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“POTENTIAL RENEWABLE STRATEGY IN GREECE”

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ABSTRACT

The subject of the thesis is to investigate a potential renewable strategy for the future in Greece. The main concern is to suggest ways for energy saving and minimise cooling energy demands and carbon emissions in private residences. It investigates the prospect of a more promising and efficient new development in the field of passive cooling and low energy cooling. It looks at ground cooling using earth-to-air heat exchangers but also covers photovoltaic systems. It determines the possible green electricity output of PV systems which could be used for air conditioning.

Initially, an overview of completely natural cooling methods and low energy methods took place. Moreover information for ground and solar energy was included for improving indoor comfort and external environment.

A complete model of a building was created and simulated in an ESP-r environment according to the Greek climate and modern building characteristics. The building was built very recently and is located in the suburbs of Athens. The implementation of PV panels and earth-to-air heat exchangers was investigated. The results of the energy demands and carbon emissions, before and after implementing the above renewable technologies, were compared and examined. A validation of the two technologies appeared to make an improvement in energy efficiency and a reduction in carbon emissions.

Chapter 1 Project Overview

1.1 Introduction

Buildings are responsible for 40-50% of total energy consumption in Europe, about two thirds of this amount is used in private buildings. [1]. In Greece, the use of energy in public and private buildings, constitutes 30% of total national energy demand and contributes about 40% of carbon dioxide emissions [2]. The heating and cooling of buildings consumes the largest amount of domestic energy use [3].

Unfortunately in Greece the last three decades, the ambient temperatures have risen [4] and will continue to rise because of the greenhouse effect. Sales of air conditioning systems rose dramatically in those years. Air conditioning units operate to cool the interior environment, yet in doing so they heat the exterior environment, increasing demand for cooling. Hot summers and cooling requirements are becoming critical factors. The more temperatures during the summer increase the more dependent Greece becomes on cooling methods.

Air conditioning units consume vast amounts of electricity. The electricity increase becomes more obvious every year. Public Power Corporation (PPC S.A.) in Greece, the company that produces and supplies electricity to all the country is unable to meet electricity demand. During the summer months electricity production often collapses, leaving areas of Athens without power causing serious problems to the public.

Increased use of air conditioning creates not only a serious peak electricity load problem but increases the cost of electricity which is a serious problem for the economy.

The environmental impact of air conditioning equipment is very considerable. Air conditioning ‘is uniquely catastrophic from an environmental point of view, since it can contribute directly to atmospheric ozone depletion through the leakage of harmful refrigerants. Moreover, it contributes directly to global warming through the leakage of refrigerants which are powerful greenhouse gases. And, finally it contributes to global warming by consuming large amounts of electricity and indirectly releases large quantities of carbon into the atmosphere.' [5]

It is evident that alternative renewable solutions to the problem have to be adopted soon not only in Greece but in all countries with similar problems in order to improve global environmental conditions.

The reduction of energy consumption in buildings can be achieved by using an appropriate building design and energy efficient systems and technologies.

1.2 Building characteristics

In this project a Greek residence was examined with the following characteristics:

1. Built by the end of 2007;
2. Located in Kapandriti, Athens, a small town 35km north of Athens (Latitude = 37°58´N, longitude = 23°43´E and altitude = 356 m);
3. 256m² floor area and 800m³ volume;
4. The occupancy is a typical family consisting of 4 people;
5. East-west direction and setting most of the windows in the south of the building;
6. Two-storied dwelling; with the ground floor semi-underground and very small windows; and the first floor with large windows and balconies that work as shading areas to the ground floor;
7. A living-room, a kitchen and three bedrooms on the ground floor and basement usually unoccupied (garage and storage space).
8. Non separated kitchen (provides heating most of the time) to the living room;
9. Double glazing high performance windows;
10. Construction of high roofed building; (good air tightness and heat recovery ventilation)
11. Use of low conductivity materials for shell walls and high insulation level*.

* Only about 3% of buildings in Greece have been constructed after 1981 (when heat insulation regulations were put into effect), it may be concluded that the limited application of insulation in the majority of residences causes significant energy losses in Greece [15].

The building now is at the final stage of construction but is not occupied at the moment. Despite the fact that the building is very new and has most of the basic techniques to save energy, the owners want to take the next step. They are interested in implementing renewable technologies in order to improve the energy efficiency of the building. The results will be very interesting to show that even new buildings can be much more efficient with natural and alternative methods of cooling.

As the residence already existed it is obvious that it would be difficult to make changes in the building design. An investigation of new potential technologies was carried out but it is important to point out that there is no unique solution. There are plenty of environmental technologies that could be used but it was impossible to examine all. Information of all the renewable solutions that can be applicable to existing buildings and new designs can be found in the literature review.

1.3 Methodology

The special emphasis of this project is utilising energy from the ground and energy from the sun to minimise cooling energy and carbon production relative to the air conditioning technology.

Work is carried out in the following phases:

1. Firstly, the creation of the complete model of the building characteristics in a software programme called “ESP-r” in order to predict the cooling loads in the case of an air conditioned dwelling set at 26°C.

2. Secondly, simulations carried out and results of total cooling requirements found.

3. Thirdly the creation of the complete model of the building after implementing PV panels in ESP-r.
4. Fourthly, simulations carried out and results analysis of potential power output found.
5. Fifthly, the analysis of the ground earth-to-air heat exchanger model took place in Excel in order to determine the minimum outlet temperature of the system that enters the building.
6. A final simulation carried out in ESP-r in order to examine the effect on the temperature inside the building of the ground earth-to-air heat exchangers.

1.4 Why Photovoltaic systems?

Solar radiation is the main natural source of energy. In a single day, the earth receives from the sun an amount of energy greater than that by consumed humanity during one year. This impressive quantity of heat is released to the sky. Absorbing solar energy allows achievement of a pleasing comfort in buildings, with a limited use of conventional fuels [12]. Photovoltaic systems enable us to take advantage of this incredible amount of energy. However, the integration of PV into building architecture in order to make a direct use of solar energy is a challenge. In the integration of solar cell technology into building roofs and facades projects, designing issues and quantification of PV energy contribution are things that need further careful study [13].

The main reason for implementing these renewable systems is because Greece is an extremely sunny country during the summer. We must take advantage of the sun considering that PV panels can be very efficient in these conditions. Air-conditioning units consume very large amounts of electricity, and so it is important that the energy is produced using clean renewable technologies.

Photovoltaic systems can produce electric current which is a direct current (DC) even during cloudy periods. Photovoltaics have a very small weight and are manufactured in order to function in unfavourable conditions [16]. They can be installed easily on the ground, on the roofs of buildings or on any other location where light can reach them easily [16]. The efficiency of photovoltaic power has increased. Over the years engineers have worked to increase the efficiency of photovoltaic power. Today, commonly available solar panels are 12% efficient [11], which is four times greater than only a few years ago. In Greece the solar radiation is approximately 1800kWh/m², a PV panel that might have a peak electrical output of around 3kW (with an area of 30m²) will produce almost 4500kWh/year, and enough to meet a family's demands consisting of 4 people. [16]

Other advantages are the low maintenance cost and the long life cycle because they do not consume raw materials. Finally, they do not have noisy effects during their operation and protect the environment from pollution of the atmosphere with CO_2 emissions. [16]

1.5 Why passive ground cooling/earth-to-air heat exchangers?

PV panels, even though they can be very efficient in very sunny regions, in general they have a very high cost (£3000/kW) [11]. An alternative approach of cooling a residence while achieving low energy and thermal comfort can be managed through passive ground cooling. The main point of using this technology is to avoid the use of the air conditioning units as much as possible. Passive refers to technologies or design features used to cool or heat buildings without power consumption. [6]

Ground cooling [7] is the dissipation of the excess heat of a building to the ground. Air is cooled by circulating through underground pipes, that play the role of earth-to-air heat exchangers and is then injected inside the building. Earth-to-air heat exchangers are suitable for cooling of buildings and so could play a significant role in reducing CO_2 emissions [14]. Other advantages are their simplicity, high cooling potential, low capital, operational and maintenance cost. A large variety of buildings with earth-to-air heat exchangers have been designed and monitored, and the performance of the systems have been proven very high [8]. Ground cooling systems have been used successfully in many housing projects [9, 10]. In particular, the use of earth-to-air heat exchangers in a new housing development in Portugal has contributed to a reduction in the cooling needs by 95% compared to an air-conditioned building, and the mean cost per building was quite low, at close to 7500 Euros/house [9]. Similar results have been obtained in Greece where earth-to-air heat exchangers have been used in a housing complex to provide cooling during the summer period [10]. One limitation of this technology is that it cannot be used in the city centre as land space is required, and so it can only be implemented in suburban and rural areas.

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Chapter 2 Energy efficiency in buildings and Passive cooling techniques

2.1 History of buildings

High consumption of electricity for mechanical cooling has already caused power outages in some developed countries such as Greece as was mentioned before. First of all, we have to go back to the roots of architecture and search for alternative solutions. In Ancient times, technologies had been used for energy saving and passive cooling, when electrical power of course was not available.

Correct orientation of dwellings for having houses cool in summer and warm in winter first took place in Greece 2500 years ago [1]. Romans were the first to use double floors for heating where heat from a fire passed through cavities in the floor. Also Romans were pioneers in covering windows with materials like mica or glass so light was admitted into the house without letting in wind and rain [2]. In 1200 A.D., the Anasazi (regarded as ancestors of Pueblo Indians in North America) built cliff dwellings that captured the winter sun [3]. The Iraqis on the other hand utilised the wind to take advantage of the night cool air and provide a cooler environment during the day. Additionally, running water was in use to provide evaporative cooling [4-5].

In 1960s, house comfort conditions were only for the few. Since then central air conditioning systems have become common in many countries due to the development of mechanical refrigeration and the rise in living standards. [4]

Oil crises since the 1970s and global warming have compelled governments and engineers to examine environmentally friendly building design and control. Passive and low-energy cooling of buildings have won a lot of interest lately as an energy efficient alternative to mechanical cooling. [4]

2.2 Environmental friendly design

The design of buildings employing low energy cooling technologies, however, presents technical difficulties and requires advanced modelling and control techniques to ensure efficient operation.

The role of engineers is very important, especially with respect to solar energy control, utilisation of thermal mass and correct ventilation of a building. In effective solar energy control, summer heat gains must be reduced while winter solar heat gains must be maximized. To move towards low energy consumption in buildings, the primary role of building design must be realised, as well as of the utilisation of renewable types of energy. [6-8]

The main concern that needs to be ensured in buildings is thermal comfort. 'Comfort is influenced by the air temperature and by the temperature of the surrounding surfaces. This can be achieved by the proper orientation and shape of the building, the use of shading devices and the selection of proper construction materials. Thermal mass, especially in hot climates can be used to reduce high cooling loads, reduce energy consumption and maintain a balanced indoor temperature. ' [9]

Bioclimatic design is one of the best approaches to reduce the energy cost in buildings. Buildings should be designed according to the climate of the site, reducing the need for mechanical heating or cooling. Hence maximum natural energy can be used for creating a pleasant environment inside buildings. The application of simple passive cooling methods can be effective in reducing cooling loads of domestic dwellings in hot climates. By using a combination of well-established technologies such as glazing, shading, insulation, and natural ventilation, 43% reductions can be achieved. More advanced passive cooling techniques such as roof pond, dynamic insulation, and evaporative water jacket need to be considered more closely, and will be discussed later. [6-10]

Bioclimatic structures are built in such a way that, during the winter months, exposure to cold temperatures is minimised and solar gains are maximised; while during the summer, bioclimatic structures are shaded from the sun and various cooling techniques are employed, often with the aid of renewable energy sources [11-13]. A bioclimatic building may be so economically efficient that it consumes 10 times less energy for heating compared to a conventional European building [14]. The additional cost of a typical bioclimatic structure is usually around 3–5% and in most cases less than 10%; this cost is usually returned within a few years [15]. Bioclimatic technologies (such as passive solar systems) may also be retrofitted to existing structures although, in such cases, the cost is typically a little higher [16]. In addition to the conservation of energy, bioclimatic architecture may improve day lighting and indoor thermal comfort conditions.

The energy efficiency of a building based on bioclimatic principles is determined by a set of environmental, technical and usage factors. First of all, the location of a building is a major determinant; geographic latitude that is related to mean temperature (with lower temperatures in places of greater latitude) should be a major influence. Also, the location of a building in an area with continental climate increases dryness and thermal variation while location in the Mediterranean implies mild winters and relatively cool summers (i.e. lack of temperature extremes). Additional factors include altitude (absolute height above sea level) that is associated with a fall in average temperature, an increase in temperature variation and a fall in humidity; topographic relief that is related to microclimatic variations especially in relation to the sun and prevailing winds; and vegetation that promotes thermal stability and increases humidity. [10]

Bioclimatic architecture literature recognizes the following factors to be taken into account in building construction [17]:

- Topography, e.g. slope, site orientation, site views;
- Movement of the sun and its impact during the year (i.e. solar altitude and azimuth);
- Climatic conditions including prevailing wind patterns, incoming solar radiation, temperature, air moisture;
- Environmental conditions such as daylight and shading of the construction site; daylight may reduce consumption of artificial lighting from 40 to 80% [18];
- Mass, volume and size of building;

- Local architectural standards and availability of local building materials.

Environmental design strategy takes into consideration the harmonious existence of the local climate. In this way it brings us near to an ecological awareness that encourages the building industry to take into account local conditions and characteristics in construction.

2.3 Alternative cooling approach

Advanced building structure that can minimise the energy wastage and improve thermal comfort presents a considerable challenge as was mentioned above. This literature review includes all aspects of technology and building design dealing with ventilation and passive cooling techniques able to minimise cooling requirements of domestic dwellings.

Low energy cooling technologies can be applied, alone or in combination, to meet the cooling needs. There are many unconventional passive cooling technologies which can be applied to residential buildings which are being developed in various summer circumstances.

The efficiency of all low energy cooling technologies depends on environmental conditions like ambient temperature and humidity. Intensive research has been carried out in recent years to develop new technologies; components, materials and techniques that permit the decrease or even elimination of the cooling demand of buildings. Ventilation in buildings permits the decrease of the cooling demand, improves comfort conditions and decreases indoor pollution. [5]

2.4 Natural cooling techniques

2.4.1 Night cooling

In this system, cool night air is used to remove heat from the interior of a building. The outdoor air can enter into the building naturally, mechanically or with both methods. During natural ventilation, air enters into the building through intentional openings left to utilise either the indoor/outdoor temperature differences (stack effect) or the wind pressures. [1]

The prevailing wind is utilised, to take advantage of the cool night air and provides a cooler environment during the day. In mechanical ventilation a fan and a duct system can be used to force air into the building. Natural night cooling is an unreliable method for air quality, quantity and controllability. Its effect depends largely on the magnitude of heat gains and ventilation rates. The building mass is of great importance when night cooling is used, since a large mass will absorb greater amounts of heat load during the day [25].

