INTERNATIONAL HELLENIC UNIVERSITY

Energy Efficiency in Medical Units

Student Name: Koutoulas Dimitrios

SID: 3302110023

SCHOOL OF SCIENCE & TECHNOLOGY

A thesis submitted for the degree of

Master of Science (MSc) in Energy Systems

OCTOBER 2012

THESSALONIKI – GREECE

Energy Efficiency in Medical Units

Student Name: Koutoulas Dimitrios

SID: 3302110023

Supervisor: Dr. D. Anastaselos

Supervising Committee Members: Prof.

Prof.

SCHOOL OF SCIENCE & TECHNOLOGY

A thesis submitted for the degree of

Master of Science (MSc) in Energy Systems

OCTOBER 2012

THESSALONIKI – GREECE

Abstract

The present dissertation deals with energy efficiency in medical units and contains a bibliographic and an experimental part. The main part of the bibliographic section of the dissertation consists of a state of the art review of energy audits that have been conducted in medical units from 1960 until the present day. The energy audits are presented chronologically in order to demonstrate the technologic development and progress in methodology. Additionally a research and review is held about legislation and standardization of energy performance of medical units and healthcare facilities around the world. Legislation about medical units' energy performance and consumption in Greece is reviewed with, emphasis on *K.E.v.A.K* and *law3361/2008*, followed by a presentation of the general European Union's *Directive 2002/91/EC* and accompanied legislation for energy performance of tertiary buildings and more specifically hospitals. European Continent's legislation review is closed with United Kingdom's National Health Service standards and guidelines. The research for legislation is continued with United States' ASHRAE's guidelines and other relevant legislative provisions and Canada's energy standards for hospitals with *CSA Z317.2* standard. Finally legislation in Brazil is reviewed as an indicator of standardization in the developing world. Comments and comparisons between legislative frameworks around the world are done and some conclusions are made. Moreover the concept of Green Hospital is explained and analyzed. The general concept of green buildings is examined. More specifically the concept of green hospital is analyzed and comparisons are made with the term of low energy hospitals and buildings. The presuppositions and actions that have to be made in order for a hospital to be considered green are presented. A case study with the Northumberland healthcare center is discussed in order for the details of Green Hospital's concept to be presented in an applied way. Additionally Green@Hospitals programme, which presents a Greek interest as well is presented. Concluding the analysis of Green Hospitals a forecast about the future of the concept is attempted. During the experimental part, the knowledge that has been acquired during the literature review is applied on a Greek medical unit. This medical unit is Euromedica Arogi rehabilitation center. A preliminary energy audit is conducted in the facilities of the medical unit, building envelope's, location's and climatic characteristics are recorded and energy consuming devises , such as HVAC, DHW, lighting systems and medical equipment are inspected. Medical unit's energy performance is simulated with the use of TEE-KENAK's (ΕΛΟΤ ΕΝ ISO 13790) software and the overall energy consumption and achieved thermal comfort of the assessed medical unit is ranked and compared with the proposed energy performance and thermal comfort by European and global legislative frameworks. Both thermal comfort and energy performance of the assessed rehabilitation center are found to be in compliance with European and ASHRAE's legislative frameworks. Medical unit's energy performance is found to have a ranking equal to Energy Class C. The total final energy consumption has been found to be equal to 319,7 kWh/m^2/year, with electricity's percentage being equal to 47,25% and natural gas' percentage, being equal to 52,75 %. The total primary energy consumption of the medical unit is found to be equal to 8.727.453 kWh/year, or 615,2 kWh/m^2/year, while the total CO_2 emissions are found to be equal to 2.588.564 kg CO_2/year. Electricity presents a percentage equal to 71,22% of the total primary energy consumption, while the same percentage for natural gas is equal to 28,78%. The biggest disadvantage of the medical unit is found to be the lack of renewable energy sources' utilization. Some energy saving measures that are suitable for the studied medical unit are proposed and the implementation of a solar thermal photovoltaics', solar thermal collector's and simple photovoltaics' installation on the building's roof is technically and economically assessed. PV installation is found to be the less riskier investment, with the lowest payback period, while PV/T energy saving measure has the higher NPV, and can be characterized as the most promising, environmentally friendly and profitable energy saving measure in the long term.

Koutoulas Dimitrios

29/10/2012

Key words: *ASHRAE, CO_2 emissions' reduction, CSA Z317.2, Directive 2002/91/EC , Energy audit conduction on Hospitals and Medical Units, Energy Conservation, Energy Performance Modeling and Simulation, Energy Saving Measures, Energy Star, Green Hospital, Low energy hospitals, K.E.v.A.K., Regenerative Design buildings concept, UK National Health Service*

Contents

Tables' and Figures' Contents

Figures' Contents	
Title	*Page*

1. Introduction

The subject of the present dissertation is the conduction of a preliminary energy audit on a medical unit and the performance of a state of the art literature review, regarding energy audits that have been conducted until the present day on medical units, energy performance for medical units legislation and standardization and a small scale research about the concept of Green hospitals.

Medical units can be characterized as the most complex buildings regarding their energy performance on a worldwide level. Due to high energy requirements for HVAC systems and energy intensive medical equipment, they are responsible for significant amounts of the total energy consumption in tertiary sector. Brazilian medical units are responsible for more than 10% of the overall energy consumption in Brazil, while healthcare facilities are responsible for 25% of the overall CO_2 emissions of public tertiary buildings in United Kingdom. The average energy consumption of a Greek hospital has been found to be ranging between 370-426 kWh/m^2/year transforming it in the most energy intensive type of building within the Greek territory. Studies have proven that HVAC system is responsible for about 48% for energy consumption in medical units, while DHW is responsible for 17% and medical equipment for 19%; for this reason these are the energy consuming systems that have to be studied with more attention, while lighting systems must be considered due to their significant energy consumption as well. Medical units can be classified according to the type of their provided health services into centers of medical examinations, rehabilitation centers, or hospitals. Moreover, they can be categorized according to their size, energy consumption or number of total beds. Medical units can be described as the most complex buildings for an energy audit due to the fact that they utilize modern technologies for the different medical equipment, which not only require great amount of energy for their operation, but also produce significant amounts of internal heat gains, drastically affecting the thermal comfort and the heating or cooling load for the internal space. In the special case of an energy audit on a hospital, the existence of a surgery must be taken into consideration due to the fact that the equipment used in a surgery is energy intensive, let alone the fact that the thermal comfort inside a surgery is a subject of great importance because it deals with the health of the patient under surgery procedure. ***(Balaras et al, 2006), (www.greenhospitals.net), (Karliner et al, 2011), (Singer et al, 2009)***

From the beginning of 1961, until the present day , numerous energy audits have been conducted on medical units. The main energy consuming devices that are examined during an energy audit are Heating Ventilation and Air conditioning system, domestic hot water preparation system, lighting systems and medical equipment. Special attention is paid on building envelope and building's location and orientation. The main incentives behind energy audits in the first years of the literature review were clearly financial as the main motive was the reduction of operational cost of the medical unit. In the most recent years though other incentives such as energy conservation and CO_2 emissions' reduction have increased their significance, being with the financial scope the main motives behind energy audits. In various energy audits different methodologies have been utilized in order to calculate the final and primary energy consumption of a medical unit, estimate the percentage of participation of each energy consuming device in overall energy consumption and research the participation of each type of fuel in the overall energy consumption. Every energy audit is finished with the proposal and implementation of energy saving measures, in order to reduce primary and final energy consumption and total CO_2 emissions. Finally it should be mentioned that with the implementation of PC based software, such as Energy Plus and TRNSYS, the assessment of medical units' energy performance and the implementation of energy saving measures were drastically facilitated.

Legislation and standardization about medical units' energy performance around the world may differ in some specific points; every legislative framework around the world though has as a common scope the promotion of energy and cost conservation and CO_2 emissions' reduction from medical units' operation. In Europe and Greece medical units are considered as tertiary buildings. Their energy performance and the procedure for the conduction of energy audits on them is covered by Greek state's law **v.** 3661/2008 and European Directive 2002/91/EC, widely known as the European Union's "Energy Performance of Buildings directive" (EPBD), while in United States of America and North America standards such as ASHRAE's Standard 90.1,2004 and Standard 62.1,2010, provide specific information about energy performance and energy audits on medical units. In United Kingdom, National Health Service is responsible for the implementation of energy conservation and CO_2 emissions reduction within medical units, while in Canada standard CSA Z317.2, 2010 is followed.

