become even higher. As a consequence, the output energy of the photovoltaic system will be higher, thus it will cover a higher percentage of the building's energy consumption.

However, the fact that photovoltaic performance declines in very high temperatures, should not be neglected. Furthermore, cooling loads will increase due to the high temperatures observed in summer. Nevertheless, economic payback period is regarded to decrease; considering the fact that payback period for a photovoltaic system in southern Europe is much lower than a photovoltaic system in northern Europe, due to the higher solar radiation.

6.2.3 Capital cost

One of the most significant factors, influencing the economic payback period of a photovoltaic system is its capital cost. The current capital costs of photovoltaic systems are very high, excluding governmental subsidies. The capital costs have to be reduced further, in order to reach a level where subsidies will not be required.

As it illustrated in figure 25, module cost has decreased significantly from 1975 to 2006. The photovoltaic module's price is predicted to decrease even more as new technologies are discovered.

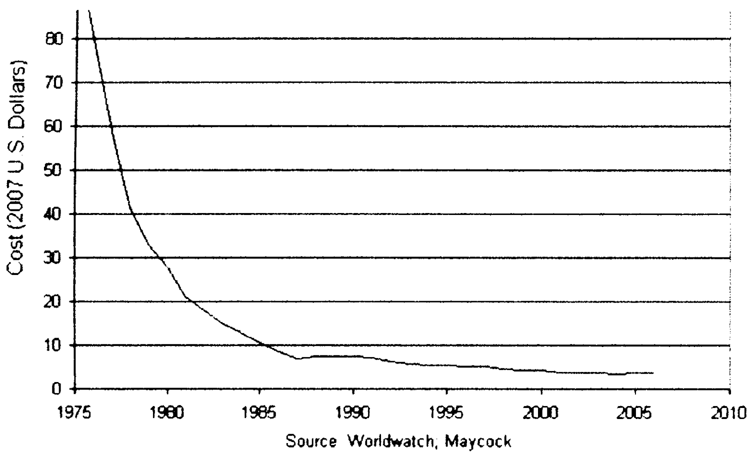


Figure 25: World average Photovoltaic Module Cost per Watt 1975-2006 (Earth Policy Institute, 2007)

Table 26 demonstrates the effect of the reduction of capital cost, according to various scenarios. The economic payback period of a system is reduced from 17.5 to 10.8 years, when the capital cost falls to 60% of its current value.

Table 26: Payback periods for different capital cost scenarios

Current economic payback time	10% reduction in capital cost	20% reduction in capital cost	30% reduction in capital cost	40% reduction in capital cost
17.5 years	15.8	14.1	12.5	10.8

6.2.4 Future electricity prices

The payback period is also dependent on electricity rates. At present, electricity in Cyprus is sold in a price of 0.198€. Cyprus electricity system is totally based on oil imports. In the previous years, the increasing price of oil has in turn contributed to an increase in electricity prices. It is important to mention that according to Eurostat (2006) the price of electricity increased by approximately 50% between the years 2000 and 2006. An increase of around 30% has been observed between 2005 and 2006.

Assuming a 30% rate of increase in the electricity prices, the economic payback period of the system is reduced to 13.4years. Table 27 illustrates the results for a further 40% and 50% increase.

Table 27: Payback periods for different future electricity prices

Current payback time	30% increase in constant electricit price rate	40% increase in constant electricit price rate	50% increase in constant electricit price rate
17.4 years	13.4 years	12.5 years	11.5 years

It is obvious that the aforementioned factors make the installation of the proposed photovoltaic system much more profitable. The benefits concerning the exploitation of photovoltaic power in Paphos and in Cyprus generally are summarized in the next chapter. Furthermore, the chapter concludes with a discussion regarding the application of a relative Merton Rule or not in Cyprus.

7. Conclusions

The consequences of global warming are more evident than ever. Measures have to be taken by all sectors that contribute to the greenhouse effect and its catastrophic results in order for global warming to be mitigated. The development of a more sustainable, ecological built environment can be one of the major steps, since building sector is responsible for approximately 40% of greenhouse gas emissions.

The use of renewable energy sources must be included in the design process of the projects, as a step to the reduction of greenhouse gas emissions. One of the most promising renewable energy technologies is photovoltaic power. The global PV market has increased during the last century, estimating to reach a value of 5.6 GW by the year 2010.

However, in Cyprus, solar energy collected by photovoltaics has just started to be exploited. As it was mentioned, Cyprus energy supply is totally dependent on oil imports. Oil industry analysts expect increased price pressure on oil as demand outstrips supply. Without a secure and affordable energy supply Cyprus become vulnerable to economic and societal decay.

Moreover, power stations are a major source of air pollution, from poor air quality and acid rain, to global warming. The burning of oil in power stations releases a number of air pollutants, including sulphur dioxide, nitrogen oxides and carbon dioxide.

In order to continue to enjoy the comforts that are taken for granted, photovoltaic power must become the cornerstone of the design philosophy in Cyprus. Instead of using less of the non-renewable fuels and creating less pollution, sustainable buildings that rely on renewable resources must be designed. We are now at a critical threshold where action must replace rhetoric.

Using the proposed design of the city hall of Paphos as a case study, it was found that photovoltaic technology has the potential to contribute significantly to electricity supply. Significant reductions in CO_2 emissions can be made through the installation of photovoltaic modules. The energy payback period for the photovoltaic roof was found to be 6.7 years. However, it is expected that with technological improvements, energy payback period will be reduced further in the future.

Concerning the economic payback period, was found to be 17.5, when no grants and feed-in tariff were included. Taking into account the available grants and the feed-in tariff the payback period is reduced to 7 years. Different scenarios for future electricity rates and capital costs where examined. In each case the PV system's payback time is within its lifetime and it looks even a more profitable investment in the future, considering the predicted decrease in capital cost and the increase of electricity rates.