2.4.2 Evaporating cooling

Evaporation is the phase change of water from liquid to vapour. This is accompanied by the absorption of large amounts of heat from the air or the surface where evaporation takes place. Evaporating cooling systems can be direct or indirect. [34]

In direct evaporative cooling, the water content of the cooled air increases since air is in contact with the evaporated water, while in indirect evaporative cooling, evaporation occurs inside a heat exchanger and water content of the cooled air remains unchanged. When evaporation occurs naturally, this is called passive evaporation. A space can be cooled by passive evaporation provided that there are surfaces of stagnant or moving water, like basins or fountains. [26]

Advantages of evaporative cooling systems over conventional air-conditioners include the provision of large ventilation rates, about 10 times higher than air-conditioning systems and energy savings of 75% are achieved. Moreover they do not require significant maintenance and their fabrication and installation, are easy and low cost. The main disadvantage however, is that it can not be applied in humid regions [26] but only to dry climates [34].

2.4.3 Radiative cooling

Radiative cooling is based on the heat loss by emission of long wave radiation, from a body towards another body of lower temperature. This technique can be successfully applied in buildings. Buildings radiate in the long wave range and the heat sink is the sky, since the temperature of the space around us is lower than the temperature of most objects on earth. In passive or direct radiative cooling; the building envelope radiates naturally because of its temperature, thus increasing the heat loss from the indoor environment of the building, without the presence of any type of mechanical device. [26]

2.5 Low energy and natural cooling technologies

❖ Reflective or cool materials

Reflective materials when compared to a conventional material of the same colour present a surface temperature which is up to 15 ºC lower. The combination of cool materials with green spaces and heat sinks can contribute to a considerable decrease in the ambient temperature. [20]

❖ Solar and heat protection

The main progress regarding solar control of transparent components comes from the development of switchable glazing technology. Electro-chromic glazing has been considerably improved and is commercially available but is very expensive. Solar and heat protection of non-transparent components can be achieved by using reflective coatings on the roofs of buildings. Extensive outdoor testing of cool white coatings during the summer period has shown that they present surface temperatures that are almost 12 K lower than reflective aluminium paints and more than 16 K lower than silver gray reflective coatings. In parallel, coloured cool coatings tested outdoors against conventional coatings of the same colour gave a reduction in the surface temperature of up to 10.2 K. [21]

❖ Heat dissipation

Heat dissipation techniques are related to the use of a low temperature heat sink to dissipate the excess heat from buildings. Ambient air, water, ground and the sky are the more important heat sinks. For example, the use of the ground for heat dissipation through the use of earth-to-air heat exchangers has gained increasing acceptance. [26] (Further information is presented in Chapter 5)

❖ Advanced ventilation

Natural ventilation is a very old technique for cooling. Important research has been carried out recently on appropriate and advanced ventilation techniques [22].

The main achievements of advanced ventilation techniques are in two aspects:

- Better understanding of airflow phenomena and of the expected comfort benefits, in particular in the dense urban environment and the development of efficient and practical procedures to design natural and hybrid ventilation systems and configurations [23,24];
- Technological developments mainly in the field of hybrid and mechanical ventilation that contribute significantly to a more comfortable and healthy indoor environment. [22]

❖ Solar chimneys

The use of solar chimneys to enhance airflow in buildings is a well known technique that can easily be integrated into low-income households. Solar chimneys are natural draft components, using solar energy to build up stack pressure and thus driving an airflow through the chimney channel. Solar chimneys can improve the ventilation rate in naturally ventilated buildings in hot climates [27, 28]. It is found that the impact of solar chimneys is substantial in inducing natural ventilation at low wind speeds. Recent research has permitted optimization of the design and operation of solar chimneys and thus the improvement of indoor environmental conditions in hot climates. [29–31]

❖ Wind towers

Wind towers are well known as they are traditionally used in the Middle Eastern and Persian architecture. Air enters the towers at the higher part of the windward facade and leaves at the lower part which is connected to the building. The air may be cooled by evaporative or convective cooling through the tower. Recent developments involve towers where the air is forced through wetted pads to decrease its temperature. [32, 33]

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Chapter 3 Design investigation and cooling potential of the residence

3.1 Introduction

The ESP-r programme will help to determine the effect of the building design, such as the wall insulation, windows shape and size and the contribution of daylight to the heating and cooling requirements.
Building simulations in ESP-r were run in order to predict the cooling potential in the case of air conditioning, but also investigate the building design and the potential methods to save energy.

3.2 ESP-r

Building simulation is a method for investigating the building design and the potential methods to save energy. In order to simulate the building performance, the ESP-r programme (Environmental Systems Performance and Research) was used.
ESP-r is a computing programme for the simulation of the thermal, visual and acoustic performance of buildings. Also the assessment of the energy use and gaseous emissions associated with the environmental control systems and constructional materials.
ESP-r is capable of modelling the energy and fluid flows within combined building and plant systems when constrained to conform to control action. Zones within a building are defined in terms of geometry, construction and usage profiles. These zones are then inter-locked to form a building or just a part. The plant network can be defined by connecting individual components. Finally, the multi-zone building and multi-component plant are connected and subjected to simulation processing against user-defined control. The control data must contain standard constructions, event profiles and plant components.

3.3 Temperature history in Greece

Athens is characterised by a warm Mediterranean climate with mild and relatively wet winters and warm dry summers. Mean monthly maximum ambient temperatures for the hot period June to September are between 25.6 – 35.8°C.

To start the model it was important to compile all the temperature history for certain period in order to ensure that the year chosen is in some way representative of the weather in the area.

The source was the National Technical University of Athens (http://www.meteo.ntua.gr) that has installed four sensors in the Campus, about 4.5 km east of Plateia Syntagmatos, on the west feet of Mount Hymettus. The webpage provides humidity and air temperature, rainfall, solar radiation, barometric pressure, wind speed, wind gust, wind direction and also sunshine duration collected by each one of the sensors. The data is stored in periods of 10 minutes. One of the sensors has been active since 1999 while the others were started later. Therefore, the period studied is from 1999 to 2007. The table below shows the average temperature calculated for June, July and August:

Y / M	June	July	August
1999	26,096	27,384	27,872
2000	25,310	29,105	27,290
2001	24,943	28,343	28,346
2002	25,383	28,029	26,439
2003	26,584	27,648	28,038
2004	24,741	27,082	26,581
2005	23,773	27,158	27,131
2006	24,217	25,911	28,537
2007	24,601	27,795	27,590

The table shows that the summer temperature for the year 1999 was similar to summer temperatures for the last 8 years. The year of 1999 is a typical meteorological year for Greece. Therefore all the results before and after the implementation of renewable technologies are expected to be realistic for the current year.

3.4 Model Definition

ESP-r was used to build a detailed model of the existing residence:

The process of modelling the building is described below:

1. Import of the Hellenic climate files;
2. Creation of the zones of the building;
3. Creation of the typical Greek materials and components;
4. A simple operational profile;
5. Attribution of control characteristics;
6. Shading and insolation analysis of the building;
7. Simulations and results analysis.

3.4.1 Import the climate files for the year of 1999

Period of simulations: Fri-01-Jan at 00h30 to Thu-30-Dec at 23h30 for the year 1999. Ambient db temperature:

- Maximum: 36.9°C in 06-Aug at 14h30
- Minimum: 2.1°C in 26-Dec at 04h30

3.4.2 Creation of the zones of the building

In order to simulate the building, 3 zones were built (construction by dimension input and vertices).

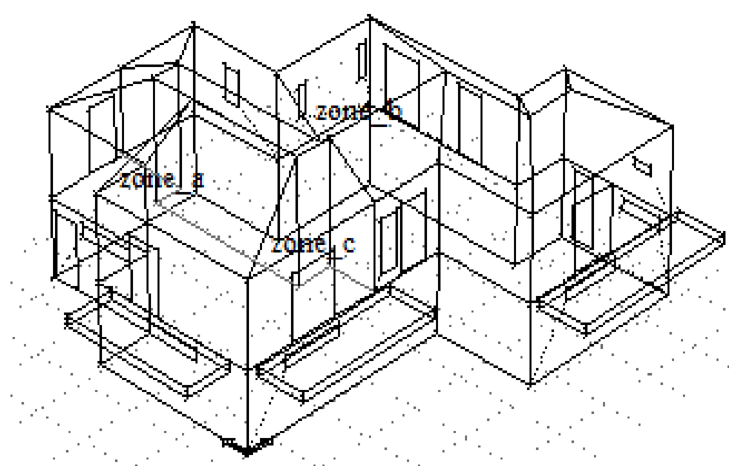

Fig. 1 Greek modern residence (The whole building)

The zones are described analytically *in the appendix on page 65.*

Some simplifications were applied in the initial arrangement of the residence in order to run the ESP-r programme:

1. Two windows assumed as a larger window (only in one wall).
2. The zones conforming the ground floor were simplified as two polygons with all the angles at 90 degrees.
3. The roof had to be rearranged taking in account the distribution of zones A and B.

The final model was built taking into account the internal dimensions of the residence.

3.4.3 Creation of typical Greek materials and components

Layers of several materials construct the building component. The exact materials used in the building are listed *in the appendix on page 66*.

3.4.4 A simple operational profile added in each zone.

ESP-r supports zone operational characteristics in terms of weekdays and two separate weekend days (Saturday and Sunday). Casual gains (e.g. people, light, small power) are one operational characteristic of a zone and schedules of infiltration (air from the outside via intentional sources such as fans or unintentional sources such as cracks in the facade) and there are a limited number of controls you can impose on infiltration schedules. That exercises the environmental system and provides an early clue as to the relationship between building use and system demands. Sensible and latent gains were input for residents.

The following operational file and timetable was attributed to each zone:

In the bedrooms are usually 4 people, with $10W/m^2$ lighting and 200W equipment. The occupancy changes throughout the day (from 0h00 till 7h00, 7h00 till 8h00, 8h00 till 16h00, and from 16h00 till 0h00) and (from 0h00 till 9h00, 9h00 till 0h00) on the weekend.

In the living room, kitchen and bedroom there are usually the same 4 people, with 10W/m² lighting and 400W equipment. The occupancy changes throughout the day (from 7h00 till 8h00, 8h00 till 9h00, 9h00 till 16h00, and from 16h00 till 0h00) and (from 0h00 till 9h00, 9h00 till 0h00) on the weekend. The basement is not occupied.

3.4.5 Attribution of different control characteristics

Control functions were attributed to all zones. The control period was the same with the operational profile. A simple infiltration system was used with 0.5AC/h air flow with a maximum cooling and heating capacity amount of 70000Watt available to meet the demands. Also, a set point at 20°C for heating and a set point at 26°C for cooling, in zone a and zone b. Finally, a set point at 17°C for heating and a set point at 28°C for cooling in zone c.

3.4.6 Shading and insolation analysis of the building

The shading blocks are the balconies of the building that affect sunlight reaching the basement. After the definition of the shading blocks an insolation analysis was performed for all of zone c that was shaded.

3.4.7 Simulations and Results analysis

<u>Simulations for all zones for the whole year of 1999</u>

	Heating hours (h)	Heating required (kWhrs)
zone a	2896	3026
zone b	2594	2594
zone c	3785	3323
Total	8583	8943

Table 1, Total heating requirements and the number of heating hours

	Cooling hours (h)	Cooling required (kWhrs)
zone a	2010	-1482
zone b	1722	-3804
zone c	0	0
Total	3732	-5286

Table 2, Total cooling requirements and the number of cooling hours

<u>Simulations from 1/1 – 30/3/1999 (winter period)</u>

	Heating hours (h)	Heating required (kWhrs)	kWatts	Watts
zone a	1656	1816	1.1	1100
zone b	1115	1776	1.6	1600
zone c	2134	2297	1.7	1700
Total				**4400***

Table 3, Total heating requirements and the number of heating hours

*This value is not realistic, the idea is to show the heating requirements. In fact air-conditioning is not being used in Greece for heating. It consumes vast amounts of power; the typical way to heat a house during winter is through central heating radiators.

The project main aim remains to determine the cooling requirements during the summer period. Diagrams show analytically what is going on through the whole period in every zone depending on the occupancy (operating profile and different control characteristics) *see the appendix on page 69*.

Simulations from 1/6 – 30/8/1999 (summer period)

	Cooling hours (h)	Cooling required (kWhrs)	kWatts	Watts
zone a	1434	-964	0.67	670
zone b	1155	-2957	2.56	2560
zone c	0	0	0	0
Total				3230*

Table 4, Total cooling requirements and the number of cooling hours

*This value is real, air-conditioning is the typical way to meet the cooling requirements in Greece during summer.

3.5 Discussion

It can be seen from the results that Greek climate is a typical Mediterranean climate with a very hot summer and a cold winter. The total results show significant amounts of heating and cooling required for all the year in order achieve thermal comfort for the occupants.

If we consider that 1 kWh of electricity produces 0.41kg of carbon dioxide (*Centre for Alternative Technology)*, the residence during summer produces 3230kWhs x 0.41kg = 1292kg carbon dioxide by the use of air-conditioning in order to keep a constant temperature of 26°C inside the building.

Heating requirements during winter for zone c are the highest even though the temperature set point for heating was only at 18°C and that is based on the following reasons:

- Unoccupied zone;
- Very low sunlight because of the balconies of the ground floor;
- Small/narrow windows
- Most of the zone is underground.

For these same reasons zone c has zero cooling requirements during the summer. This show how important is to keep a balance in cooling and heating requirements by using the correct design techniques.
Cooling requirements for zone a and zone b are higher than zone c because they receive direct sunlight.
It is necessary at this point to try to find more sustainable and environmental solutions in order to save energy and reduce carbon emissions in maintaining a safe and productive environment for the occupants. The residence has a building design with high cooling demands for zone a and b. The critical factor in mechanical systems energy consumption, such as air-conditioning, is reducing cooling loads and carbon emissions by integrating renewable technologies.

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Chapter 4 'Energy from the sun'

Chapter 4a Theoretical part

4a.1 Introduction

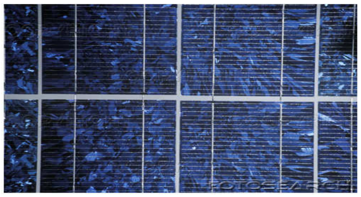
In chapter 2, building design techniques were introduced in order to protect a building from the sun during the summer and to save energy for cooling needs. In this chapter are listed some technologies that actually take advantage of the sun.

Today, solar power is used in two primary forms: thermal solar, where the heat of the sun is used to heat water or another working fluid, which drives turbines or other machinery to create electricity; and photovoltaic, where electricity is produced directly from the sun with no moving parts.