Green hospital is the evolution of low energy and energy efficient hospital concept. It considers wider sustainability and the main scope of the concept is the minimization of hospitals' negative impact on the environment. Apart from energy conservation and CO_2 emissions' reduction, additional targets are set during the operation of a green hospital such as, water and resources' conservation and waste minimization and safe disposal. Due to the fact that Green hospital concept contributes in the overall maintenance of sustainability and environmental protection, it is going to be a subject that is going to be studied a lot by the scientific community in the near future. ***(http://www.medical.siemens.com), (Siemens Healthcare Department, 2012)***

The experimental part of this Thesis contains the conduction of a preliminary energy audit on a medical unit. The medical unit that has been studied was the EUROMEDICA AROGI rehabilitation and recovery center. EUROMEDICA AROGI is located in Thessaloniki, Greece and the energy audit was conducted in August and September 2012. A complete energy audit needs at least 6 months - 1 year in order for it to be completed . This happens because building's energy performance must be assessed for both heating and cooling periods and data about the energy consumption of energy consuming devices must be collected for both periods . For this reason a preliminary energy audit has been chosen to take place in order to fulfill the narrow time limits that were available for the dissertation's completion. The energy audit was conducted according to European Building Energy Performance Directive guidelines. Building envelope, building's location and orientation, HVAC, DHW, lighting and medical systems' energy performance were assessed and the final and primary energy consumption and CO_2 emissions of the building were calculated. Medical unit's energy performance's compatibility with ASHRAE's or EPBD's guidelines was examined and energy saving measures for the reduction of energy consumption and CO_2 emissions were proposed. The assessment was facilitated with TEE-KENAK's (ΕΛΟΤ EN ISO 13790) software and the energy performance of the rehabilitation center was ranked as Energy Class C. Due to the complexity of a medical unit the knowledge and experience that was acquired from the conduction of an energy audit on a medical unit is valuable and significant and the whole study may provide a significant opportunity to utilize the knowledge that has been acquired, not only during the literature review, but also during the whole MSc in Energy Systems Programme studies.

A. BIBLIOGRAPHIC PART

2. State of the art review of energy audits in medical units

During the first section of the thesis a state of the art review of every energy audit that has been conducted on medical units and it is available in scientific and online databases is performed. The presentation of the energy audits will take place chronologically, from the first energy audits that have been conducted in the early sixties until the modern energy audits that are conducted in the present day. This way of presentation has been chosen over the alphabetical presentation in order to demonstrate the technologic development and level of detail increase concerning energy audits with the progress of time. Apart from scientific sources that have been used for the bigger part of the review, such as scientific databases like science direct, industrial sources have been used as well for the performance of the literature review, like websites of companies and personal contact with companies that undertake energy audits. This happens in order to give to the whole presentation a more financial, holistic and complete character. If a source has been found in an article during which a bibliographic review had been conducted, then as a source the name of the reviewer is provided, in order to give to the reviewer the required credits for his work. The interested reader may go back to the stated scientific source and find the initial source in the bibliography of the author. Of course the original article has been found and studied before information was extracted from it.

2.1. Energy audits that have been conducted until 1980

In 1961, Jenkins Clinic hospital's (in Kentucky) energy performance was audited. In order to promote energy conservation a double diesel fueled domestic hot water heating system was installed. The overall energy consumption for DHW preparation was reduced by a percentage of 50%. In 1966 New York City's Trafalgar Hospital was the first New York medical unit that made investments for the purchase of more efficient energy consuming equipment, in order to reduce in the short and medium term the operating cost. An energy audit was conducted within the medical unit's facilities and some energy saving measures were proposed. In 1969 an energy audit was conducted on Franklin Foundation Hospital. As energy saving measure, a cogeneration of heat and power system was installed. The annual operating cost reduction, resulting from this measure was equal to 36000 $. New provident Hospital installed in 1971 an automated energy management system. HVAC , lighting , Domestic Hot Water preparation system and medical systems were electricity fueled. The annual savings were calculated to be equal to 70000$. (In comparison to the above system's fueling by natural gas or oil). In 1972 US Government after the conduction of numerous energy audits on US medical units published a guide for the efficient implementation of energy conservation measures for hospitals and medical units**.** Reynolds et al conducted a number of energy audits on Veterans Administration Hospitals, in 1974. HVAC system was found responsible for the majority of energy consumption. Energy saving measures, which were relevant with HVAC efficiency , thermal insulation of building's envelope and internal temperature and relative humidity set point, could contribute to energy conservation up to 70%. Additionally medical units' energy performance was simulated with the implementation of mathematical models. Daystar Corporation conducted an energy audit on the DHW systems on south country Hospital in Rhode Island, US. The main purpose was to find why the efficiency of DHW preparation systems was lower than the expected. Some leakages and insulation problems were identified and corrected. ***(Pollack, 1979)***

In 1975, Smith et al conducted energy audits on 492 US hospitals, in order to assess the feasibility of the implementation of waste incineration systems, in order to recover and utilize the produced heat. In 1975 Kuns et al implemented on Santa Barbara hospital in US a variety of energy saving measures, the most important of which were, the reduction of lighting power density in corridors and offices, the maintenance of cooling system and the implementation of an equipment's operational schedule, according to which, the unneeded equipment should be turned off in non operating hours. As a result, the power factor was increased to 98% (from 77 %). In 1976 in Alabama Hospital a variable volume cooling system was implemented as energy saving measure and it was technically and financially assessed. The monthly cost for space cooling was reduced by 3000$. Swan et al conducted an energy audit on St Natty hospital. Numerous energy conservation measures were implemented. More efficient sodium lamps replaced old incandescent lamps, elevators were turned off during non operating hours and a high efficiency cooling system was installed. As a result 21000$ were conserved on an annual basis. In 1977 Energy Management Service and Fuel and Energy Consultants Corporation conducted energy audits on 55 Hospitals in Philadelphia. The average energy saving potential was found to be equal to 15% (7,9% from lighting systems efficiency and electric equipment's operational schedule, 4% from boilers and space heating systems). In 1977 Ziedan et al conducted an energy audit in St Navy Hospital in Minnesota. The energy performance of transparent elements was assessed. As energy conservation measure, the installation of double glazed windows, with lower U value and lower infiltration was proposed. Blue Cross of Greater Philadelphia conducted energy audits on 6 hospitals in Philadelphia in 1977. The energy consumption within the hospitals' facilities breakdown was the following. For HVAC systems the 65% of overall energy was consumed, for sterilization of equipment 2%, for medical equipment 5%, for cooking 10 % and for lighting 10 %. As energy saving measures, the implementation of more efficient lighting systems and HVAC systems with heat recovery provision and the installation of more efficient windows were proposed. Boyle et al, after the conduction of energy audits on numerous US hospitals, proposed a methodology for the technical and financial analysis of energy consumption in hospitals, during their whole lifecycle in 1978. In 1978 US Department of Energy published guidelines for the standardization of the conduction of energy audits for medical units. Stroeh et published in 1978 the hospital energy management index, a tool that calculates energy consumption in hospitals and ranks the energy performance of medical units. The same use had The Total Energy Management (TEM), which had been published in 1977 by Department of Health Education and Welfare. Anco Engineers conducted an energy audit on St John Hospital in Santa Monica US, in 1978. They found that with small operational changes and proper maintenance of HVAC system there is energy saving potential equal to 16%.***(Pollack, 1979)***

Ross and Barazzini conducted energy audits on numerous hospitals. From energy saving measures' implementation on HVAC and lighting systems, the average energy saving potential was found to be equal to 13%. Stein et al studied the energy performance of Peekskill Community Hospital in New York in 1978. Energy consuming equipment was categorized into HVAC, lighting DHW, exhaust fans, incinerators and generator. An energy management and adjustment system, a solar collector for DHW and space heating and cooling and an onsite electricity generation system were the most important energy saving measures that were proposed. Colorado Energy Conservation and Alternatives Center for Commerce and Industry published in 1978 guidelines for the conduction of energy audits on medical and tertiary buildings. ***(Pollack, 1979)***