There is no doubt that PV technology can become a promising alternative source for the production of energy in Cyprus. Yet, it still suffers form problems that need to be solved in order to be widely accepted. Unfortunately there is not enough information regarding the environmental and economic impacts of the photovoltaic technology and the process required to obtain the operation permit is excessively time consuming and cumbersome.

The simplification of the licensing procedure and the organization of seminars regarding the benefits of photovoltaic systems will undoubtedly set the ground for a stronger market in Cyprus to be established. Clearly this is one field of science that Cyprus should be actively involved in, given its ideal geographical position and 300 days of pure sunshine a year.

As it was mentioned in a previous chapter, UK government include in its national planning policy guidance, the Merton Rule, as an attempt to reduce the energy consumed by the building sector. According to the Merton Rule the new non-residential developments have to generate at least 10% of their energy needs from renewable energy equipment. Should Cyprus follow a relative legislation in order to reduce its own CO_2 emissions?

The analysis of the case study shows that 10% of the building's total energy demand can be covered by photovoltaic modules, installed on the roof of the building.

As an EU member, Cyprus has set a target to increase the use of renewable energy sources to 13% by 2020, compared to a 2.9% reported in 2005. Feed-in tariffs and grants are encouraging the aforementioned goal. One can logically set the question: Do those feed-in tarriffs and grants alone have the power to make people succeed the goal, or more incentives need to be taken. It is regarded that the application of Merton Rule can play this role, persuading people and companies to include renewable energy technologies in their future projects.

Introducing a relative legislation in Cyprus will lead individuals and companies to invest in renewable energy technologies. However, a good organization is needed in order to achieve this goal. As mentioned, seminars must be organized by the authorities regarding the benefits of renewable energies. Applying these simple measures will make a relative Merton Rule acceptable and thus Cyprus will make a significant step towards its goal to increase the use of RES to 13% by 2020.

It is clear that installing PV into the built environment offers considerable scope for energy demand offsets and reduction of greenhouse gas emissions. Since "...not only does human-caused global warming exist, but it is also growing more and more dangerous at a pace that has now made it a planetary emergency", governments around the world have to confront this global problem. To conclude, despite the fact that Cyprus as a small country is not producing great amounts of CO2, Cypriots have to set their own battle against global warming.

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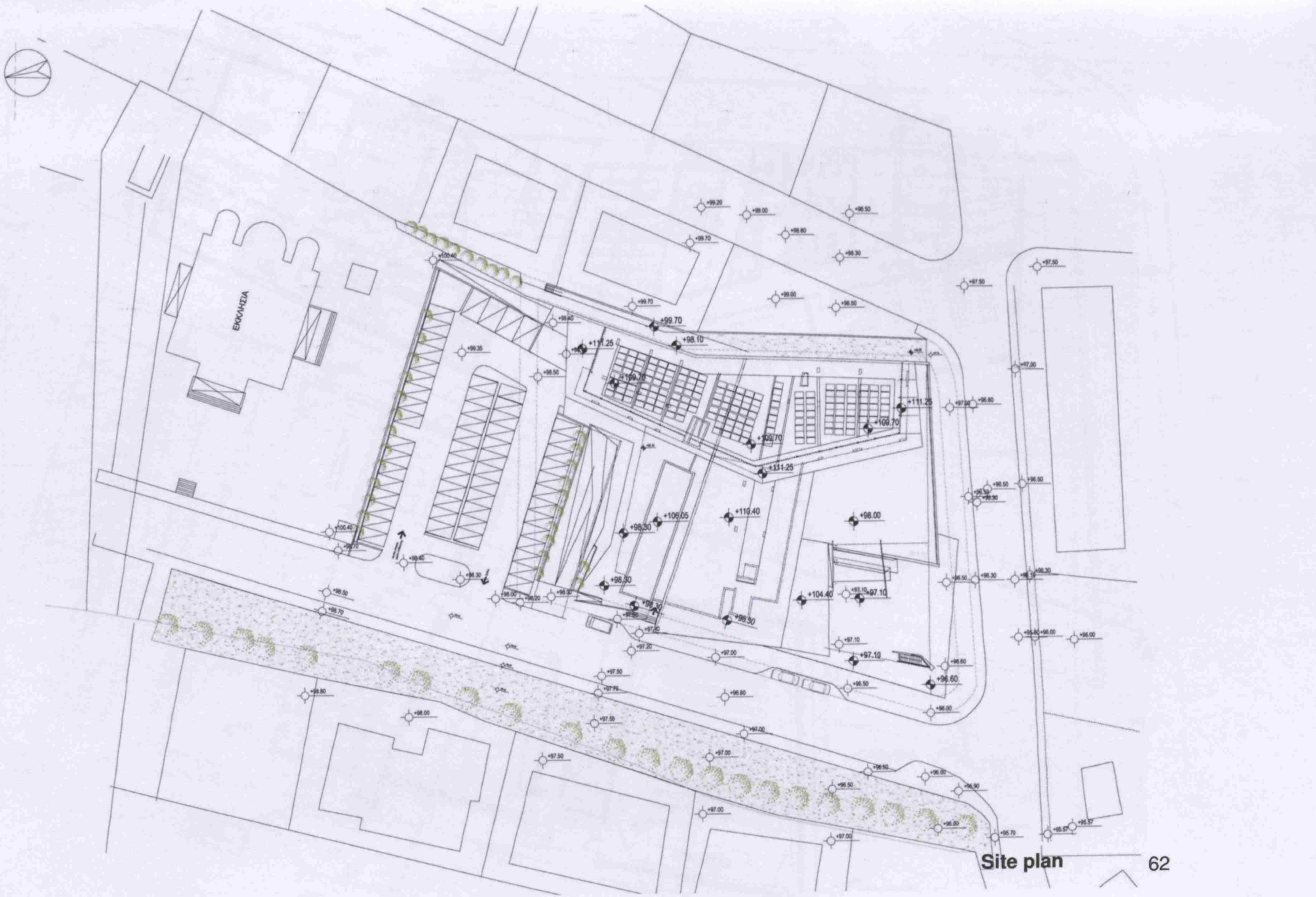
Appendix I:

Drawings of the case study


ΕΚΚΛΗΣΙΑ
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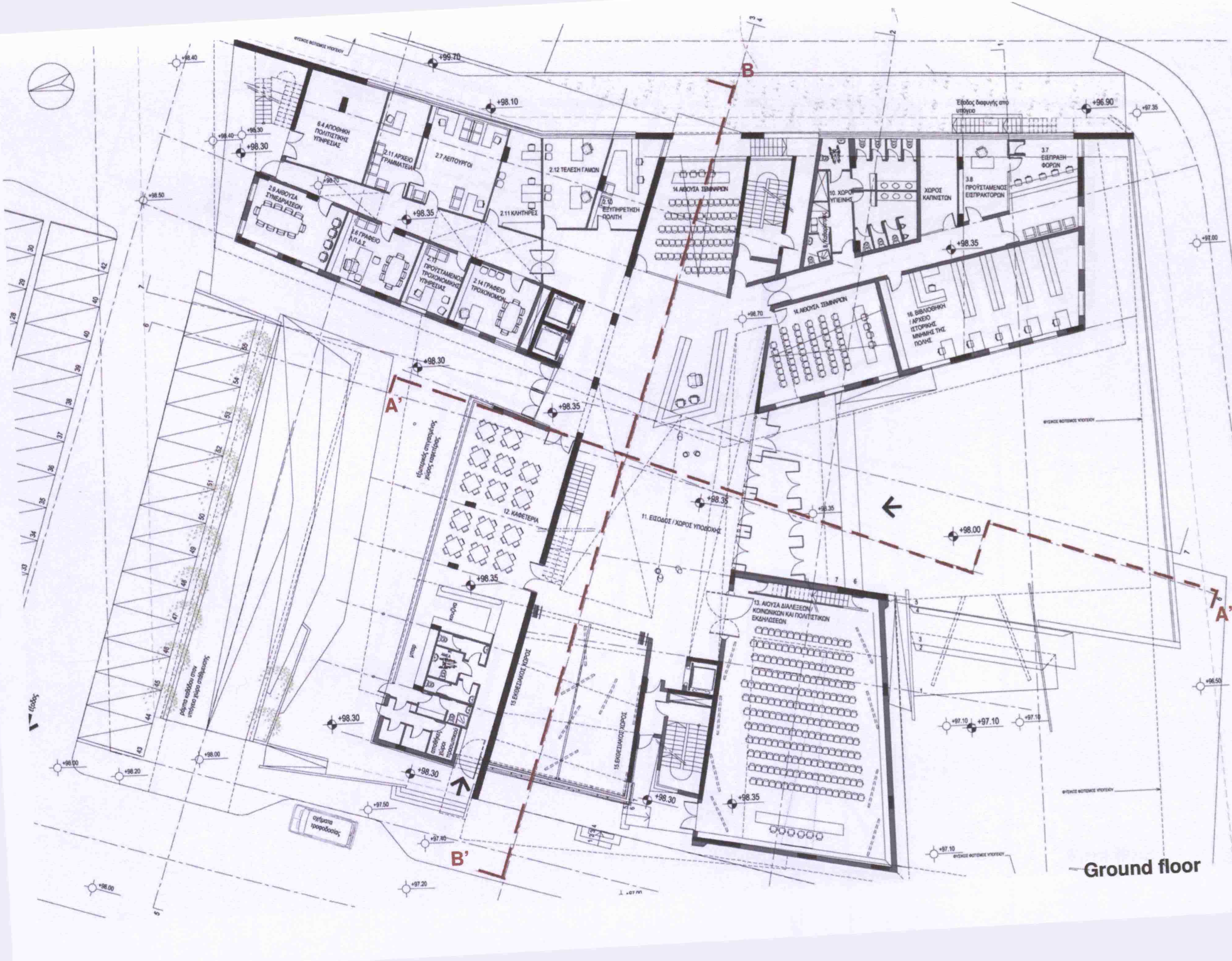
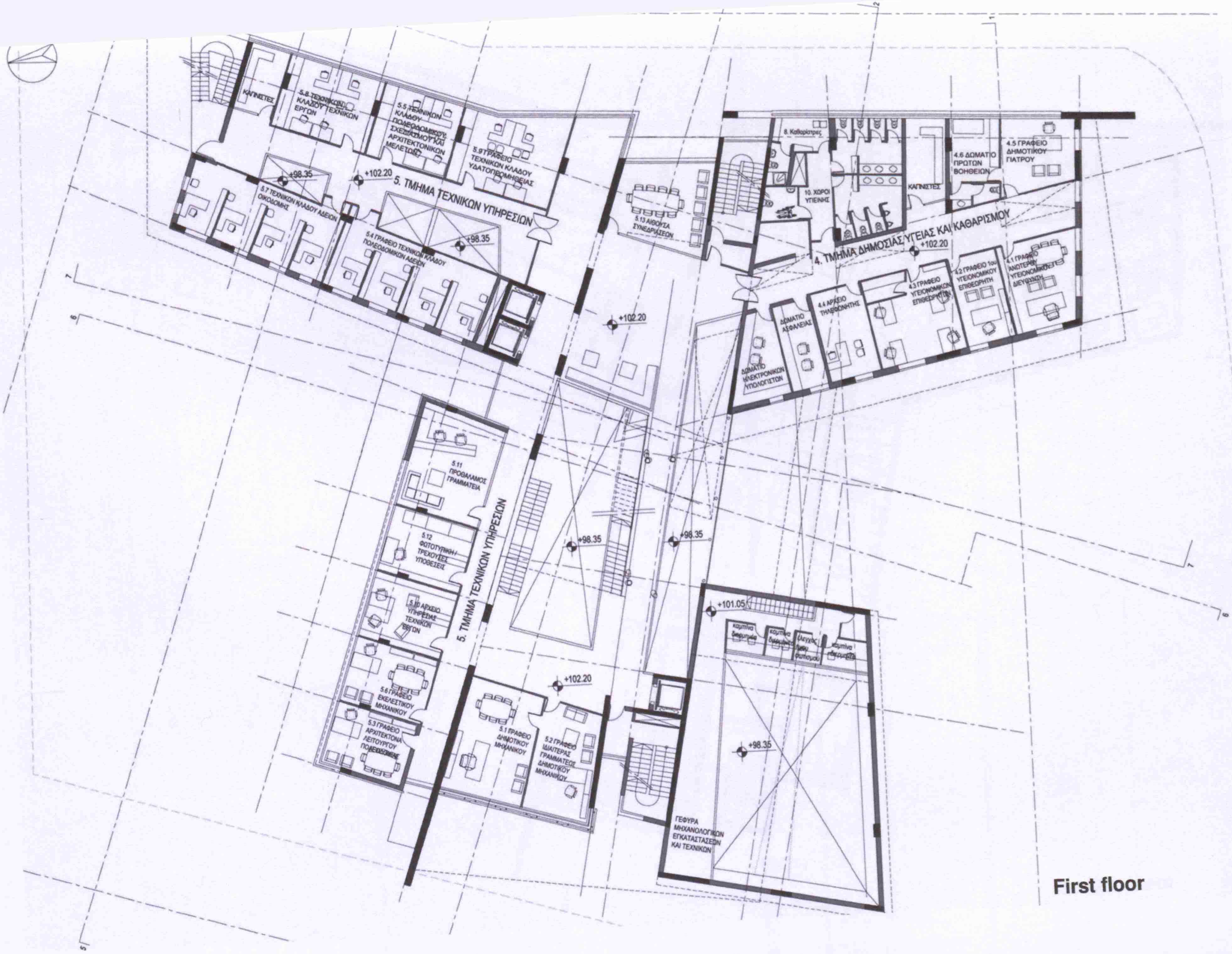
+111.25
+110.40
+106.05
+98.30
+98.00
+98.30
+98.30
+104.40
+97.10
+97.10
+96.60