During the design process, final costs of low energy cooling technologies should be considered, against the price of electricity required to power electrically driven cooling equipment, which strongly depends on the way electricity is produced. [1]

Due to the great quantity of solar energy and the high ambient temperatures available in hot dry climates, a direct solar cooling system could meet a large part of the daily cooling load. There are plenty of techniques considered as hybrid (controlled naturally and mechanically), ventilation including night ventilation, thermo-active building mass systems with a free cooling tower or ground heat exchangers. But for residential buildings, the electricity demand remains one of the crucial elements to meet the requirements [2].

4a.2 Photovoltaics system



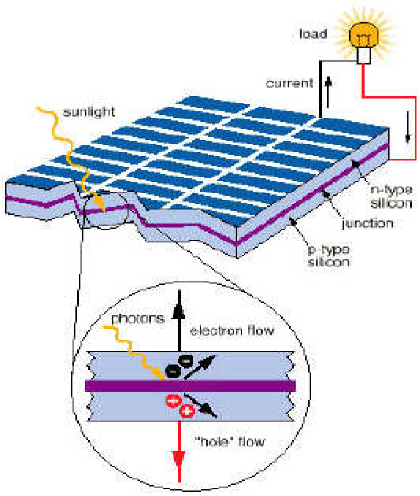
Photovoltaics or PV panels were first developed in the 1950s in the space industry for use on satellites, but interest in their use emerged with fuel crisis of the early 1970s. Since then, there has been a steady growth in their global use. [3]

Photovoltaics are manufactured from special semiconductor materials that use the energy of the photons from solar radiation striking the cell to produce an electric current [5], through the "photovoltaic effect".

The "photovoltaic effect" is the basic physical process through which a solar cell converts sunlight into electricity. Sunlight is composed of photons that contain various amounts of energy corresponding to the different wavelengths of light. When photons strike a solar cell, they may be reflected or absorbed, or may pass right through. When a photon is absorbed, the energy of the photon is transferred to an electron in an atom of the cell which is actually a semiconductor. The electron is able to escape from its normal position associated with that atom to become part of the current in an electrical circuit. By leaving this position, the electron causes a hole to form. Special electrical properties of the solar cell a built-in electric field (with a P-N junction*) provide the voltage needed to drive the current through an external load. [16]

* P-N junction

The basic structure formed by the contact of P-type and N-type semiconductors, a positive-negative (P-N) junction.



[14] *"Photovoltaic effect"*

The most common material used in PV panels is silicon, which is usually doped with phosphorus or similar material to ensure that free electrons are released when the materials absorbs the incident photons. The cells also incorporate a conducting metallic mesh so that as many of the free electrons as possible can be collected. [5]

4a.2.1 Energy produced

A typical PV solar panel consists of many individual solar cells connected together so that enough current can be generated to provide power to the external load. The efficiency of these panels, defined the electrical power output divided by the solar insolation input, is around 10-15% for most commercial crystalline silicon PV panels, and about one-half of these values for the cheaper amorphous silicon panels. Groups of individual cells are connected together in series to increase the voltage; usually to between 12 and 24V DC, and then these groups are connected in parallel to form a complete panel. [5]
A photovoltaic cell with an area of $1m^2$ should produce approximately 3.5A in strong sunlight. [4]
A typical US home uses 5000kWh of electrical energy per year, or on average nearly 15kWh per day. In a region with an average insolation of $5kWh/m^2$ per day, this indicates that a solar collector area of some $30m^2$ would be required to meet the total electrical requirements,

assuming an average of efficiency of 10%. The 30m² of PV panel might have a peak electrical output of around 3.5kW, which should accommodate most of the electrical load from the house while is in direct sunlight. However, there is usually a mismatch between peak generating capacity and household electrical demand. [5]

Manufacturers subject their photovoltaic modules to a standard test condition of a solar irradiance of 1000W/m² at an operating temperature of 25ºC, which approximately equivalent to the solar radiation which would be experienced by a horizontal surface, at noon, in June in Saudi Arabia. It should be noted that the performance of photovoltaic modules drops off as the ambient air temperature increases above 25ºC. This is of practical importance as photovoltaic modules are often used in environments which are much warmer than 25ºC. It has been calculated that operating power reduces by about 0.5% for every 1ºC increase, thus a 100W module (rated at 25ºC) when operating at 41ºC would actually produce only 92W. [3]

The energy payback for PV systems is dependent on the available solar resource and on the degree to which the system is operational.

4a.2.2 Examples of photovoltaic panels integrated in building

a) Installation in Torre Garena [6]: The solar PV installation is located on the roof and on the facade of the building, giving a total power of 85kWatts. The installation on the facade of the building is comprised of 948 BP 380 photovoltaic panels. The building's facade and roof include two different solar PV power generation plants.

The PV installation on the facade has been built using 948 photovoltaic modules manufactured by BP solar. This installation has a total power of 75840Watts, representing a savings of 85 tonnes of carbon emissions per year. These modules have been installed at a 608 gradient to take full advantage of the available sunlight. The BP 380 modules have been manufactured using state of the art polycrystalline technology and consist of 36 cells with antireflection coating connected in series. Each panel has a nominal power of 80Watts. The roof application incorporates an array of 93 glass-glass modules of polycrystalline solar cells each with nominal power of 100Watts. They are located on the south facing roof with a gradient of 308, being perfectly integrated into the building's design.

Photo 1 PV installation in Torre, Garena/ Spain

b) The Beddington Zero Energy Development (BedZED) [7] is the UK's largest carbon-neutral eco-community. Only energy from renewable sources is used to meet the energy needs of the development. The design is to a very high standard and is used to enhance the environmental dimensions, with strong emphasis not only to solar energy but on roof gardens, sunlight and reduction of energy consumption, waste water, recycling natural, recycled or reclaimed materials with low embodied energy.

Photo 2 BedZED in UK

c)

Photo 3 Residence in Greece

4a.3 Solar Energy in Greece

Greece is located in a major geographical region with rich and reliable supply of solar energy, even during the winter. Despite the excellent solar potential of Greece, development of PV systems for electricity generation had been hindered due to their high installation cost [15]. Last years subsidies up to 60% of the total price are given in order to motivate people. Solar water heating systems are much more commonly used.

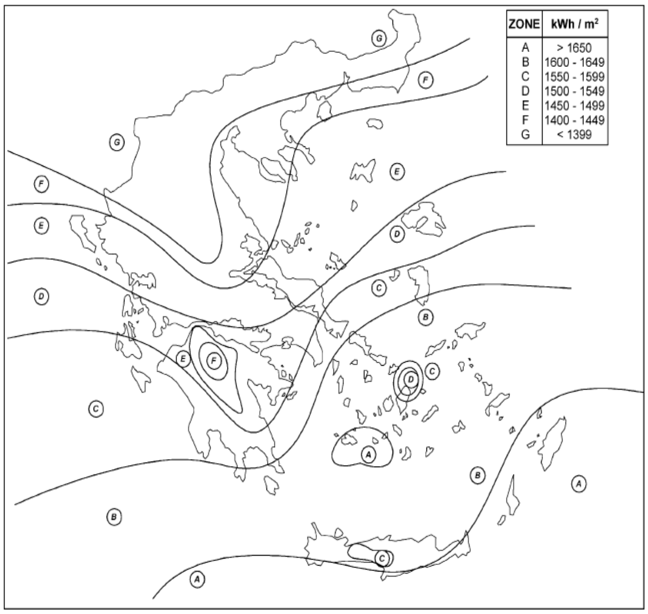


Fig. 1 Solar potential zones in Greece [8]

4a.4 Solar water heating system

Solar water heating system can be used in order to reduce the energy use of the residences.

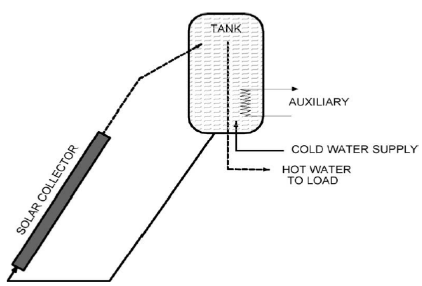


Fig 2 Typical domestic solar water heating systems [9]

Solar hot water systems are devices that utilise sun's energy to directly heat water providing it to the recipients. Such systems typically integrate a roof-mounted solar collector, an insulated hot water storage tank and a hydraulic heat transport system with sensors and controls. A solar collector receives solar irradiance and converts it into heat. To minimise heat losses the collector is thermally insulated and has a transparent cover made of special glass or plastic. Hot water is circulated to and from the storage tank by means of a circulation pump, or by gravity as in the thermos phonic systems (the latter being the most commonly used in Greece). Such a system may provide more than 2/3 of the annual hot water demand, while a conventional heat source (such as a gas-oil boiler or an electric heater) provides the rest. [9]

4a.5 Further solar technologies

Using more commercial types of technologies in the future is a challenge for Greece. Moreover, there are more solar types of technology existing and not very widely known. These are planned to replace the air-conditioning units proposing more environmental solutions. Here is a list of some of these types:

1. Solar cooling systems (most of them are not commercial yet) [1]

- Solar sorption cooling;
- Solar-mechanical systems;
- Solar related air conditioning*

* The effect of solar collector area, tilt angle, and storage tank size must be investigated for various types of loads (cooling or combined cooling and domestic hot water loads), single or double glazing collectors and degree of atmospheric turbulence which affects the top loss coefficient of the collector field. The expected payback for solar air conditioning was found to be considerably long, owing to the relatively low cost of electrical energy which is usually subsidized for socioeconomic reasons and to the complexity to account and quantify

the costs of environmental pollution in the calculations. The prospects of solar air conditioning are expected to further improve with a growth of a local building comfort branch of the solar industry and especially if solar heating will be accounted as a potential option to provide year round comfort, using the same main solar system components. [11]

2. Combining solar energy with other sources of energy in order to increase efficiency.

For example the heating and cooling system of the buildings can be met with combining solar energy with geothermal energy. In particular, the integration of solar collectors to a geothermal heat pumps system can be used for the heating and cooling of the buildings. [10]

Chapter 4b Integrating renewable technologies 1/ PV panels

4b.1 Introduction

ESP-r will help to calculate the power output of PV panels and to determine their feasibility in meeting the cooling requirements in the case of an air-conditioned residence.

4b.2 Model Description

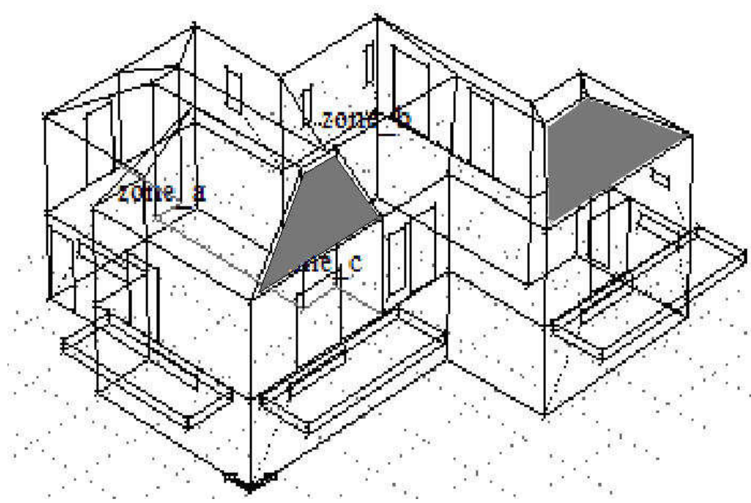


Fig 1 PV panels installation (with grey colour)

The procedure is described in the following list:

1. Add PV panels

Photovoltaic modules BP 380 were added on the south roof. The exact placements on the roof of zones a and b are shown in fig 1. The total surface of 1 PV panel is 0.53m x 1.197m = 0.634441m². The total surface area in zone a, is 7.424m², so the maximum number of PV panels is 11. And, the total surface area in zone b is 10.047m², so the maximum number of PV panels is 15.

26 PV panels is the total number of installation which is the maximum number the building can get.

2. Change the composite construction database for the two surfaces. The exact materials used in the building are listed *in the appendix on page 71*.

Construction and materials [12]:

• 36 multicrystalline silicon solar cells in series, efficiency enhanced by improved cell coating;

• Cells are laminated between sheets of ethylene vinyl acetate (Tedlar) and high transmissivity low-iron 3 mm tempered glasses;

• Frame strength exceeds requirements of certifying agencies.

Material and optical properties for the Tedlar:

- ✓ Conductivity: 0.4W/mdegC
- ✓ Density: 1500kg/m3
- ✓ Specific Heat: 1760J/kgdegC
- ✓ Emisivity: 0.9
- ✓ Absorptivity: 0.5W/Mk2

The electrical characteristics of BP 380 are [13]:

- P_{max} (nominal maximum power): 80W
- V_{oc} (open circuit voltage): 22.1V
- I_{sc} (short circuit current): 4.8A
- V_{mpp} (max power point voltage): 17.6V
- I_{mpp} (max power point current): 4.55A

The Mechanical Characteristics of BP 380 are:

Weight: 7.7 kg (17 pounds)

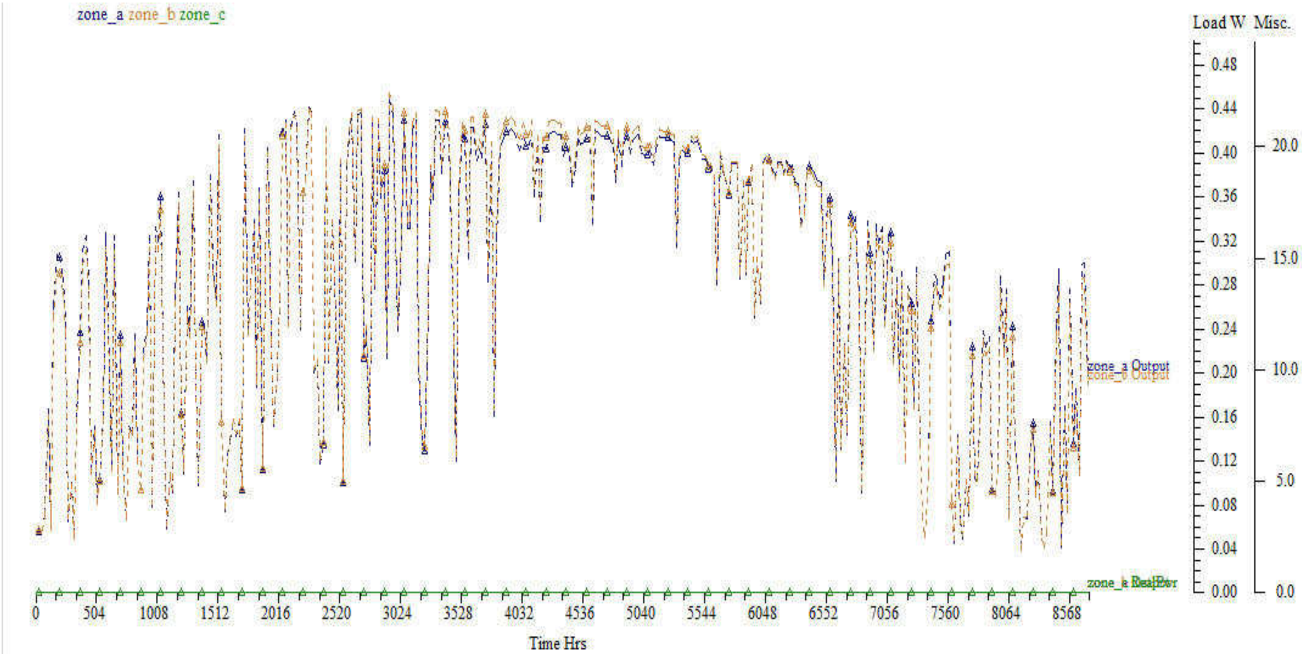
Dimensions: 1197mm x 530mm x 20 mm

4b.3 Simulations and Results analysis

<u>Simulation for the whole year of 1999</u>

Simulation was run for zones a and b considered for PV panels power output (Pout).