In 1978 Oak Ridge Associated University engineering Staff made one of the first attempts on the conduction of energy audits on medical units in 48 hospitals, the majority of which were located in New York, Pennsylvania, Virginia and Tennessee States. The results were processed, organized and presented on an electronic database. More specifically the database contained information about annual primary and final energy consumption for every hospital, proposals for energy conservation measures for each unit and financial assessment of each measure. ***(http://harvard.edu)***

The process that had been followed was the following: First of all the location and orientation of the hospitals were identified. Secondly the useful and heated floor area of each medical unit was configured. The primary or final energy consumption for each hospital was found both for fossil fuels and electricity. The total energy saving potential for each hospital was estimated and energy saving measures were proposed. The main concept was the implementation of low cost or no cost energy saving measures and the estimation of how much energy could be saved with their implementation. The energy consumption before and after the completion of the energy audit was estimated in order to calculate the energy saving potential. Financial assessment for the implementation of the energy saving measures was performed, with the main criterion being simple payback period. The results were collected and presented in an organized electronic database. In the database everyone interested could find data such as the annual average energy consumption for hospitals and the average energy saving potential. It was determined that medical units are the most energy intensive tertiary buildings in US, having 66% more energy consumption per m^2 than the average US tertiary building. Their total primary energy consumption was equal to the 12 % of the overall energy consumption of US commercial sector. The average energy saving potential , resulting from the implementation of low or no cost energy saving measures was found to be equal to 20%. The 66% of this amount referred to energy saving measures for fossil fuels, such as natural gas or oil conservation. The rest 33% referred on energy saving potential related to electricity. The average cost of low cost energy saving measures' implementation was found to be equal to 2,65$ / m^2 and the average payback period equal to 1 year. The annual average energy consumption for each hospital was found to be equal to 780 kWh/m^2 for fossil fuels and 730 kWh/m^2 for electricity. The overall average annual energy consumption was found to be equal to 1510 kWh/m^2. The low cost energy saving measures referred to HVAC system (50%), to central heating system (25%) and to lighting and cooling infrastructure (25%). Finally the energy consumption, buildings' energy performance and energy saving potential were modeled with the use of NECAP computer code and hour by hour thermal loads were identified for each hospital. Additionally an equation that correlates achieved energy savings with required cost for the implementation of energy saving measures on heating and cooling, HVAC, and lighting and other systems was created. Due to the fact that there were wide variations in the annual energy consumption and energy saving potential among the participated hospitals, a regression equation was created, whose purpose was the calculation of total energy saving potential in correlation with each hospital's characteristics (useful floor area and number of beds), hospital's location and orientation, annual energy consumption (both electricity and fossil fuels), fuels' and electricity's unit's price, heating and cooling degree days etc. ***(Hirst et al, 1982)***

2.2. Energy audits that have been conducted from 1980 to 1990

In 1981 Unites States Army Corps of engineers conducted on Kimborough hospital a completely innovative and revolutionary for that time energy audit. An organized effort for computer modeling of the hospital's energy performance was made, and created new standards for the performance of energy audits on medical units. The steps of the energy audit were the following. First of all the drawings of the hospital were made on a computer designing program. The energy consuming devices and equipment were inspected and calculations were made by hand in order to estimate the final energy consumption for each purpose. For this reasons energy recorders were installed on the facilities of the hospital. The energy consumption was calculated as following: For space heating 3 oil boilers had been utilized and the annual energy consumption was equal to 7000000 kWh. The percentage of the overall energy consumption was equal to 38,8 %. For space cooling, the annual energy consumption was equal to 2000000 kWh and the percentage compared to the overall energy consumption was equal to 5,2%. For ventilation needs the annual energy consumption was equal to 1428000 kWh/year and for equipment (medical or not) the energy consumption was equal 805220kWh/year. Moisture and humidity control system was responsible for 23,3% of the annual energy consumption, while lighting systems were responsible for the 8,3% of the overall energy consumption with 892000 kWh/year. Important percentage of the energy consumption had the DHW preparation system as well. The energy performance of the building was found to be more than satisfying (there was no energy performance scale at that time), with utilization of double glazed windows, efficient and regular maintenance of HVAC and DHW system, efficient fluorescent lighting systems and paired doors in order to reduce infiltration. Some energy saving measures, were proposed though, in order to make the energy performance of the hospital even better. These would be: Better insulation of roof, ceiling and vertical walls (0,05 m of high thermal resistance material), implementation of heat recovery on HVAC system and utilization of the exhaust heat, ventilation fans' rotational speed's reduction according to the occupancy patterns and air quality requirements of each space, installation of more efficient lighting systems and utilization of day lighting, insulation of distribution pipes for space heating and cooling system and DHW and chilled water system's maintenance and malfunctions' correction on HVAC and medical equipment in order to promote and maintain their efficient operation. The greatest innovation of this study was the fact that the building's energy performance was simulated with DOE- II computer code. This way each energy saving measure was assessed in a more complete way and its effect was examined in correlation with the overall performance of the building. For example the lighting installation upgrade measure had an indirect effect on HVAC energy consumption by affecting the internal temperature, with the reduction of internal heat gains. With the classic approach this could not be seen. But with the simulation of the building's energy performance, a sensitivity analysis for every change on the building could be performed. Finally a financial assessment of each energy saving measure was held. ***(Unites States Army Corps of engineers, 1981)***

In 1987 Benatech, INC conducted one of the first modern energy audits in the medical facilities of a US army installment in Georgia, US. The medical facilities contained 4 buildings which were used from Moncrief Army Community hospital, Oliver Dental Clinic, Caldwell dental clinic and Hagen Dental Clinic. On these facilities an energy audit was conducted with the codename "energy engineering analysis program". The energy audit was conducted by the monitoring of the annual energy consumption of domestic hot water system, lighting system, HVAC installation, emergency generator systems and medical equipment electricity needs. The annual energy consumption of the medical facility was found to be equal to 28200000kWh and the cost for energy needs was equal to 524600$ annually. During the conduction of the energy audit PC DOE simulation method was implemented. More specifically the annual energy consumption for DHW preparation was 400000 kWh, for lighting 1430000kWh and for HVAC system 23590000 kWh. All in all HVAC system was responsible for the biggest part of energy consumption, followed by medical equipment. As fuels, mainly natural gas was utilized, followed by electricity and oil. In order to reduce energy consumption and cost for energy needs a variety of energy saving measures were implemented. These were named by Benatech as "Energy Conservation Opportunities". The main energy saving measures that were implemented, had to do with HVAC system's and building envelope's optimization (with payback period equal to 0,88 years) and lighting systems (with payback period equal to 3,89 years). The main energy saving measures may be synopsized into the following: Reduction of outside air intake flow rate , heating or cooling of outdoor air before utilization for ventilation , fans' rotational speed reduction , decrease of domestic hot water's temperature set point , increase of medical purpose chilled water's temperature set point , automatic indoor air quality and thermal comfort adjusting system, with the implementation of thermostats and thermostatic valves , insulation of walls and opaque elements, increased lamps' efficiency and implementation of occupancy sensors , insulation of heating, cooling and domestic hot and chilled water system's distribution system, such as piping, installation of double glazed transparent elements, creation of south facing overhangs and implementation of external shading devices , replacement of the centralized hot water preparation system, with distributed DHW systems in order to reduce transmission and distribution losses and implementation of cogeneration of heat and power solutions. The implementation of the above mentioned energy saving measures had as a result the conservation of 11450000 kWh of final energy and the cost reduction by 206300 $ on an annual basis. The importance of this study is that it is one of the first energy audits on medical units, available on bibliographic reference and that energy conservation measures were successfully implemented without even the reference about terms such as renewable energy sources and CO_2 emissions. It shows the importance of the first steps of energy conservation measures (Firstly reduce energy demand, then increase efficiency and then utilize RES), regarding the effectiveness of their implementation. ***(Anastaselos,2012), (Benatech, 1987)***