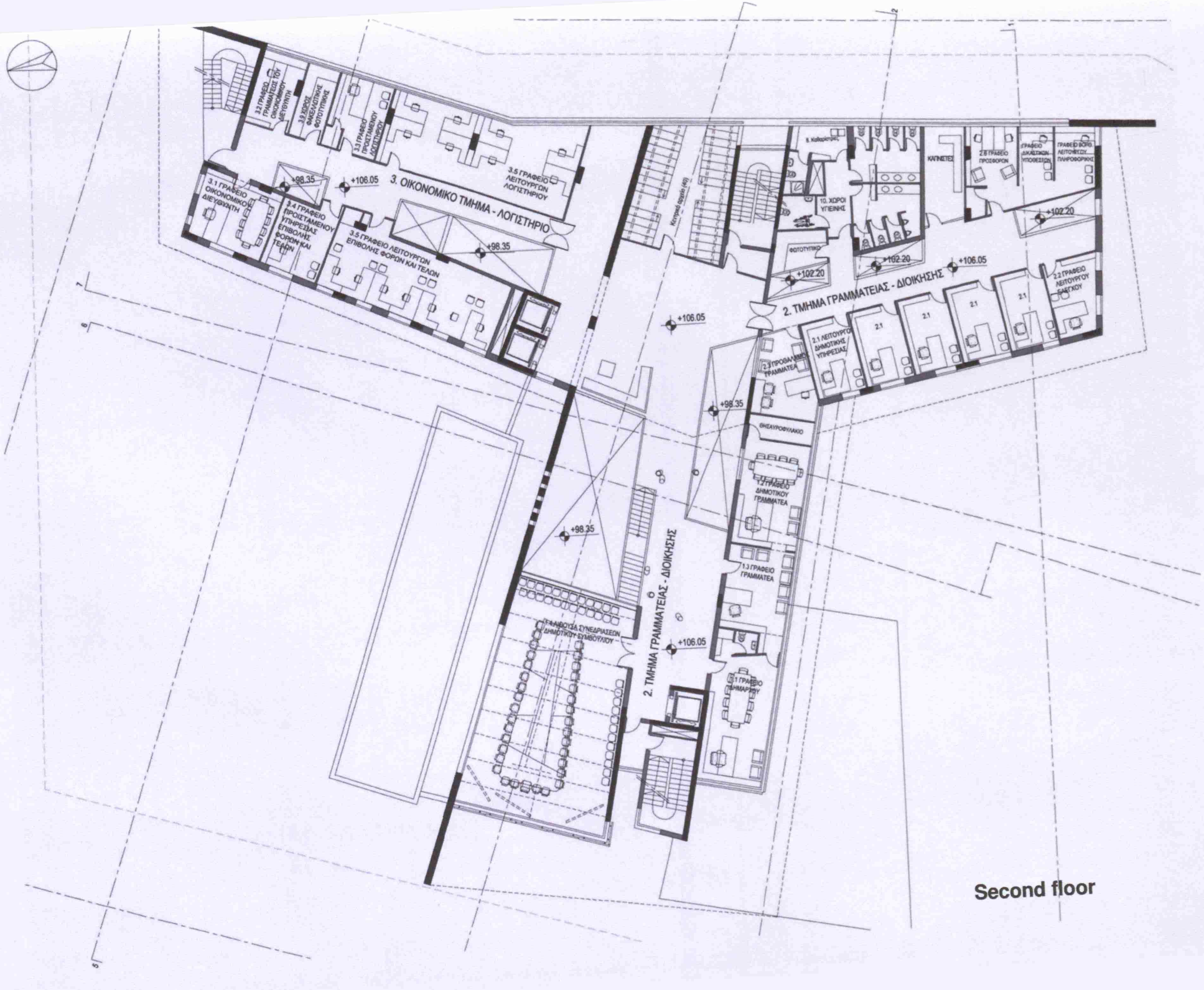
Site plan



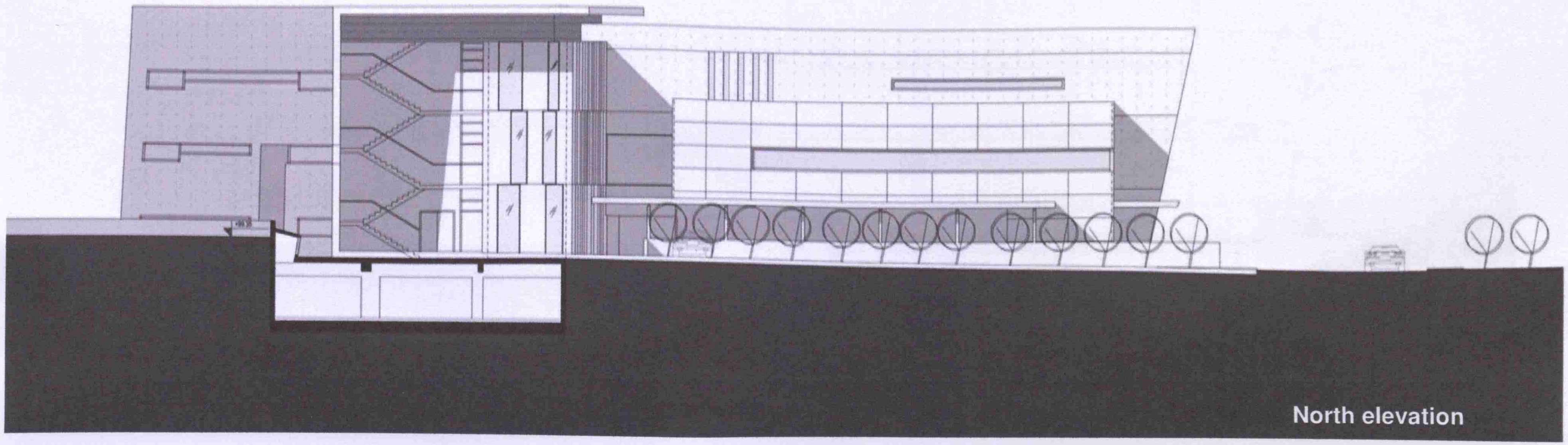
Ground floor


5. ΤΜΗΜΑ ΤΕΧΝΙΚΩΝ ΥΠΗΡΕΣΙΩΝ
4. ΤΜΗΜΑ ΔΗΜΟΣΙΑΣ ΥΓΕΙΑΣ ΚΑΙ ΚΑΘΑΡΙΣΜΟΥ
ΚΑΓΚΙΝΣΕΤΕΣ
5.8 ΤΕΧΝΙΚΩΝ ΚΛΑΔΟΥ ΤΕΧΝΙΚΩΝ ΕΡΓΩΝ
5.5 ΤΕΧΝΙΚΩΝ ΚΛΑΔΟΥ ΠΟΛΕΟΔΟΜΙΚΟΥ ΣΧΕΔΙΑΣΜΟΥ ΚΑΙ ΑΡΧΙΤΕΚΤΟΝΙΚΩΝ ΜΕΛΕΤΩΝ
5.9 ΓΡΑΦΕΙΟ ΤΕΧΝΙΚΩΝ ΚΛΑΔΟΥ ΥΔΑΤΟΠΡΟΜΗΘΕΙΑΣ
5.7 ΤΕΧΝΙΚΩΝ ΚΛΑΔΟΥ ΑΔΕΙΩΝ ΟΙΚΟΔΟΜΗΣ
5.4 ΓΡΑΦΕΙΟ ΤΕΧΝΙΚΩΝ ΚΛΑΔΟΥ ΠΟΛΕΟΔΟΜΙΚΩΝ ΑΔΕΙΩΝ
+98.35
+102.20
5.13 ΑΙΘΟΥΣΑ ΣΥΝΕΔΡΙΑΣΕΩΝ
8. Καθαρίστριες
10. ΧΩΡΟΙ ΥΓΙΕΙΝΗΣ
4.6 ΔΩΜΑΤΙΟ ΠΡΩΤΩΝ ΒΟΗΘΕΙΩΝ