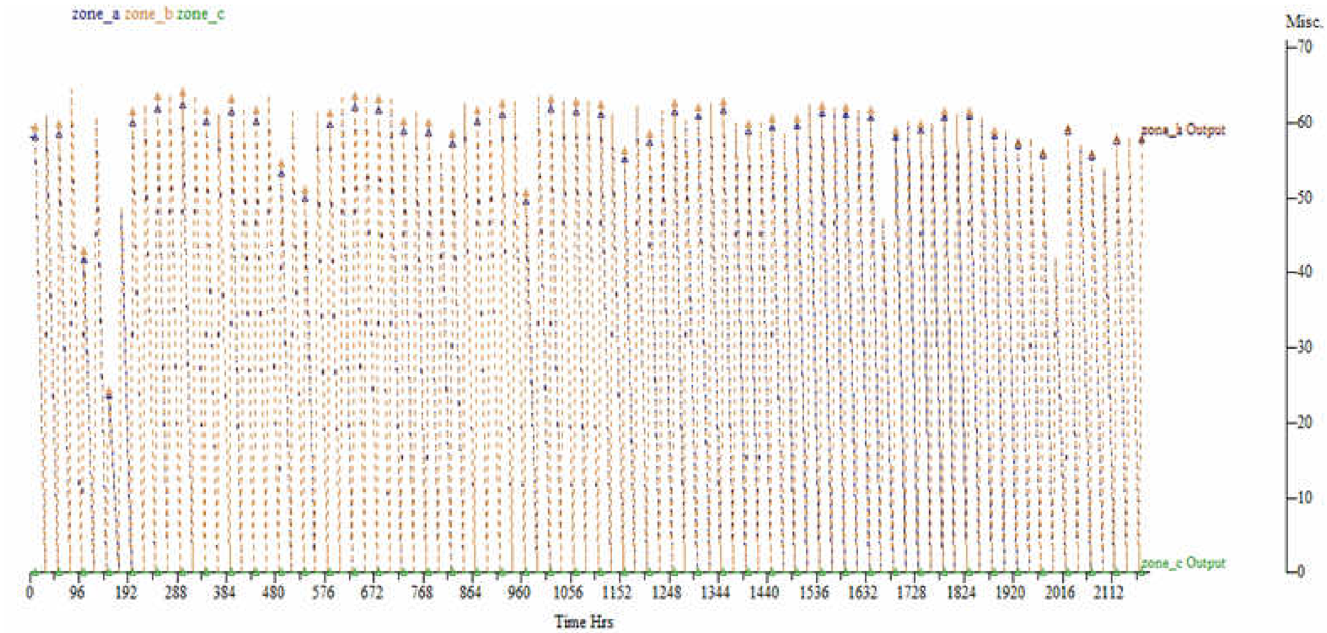
For **zone a:** The maximum Pout is 185.9W for 04-Apr at 12h30 and the minimum 0 for 01-Jan at 00h30. The mean Pout is 35.2W per day.
For **zone b:** The maximum Pout is 185.2W for 04-Apr at 12h30 and the minimum 0 for 01-Jan at 00h30. The mean Pout is 35.2W per day.



Simulations from 1/6 – 30/8/1999 (summer period),

Simulation was run in order to calculate the power output of PV panels and to determine their feasibility in meeting the cooling requirements in the case of an air-conditioned residence.

For **zone a:** The maximum Pout is 62.9 for 04-Jun at 10h00 and the minimum 0 for 02-Jun at 06h00. The mean Pout is 29.4W per day.
For **zone b:** The maximum Pout is 64.4 for 04-Jun at 10h00 and the minimum 0 for 02-Jun at 06h00. The mean Pout is 29.9W per day.



4b.4 Discussion

Photovoltaics can be more efficient and produce more electricity generation during the day, during the night the electricity is almost zero. A better understanding of this can be achieved through the above graphs. Also a remarkable result from the simulation for the whole year is that the maximum mean value 35.2W per day in both zones a, b was in April. This means that PV panels are more efficient during the spring period than in summer.

For this project we are going to focus on the results of the summer period and see if the total cooling requirements can be met. These were calculated as 3230Watts in chapter 3 which means 35.9Watts per day. In order to determine the impact of photovoltaics on a building and gain a general idea of how beneficial is; we must know the exact total energy delivery to the grid, the total energy savings and the total avoided emissions in CO_2. PV solar cells which are installed with an optimum power output of about 1 kW, in a year's period of operation can save around 1300kWh of electrical energy and 800kg of CO_2 emissions.

26 PV panels (17m^2) was the total number of installation which was the maximum number the building can get. The optimum power output

is 59.3Watts per day which is more than the total cooling requirements (35.9Watts per day) so the number of PV panels can be reduced.

Results present a very interesting potential for PV power supply and carbon emissions saving. It has to be mentioned at this point that the power output was examined to realise the feasibly of meeting the cooling requirements. The important factor is the amount of green electricity that can be produced for air-conditioning supply. The photovoltaic systems generate more energy than building cooling demand for the summer period. The rest electricity could be used for the lights and equipments or even it could be supplying the energy excess to the public electricity grid.

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Chapter 5 'Energy from the ground'

Chapter 5a Theoretical part

5a.1 The ground...

Ground high thermal capacity keeps the soil temperature, below a certain depth, considerably lower than the ambient air temperature during summer or higher that the ambient air temperature during winter. Variation of the earth temperature decreases with increase of depth, moisture content of soil and soil conductivity. In regions with a temperate climate, the temperature of the soil at depth of 2-3 meters can be low enough during summer (or high enough during winter), to serve as a cooling or heating source. [1]

Here is a list of the ground technologies:

5a.2 Ground Source Heat Pumps

The types of heat pumps typically available for residences are air-to-air, water source and ground source. Heat pumps collect heat from the outside air, water, or ground and concentrate it for use inside the house. [2]

A ground-source heat pump, working like a refrigerator in reverse, takes in energy from the ground at a relatively low temperature, and then delivers it at a higher temperature. In this type of installation a pipe loop is buried in the ground near the building to be heated, and refrigerant from the evaporator side of the heat pump is then circulated through this loop. The ground heat is used to evaporate the refrigerant, which is then compressed to a higher pressure and temperature before being piped to the condenser. The condenser is a heat exchanger which transfers heat to a building heating system as the refrigerant is cooled and conversed back to liquid form. Electrical energy is required to drive heat pump, of course, but with 'a coefficient performance' of the heat pump greater than unity, this is much more efficient use of electricity for heating than electric resistance heating. The heat pump can be run in diverse during summer and can therefore provide both summer air conditioning as well as winter heating. [2, 3]

A typical electrical heat pump needs 100kWh of power to turn 200kWh of freely available environmental or waste heat into 300kWh of useful heat. Heat pumps are an important technology for reducing emissions of gases that harm the environment. Heat pumps driven by electricity from, for instance, renewable energy systems of electricity production such as PV panels reduce emissions more significantly than if the electricity is generated by coal, oil or gas-fired power plants. [2]

Heat exchangers are located in the underground (either in a horizontal, vertical or oblique fashion), and a heat carrier medium is circulated within the heat exchangers, transporting heat from the ground to the heat pump (or vice versa).

Types of ground systems are described in pictures as following:

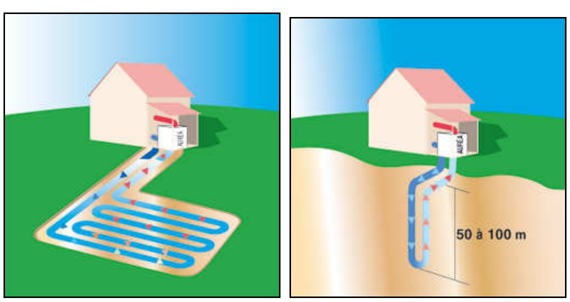


Figure 1, A horizontal heat exchanger (left), a borehole heat exchanger (right) [2]

5a.3 Natural Ground cooling techniques

5a.3.1 Direct contact

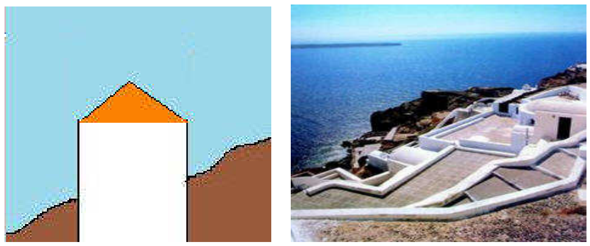


Figure 3, Principle of direct ground cooling [8] *(left) Example of semi-buried house in Santorini, Greece (right)* [3]

Underground buildings have a good thermal behaviour during summer by being contact with the ground; their indoor environment is protected from the extreme variation of the indoor conditions. Also, the average ground temperature being lower than the indoor temperature, heat from the buildings is dissipated to it.

The strategy is most suitable in hot-dry climates with a mild winter, as the direct coupling of the building with the earth, which is necessary for effective cooling during summer, can encourage heat loss during winter. Their cost is sometimes a drawback to their realisation together with other problems, like the availability of natural light, contention and indoor quality. However these problems can be successfully faced by careful studies during the design phase. [3, 8]

5a.3.2 Earth-to-air heat exchangers

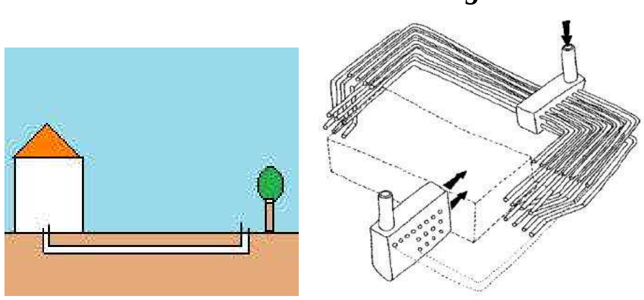


Figure 4, Principle of earth-to-air heat exchangers [3] *(left) Drawing of the earth-to- air heat exchanger, DB Netz AG (Hamm) (right)*

The technique has been developed recently, but the principle dates from the ancient Persian and Greek times. More recent constructions are reported from the 16th century using natural cavities, found in the hills of Vicenza, Italy. [3]

The earth-to-air heat exchanger is a basic technology but there are things that make it more difficult such as, complex dynamics (thermal inertia of the soil) and soil temperature (uneasy to evaluate). [1]

An earth-to-air heat exchanger is a pipe buried horizontally at a certain depth, through which air circulates by means of electric fans. Hot external air is cooled by circulating through the tubes positioned in the ground. The underground pipes play the role of earth-to-air heat exchanger and cold air after the procedure injected inside the building. This is possible happens after a depth of 1.5m, the ground temperature during summer is lower than the average ambient temperature. This is due to the important thermal inertia of the ground that results in protecting the underground from the important surface temperature variations. Heat can be dissipated to the ground. The temperature drop of the circulated air and the efficiency of the system is a function of the inlet air dry bulb temperature, the ground temperature, the thermal characteristics of both pipes and soil, as well as the air velocity and pipe dimensions. The entrance of the outdoor air to the pipes should be in a shaded location, preferably with cool air currents. The pipes can be plastic, concrete or metallic. The length and the diameter of the pipes depend on the cooling load of the building. Usually they are about 10-30 cm in diameter and 12-60 m in length. When restricted space is available, an array of pipes can be used instead of one big pipe. Circulation of the indoor air through earth pipes can alter the indoor air temperature by 10^{o}C compared to the external ambient one. [3, 7, 8]

The temperature [3] decrease of the air that enters the building depends upon the following parameters:

- the inlet air tempetature,
- the ground temperature at the depth of the exchanger is installed,
- the thermal conductivity of the pipes,
- the thermal diffusivity of the soil,
- the air velocity,

- the length of tubes
- the tube diameter
- the number of tubes

Detailed calculations are needed to optimise such a system.

Problems with earth-to-air heat exchanger applications: [3]

- Possible water inside the tubes or evaporation of accumulated water, which affects the quality of the air injected into the building. This can be faced by placing appropriate filters at the air-outlet or one other option is to link the earth-to-air heat exchangers with the conventional air conditioning
- In order to maximise the control of such a system it is necessary to provide automatic control algorithm. This must compare the indoor and outdoor temperature and in the case that is lower the fan must be stopped.
- Attention should be paid to avoid noisy fans.

Chapter 5b Integrating renewable technologies 2/ Earth- to-air heat exchangers

5b.1 Main phenomena occurring in the system

5b.1.1 Physical interpretation

The principle of an earth-to-air heat exchanger is directly related to the thermal properties of the ground. The heat transfer mechanisms in soils are in order of importance: conduction, convection and radiation. Conduction occurs throughout the soil but the main flow of heat is through the solid and liquid constituents. Convection is usually negligible, with the exception of rapid water infiltration after irrigation or heavy rain. Radiation is important only in very dry soils with large pores, when temperature is high. Therefore the main parameters influencing the thermal behaviour of the soil are thermal conductivity and heat capacity. [3, 5]

Heat transfer in earth ducts:

[5] Air enters the underground duct at a mass flow m_a, enthalpy h_o, temperature T_o, humidity g_o. It is moving at a constant velocity V and along the duct transfers heat Q by convection to the surrounding ground.

$$Q = h_c * A * (T - T_d)$$

With:

h_c = the convective heat transfer coefficient

A = the surface of the duct through which heat transfer occurs

T = temperature of the air in the duct

T_d = temperature of duct on its external surface.

5b.1.2 Modelling the earth-to-air heat exchangers

In order to evaluate the cooling potential of the technology, we have to model the earth-to-air heat exchangers. The procedure of modelling earth-to-air heat exchangers (Mihalakakou and colleagues 1994 model) [3, 4] can be seen in the appendix *on page 71*.