In 1987 Adderley et al performed a bibliographic study. regarding the energy performance of 164 hospitals that were located in Wales. The hospitals were categorized into 10 categories (A, B, C, D, E, F, G, H, I, and J) regarding the number of beds they had, the type of health services they offered and the constructional characteristics of their building envelope. For each category, the annual energy consumption and the energy consumption breakdown into final energy forms such as coal, natural gas, electricity and ready to use steam was done. It was observed that the energy consumption was continuously reducing from 1980 to 1985 due to the implementation of energy saving measures and that coal and gas were responsible for the 25% of the final overall energy consumption. Moreover it was found that HVAC system was responsible of 70% of overall energy consumption in Welsh hospitals. Energy saving measures , such as utilization of day light, implementation of natural ventilation, installation of additional insulation to the opaque building elements, installation of more efficient windows, implementation of heat recovery in the HVAC system, decrease of internal spaces' and DHW's desired temperature, insulation of distribution pipes and implementation of switch off policy regarding lights and appliances when they were not needed were proposed and implemented. In a Neutral Nucleus Hospital , the overall energy consumption for HVAC, lighting and DHW systems, cooking and sterilizing purposes, was reduced after the implementation of the above energy saving measures, from 8829 MWh/year, to 3587 MWh/year. ***(Adderley et al, 1987)***

Adderley et al conducted energy audits in four medical units within United Kingdom in 1989. The energy audits were based on the creation of a mathematic model, which would be able to simulate hospitals' energy performance, with the combination of objective measurements and subjective assessment of indoor conditions. The created model was based on the measurement of the internal temperature, its comparison with a base temperature, and the assessment of the measured data with the heating and cooling degree day method, in order to calculate the energy performance, energy consumption and efficiency of HVAC system. The efficiency and the heat losses of the boilers were calculated with the combination of the created model and the implementation of thermodynamic calculations. Moreover indoor air changes that were required and achieved were measured and a method for solar and internal heat gains measurement was implemented. Building envelope's average U value was estimated and energy consumption for DHW preparation system, steam creation system, lighting and cooking system were calculated in addition to HVAC system's energy consumption. Stanley Complex hospital was parted from more than 20 buildings and as a space heating and DHW system, a central boiler was used. The average internal temperature was equal to 20,9 ^{o}C and the energy consumption for space heating , cooling, DHW preparation and ventilation was equal to was 38787 GJ/year. The achieved air changes were equal to 1,60 air changes per hour. The average U value of the building was found to be equal to 1,46 W/m^{2}K and for the roof equal to 0,46 W/m^{2}K. For Lluesty Hospital the average internal temperature was equal to 21,1 ^{o}C and the energy consumption for space heating , cooling, DHW preparation and ventilation was equal to was 14404 GJ/year. The achieved air changes were equal to 1,40 air changes per hour. For Abergele Hospital the average internal temperature was equal to 18,8 ^{o}C and the energy consumption for space heating , cooling, DHW preparation and ventilation was equal to was 40606 GJ/year. The achieved air changes were equal to 1,46 air changes per hour. Finally for Glan Clwyd Hospital the average internal temperature was equal to 20,8 ^{o}C and the energy consumption for space heating , cooling, DHW preparation and ventilation was equal to was 78417 GJ/year. The achieved air changes were equal to 2,20 air changes per hour. ***(Adderley et al, 1989).***

2.3. Energy audits that have been conducted from 1990 to 2000

Argiriou et al conducted energy audits on 30 office and hospital buildings in Athens, in 1993. The purpose of the study was the estimation of the annual energy consumption of the above buildings, and its correlation with the indoor air quality, either it was achieved by natural or by mechanical ventilation. The energy audits were conducted by 4 auditors per building, while the indoor air quality was determined with the implementation of post occupancy evaluation of the buildings. Special questionnaires were answered by employees and patients regarding the presence of health symptoms inside the buildings. The health symptoms ranged from mild to more severe symptoms such as sore throat, headache and eye irritation. From the surveyed buildings, 18 were mechanically ventilated and the other 12 were naturally ventilated. Special attention was paid into the average concentration of SO_2 and NO_2 emissions in medical units and especially near the surgery room. NO_2 concentration was measured with Griess Saltzman method, while SO_2 concentration was measured with TCM pararozaniline methodology. The measurements were taken on a 24 hour basis for several months in order to cover both summer and winter periods. The average NO_2 concentration was equal to 50 $\mu g/m^3$, while the average SO_2 concentration was found to be equal to 25 $\mu g/m^3$, both complying with WHO standards. Health symptom's occurrence frequency was mentioned and a presentation of the correlation between health symptoms and natural or mechanical ventilation took place. An equation that correlated energy consumption per unit area in hospitals and offices with number of occupants, existence of natural or mechanical ventilation and health symptoms frequency was extracted and the relevant graphs were presented. For naturally ventilated spaces, the overall average .energy consumption was equal to 128 kWh/m^2/year and for mechanically ventilated spaces the overall average energy consumption was equal to 171 kWh/m^2/year. For naturally ventilated spaces symptoms' frequency was increasing with increase in the average energy consumption (meaning that more energy is used to create indoor thermal comfort, but not air quality. In other words the higher the amount of energy that is consumed for the creation of artificial thermal comfort is , the higher occupants' discomfort is). For mechanically ventilated spaces the number of health symptom's frequency was increased with increase in the overall average energy consumption (because part of it was used for ventilation and provision of indoor air quality conditions). ***(Argiriou et al, 1993)***

Chirarattananon et al, examined in 1993 the effect of ECP (Energy Conservation Promotion) Act, a Thai law regarding energy performance, on commercial buildings, among them hospitals. ECP Act had special provisions for electricity consumption, for building envelope's characteristics and for air-conditioning installations in tertiary buildings and hospitals. The effect of the legislative framework on hospitals was examined with the utilization of DOE II software. A typical 600 beds' hospital, which was located in Bangkok was designed and its energy performance was simulated before and after the implementation of the legislative framework. Electricity's consumption for air-conditioning was reduced from 5704 MWh/year to 4487 MWh/year, while electricity's consumption for lighting systems was reduced from 893 MWh/year to 837 MWh/year. The energy consumption for elevators movement was simulated to be equal to 499 MWh/year. The overall electricity reduction was simulated to be equal to 17% and the installed capacity was reduced by a percentage of 18%. The investment for the implementation of high insulation properties' building materials (both opaque and transparent), for the retrofitting of air-conditioning units and for new lighting systems' installation was equal to 7,43 Million Baht and the annual cost energy related savings were equal to 1,361 Million Baht. ***(Chirarattananon et al, 1993)***

In 1993, Santamouris et al conducted energy audits in 33 Greek medical units. From them 24 were hospitals and 9 clinics. The auditing process was the following. First of all the general characteristics of each medical unit(area, number of beds, type of services) were determined. Secondly information about the building's envelope characteristics, such as orientation and location, U value of opaque elements, U and SHGC value for transparent elements, infiltration, indoor designed temperature and relative humidity set point, were collected. Then the type , nominal and actual power and efficiency for HVAC, DHW and lighting systems were determined. Moreover their operational schedule was determined, in order to calculate their annual consumption. The same happened for medical and general use electrical equipment. The result was the calculation of the annual energy and electricity consumption for each medical unit. The average energy consumption for hospitals (continuous operational schedule) was found to be equal to 407 kWh/m^2/year and for clinics (intermittent operational schedule) 275 kWh/m^2/year. Space heating was responsible for the 73,4% of the overall energy consumption in hospitals and for 65,3% in clinics. Lighting was responsible for the 12,8% in hospitals and 9,4% in clinics. Space cooling was responsible for the 0,8% in hospitals and 17,6 in clinics. Medical and other electric appliances were responsible for 13% of the overall energy consumption in hospitals and 7,9 % in clinics. The annual thermal energy consumption was equal to 332 kWh/m^2/year for hospitals and 200 kWh/m^2/year for clinics, while the annual electricity consumption was equal to 133 kWh/m^2/year for hospitals and 102 kWh/m^2/year for clinics. The energy consumption was found to depend on type of medical facility and type of offered services, size of medical unit, building's envelope's type and HVAC and lighting and medical equipment type, efficiency and size. With the use of computer software SPIEL and CASAMO energy saving measures' implementation was simulated on healthcare facilities. The overall energy saving potential was found to be equal to 20% , 15% for space heating for hospitals and 11 % for clinics, 68% for hospitals and 56 % for clinics for space cooling and 50 % for lighting. Different combinations of energy saving measures were simulated and their saving potential was estimated. The most important of the energy saving measures, that were virtually implemented were the following: Increase of the thermal resistance of the building envelope (reduction in energy consumption of 173 kWh/m^2/year for hospitals and 103 kWh/m^2/year for clinics), increase the efficiency of HVAC and DHW systems by renovating them, insulating their distribution system and regularly servicing them, utilization of natural day lighting, installation of occupancy and movement sensors and installation of more efficient fluorescent and metal halide fluorescent lamps (this way not only the energy consumption for lighting can be reduced but also the internal heat gains from lighting operation can be significantly decreased), installation of external selective shading devices in order to reduce solar heat gains and cooling loads in cooling period, implementation of night ventilation and installation of ceiling fans. ***(Santamouris et al, 1993)***

Sofronis et al made one of the first organized energy audits in a Greek national level. They measured the energy consumption of the 70% of the biggest Greek public hospitals, among them, Seismanogleio and Aglaia Kyriakou children's Hospital.