4.5 ΓΡΑΦΕΙΟ ΔΗΜΟΤΙΚΟΥ ΙΑΤΡΟΥ
4.1 ΓΡΑΦΕΙΟ ΑΝΩΤΕΡΗ ΥΓΕΙΟΝΟΜΙΚΟΥ ΔΙΕΥΘΥΝΤΗ
4.2 ΓΡΑΦΕΙΟ 1ου ΥΓΕΙΟΝΟΜΙΚΟΥ ΕΠΙΘΕΩΡΗΤΗ
4.3 ΓΡΑΦΕΙΟ ΥΓΕΙΟΝΟΜΙΚΩΝ ΕΠΙΘΕΩΡΗΤΩΝ
4.4 ΑΡΧΕΙΟ ΤΗΛΕΦΩΝΗΤΗΣ
ΔΩΜΑΤΙΟ ΑΣΦΑΛΕΙΑΣ
ΔΩΜΑΤΙΟ ΗΛΕΚΤΡΟΝΙΚΩΝ ΥΠΟΛΟΓΙΣΤΩΝ
5.11 ΠΡΟΘΑΛΑΜΟΣ ΓΡΑΜΜΑΤΕΙΑ
5.12 ΦΩΤΟΤΥΠΙΚΗ / ΤΡΕΧΟΥΣΕΣ ΥΠΟΘΕΣΕΙΣ
5.10 ΑΡΧΕΙΟ ΥΠΗΡΕΣΙΑΣ ΤΕΧΝΙΚΩΝ ΕΡΓΩΝ
5.6 ΓΡΑΦΕΙΟ ΕΚΤΕΛΕΣΤΙΚΟΥ ΜΗΧΑΝΙΚΟΥ
5.3 ΓΡΑΦΕΙΟ ΑΡΧΙΤΕΚΤΟΝΑ ΛΕΙΤΟΥΡΓΟΥ ΠΟΛΕΟΔΟΜΙΑΣ
5.1 ΓΡΑΦΕΙΟ ΔΗΜΟΤΙΚΟΥ ΜΗΧΑΝΙΚΟΥ
5.2 ΓΡΑΦΕΙΟ ΙΔΙΑΙΤΕΡΑΣ ΓΡΑΜΜΑΤΕΩΣ ΔΗΜΟΤΙΚΟΥ ΜΗΧΑΝΙΚΟΥ
+101.05
ΓΕΦΥΡΑ ΜΗΧΑΝΟΛΟΓΙΚΩΝ ΕΓΚΑΤΑΣΤΑΣΕΩΝ ΚΑΙ ΤΕΧΝΙΚΩΝ