5b.1.3 Cooling potential of the technology

According experiments and long investigation by Mihalakakou and colleague in 1994 the cooling potential (↓T) of earth-to-air heat exchange depends on the following parameters:

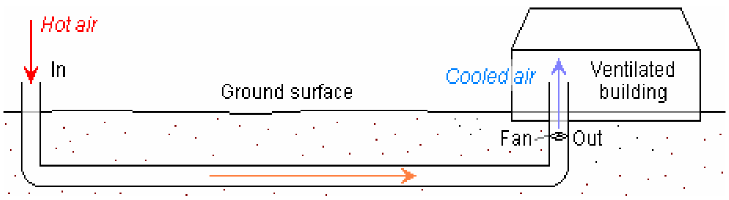
- ✓ Different duct lengths; an increase of the length of the pipe decrease the outlet-air temperature. (↑L , ↓T)
- ✓ Different duct diameters; a decrease of the diameter of the pipe decrease the outlet-air temperature. (↓d , ↓T)
- ✓ Different air velocities; the air velocity increase leads to a slight increase of the outlet-air temperature. (↓v , ↓T)
- ✓ Different depth; an increase of the ground depth of the pipe decrease the outlet-air temperature. (↑D , ↓T)
- ✓ Different surface; for example bare soil, the multiyear annual mean temperature is close to 21°C while for the short grass- covered soil, the corresponding value is close to 18.5°C [6] which is basically around 2°C.

5b.2 Model Description

A theoretical model of an earth-air heat exchanger was developed for predicting the outlet-air temperature (Tout). The Tout of the air is a function of several variables, such as pipe length, pipe diameter, depth, flow speed, etc. as already mentioned. A sub-soil temperature model was adapted for the specific conditions of the year 1999. In order to obtain the optimum Tout (which means the minimum) a model was built in Excel programme. The Excel method is validated against other published models and shows good agreement. The earth-to-air heat exchanger was implemented in the Greek dwelling with the following way. Zones a and b were ventilated through the optimum

Tout calculated in Excel. The examination took place in the ESP-r programme. The earth-air heat exchanger was assumed as a new zone that supplies cool air to zone a and b. Ventilation from the earth-air heat exchanger is expected to decrease the temperature in both zones.

5b.2.1 Building the model



[1]

The ground earth-to-air heat exchanger system was built through the following steps:

a) Ground temperature calculation

The year chosen to carry out the study was 1999. The data collected for the whole year 1999 (from January 1st until December 31st) gives an average of 18.248°C. This data is required to calculate the ground temperature at certain depth, given by the following expression [2]:

$$T_G = gm \cdot \left[T_{AM} - AH \cdot \Delta T_A \cdot sin\left[\frac{2 \cdot \pi}{8760} * [JH - VS + 24 \cdot 25] \right] \right]$$

Where:

g_m: ground material factor

T_{AM}: annual mean outside temperature

AH: amplitude correction factor

ΔT_A: amplitude of the annual outside air temperature swing

JH: annual hour

VS: curve shift

The *gm* can be obtained with the help of this table:

	Conductivity W/mK	Density Kg/m^3	Capacity J/kgK	Correction gm factor
Moist soil	1,5	1400	1400	1
Dry sand	0,7	1500	920	0,9
Moist sand	1,88	1500	1200	0,98
Moist clay	1,45	1800	1340	1,04
Wet clay	2,9	1800	1590	1,05

The amplitude correction factor and the curve shift are calculated using these equations:

$$AH = -0.000335 * depth^3 + 0.01381 * depth^2 - 0.1993 * depth + 1$$

$$VS = 24 * (-0.0195 * depth^4 + 0.3385 * depth^3 - 1.0156 * depth^2 + 10.298 * depth + 0.1786)$$

b) Optimisation model for the ground cooling system

In order to obtain the best Tout a model was built in Excel, using the software available in the university Premium Solver. The thinking behind this decision was to change the variables previously mentioned in such way that the best Tout is obtained.

Premium Solver is an advanced version of the Solver found in Excel. It includes a more powerful optimisation engine and provides faster calculations. An objective is set (objective that can be minimised, maximised or equal to certain number) and the variables are chosen including upper and lower boundaries.

Ideally the model would have to set as objective to minimise the Tout, but due to an incompatibility of Premium Solver with the link that changes the constant values with the change of variables, the objective was to minimise the dimensionless value U. This value is directly related to the final Tout, therefore, minimising it a lower Tout is obtained.

The following [3] rules were considered in order to build the model for the required data:

- The ground temperature around the tubes should be at least 5-6 degrees lower than the ambient temperature.
- The length of the exchanger should be at least 10m
- The diameter of the exchanger should range between 0.2 and 0.3m
- The depth of the exchanger should range between 1.5 and 4m
- The air velocity through the buried pipe should range between 4 and 8m.s^{-1}.

The calculation procedure is shown below:

Q: Air volume rate in the tube (m^3/sec)	$\pi \times r^2 \times u$
P1: Parameter P1	0.0161896 x L
P2: Parameter P2	0.00019058 x L^2
P3: Parameter P3	0.000000957 x L^3
U: Dimensionless parameter	0.9995242 + P1 + P2 + P3

L: Tube Length (m), r: Radius of the tube (m), D: Depth of the tube (m), u: Air velocity inside the tube (m/s)

QD1	a1 x D
QD2	a2 x D^2
QD3	a3 x D^3
CV1	a0 + QD1 + QD2+ QD3

a0, a1, a2, a3 coefficients were taken from the table 1 see appendix on page 74.

QV1	b1 x Q
QV2	b2 x Q^2
QV3	b3 x Q^3
CV2	b0 + QV1 + QV2+ QV3

b0, b1, b2, b3 coefficients were taken from the table 2 see appendix on page 74.

Ucor	U x CV1 x CV2
Tout	Tg + Ucor x (Tin - Tg)

Tin: Inlet air temperature (ºC) for the summer period of 1999,

Tg: Ground temperature (ºC) calculated before.

Tow different scenarios were analysed, both of them temperatures taken during the summer of 1999:

- June, July and August average T (27,117ºC)
- Maximum T measured during the three months (21st of August, 39,98°C)

5b.2.2 Results analysis of the excel model

June, July and August average T:

L	60	m	Tube Length
r	0,14497863	m	Radius of the tube
D	3,648779647	m	Depth of the tube
u	6,004353	m/s	Air velocity inside the tube
Tin	27,117	C	Inlet air temperature
Tg	20,30406556	C	Ground temperature
Q	0,396482574	m^3/s	Air flow

Tout minimum	21,84548 ºC

Maximum T measured during the three months:

L	60	m	Tube Length
r	0,142649391	m	Radius of the tube
D	3,0733903	m	Depth of the tube
u	6,929811338	m/s	Air velocity inside the tube
Tin	39,980	C	Inlet air temperature
Tg	23,06379677	C	Ground temperature
Q	0,443007548	m^3/s	Air flow

Tout minimum	28,63798 ºC

b.2.3 Results analysis of the ESP-r model

Simulations for summer period:

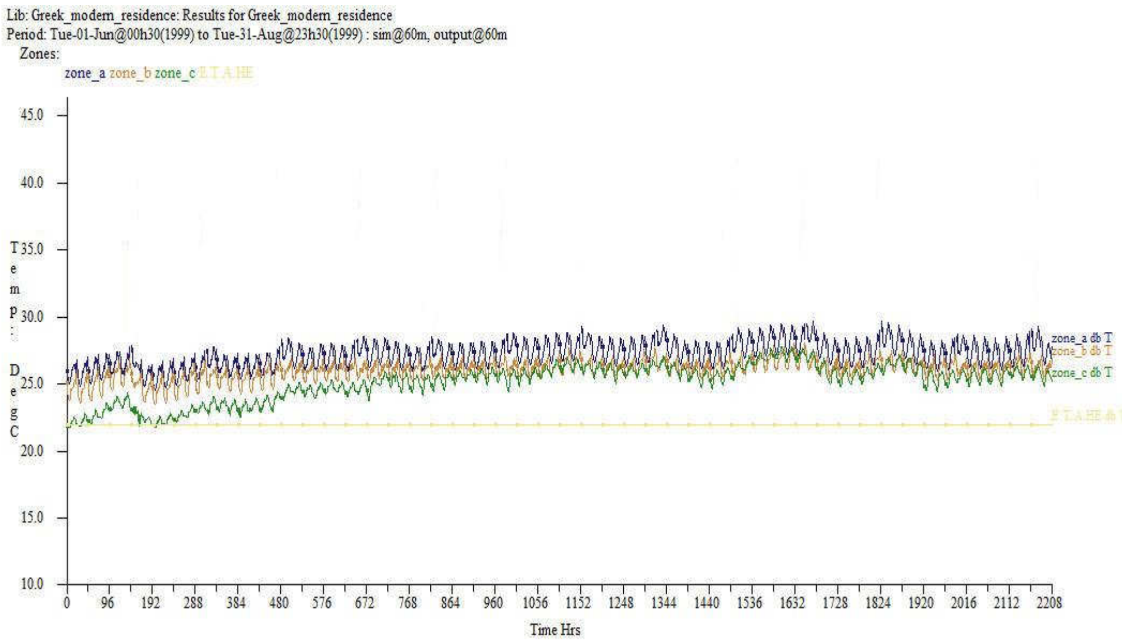


Table 4, Temperatures inside the building

5b.2.4 Discussion

The tool designed in Excel proved that the optimum outlet temperature of an earth-to-air heat exchanger was significantly lower than the inlet.

When an ambient T of almost 40ºC enters the system (the worst case scenario) Tout that enters the building will be 11ºC less. And when the T average of around 27ºC enters the system the Tout that enters the building will be almost 22ºC**.**

Simulation results in ESP-r by using earth-air heat exchangers with a constant temperature Tout 22ºC in zone a and zone b have shown that thermal comfort of 25-27ºC can be achieved most of the time with zero air-conditioning devices. For zone a the temperature range is between 25 and 27ºC and for zone b the temperature is range between 24 and 26ºC. Both zones are achieving thermal comfort with zero cooling requirements and a similar temperature to zone c which is the basement. The basement from the beginning did not require any cooling.

References

Articles:

[1] *Stephan Thiers, Bruno Peuportier, Thermal model of an earth-to-air heat exchanger for passive cooling of buildings, CENTER FOR ENERGY AND PROCESSES in Paris, 2007*

[2] *Ventilation for buildings- Calculation methods for energy losses due to ventilation and infiltration in commercial buildings, 2006, (on page 24)*

[4] *G. MIHALAKAKOU, M. SANTAMOURIS, and D. ASIMAKOPOULOS, Modelling the thermal performance of earth-to-air heat exchangers, University of Athens, Department of Applied Physics, Greece*

[6] *C. P. JACOVIDES, G. MIHALAKAKOU, M. SANTAMOURIS and J. LEWIS, On the ground temperature profile for passive cooling applications in buildings, University of Athens, Department of Applied Physics, and Energy Research Group, University College Dublin, Ireland, 1996*

[7] *Stephane Thiers, Bruno Peuportier, Associate Editor Matheos Santamouris, Thermal and environmental assessment of a passive building equipped with an earth-to-air heat exchanger in France, CENTER FOR ENERGY AND PROCESSES in Paris, 2008*

Bibliography:

[3] *M. Santamouris, D. Asimakopoulos, Natural cooling techniques-energy conservation in buildings, Athens 1995*

[5] *Fundamentals of heat and mass transfer Calculation of convective heat transfer coefficient, Incropera, DeWitt, Bergman and Lavine, 2007*

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[8] **http://www.learn.londonmet.ac.uk/**. *Low Energy Architecture Research Unit of the London Metropolitan University*

Chapter 6 Conclusion

In order to assess the performance of a typical modern house in the Greater Athens area, a model was developed in ESP-r. Initial results showed high cooling requirements in order to keep thermal comfort during summer period. An integrated renewable alternative scenario for improving the energy efficiency of the building in summer was presented and examined.

Research in renewable processes took place. Two options were investigated in depth. New models were built in ESP-r environment. Separate simulations were run using PV panels and earth-air heat exchangers and their impact was validated against experimental results.

Absorbing solar energy allows the achievement of thermal comfort in the buildings, with a limited use of conventional fuels. 26 PV panels ($17m^2$) were installed on the building's roof which was the maximum number the building can get. Simulation results showed that the renewable electricity output per day produced meets 165% of the energy needed per day for maintaining the indoor building temperature at 26ºC. This percentage of green electricity helps in reducing carbon emissions. Results present a very promising potential for PV power supply and carbon emissions saving. Non electricity will be required from the grid. The photovoltaic systems generate more energy than building cooling demand for the summer period. The rest electricity could be used for the lights or other equipments or even it could be supplying the energy excess to the public electricity grid.

Greece is a particularly sunny country during the summer and we must take advantage of that but PV panels have extremely high capital cost.

An alternative approach of cooling while achieving low energy consumption and thermal comfort can be managed through earth-to-air heat exchangers. In particular, simulation results for earth-air heat exchangers have shown a reduction in the cooling needs by almost 100% (assuming an optimum constant temperature Tout from earth-to-air heat exchangers of 22°C) compared to an air-conditioned building. Thermal comfort of 25-27°C can be achieved most of the time using earth-air heat exchangers with zero air-conditioning devices.

This project has indicated the feasibility of these technologies in meeting the cooling demand while reducing carbon emissions.

Modelling a typical new residence with improved insulation and other modern techniques showed important problems in cooling requirements. But it is possible to achieve significant energy savings in the residential environment with simple methods and techniques.

The above proposed solutions for energy reduction for cooling are not unique solutions; this dissertation was an effort to prove that alternative technologies can be used to provide comfort while protecting the environment. The efficiency of these systems depends on the building needs. Every building requires a different study. The potential renewable energy strategy could implement just one of these technologies or a combination.

Research commenced with a literature review which examined most of the possible alternative scenarios for reducing demand on the grid. It was decided that simulations would be carried out on an already constructed residential building and so ground energy and solar energy were selected as the most applicable renewable sources. Further techniques have been included in the literature review which can be used to improve the energy performance of other aspects of buildings. For example, night ventilation could be incorporated to reach a higher comfort level. Therefore, the passive concept seems to be a valid and efficient solution to improve the environmental performance of dwellings.

About two thirds of the total energy consumed in buildings is used in private buildings. Energy consumption for cooling, heating, lighting, ventilation and domestic hot water are the main concerns in private buildings. This dissertation has focused on the development of low energy buildings by the use of various techniques in order to reduce carbon emissions while achieving thermal comfort in summer. The potential renewable strategy was suggested and investigated. A new way of thinking in the building industry has to be adopted soon. In parallel, low energy consumption for cooling new generation buildings has to be realised and monitored. A re-examination of the activities in energy efficiency is an urgent requirement. Finally the real challenge for the future is managing thermal comfort by natural means, and this project has demonstrated the feasibility of two such residential systems in the Greek summer climate.