Their purpose was to create a base for the development of an automated mechanism for recording, monitoring and adjusting energy consumption for space heating, cooling, DHW, ventilation, lighting and medical equipment operation in Greek medical units in order to be able, with the implementation of proper energy saving measures to achieve 10% energy conservation in Greek healthcare sector. In the audit 84 medical units around Greece participated. The energy audit procedure was as following: Firstly, the energy consumption of each hospital was recorder on annual basis through utility's bills and fuels' cost. Secondly a statistical processing of the result was made, and finally implementation of energy saving measures took place on a pilot level on hospitals' environment. The total energy consumption of medical units in Greece was found to be equal to 650 GWh per year for the year 1994. The main factors that affect energy consumption in hospitals are , medical use of hospitals, construction year of each medical facility, building envelope, climatic zone, HVAC systems' efficiency and maintenance level. 8% of the hospitals were found to have energy consumption, lower than 200 kWh/m^2/year, 56% of hospitals 200-400 kWh/m^2/year, 36% more than 400kwh/m^2/year and 17 % more than 500 kWh/m^2/year. The average Greek medical unit's energy consumption was found to be equal to 370 kWh/m^2/year, from which the 290 kWh/m^2/year were consumed for space heating needs and 71 kWh/m^2/year was electric energy. From electricity needs only the 18% was found to be required for medical equipment. Hospitals in climatic zone A required the greatest amount of energy for space heating, while climatic zone B hospitals required the greater amounts of electricity (mainly for space cooling, due to Athens' high temperature during summer). Finally the higher energy consumption in healthcare facilities was found to be in climatic zones B and C. The greatest conclusion of this research was that the greater amount of energy consumption in medical units within Greece is covering needs for space heating and cooling, and for this reason energy efficiency measures should be concentrated on improving energy efficiency of space heating and cooling systems and optimizing the characteristics of building envelope.***(Sofronis et al, 1994)***

An energy audit was conducted in 1998 by OHCS on Kingston's General hospital in Ontario. The purpose was the examination of the possibility for energy related annual cost reduction, which was equal to 1500000 $ for electricity and 2600000 $ for total energy requirements. Some energy saving measures had been proposed, the investment of whose implementation was equal to 1000000$. The annual savings were estimated to be equal to 200000$ per year and the CO_2 emissions' reduction due to their implementation was equal to 500000 kg annually. The most important energy saving measures that were implemented on Kingston General Hospital were: Installation of heat recovery system on HVAC device, heating and cooling distribution system's insulation, installation of efficient lighting systems, replacement of local cooling systems with a central and more efficient absorption chiller, installation of movement and occupancy sensors, maintenance of HVAC system, correction of power factor and installation of an automated energy management system ***(www.kgh.on.ca), (Natural Resources Canada, 1998)***

In 1998, UK Audit Commission conducted audits in more than 150 hospitals, and with the utilization of energy audits' data, that had been conducted in the previous years, collected data about the energy performance and consumption of more than 200 medical units, within united Kingdom. The examined medical units were categorized to large acute hospitals , small scale hospitals and long stay hospitals. In order to assess energy consumption two indicators were used. Electricity performance indicator and Fossil fuel performance Indicator. Electricity indicator was defined as the electricity consumption per unit of medical unit's useful area, while fossil fuel performance indicator was defined as the consumption of fossil fuels (oil, gas etc) per unit of medical unit's useful area. For large acute hospitals the average electricity performance indicator was equal to 97 kWh/m^2 and the average fossil fuel performance indicator equal to 470 kWh/m^2, while for long stay hospitals the average electricity performance indicator was equal to 70 kWh/m^2 and the average fossil fuel performance indicator equal to 467 kWh/m^2. The main factors that affected energy consumption in medical units were , the age of a medical unit, the type of services of the medical unit, the surface to volume ratio of the medical unit and the amount of mechanical ventilation, that the medical unit required in order to maintain the ideal indoor air quality. Modern and newly designed hospitals had complied with stricter requirements about HVAC systems and lighting systems and building envelope than older hospitals. On the other hand they had more modern and energy intensive medical equipment. Their energy consumption was slightly higher than older medical units. The type of healthcare services played its role as well. Large acute hospitals, with their energy intensive medical equipment for surgeries and examinations required slightly more energy than long stay hospitals. The effect of the above 2 factors was low in comparison to the amount of the mechanical ventilation that the building required. The higher the amount of mechanical (and the lower the amount of natural) ventilation the medical units required (as a result from their constructive peculiarities) the higher the amount of its energy consumption (regarding both electricity and fossil fuels performance indicators). Moreover a mathematic formula for the modeling of the energy consumption of electricity and fossil fuels of medical units, depending on the percentage of the required mechanical ventilation was created. Needles to say that the surface to volume ratio was found that it was needed to be minimized and the compactness needed to be increased, in order to reduce heat losses to the environment. ***(Williams et al, 1998)***

In 1999 AGL and Exergy performed an energy audit on Murray Health Service and more specifically on Albury and Wagga Wagga hospitals (located in Australia). After the energy audit, energy saving measures were implemented, regarding light power density, occupancy controls , lighting efficiency, installation of efficient space heating and cooling systems and installation of building energy management systems. The investment's cost was 1000000$ and the annual savings were 188000 $. ***(www.exergydevelopment.com), (Exergy Development Group, 2012)***

2.4. Energy audits that have been conducted from 2000 until the present day

AGL and Exergy performed an energy audit on New Children's hospital at Westmend, Sydney in 2000 and implemented energy saving measures such as: Installation of more efficient lighting systems, installation of solar collectors for DHW heating and renovation of space cooling system. The result was 16% of primary energy conservation on an annual base. ***(www.exergydevelopment.com), (Exergy Development Group, 2012)***

In 2002 AGL and Exergy again, made an energy audit on John Hunter Hospital, which is located in Sydney. Energy conservation measures, such as installation of energy efficient halogen lamps and energy efficient space cooling and heating automated energy management system were implemented. The result was energy savings about 10% on an annual basis. ***(www.exergydevelopment.com), (Exergy Development Group, 2012)***

Paksoy et al studied the implementation of an aquifer thermal energy storage solution in combination with solar energy in order to reduce the total heating and cooling requirements of a hospital, in 2000. The medical unit was the Cukurova University Balcali Hospital in Adana of Turkey. First of all an energy audit was conducted on the hospital. It was determined that for space heating 3000 tons of oil had been used, while for space cooling 10000 MWh of electricity had been used on an annual basis. The purpose of the study was the implementation of an underground thermal energy storage solution in order to promote primary and final energy conservation, increase energy efficiency, reduce cost and reduce the emissions of CO_2, SO_x and NO_x. The installation had 2 modes, summer and winter mode of operation. During summer hot water from ventilated air was stored in the warm well. During winter cold water from a nearby lake and from cold ventilated air was stored in the cold well. Additionally hot water from the solar collector was stored in the hot well during the whole year. The system had 2 heat exchangers and the implementation of proper heat pumps was proposed as an optional solution. During the summer mode cold water from cold well was used (with the implementation of heat exchangers or heat pumps) for space cooling, while during the winter mode, hot water from hot well was used in order to pre heat hospital's ventilation air. In order to calculate the amount of energy that could be conserved, a special thermo hydraulic simulation software was used, which was named CONFLOW. The hot well had water with temperature equal to 40 ^oC, while the cold water's temperature was equal to 9 ^oC. The annual savings were calculated to be equal to 3000 MWh of electricity and more than 1000 m^3/year of oil. Here it should be mentioned that some energy was used for the operation of pumps and distribution systems and there were some heat losses regarding the storage and distribution system. Additionally 2100000 kg of CO_2 emissions, 7000 kg of SO_X , 8000 kg of NO_X and 700 kg of Freon 12 emissions were saved due to the implementation of this solution on an annual basis. ***(Paksoy et al, 2000)***