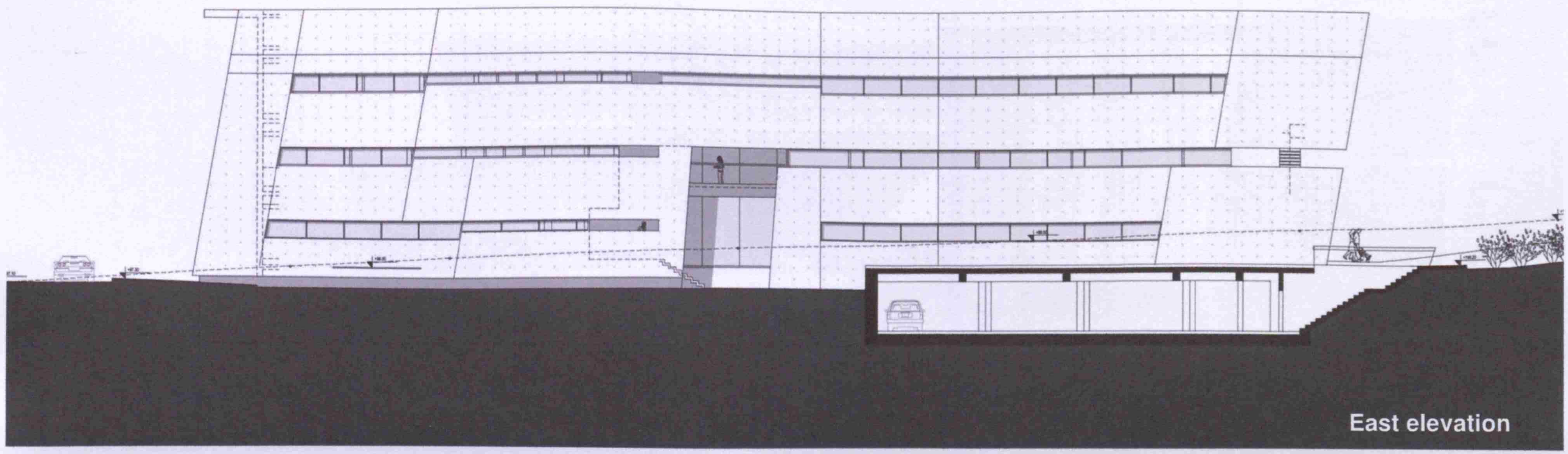
First floor



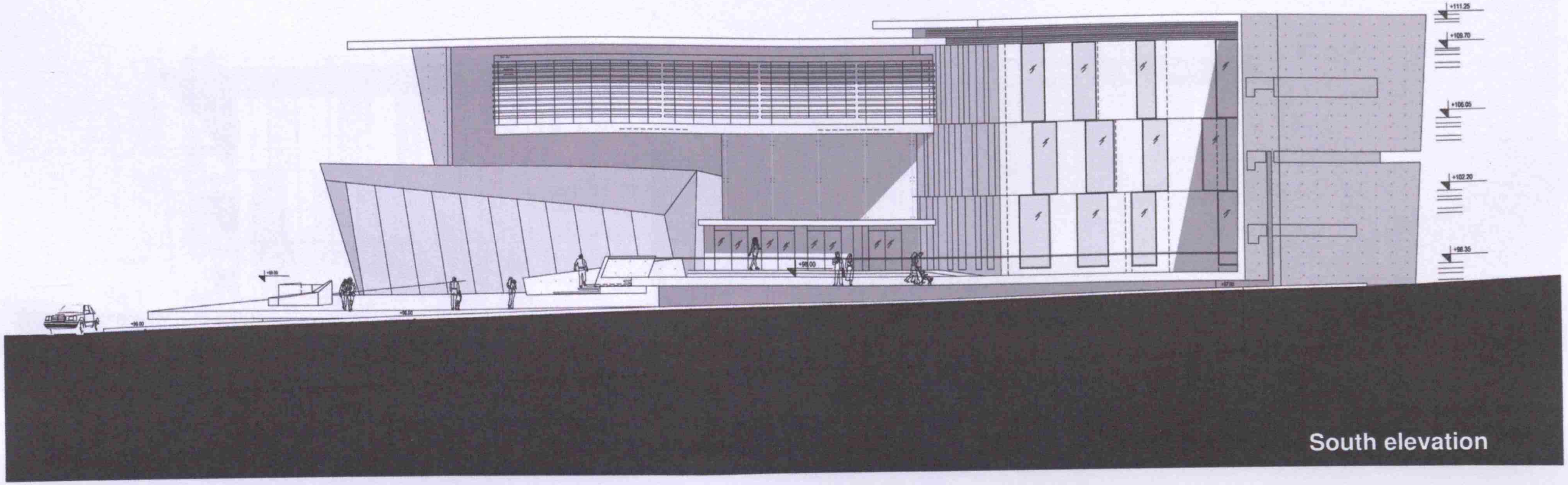
Second floor



North elevation