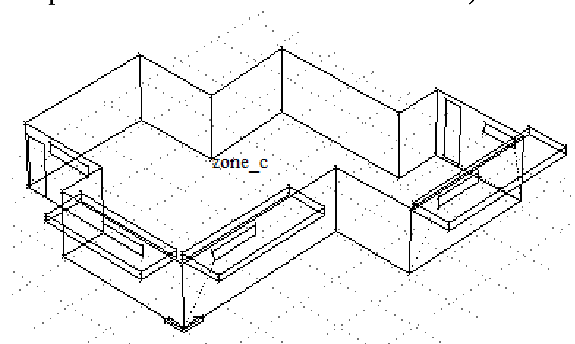
Appendix

For chapter 3

1. The zones of the model are:

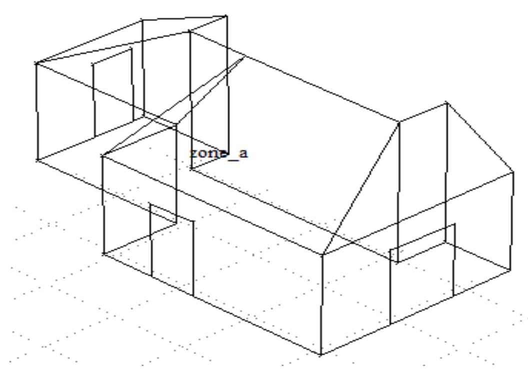
Zone c, is the basement. A large zone below ground used for storage and mostly unoccupied.

(Volume = 346m³, Floor area = 128m², opaque construction = 406m², transparent construction = 3.89m²)



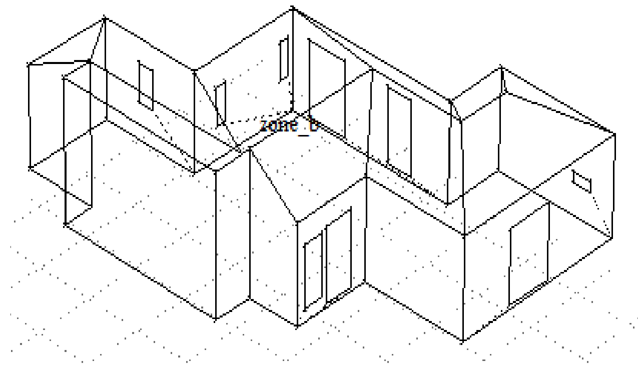
Zone a, is all the bedrooms at the ground floor.

(Volume = 133m³, Floor area = 38m², opaque construction = 184m², transparent construction = 9m²)



Zone b, is the living room, the kitchen and the bathroom at the ground floor.

(Volume = 323m³, Floor area = 90m², opaque construction = 337m², transparent construction = 9.47m²)



2. Composite construction database:

Layers	**Description**	**Optics**
5	external wall No1	opaque
Db ref	**thickness (mm)**	**db name**
183	30	Asbestos sheet
6	90	Lt Brown brick
205	60	Polyurethane foam b
6	90	Lt Brown brick
107	20	Gypsum plasterboard

Layers	**Description**	**Optics**
5	external wall No2	opaque
Db ref	**thickness (mm)**	**db name**
183	30	Asbestos sheet
32	100	Heavy mix concrete
32	100	Heavy mix concrete
32	100	Heavy mix concrete
107	20	Gypsum plasterboard

Layers	**Description**	**Optics**
7	external wall No3	opaque

Db ref	thickness (mm)	db name
263	100	Common earth
263	100	Common earth
263	100	Common earth
32	100	Heavy mix concrete
32	100	Heavy mix concrete
32	100	Heavy mix concrete
107	20	Gypsum plasterboard

Layers	Description	Optics
3	eternal wall	opaque
Db ref	**thickness (mm)**	**db name**
107	20	Gypsum plasterboard
6	60	Lt Brown brick
107	20	Gypsum plasterboard

Layers	Description	Optics
3	double glazing	transparent
Db ref	**thickness (mm)**	**db name**
242	6	Plate glass
0	12	air 0.17
242	6	Plate glass

Layers	Description	Optics
1	external doors	opaque
Db ref	**thickness (mm)**	**db name**
43	25	Aluminium

Layers	Description	Optics
1	internal doors	opaque
Db ref	**thickness (mm)**	**db name**
63	25	Hardboard

Layers	Description	Optics
4	roof for zone c	opaque
Db ref	**thickness (mm)**	**db name**
153	10	Floor tiles
36	100	Concrete block
36	100	Concrete block
151	8	Ceiling (plaster)

Layers	Description	Optics
5	roof for zones a, b	opaque
Db ref	**thickness (mm)**	**db name**
141	15	Clay tile
164	5	Asphalt
205	80	Polyurethane foam b
164	5	Asphalt
72	12	Plywood

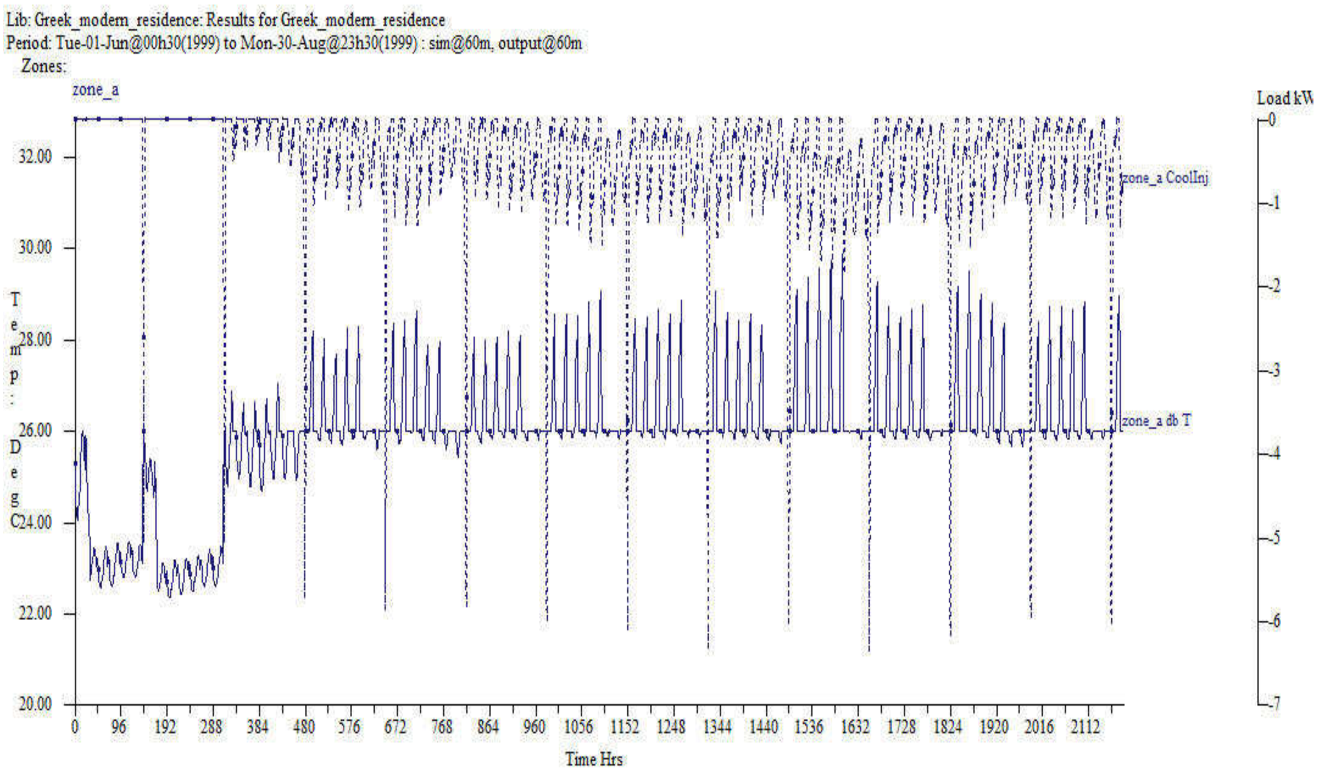
Layers	Description	Optics
6	floor for zone c	opaque
Db ref	**thickness (mm)**	**db name**
263	100	Common earth
263	100	Common earth
263	100	Common earth
36	100	Concrete block
36	100	Concrete block
153	10	Floor tiles

Layers	Description	Optics
3	floor for zones a, b	opaque
Db ref	**thickness (mm)**	**db name**
107	10	Gypsum plasterboard
36	100	Concrete block
36	100	Concrete block
153	10	Floor tiles

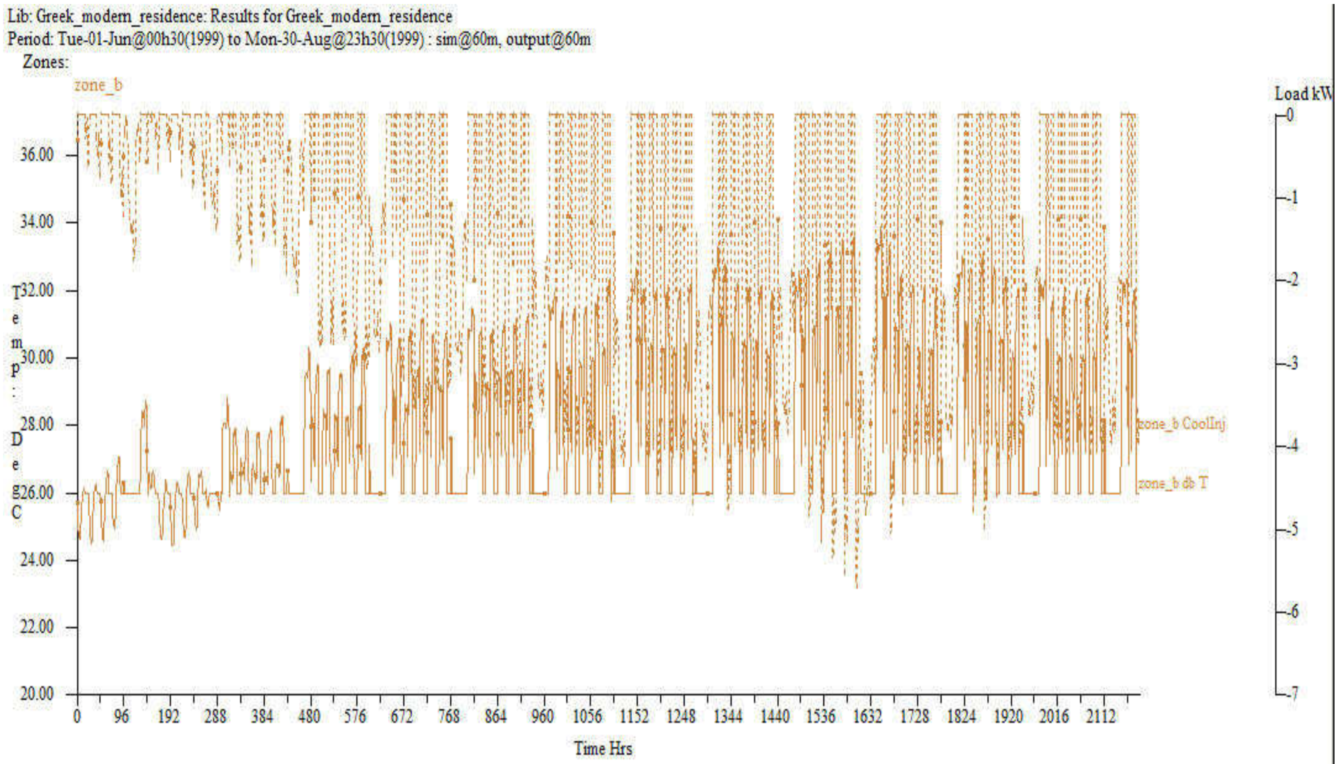
3. The diagrams show analytically what is going on trough the whole period in every zone depending on the occupancy (operating profile and different control characteristics).

Simulations from 1/6 – 30/8/1999 (summer period)

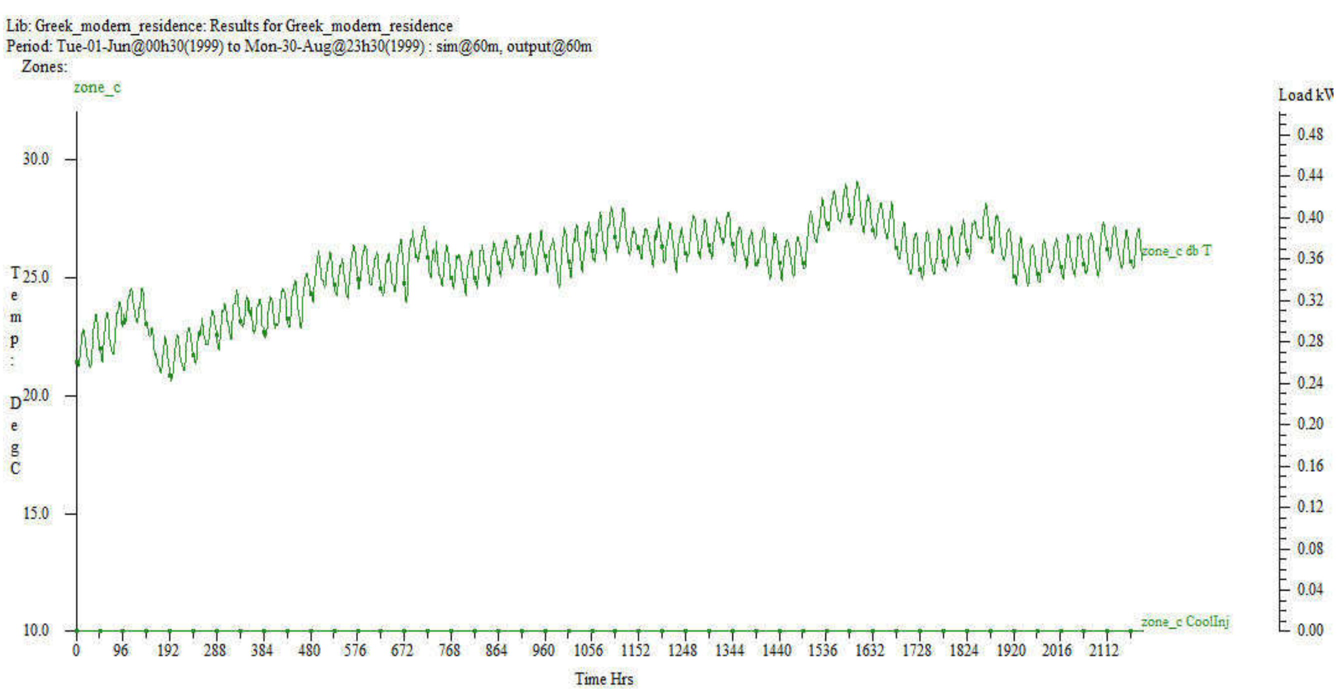
Zone a



Zone b


Lib: Greek_modern_residence: Results for Greek_modern_residence
Period: Tue-01-Jun@00h30(1999) to Mon-30-Aug@23h30(1999) : sim@60m, output@60m
Zones:
zone_b
Load kW
0
-1
-2
-3
-4
-5
-6
-7
36.00
34.00
32.00
30.00
28.00
26.00
24.00
22.00
20.00
Temp: DegC
zone_b CoolInj
zone_b db T
0
96
192
288
384
480
576
672
768
864
960
1056
1152
1248
1344
1440
1536
1632
1728
1824
1920
2016
2112
Time Hrs

Zone c


Lib: Greek_modern_residence: Results for Greek_modern_residence
Period: Tue-01-Jun@00h30(1999) to Mon-30-Aug@23h30(1999) : sim@60m, output@60m
Zones:
zone_c
Load kW
0.48
0.44
0.40
0.36
0.32
0.28
0.24
0.20
0.16
0.12
0.08
0.04
0.00
30.0
25.0
20.0
15.0
10.0
Temp: DegC
zone_c db T
zone_c CoolInj
0
96
192
288
384
480
576
672
768
864
960
1056
1152
1248
1344
1440
1536
1632
1728
1824
1920
2016
2112
Time Hrs

For chapter 4b

New Composite construction database:

Layers	**Description**	**Optics**
7	new roof for zones a, b	opaque
Db ref	**thickness (mm)**	**db name**
246	3	CF low- e glass
247	3	Tedlar
246	3	CF low- e glass
141	15	Clay tile
164	5	Asphalt
205	80	Polyurethane foam b
164	5	Asphalt
72	12	Plywood

The Low-e glass and the Tedlar are the construction materials of the PV model. BP 380 operates DC loads directly or, in an inverter-equipped system, AC loads.