In 2000, Wastren energy services conducted numerous energy audits on medical units within US territory. Their methodology was a combination of HVAC, lighting, DHW preparation systems' and medical and general equipment's inspection, study of medical units' electricity bills on an annual basis and performance of pre and post occupancy evaluation for hospitals' energy performance and thermal comfort from patients and medical staff 60 days before and after the conduction of the energy audit, in order to assess hospitals' energy performance before and after the implementation of energy saving measures. Energy saving measures such as substitution and maintenance of HVAC systems, installation of more efficient lighting and low cost methods to increase medical units' power factor were implemented on audited medical units. The major innovation of Wastren's methodology was the implementation of energy star approved devices, which had as a purpose to turn off devices when they were not needed. For instance Office miser, Laser miser and Monitor miser, were responsible for switching off office equipment, personal computers and energy intensive laser printers, when they were not needed. Moreover with the implementation of vending miser, energy conservation on food vending machines equal to 50% could be achieved. Finally special controls for lighting and HVAC systems were installed with scope to promote energy efficiency and energy conservation from their operation. ***(www.wastrenadvantage.com), (Wastren Energy Services, 2000)***

Herrera et al implemented in 2001 Pinch Technology in a diesel fueled heated hospital in Instituto Mexicano del Seguro Social in Mexico. Pinch Technology is a specially designed methodology according to which, the total thermal energy saving potential in a building may be identified. Moreover the required percentage of heat recovery in HVAC system that must be utilized in order to achieve maximum efficiency and the number and form of heat exchangers that have to be utilized can be calculated. First of all the drawings of the hospital, including the energy consuming devices were designed. Next information of thermodynamic character was collected about HVAC systems , such as hot and cold streams number and their absolute temperatures and temperatures differences. A characteristic Pinch temperature was identified. According to it the number of required heat exchangers and thermal utilities was identified . Moreover the optimum amount of heat recovery and the thermal energy savings were selected according to Pinch technology's findings. The results were that heat demand was equal to 388,64 kW, while the energy saving potential was equal to 236,64. kW. 4 heat exchangers were required , and around 60% of required heat to cover energy demand could be characterized as low enthalpy heat.

This means that part of the energy that was covered by diesel could be efficiently replaced by alternative RES such as solar energy or geothermal energy. ***(Herrera et al, 2001)***

Szklo et al conducted an energy performance review on hospitals within Brazilian territory in 2003. The purpose of the research was the review of the energy performance of Brazilian hospitals in comparison with SUS standards. Additionally a classification of hospitals according to their size and energy use patterns was performed, Furthermore a review of CHP technical potential in Brazilian medical units was performed. The energy consumption data were collected by IBGE and DATASUS databases. Additionally energy audits were conducted on randomly selected hospitals of different sizes. Inspection of the insulation properties of the building envelope was performed, with the majority of the hospitals requiring the implementation of additional insulation as an energy saving measure. Moreover inspection of boilers and HVAC systems (where it was available) was performed. The total electricity consumption in healthcare facilities in Brazil was equal to 3861200 MWh/year. The hospitals were categorized to different sizes according to their energy consumption and number of beds. The five categories were large hospitals, medium size hospitals with high quality services, medium size hospitals with poor and depreciated quality services, small hospitals and hospitals with less than 50 beds. ***(Szklo et al, 2003)***

Large hospitals are hospitals with more than 450 beds and useful floor area more than 100000 m^2. Their energy consumption is 3300 kWh/bed on an monthly basis. The electricity is the 63,6 % of the total energy consumption (Air-conditioning 41%, lighting 26% and DHW heating 4,8% of total electricity consumption). They are responsible for the 17% of annual energy consumption of medical facilities in Brazil. Their HVAC systems' efficiency was found to be equal to 74,6 %.***(Szklo et al, 2003)***

Medium Size hospitals with high quality services have 150- 450 beds. Their monthly energy consumption is equal to 2682 kWh/bed. Their percentage of electricity over the total energy consumption is equal to 57% (from which for lighting 23%, for space cooling 27% and for DHW preparation 9%). They are responsible for the 23,7% of the total energy consumption of medical units in Brazil. Their HVAC systems' efficiency was found to be equal to 80%.***(Szklo et al, 2003)***

Medium sized hospital with poor and depreciated quality of services have monthly energy intensity equal to 952 kWh/bed. The percentage of electricity in comparison with the overall energy consumption is equal to 74,4% (for lighting 22%, for space cooling 24% and for DHW preparation 12%). They are responsible for the 6,6% of the total energy consumption in Brazil. ***(Szklo et al, 2003)***

Small hospitals, have from 50 to 150 beds. Their monthly energy intensity was equal to 977 kWh/ bed. Their electricity share is equal to 76% (for lighting 22%, for space cooling 25% and for DHW 13%). They correspond to the 33 % of the overall energy consumption of medical unit's in Brazil, being responsible for the biggest part of energy consumption. ***(Szklo et al, 2003)***

Hospitals with less than 50 beds have monthly energy intensity equal to 619 kWh/bed. Their electricity share is equal to 85,4% (for lighting 30% , for space cooling 51% and for DHW 15%) They are responsible for the 8,2% of the energy consumption of medical units in Brazil. ***(Szklo et al, 2003)***

Furthermore the research had been continued with the search of CHP potential on Brazil's medical units. The CHP must be fueled with natural gas, in order to increase the efficiency and promote energy conservation and environmental protection. In order to implement CHP on a hospital, it must have low power load factor. Additionally the CHP offers low quality heat and this must be taken into consideration. The steam that may occur from CHP can be utilized for cooking and sterilizing medical equipment. CHP is ideal where there are at the same time both heating and electricity requirements. The trend that was presented on this research is that the electricity share was increased from large to smaller hospitals. For this reason CHP was found to be more ideal for large and medium size hospitals, which have high electricity requirements and at the same time may utilize the produced heat . Additionally the utilization of CHP for space cooling , with combination with absorption chillers was examined and technical specifications were provided for the absorption systems. Both single staged and 2 staged CHP gas fueled systems were examined and their achieved efficiencies were estimated. The technical potential of CHP in Brazilian medical units was equal to 497000kW. For large medical units it was equal to 73000kW, with average gas consumption equal to 16000 m^3/month. For small medical units it was equal to 220000kW, with gas consumption equal to 23000

m^3/month (for single staged CHP). For medium sized medical units (both high and low quality) it was equal to 140000 kW. Gas consumption was equal to 12000 m^3/month (an average of high and low quality medium sized medical units). The potential for small and medium size medical units is higher due to their higher number, compared to the large medical units. Finally it was concluded that average gas consumption for CHP is the lowest for large hospitals and for this reason this solution matches the best to them, while as it is logical the gas consumption for 2 stages CHP was lower, compared with single staged, with higher investment though, for the first solution. ***(Szklo et al, 2003)***

Aspinall et al conducted numerous energy audits in United Kingdom's medical units, which were registered to National Health Service, in 2004. The audits were conducted with the contribution of NHS and the provision of energy consumption data about a variety of hospitals. The assessed medical units were categorized to good practice hospitals, which were compatible with NHS guidelines and typical hospitals, which provided an indication about the energy performance of an average hospital. The average good practice hospital had annual primary energy consumption equal to 445kWh/m^2/year. The average UK hospital had annual primary energy consumption equal to 550kWh/m^2/year. For HVAC the annual final energy consumption was equal to 27300000 kWh/year, for lighting 1925000kWh/year, for food preparation 1100000kWh/year and for medical equipment equal to 935000 kWh/year. Furthermore energy saving measures were proposed, in order to promote energy conservation and CO_2 emissions' reduction and compliance with NHS standards. The most important of them were implementation of cogeneration of heat and power in the hospital, waste incineration and utilization of the produced heat, regular maintenance of HVAC and lighting systems and turning off devices when they are not needed. ***(Aspinall et al,2004)***