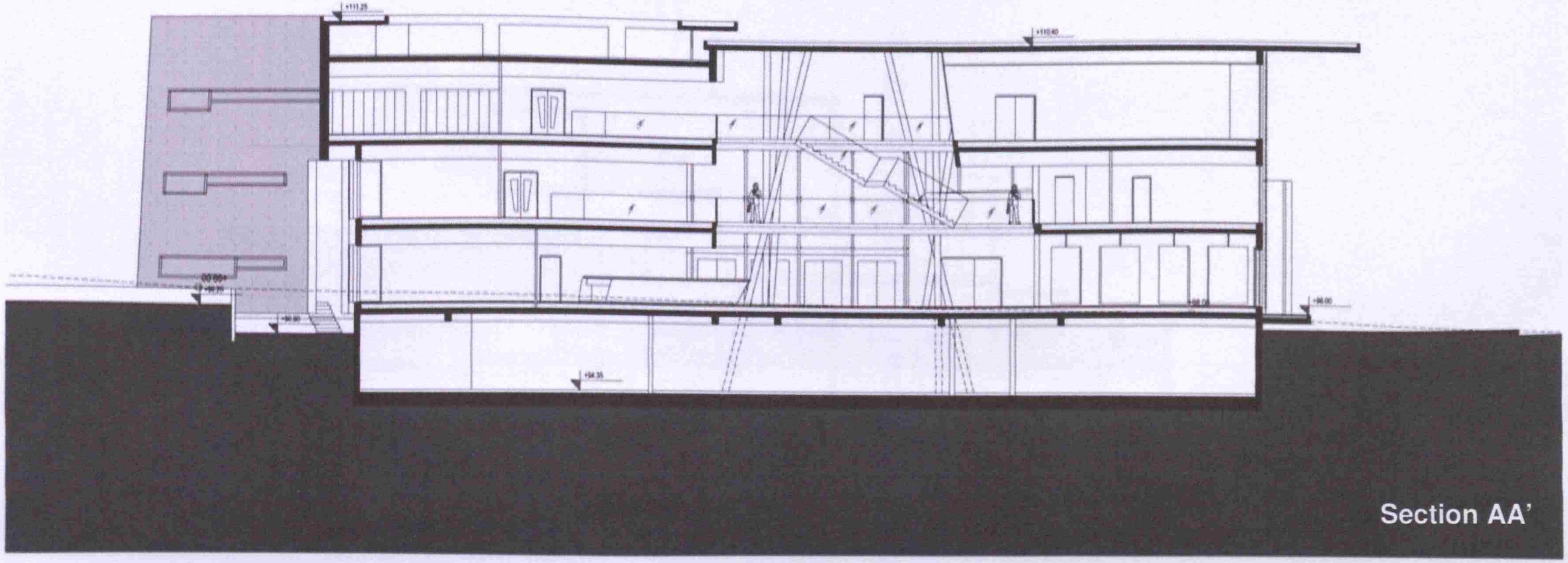


East elevation

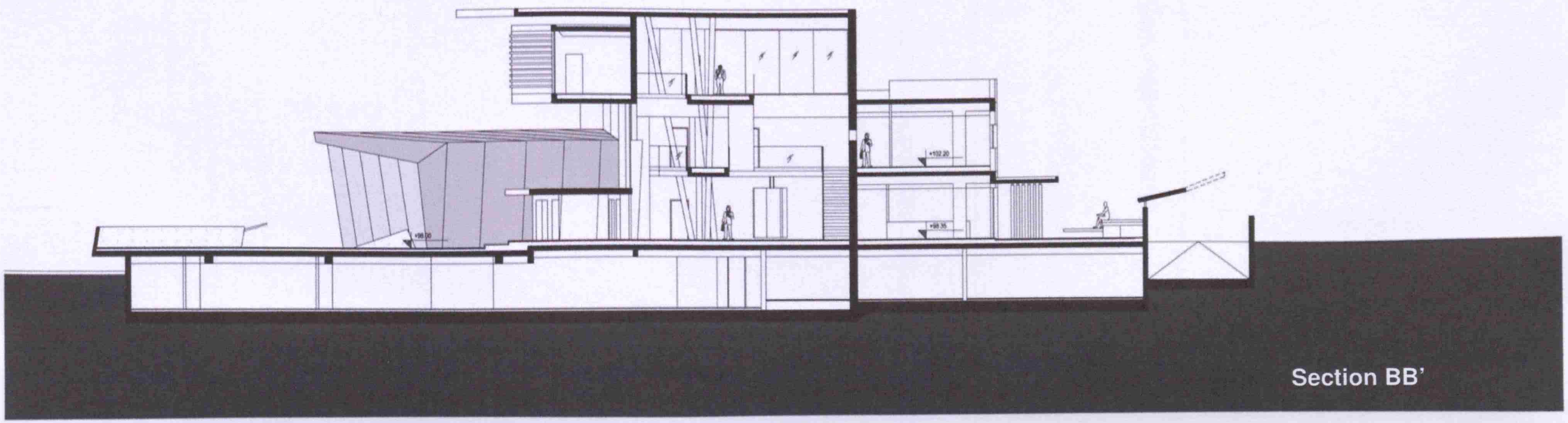


South elevation

West elevation



Section AA'