For chapter 5b

1. The model was built following the procedure (Mihalakakou and colleagues 1994 model) [3, 4]

The transport phenomena that determine the operation of an air to earth heat exchanger to the ground are the heat transfer from the air circulating in the exchanger and the ground, but also the moisture transfer induced by the heat transfer process. Therefore this process is described by the heat balance differential equation and the mass transfer differential equation. This system of equations is solved, taking into account the initial and boundary conditions for each one of them.

The heat balance equation, in cylindrical co-ordinates is:

$$\rho c_p \frac{\vartheta T}{\vartheta t} = \frac{1}{r}\frac{\vartheta}{\vartheta r}\left(kr\frac{\vartheta T}{\vartheta r}\right) + \frac{\vartheta}{\vartheta y}\left(k\frac{\vartheta T}{\vartheta y}\right) - l_g \rho_m \frac{1}{r}\frac{\vartheta}{\vartheta r} \times \left(D_{u,vap} r \frac{\vartheta h}{\vartheta r}\right) - l_g \rho_m \frac{\vartheta}{\vartheta y}\left(D_{u,vap}\frac{\vartheta h}{\vartheta y}\right)$$

With:

T = soil temperature of the soil surface,

ρ = soil density

Cp = specific heat of soil

k = thermal conductivity of the soil

lg = heat of vaporisation of the moisture content of the soil

ρm= moisture density

Du, vap = isothermal diffusivity of moisture in vapour form,

h = moisture content of the soil

The mass transfer equation:

$$\frac{\vartheta h}{\vartheta t} = \frac{1}{r}\frac{\vartheta}{\vartheta r}\left(D_T r\frac{\vartheta T}{\vartheta r}\right) + \frac{\vartheta}{\vartheta y}\left(D_T\frac{\vartheta T}{\vartheta y}\right) + \frac{1}{r}\frac{\vartheta}{\vartheta r}\left(D_u r\frac{\vartheta h}{\vartheta r}\right) + \frac{\vartheta}{\vartheta y}\left(D_u\frac{\vartheta h}{\vartheta y}\right)$$

Where,

$$\frac{1}{r}\frac{\vartheta}{\vartheta r}\left(D_T r\frac{\vartheta T}{\vartheta r}\right) + \frac{\vartheta}{\vartheta y}\left(D_T\frac{\vartheta T}{\vartheta y}\right)$$

Is the component of moisture flux due to temperature gradient and

$$\frac{1}{r}\frac{\vartheta}{\vartheta r}\left(D_u r\frac{\vartheta h}{\vartheta r}\right) + \frac{\vartheta}{\vartheta y}\left(D_u\frac{\vartheta \mathrm{h}}{\vartheta \mathrm{y}}\right)$$

is the component of moisture flux due to the moisture gradient

The heat and mass transfer problem has the following initial conditions:

T(r, y, t=0) = To(r)

h(r, v. t = 0) = ho(r)

The boundary conditions are:

1. for the r co-ordinate:

(a) *at* $r = R_L$.

$$T(R_L, y, t) = T(R_L)$$

$$h(R_L, v, t) = h(R_L),$$

where R_L *is a large radial distance in the soil at this distance the temperature and moisture distributions are not influenced*

(b) *at* $r = R_P$

The calculated heat transfer in the soil is equal to the amount of heat losses as air flows along the pipe.

$$G(T_a(y) - T(R_p, y, t) = -m_a C_a[dT_a(y)/dy]$$

Where G is the overall thermal conductance of the whole earth-to-air heat exchanger system including air, pipe and soil.

Thus, G can be expressed as:

$$G = 2\pi l / \{(1/r_{in}h_c) + [ln(R_p/r_{in})/K_p]\}$$

And Ta(O) equals the ambient air temperature. At $r = R_P$*, the moisture content is caused by the temperature gradient since the pipe is impervious. Thus, the component of moisture flux due to moisture gradient is equal to zero.*

$$\partial h/\partial r(R_p, y, t) = 0$$

2. for the y co-ordinate:

(a) at $y = y_A$

$$T(r, y_A, t) = T_s(r)$$

$$h(r, y_A, t) = h_s(r),$$

(b) at $y = y_B$

$$T(r, y_B, t) = T_s(r)$$

$$h(r, y_B, t) = h_s(r),$$

The diffusivity values (D_T, *Du, Du, vap) used in this study was obtained from Puri (1986) and Gee (1966). The soil temperature at a point in the pipe vicinity is estimated by superposition of the* *temperature field due to the pipe system T(r, y, t) and the undisturbed temperature field Tu(z,t) due to the ground surface temperature. Undisturbed soil temperature can accurately be modelled by the following one dimensional, transient, heat conduction equation:*

$$\partial^2 T_u(z, t)/\partial z^2 = 1/a * \partial T_u(z, t)/\partial t$$

Where u is the soil thermal diffusivity and z is the depth below ground surface. The corresponding boundary conditions at z = 0 were the following:

$$T_u = T_{surface} = T_m - A_s * \cos[w * (t - t_0)]$$

$$\text{for } z \rightarrow \infty \quad T_u \text{ is finite}$$

Carslaw and Jaeger (1959). According to this analytical solution, the temperature at any depth z and time t can be found by the expression:

$$T_u(z, t) = T_m - A_s * \exp(-\lambda z) \times \cos[w(t - t_0) - \lambda z]$$

where As is the amplitude of temperature wave at the ground surface, Tm is the mean annual soil temperature, w is the frequency of annual temperature wave, and λ can be defined by the expression: ***λ = (w/2α)½.***

The transient earth-tube system described before incorporates three independent (r, y, t) and two dependent variables (T, h).

2. Two tables helped to get the constant values a0, a1, a2 and a3 (pipe length-airflow) and b0, b1, b2 and b3 (pipe length-depth). [3]

Table 1

Q/L	a	10	15	20	25	30	35	40	45	50	55	60
0.393	a0	1.165520	1.489015	1.645340	1.800090	1.951960	2.033872	2.168868	2.220354	2.263630	2.030870	2.350390
0.425	a0	1.149400	1.442890	1.598730	1.700350	1.901170	1.967892	2.103820	2.127432	2.137451	2.187293	2.265720
0.458	a0	1.142600	1.418300	1.520700	1.068200	1.863730	1.946295	2.078430	2.108325	2.109485	2.127295	2.198370
0.528	a0	1.139350	1.407850	1.499300	1.672890	1.721020	1.871430	1.998620	2.076320	2.078360	2.096472	2.178090

0.565	a0	1.138740	1.394650	1.482600	1.652890	1.658346	1.850427	1.928548	2.058290	2.088210	2.096270	2.130940
0.604	a0	1.135090	1.381623	1.479900	1.631498	1.614723	1.850427	1.928548	2.041320	1.963780	2.004350	2.107870
0.643	a0	1.132170	1.362930	1.476971	1.592830	1.608790	1.837421	1.908032	2.001700	1.947830	1.992840	2.102380
0.684	a0	1.128070	1.359830	1.458030	1.548940	1.597870	1.820071	1.874324	1.978760	1.921350	1.972430	2.099360
0.726	a0	1.112890	1.339400	1.439230	1.507980	1.582810	1.787361	1.829760	1.967400	1.899320	1.923763	2.095400
0.770	a0	1.010133	1.315670	1.429520	1.498730	1.179890	1.752540	1.798630	1.947832	1.890220	1.907893	2.090320
0.811	a0	1.010087	1.309270	1.410930	1.486440	1.572060	1.730580	1.780600	1.928539	1.889630	1.897214	2.086270
0.860	a0	1.010043	1.300020	1.390820	1.466530	1.569870	1.699271	1.765900	1.902735	1.884030	1.877640	2.083250
0.907	a0	1.100101	1.298730	1.377600	1.448730	1.569570	1.672720	1.748200	1.897450	1.884030	1.860780	2.069250
1.005	a0	1.092380	1.288350	1.368270	1.427830	1.565190	1.652010	1.720580	1.867540	1.879350	1.852704	2.058380
1.056	a0	1.089423	1.279900	1.352784	1.419980	1.548199	1.632100	1.717986	1.832430	1.875908	1.832778	2.045508
1.108	a0	1.087309	1.270730	1.341574	1.410985	1.520730	1.60984	1.707986	1.809273	1.863292	1.829788	1.989750
1.162	a0	1.082493	1.269870	1.336128	1.409340	1.502780	1.598991	1.689720	1.799853	1.820721	1.809400	1.952850
1.216	a0	1.080935	1.259210	1.624859	1.399650	1.484762	1.587220	11.659430	1.772130	1.794520	1.802600	1.930120
1.272	a0	1.079272	1.247010	1.310912	1.397560	1.474960	1.580910	1.637340	1.742183	1.178352	1.799478	1.826372
1.330	a0	1.078507	1.235614	1.130361	1.390460	1.465173	1.574669	1.629470	1.705842	1.771453	1.796258	1.823225
0.393	a1	-0.109210	-0.334799	-0.423397	-0.540170	-0.639415	-0.692990	-0.795803	-0.795660	-0.858780	-0.863890	-0.895700
0.425	a1	-0.101860	-0.313780	-0.398070	-0.501202	-0.611729	-0.612783	-0.767896	-0.772850	-0.794532	-0.824895	-0.852813
0.458	a1	-0.098210	-0.309873	-0.376730	-0.491837	-0.598730	-0.632981	-0.739628	-0.740720	-0.743870	-0.792563	-0.843710
0.528	a1	-0.091420	-0.283985	-0.358780	-0.472893	-0.510870	-0.592743	-0.662782	-0.723214	-0.702890	-0.768270	-0.828930
0.565	a1	0.088900	-0.272980	-0.339670	-0.449880	-0.449326	-0.187830	-0.601979	-0.643972	-0.680667	-0.752912	-0.810804
0.604	a1	-0.081400	-0.264954	-0.324860	-0.450794	-0.419783	-0.587832	-0.601979	-0.693217	-0.677820	-0.738962	-0.792694
0.643	a1	-0.079200	-0.250890	-0.317577	-0.422790	-0.402743	-0.528711	-0.174362	-0.657224	-0.670382	-0.722963	-0.790080
0.684	a1	-0.077300	-0.242711	-0.308975	-0.408294	-0.400873	-0.567213	-0.130893	-0.632743	-0.662893	-0.702814	-0.782694
0.726	a1	-0.073800	-0.230271	-0.296580	-0.392721	-0.399273	-0.552984	-0.500945	-0.618732	-0.653394	-0.698714	-0.773845
	a1	-	-	-	-0	-	-	-	-	-	-	-

0.770		0.070708	0.248930	0.283390	377730	0.396270	0.548971	0.498730	0.608714	0.642794	0.672873	0.762945
0.811	a1	-0.069502	-0.232810	-0.264090	-0.350721	-0.391870	-0.537812	-048685	-0.572364	-0.637943	-0.667273	-0.758913
0.860	a1	-0.067830	-0.227830	-0.258070	-0.322721	-0.390870	-0.522994	-0.480760	-0.552895	-0.624894	-0.652789	-0.752032
0.907	a1	-0.065930	-0.215631	-0.250912	-0.312783	-0.390870	-0.508741	-0.470760	-0.549436	-0.612943	-0.652789	-0.736720
1.005	a1	-0.061407	-0.209630	-0.242183	-0.302594	-0.389712	-0.483714	-0.469920	-0.539421	-0.609274	-0.648723	-0.724732
1.056	a1	-0.058381	-0.193694	-0.234840	-0.299862	-0.037674	-0.477213	-0.468350	-0.522743	-0.606392	-0.622794	-0.716440
1.108	a1	-0.011798	-0.189413	-0.227625	-0.290278	-0.358790	-0.452920	-0.462330	-0.503381	-0.594721	-0.609210	-0.693780
1.162	a1	-0.056327	-0.183020	-0.220809	-0.282764	-0.348940	-0.448742	-0.458780	-0.499763	-0.578932	-0.587223	-0.678430
1.216	a1	-0.055480	-0.178730	-0.217650	-0.278976	-0.326790	-0.043540	-0.447851	-0.496215	-0.543928	-0.573440	-0.645430
1.272	a1	-0.054802	-0.169853	-0.209260	-0.269580	-0.317940	-0.412773	-0.438963	-0.489813	-0.536280	-0.568236	-0.574340
1.330	a1	-0.053080	-0.164852	-0.206030	-0.260534	-0.304690	-0.401806	-0.423040	-0.485759	-0.527006	-0.552746	-0.172990
0.393	a2	0.016410	0.048229	0.057187	0.077390	0.090087	0.096990	0.116046	0.105440	0.125112	0.121352	0.120720
0.425	a2	0.015759	0.046080	0.055895	0.070280	0.088372	0.092743	0.109874	0.101074	0.105022	0.113278	0.115371
0.458	a2	0.014673	0.045298	0.013793	0.069270	0.076894	0.088731	0.089432	0.096285	0.009927	0.104496	0.113807
0.528	a2	0.013983	0.043987	0.049873	0.068200	0.069785	0.085478	0.088060	0.093821	0.097871	0.095360	0.111708
0.565	a2	0.013578	0.041962	0.047967	0.064293	0.065225	0.083773	0.077240	0.080521	0.095070	0.096289	0.109953
0.604	a2	0.012972	0.040761	0.045879	0.062799	0.062783	0.083773	0.077240	0.092211	0.094872	0.092803	0.109287
0.643	a2	0.012235	0.038279	0.043600	0.061897	0.060894	0.081235	0.075089	0.089072	0.094038	0.090225	0.109028
0.684	a2	0.011870	0.037003	0.041720	0.058072	0.059713	0.079925	0.070439	0.088072	0.093481	0.089821	0.108987
0.726	a2	0.011090	0.035923	0.039870	0.056078	0.058278	0.077251	0.068485	0.086278	0.093087	0.088274	0.108302
0.770	a2	0.010730	0.035072	0.038432	0.054077	0.056893	0.075544	0.066893	0.085245	0.092994	0.086874	0.108085
0.811	a2	0.010128	0.034872	0.036208	0.052272	0.055276	0.073231	0.065754	0.084274	0.092744	0.085273	0.107992
0.860	a2	-0.010099	0.032227	0.031879	0.050897	0.014927	0.071892	0.064917	0.081746	0.092675	0.084723	0.107873
0.907	a2	0.010040	0.031927	0.034298	0.048874	0.054927	0.069879	0.064017	0.080694	0.092078	0.083279	0.107089
	a2	0.0094	0.0302	0.0337	0.0467	0.0548	0.0678	0.0640	0.0796	0.0919	0.0822	0.1069