In 2004 PEPS Act (Promoting Energy Efficient Public Sector) which was supported by US Agency for international Development and US Department of Energy, studied the implementation of energy saving measures in Sir J J hospital, which is located in Mumbai, India. Sir J J Hospital is one of the oldest medical units in Asia with capacity of 1352 beds and continuous operation on a 24h basis. The energy consumption requirements of the studied medical units used to bring to its limits the local electric utility's infrastructures. For this reason the local electric utility threatened the medical unit with disconnection from the electricity grid, if it did not reduce its energy requirements. PEPS energy audit on J J hospital showed that more than 75% of the medical unit's electricity needs were utilized to cover HVAC, DHW heating, medical equipment and water pumps' operational needs. The PEPS's study had as a purpose the implementation of zero or no cost energy efficiency measures (due to the low available budget) , in order to achieve up to 20% energy conservation and reduction of CO_2 emissions within the hospital operation. Some simple energy conservation measures were implemented , the most important of which were: Improvement of the operational schedule of electric consuming equipment (equipment should be turned off when not needed), utilization of natural daylight, increase of awareness of patients and medical staff for the need for energy conservation with simple methods (this took place with special seminars and simple and easy to follow guidelines), improvement of the regular maintenance of HVAC and medical equipment **,** implementation of more efficient lamps and installation of solar collectors for water heating. The result was that with the implementation of these low cost solutions, energy conservation to a level of 20% was achieved. In the period from 2002 to 2004, 812,000 kWh were saved and more than 90000$ were conserved. The greater contribution to this study was that it was proven that energy conservation can be achieved, not only by implementation of expensive energy efficiency measures, but also with the implementation of zero or low cost simple solutions. For each case first of all these cheap solutions may be implemented, and then more cost intensive energy saving measures may be applied in order to achieve further energy conservation. ***(Kumar et al, 2004)***

In 2006 ASHE and American Hospital Association conducted a wide range energy audit in more than 3000 hospitals around US in order to identify the most efficient energy saving measures. Installation of efficient lighting systems was considered to be one of the most efficient energy saving measures. Presbyterian New York hospital installed ultra high efficiency lighting systems. With this measure and with modifications and renovation of the absorption chiller, annual energy savings around 900000$ were presented with an initial investment of 4000000$. Moreover installation of high efficiency space and chilled water cooling systems was widely utilized. Anchorage Alaska's Medical center installed a groundwater fuelled space and chilled water cooling system. This was an innovative idea , according to which cooling needs were covered by geothermal energy. The initial investment was 450000$ and the annual savings were estimated to be equal to 50000$. Additionally the implementation of high efficiency space and DHW heating systems took place in a fair number of medical facilities. St Jake and St Joseph hospitals replaced their obsolete boilers with new ones with significantly higher efficiency. The energy conservation that was achieved with this measure was equal to 20%. This fact demonstrates the significance of space and DHW heating system's efficiency in a medical unit's energy consumption. Finally the utilization of Energy Star certified energy efficient equipment was a common ESM, while efficient fuel and electricity supply strategies, such as long term contracts with reliable fuel suppliers, in order to achieve favoring prices, and promote financial efficiency of medical units' operation were followed by numerous hospitals. ***(Carpenter et al, 2006)***

Chinese et all prepared a study for University of Udine, regarding the installation of a CHP unit in the northwest side of the city's general hospital. First of all a bibliographic review about the implementation of cogeneration of heat and power in hospitals and medical units was made. Energy audits on the buildings of the nearby area were conducted in order to find the CHP installation's possible range. Data about buildings' energy consumption on a monthly and annual base were collected. The nearby buildings were university buildings, medical facilities and a swimming pool, all of them buildings with high energy demand and continuous operation. For this reason it was concluded that a CHP solution would be ideal not only for hospital's needs, but for the nearby buildings' needs as well. For this reason the possibility of covering part of the other buildings' energy demand with the hospital's cogeneration systems was examined. 4 scenarios were examined: Coverage of Hospital's energy needs with onsite cogeneration of heat and power, coverage of hospital's needs with onsite cogeneration of heat and power and extraction of the surplus generated electricity to the grid, creation of a district heating network, providing heat to nearby buildings with the utilization of the hospital's cogeneration of heat and power systems and creation of a municipal cogeneration system, covering the heat and power demand of the hospital and other buildings. In all of the scenarios the fuel for CHP units was decided to be natural gas, due to the proximity of the natural gas' transmission point and the good quality of natural gas' distribution system in Udine. The hospital presented after the energy audit , the higher annual consumption of heat and power. Power was used in the energy intensive lighting and medical equipment, while heat was utilized for space heating in the winter and for DHW preparation in the summer. For this reason the CHP system was decided to be installed in the hospital in order to reduce transmission and distribution losses in the first 3 scenarios. All the scenarios were assessed with electronic simulation, in order to find the ideal size of CHP boilers for each case. A financial assessment for each scenario was performed as well. A time dependent MILP model was used with utilization of AMPL and CPLEX technologies, in order to perform optimization for the operation for each scenario. Energy consumption patterns were analyzed for each building and peculiarities for each building's old heating systems' were taken into consideration. Sensitivity analysis of the model for each scenario regarding its performance with the change of some external variables such as: Thermal capacities, electric capacities, electric and thermal installed power in each building, initial investments for CHP installation, electricity costs, efficiency and size of equipment, cost of natural gas fuel and operational cost, taxation and feed in tariff in case of extracting the surplus generated electricity into the grid. The examined variables were increasing from the first to the last scenario. The first scenario presented to be the less riskier, judging with economic criteria, such as NPV and payback period. The 3rd scenario presented to be the best, judging from the summation of not only financial criteria, but also from energy conservation and reduction of CO_2 emissions potential. Finally the 4th scenario presented to be the more sensitive, regarding the variation of variables. ***(Chinese et all, 2006)***

In 2006, Tudor et al conducted a research in numerous National Health Service's hospitals in UK. The purpose of the review was an effort to create a standardization in measurement of medical waste, that are generated within hospitals. This research may seem different form the classic energy audits. It offers though, great information for waste generation in hospitals. This can provide great information for waste minimization strategies, in order to promote the operation of the green hospital concept, which is the next and more sustainable level of low energy hospital. Furthermore as it can be extracted from other studies, medical waste can be used as a fuel in order to promote heat recovery for space and DHW heating in medical units, conserving great amounts of energy. Additionally medical waste , when it is not properly treated, may cause disease infection and be hazardous for the environment and people. Tudor et al found that waste generation depends on the type and activity of medical facility (rehabilitation center, dental clinic, surgery) or non medical facilities (offices and cafeterias in medical facilities) and the number of the patients that are treated (less than 3000, from 3000 to 6000 and more than 6000). Medical waste was measured in the form of medical waste bags (each bag had 80 lt of medical waste). Then with the proper calculations, per capita medical waste for each healthcare facility could be extracted in a monthly base (kg/person/month). The medical facilities with the higher amount of medical waste were general hospitals with surgery rooms and acute care medical units. In offices and cafeterias the medical waste was significantly reduced. The greater contribution of this research is that a common standardized unit for medical waste's measurement had been created and the basis for waste minimization strategies and disposal had been established. ***(Tudor et al, 2006)***

In 2006 Balaras et al made a literature review regarding the indoor thermal comfort's legislation and standardization for operating rooms around the world and published guidelines regarding internal space temperature and relative humidity , ventilation rates, required air changes per unit time, filters' requirements, maintenance procedures and implementation of controls on HVAC systems' for operating rooms. The main concept behind the legislative frameworks for thermal comfort in medical units was found to be disease spread prevention. More specifically legislation and standardization that had been published by ASHRAE, AIA and German Institute for standardization was reviewed. The required indoor temperature for operating rooms was found to be equal to 20-24 ^{o}C and the required relative humidity 30-60%. Operating rooms must have at least 20 air changes per hour, or ventilation rate equal to 51 m^3/hour per person and the utilized air must be outdoor air. Operating rooms must have at least 3 stages of filters and each operating rooms must be served by at least one air handling unit. Specially designed thermostats and humidistats must be installed on air handling units. Furthermore design and maintenance guidelines for HVAC systems of operating rooms were provided, while energy conservation techniques such as implementation of heat recovery and variable air volume HVAC systems are explained. Moreover the literature review showed that the average energy consumption of Greek hospitals was between 370 and 426 kWh/m^2/year. The same scientific team conducted energy audits in 20 operating rooms that were located in 10