Section BB'

Appendix II:

Retscreen International Calculation Sheets

Natural Resources Canada | Ressources naturelles Canada | Canada

RETScreen® International

www.retscreen.net

Clean Energy Project Analysis Software

Project information

See project database

Project name	Proposed city hall of Paphos
Project location	Paphos
Prepared for	
Prepared by	
Project type	Power
Technology	Photovoltaic
Grid type	Central-grid
Analysis type	Method 1
Heating value reference	Higher heating value (HHV)
Show settings	☐

Site reference conditions

Select climate data location

Climate data location	Paphos/Baf Intl
Show data	☑

	Unit	Climate data location	Project location
Latitude	°N	34.7	34.7
Longitude	°E	32.5	32.5
Elevation	m	8	8
Heating design temperature	°C	5.8	
Cooling design temperature	°C	30.2	
Earth temperature amplitude	°C	14.5	

Month		Air temperature	Relative humidity	Daily solar radiation - horizontal	Atmospheric pressure	Wind speed	Earth temperature	Heating degree-days	Cooling degree-days
		°C	%	kWh/m²/d	kPa	m/s	°C	°C-d	°C-d
January		12.2	71.9%	2.74	100.8	4.1	14.6	180	68
February		12.1	70.7%	3.70	100.7	4.4	14.6	165	59
March		13.4	72.5%	5.11	100.6	4.2	16.6	143	105
April		16.5	71.7%	6.28	100.4	4.0	20.2	45	195
May		19.8	73.1%	7.46	100.3	3.6	24.3	0	304
June		23.2	74.7%	8.40	100.1	3.3	28.7	0	396
July		25.6	75.0%	8.14	99.8	3.2	31.9	0	484
August		26.0	74.9%	7.32	99.9	3.1	32.0	0	496
September		24.1	70.6%	6.23	100.2	3.3	29.4	0	423
October		21.2	66.5%	4.66	100.6	3.5	25.3	0	347
November		17.0	68.1%	3.21	100.8	3.8	20.2	30	210
December		13.8	71.4%	2.45	100.9	4.0	16.1	130	118
Annual		18.8	71.8%	5.48	100.4	3.7	22.9	693	3,205
Measured at	m					10.0	0.0		

NASA UNEP GEF reeep

Complete Energy Model sheet

RETScreen Energy Model - Power project

☐ Show alternative units

Proposed case power system | **Incremental initial costs**

Technology		Photovoltaic	
Analysis type		Method 1	
		Method 2	
Resource assessment			
Solar tracking mode		Fixed	
Slope	°	30.0	
Azimuth	°	0.0	

☑ Show data

Month	Daily solar radiation - horizontal kWh/m²/d	Daily solar radiation - tilted kWh/m²/d	Electricity export rate $/MWh	Electricity exported to grid MWh
January	2.74	4.04	0.0	7.096
February	3.70	4.88	0.0	7.689
March	5.11	5.96	0.0	10.270
April	6.28	6.49	0.0	10.664
May	7.46	7.03	0.0	11.728
June	8.40	7.55	0.0	11.955
July	8.14	7.47	0.0	12.092
August	7.32	7.30	0.0	11.789
September	6.23	7.02	0.0	11.059
October	4.66	6.05	0.0	10.050
November	3.21	4.69	0.0	7.764
December	2.45	3.73	0.0	6.521
Annual	**5.48**	**6.02**	**0.00**	**118.676**

Annual solar radiation - horizontal	MWh/m²	2.00	
Annual solar radiation - tilted	MWh/m²	2.20	
Photovoltaic			
Type		poly-Si	
Power capacity	kW	68.00	$ -
Manufacturer		BP Solar	
Model		poly-Si - BP 3160 S	425 unit(s)
Efficiency	%	12.7%	
Nominal operating cell temperature	°C	45	
Temperature coefficient	% / °C	0.40%	
Solar collector area	m²	535	
Miscellaneous losses	%	5.0%	
Inverter			
Efficiency	%	90.0%	
Capacity	kW	100.0	
Miscellaneous losses	%	0.0%	
Summary			
Capacity factor	%	19.9%	
Electricity exported to grid	MWh	118.676	

See product database

☑ Emission Analysis

Base case electricity system (Baseline) Country - region	Fuel type	GHG emission factor (excl. T&D) tCO2/MWh	T&D losses %	GHG emission factor tCO2/MWh
Cyprus	All types	0.758	5.0%	0.798

Electricity exported to grid	MWh	119	T&D losses	0.0%	
GHG emission					
Base case	tCO2	94.7			
Proposed case	tCO2	0.0			
Gross annual GHG emission reduction	tCO2	94.7			
GHG credits transaction fee	%	2.0%			
Net annual GHG emission reduction	tCO2	92.8	is equivalent to	18.9	Cars & light trucks not used
GHG reduction income					
GHG reduction credit rate	$/tCO2				