1.005		22	87	81	93	55	23	02	21	89	94	92
1.056	a2	0.009230	0.029781	0.032905	0.044878	0.053972	0.065471	0.063860	0.079026	0.091265	0.080783	0.106750
1.108	a2	0.008928	0.028832	0.031069	0.042279	0.048927	0.064981	0.063070	0.077843	0.088474	0.080078	0.094387
1.162	a2	0.008749	0.028287	0.030962	0.040783	0.045879	0.064722	0.062574	0.076274	0.084271	0.079965	0.093837
1.216	a2	0.008431	0.027498	0.030207	0.038276	0.042479	0.064527	0.061473	0.075821	0.080721	0.079256	0.090721
1.272	a2	0.008280	0.027008	0.029871	0.036721	0.040896	0.064271	0.060831	0.074621	0.078271	0.079008	0.079321
1.330	a2	0.008077	0.026940	0.029226	0.035419	0.039477	0.063922	0.059310	0.072673	0.076872	0.078279	0.079625
0.393	a3	0.000850	-0.002200	-0.002326	-0.003544	-0.004020	-0.004267	-0.005450	-0.004069	-0.006097	-0.005920	-0.005800
0.425	a3	-0.000840	-0.002196	-0.002270	-0.003308	-0.003897	-0.004072	-0.004635	-0.004008	-0.005872	-0.001727	-0.001706
0.458	a3	-0.000790	-0.002179	-0.002186	-0.003128	-0.003521	-0.003929	-0.003650	-0.003987	-0.005501	-0.005587	-0.005683
0.528	a3	-0.000690	-0.002169	-0.002087	-0.003049	-0.003289	-0.003897	-0.003090	-0.003908	-0.004920	-0.001479	-0.005570
0.565	a3	-0.000640	-0.002159	-0.001939	-0.003003	-0.003086	-0.003374	-0.002800	-0.003521	-0.004839	-0.005385	-0.005540
0.604	a3	-0.000621	-0.002114	-0.001891	-0.002960	-0.002981	-0.003874	-0.002800	-0.003887	-0.004737	-0.005227	-0.005508
0.643	a3	-0.000602	-0.002074	-0.001865	-0.002523	-0.002803	-0.003852	-0.002793	0.000385	-0.004708	-0.005188	-0.005508
0.684	a3	-0.000593	0.000203	-0.001703	-0.002307	-0.002703	-0.003795	-0.002748	0.000383	-0.004687	-0.850780	-0.005508
0.726	a3	-0.000582	-0.001989	-0.001678	-0.002289	-0.002508	0.003778	-0.002739	-0.003819	-0.004658	-0.004970	-0.005498
0.770	a3	-0.000542	-0.001917	-0.001551	-0.002147	-0.002498	-0.003753	-0.002720	-0.003807	-0.004647	-0.004729	-0.001398
0.811	a3	-0.000529	-0.001192	-0.001527	-0.002098	-0.002430	0.003721	-0.002715	-0.003797	-0.004637	-0.004663	-0.005325
0.860	a3	-0.000513	-0.001898	-0.001486	-0.001927	-0.004111	-0.003708	-0.002712	-0.003769	-0.004602	-0.004527	-0.005298
0.907	a3	-0.000501	-0.001867	-0.001428	-0.001888	-0.002411	-0.003692	-0.002709	-0.003759	-0.004592	-0.004472	-0.005201
1.005	a3	-0.000471	-0.001768	-0.001408	-0.001809	-0.002300	-0.003677	-0.002700	-0.003728	-0.004578	-0.004227	-0.005198
1.056	a3	-0.000436	-0.001730	-0.001390	-0.001789	-0.002100	-0.003633	-0.002699	-0.003708	-0.004558	-0.004128	-0.005173
1.108	a3	-0.0004	0.001698	-0.0013	-0.0017	-0.0019	-0.0035	-0.0026	-0.0036	-0.0042	-0.0039	-0.0049

		09		88	29	70	97	78	99	89	90	27
1.162	a3	-0.000402	-0.001659	-0.001370	-0.001654	-0.001860	-0.003567	-0.002653	-0.003683	-0.004099	-0.003827	-0.004680
1.216	a3	-0.000399	-0.001636	-0.001360	-0.001594	-0.001736	-0.003549	-0.002609	-0.003654	-0.003927	-0.003792	-0.004280
1.272	a3	-0.000395	-0.001601	-0.001340	-0.001505	-0.001582	-0.003508	-0.002540	-0.003633	-0.003876	-0.003703	-0.003902
1.330	a3	-0.000391	-0.001596	-0.001339	-0.001440	-0.001416	-0.003494	-0.002561	-0.003615	-0.003657	-0.003697	-0.003720

TABLE 2

D /L	b	10	15	20	25	30	35	40	45	50	5
0.500	b0	0.973237	0.984554	0.326835	0.932432	0.919087	0.921654	0.934780	0.932112	0.896039	0.90164
0.750	b0	0.964251	0.987236	0.936781	0.911445	0.900188	0.878759	0.890215	0.830453	0.867342	0.86023
1.000	b0	0.943157	0.942228	0.933072	0.914131	0.895504	0.890297	0.886878	0.846869	0.878355	0.83268
1.250	b0	0.934129	0.862693	0.843289	0.851786	0.824018	0.848365	0.868781	0.846622	0.766978	0.83268
1.500	b0	0.915252	0.751792	0.843289	0.719697	0.735950	0.775079	0.804484	0.793500	0.752700	0.82979
1.750	b0	0.929652	0.737016	0.843289	0.870439	0.900070	0.903584	0.929405	0.922783	0.928778	0.76399
2.000	b0	0.926914	0.767547	0.843289	0.578765	0.415915	0.353813	0.323308	0.335499	0.311043	0.93996
2.250	b0	0.914591	0.705065	0.665839	0.474699	0.383697	0.311219	0.292052	0.299266	0.283216	0.29393
2.500	b0	0.905220	0.667638	0.601498	0.376480	0.344708	0.320282	0.296884	0.233061	0.251109	0.26073
2.750	b0	0.924269	0.674073	0.472514	0.408116	0.342890	0.283230	0.277736	0.142827	0.174460	0.26168
3.000	b0	0.886844	0.525949	0.463996	0.416583	0.283646	0.233365	0.246983	0.147332	0.158649	0.11513
3.250	b0	0.893665	0.469679	0.469459	0.366157	0.279221	0.205594	0.190265	0.075588	0.073233	0.01898
3.500	b0	0.347735	0.417231	0.376069	0.318394	0.209448	0.194682	0.191679	0.024519	0.005535	0.04106
3.750	b0	0.883030	0.335935	0.340092	0.232365	0.129926	0.133263	0.133291	-0.525600	-0.047419	0.04722
4.000	b0	0.875150	0.341413	0.297175	0.214027	0.061206	0.133263	0.139015	-0.052571	-0.056730	0.05860
4.250	b0	0.877611	0.342725	0.326480	0.166084	0.057348	0.696672	0.064383	-0.017931	-0.007733	0.04802
0.500	b1	0.070519	0.017476	2.225822	0.204429	0.258050	0.241741	0.180760	0.182248	0.339175	0.31399
0.750	b1	0.099620	-0.009466	0.188054	0.278246	0.316501	0.409781	0.345308	0.389427	0.450719	0.47755
1.000	b1	0.187090	0.176478	0.230717	0.269495	0.333413	0.358894	0.371761	0.539791	0.414013	0.59235
1.250	b1	0.239084	0.332401	0.420427	0.389340	0.668460	0.563985	0.477142	0.562166	0.763249	0.59235
1.500	b1	0.298709	0.773208	0.420427	0.917625	0.859183	0.763326	0.676103	0.723438	0.899990	0.62781

1.750	b1	0.261440	0.837941	0.420428	0.215834	0.057796	0.040890	-0.073721	-0.024182	-0.031092	0.86137
2.000	b1	0.262270	0.748543	0.420428	1.376202	0.203344	2.322206	2.459221	2.422317	2.534951	0.10010
2.250	b1	0.270990	1.008623	1.184661	1.984768	2.169122	2.504189	2.598345	2.579707	2.648889	2.62118
2.500	b1	0.302190	1.170535	1.468510	2.398256	2.336022	2.469079	2.578260	2.847635	2.767559	2.75201
2.750	b1	0.255947	0.998754	1.839883	2.083679	2.357645	2.626279	2.668508	3.202602	3.112508	2.72449
3.000	b1	0.417362	1.561626	1.804119	2.000029	2.588219	2.811538	2.792266	3.211882	3.199118	3.36529
3.250	b1	0.385441	1.765941	1.762330	2.246018	2.611033	2.943951	3.045912	3.534070	3.543805	3.76666
3.500	b1	0.552660	1.967172	2.108582	2.394992	2.918789	3.004595	3.034765	3.743594	3.823755	4.01394
3.750	b1	0.418251	2.266396	2.223635	2.739005	3.229980	3.228278	3.266448	4.048362	4.044835	4.04932
4.000	b1	0.458460	2.207632	2.395603	2.784745	3.508352	3.228278	3.236331	4.071914	4.113760	4.11124
4.250	b1	0.378486	2.194540	2.258263	2.983711	3.501942	3.497629	3.552356	3.932336	3.892151	4.06505
0.500	b2	-0.019417	0.059640	-1.409554	-0.107430	-0.167547	-0.138176	-0.048576	-0.040050	-0.239138	0.20067
0.750	b2	-0.030200	0.121604	-0.071871	-0.168678	-0.199395	-0.315263	-0.204793	-0.259733	-0.339269	0.36111
1.000	b2	-0.124800	-0.082171	-0.130540	-0.142208	-0.205648	-0.238440	-0.248076	-0.447952	-0.302136	0.48855
1.250	b2	-0.214145	0.021589	-0.073370	-0.025450	-0.607523	-0.465888	-0.346319	-0.430653	-0.662467	0.48855
1.500	b2	-0.243880	-0.443959	-0.073366	-0.595792	-0.506930	-0.475420	-0.404196	-0.450382	-0.659302	0.47921
1.750	b2	-0.217096	-0.505118	-0.073366	0.386988	0.665393	0.705634	0.880760	0.810567	0.836506	0.60142
2.000	b2	-0.194330	-0.389507	-0.073367	-0.850035	-1.573690	-1.946369	-2.099215	-2.037891	-2.170177	0.95165
2.250	b2	-0.165910	-0.680109	-0.887789	-1.888100	-1.723887	-2.144810	-2.261188	-2.207337	-2.280849	2.28992
2.500	b2	-0.194200	-0.858392	-1.228272	-2.367726	-1.916167	-2.087819	-2.225290	-2.496618	-2.366066	2.33957
2.750	b2	-0.145850	-0.381002	-1.367766	-1.623140	-1.935278	-2.262320	-2.322737	-2.878610	-2.708115	2.27577
3.000	b2	-0.347610	-0.960613	-1.208119	-1.434385	-2.190531	2.459719	-2.439420	-2.881440	-2.876757	3.05990
3.250	b2	-0.297580	-1.143981	-1.096898	-1.764339	-2.198228	-2.611646	-2.752617	-3.272345	-3.267405	3.51993
3.500	b2	-0.452310	-1.349851	-1.449095	-1.835936	-2.569710	-2.658915	-2.699009	-3.496710	-3.584013	3.78984
3.750	b2	-0.309536	-1.639372	-1.525580	-2.213976	-2.867527	-2.858651	-2.928204	-3.832799	-3.827527	3.82127
4.000	b2	-0.364500	-1.481885	-1.707705	-2.209309	-3.163874	-2.858651	-2.822988	-3.858930	-3.918686	3.88393
4.250	b2	-0.216830	-1.443030	-1.507623	-2.416420	-3.075666	-3.077707	-3.162026	-3.641212	-3.583629	3.78943
0.500	b3	-0.000453	-0.019890	0.337021	0.024964	0.046290	0.032819	-0.005337	-0.010682	0.068789	0.05238
0.750	b3	-0.003700	-0.051564	0.006301	0.040429	0.049742	0.093959	0.044373	0.066940	0.099763	0.10487
1.000	b3	0.030800	0.023893	0.037281	0.031040	0.052904	0.067515	0.070307	0.144692	0.094942	0.15474

1.250	b3	0.074150	-0.056310	-0.220640	-0.042405	0.210770	0.154572	0.106971	0.131526	0.213706	0.15474	
1.500	b3	0.070790	0.101288	-0.220640	0.153534	0.113296	0.123151	0.090125	0.106114	0.184404	0.14062	
1.750	b3	0.066200	0.126232	-0.220640	-0.200631	-0.322900	-0.340089	-0.417277	-0.386555	-0.401961	0.16037	
2.000	b3	0.050650	0.087590	-0.022064	0.192006	0.458932	0.606394	0.658515	0.630029	0.678288	0.45130	
2.250	b3	0.033608	0.188470	0.264176	0.676525	0.512640	0.676586	0.721232	0.691455	0.716206	0.73562	
2.500	b3	0.045700	0.250631	0.391168	0.862860	0.581916	0.650636	0.708428	0.790365	0.730697	0.72334	
2.750	b3	0.029410	0.005263	0.361538	0.473955	0.587120	0.717100	0.745985	0.923098	0.888232	0.69150	
3.000	b3	0.110560	0.233349	0.314976	0.395789	0.678359	0.787635	0.780099	0.926711	0.926771	0.99260	
3.250	b3	0.088986	0.285544	0.256598	0.525127	0.675482	0.845920	0.902249	1.074729	1.070178	1.16254	
3.500	b3	0.130502	0.363345	0.379645	0.521886	0.821664	0.853060	0.870203	1.153075	1.183406	1.25467	
3.750	b3	0.085784	0.455158	0.394496	0.656915	0.913115	0.908642	0.942279	1.272034	1.268936	1.26711	
4.000	b3	0.109153	0.372982	0.458942	0.655489	1.028335	0.908642	0.889634	1.281729	1.307218	1.29086	
4.250	b3	0.042491	0.354063	0.377560	0.723122	0.976271	0.979328	1.015718	1.201078	1.178372	1.25547	