Greek Hospitals. The main scope was the determination of internal thermal comfort and the inspection of the HVAC systems of operating rooms. Measurements in each operating room lasted 2 weeks and were done with the implementation of 5 data loggers. The average energy consumption of participated hospitals was found to be equal to 426kWh/m^2/year, and the average energy requirement for HVAC systems was 269 kWh/m^2/year, while average electricity consumption was equal to 168 kWh/m^2/year. The average temperature of operating rooms was equal to 22^{o}C and the average relative humidity was found to be equal to 37%. Finally the achieved air change rate in the internal space of participated operating rooms was found to be in the range between 3,2 and 58 air changes per hour. This study was continued by the scientific team of Dascalaki et al, in 2007, in order to research indoor air quality of the same operating rooms as it is described later. ***(Balaras et al, 2006)***

Piacentino et al performed in 2006 a techno economic study for the implementation of a trigeneration system on medical units and found that this solution was ideal for hospitals, offering the opportunity for both energy and cost savings. ***(Pagliarini et al, 2012)***

Pavlasa et al studied the energy performance of various hospitals and proposed the implementation of RES fueled cogeneration of heat and power systems. As a typical RES fuel for CHP, biomass was proposed. The implementation of such a solution was economically assessed as well. ***(Pagliarini et al, 2012)***

Melhado et al , in 2006, conducted energy audits on 3 different configurations of HVAC systems, installed in 60 surgery rooms in medical units within Brazil. With the utilization of Energy Plus software, energy consumption, achieved thermal comfort and indoor air quality and their correlation to patient's health and disease prevention targets was examined. (***Khodakarami et al, 2012)***

Murphy et al studied the energy performance and the effect on patients' health of 3 different air-conditioning systems, installed in operating rooms and published specific guidelines about internal temperature, relative humidity and indoor air quality for each system. More specifically the 3 systems were upstream cooling coils, downstream cooling coils and desiccant wheels. (***Khodakarami et al, 2012)***

Skoog et al, in 2006, researched relative humidity in various medical units and its effect on patients' health and worker's productivity. This took place not only with actual measurements, but with the implementation of post occupancy evaluation questionnaires as well. (***Khodakarami et al, 2012)***

In 2006 Bizzarri and Morini investigated the energy saving potential and the CO_2 emissions' reduction potential in healthcare facilities, that could be resulted from the implementation of state of the art and innovative RES based solutions such as Hydrogen Fuel cells, Mono and Multi Si PV systems and solar thermal collectors. ***(Saidur et al, 2010)***

In 2007, Greentech conducted energy audits in numerous Malaysian public hospitals. The main purpose, was the calculation of the annual energy consumption of each hospital and the proposal of energy saving measures in order to promote energy conservation. The energy audits showed that cooperated Malaysian hospitals used electricity equal to 65% of their total annual energy consumption, and oil and gas for heating and other purposes equal to 31% of their overall annual energy consumption. The annual cost of electricity only was found to be equal to RM 125000000, with a 300 power factor penalty. The estimated average energy saving potential by implementation of proper energy saving measures was found to be equal to 30%. The comparison standard was called BEI. BEI shows the annual energy consumption of a building per floor area. ($kWh/m^2/year$). Greentech listed the 20 most energy intensive hospitals within Malaysian territory according to their BEI, with the first having BEI equal to 350 $kWh/m^2/year$ and the 20th 170 $kWh/m^2/year$. Moreover Greentech implemented an energy management system on hospitals, as an energy conservation measure, similar to the one that was implemented to Pittsburg University Medical Unit. ***(Greentech,2007)***

Dascalaki et all performed audits in the operation rooms of 10 Greek hospitals in 2007. The subject of the audits was the inspection of the HVAC system and the determination of operating rooms' indoor air quality. The building envelope of the operating rooms was examined and the HVAC was inspected and audited. From the participated operating rooms, 10 % contained air handling units , and 20% had installed thermostats. From the operating rooms that utilized AHU's, 70% had a system that could turn AHU automatically off at night in order to reduce energy consumption and 35% had implemented AHU economizes. All of the operating rooms used outside air in order to maintain indoor air quality at the desired standards. Furthermore the indoor air quality of operating rooms, which are the most sensitive spaces in hospitals was determined. This was performed by taking sample of the operating rooms' air and analyzing it with thermal desorption and gas chromatography methodologies. The average concentration of volatile organic compounds in operating rooms was equal to 8862 $\mu g/m^3$, with the majority of them being particles from anesthetic gases, formaldehyde and aromatic compounds. Finally measures that could be used to improve indoor air quality of operating rooms with the minimum possible energy consumption were proposed. ***(Dascalaki et al,2007)***

In 2008, US department of energy conducted an energy audit on University of Pittsburg Medical center, which contains more than 20 hospitals and rehabilitation centers. The methodology of the energy audit followed the following simple steps: First of all data for the medical center's energy consumption had been collected on monthly basis, for 2 years. Then the actual energy audit was conducted on the medical unit according to US department of Energy and ASHRAE's guidelines. Energy saving measures were proposed and economic assessment of the energy saving measures took place. The most appropriate energy saving measures were selected and implemented, while data for energy consumption of the medical unit after the implementation of energy saving measures were collected. Finally a schedule for the proper maintenance of the HVAC system and lighting systems was created. More specifically a pc based software was used in order to record energy consumption in an annual basis. Moreover another specially designed PC software was used in order to control the operation of medical unit's PCs. Where electronic computers were not needed, they were automatically turned off. A schedule for the maintenance and proper adjustment of HVAC system twice a year according to the heating or cooling period's requirements was created. More efficient lighting installations and occupancy sensors were installed and a burner's operation analyzer was installed. The results of the energy saving measures' implementation were that energy conservation by 3% was achieved. This percentage is going to be increased by 2015 to 15% according to software simulations. Moreover 6250000 kWh/year were saved only from PC's new operational schedule implementation. Finally from HVAC system's maintenance and adjustment of operation according to the requirements of each period, 2000000 $ were saved annually.***(Tadonnio et al, 2008)***

Finn Projects conducted an energy audit on 8 hospitals which are located in Ontario, in 2009. First of all the internal temperature set point was measured and the hospitals' monthly and annual energy consumption was determined, following the Heating and Cooling degree day method. The results that occurred were organized in an online database and the electricity load profiles for each hospital were determined with a methodology, which was based on Matrix Utility accounting System. The energy audits took place after Independent electricity systems operator's request. The main purpose was to examine if it is financially and technically feasible, for hospitals to move from Regulated Price Plan (RPP) to hourly electricity pricing (HOEP). The energy audits showed that it was more than feasible, because with this change on electricity pricing and the parallel combination of some energy saving measures on hospitals' facilities, there was a significant energy (final and primary) conservation, with an average of 30% and a significant cost reduction for each hospital. ***(IESO,2009)***

The proposed energy saving measures were the following: First of all Heat Recovery provision was implemented on HVAC systems: Heat can be collected from HVAC exhausts and from dissipated heat from medical equipment and can be reused either for space heating, or for steam generation. Secondly installation of new and efficient HVAC systems or renovation of the old and depreciated ones was proposed. Distribution pipes of HVAC system must be properly insulated and variable speed fans, according to the requirements of each space must be utilized. Moreover the implementation of efficient lighting systems was proposed. T12 lighting systems must be replaced with T8 and incandescent lighting systems must be replaced by more efficient and environmentally friendly fluorescent lighting systems. Additionally occupancy and movement sensors must be installed, and adjustments of each space's lighting power density according to its requirements must be implemented. Additionally occupancy sensors on medical and electronic equipment were installed. With these sensors medical and electronic equipment would automatically be turned off when they were not needed. Moreover maintenance of equipment took place in order to maintain high efficiency and change of the operational schedule of equipment in order to promote energy conservation (retrocommisionig). An effort to increase patients' and medical staff's awareness about energy conservation and train them with seminars was held. Finally real time energy and electricity consumption's measurements took place, with the utilization of energy flow meters and web based online applications and the replacement of the pricing system of purchased electricity (from PPC to HOEP) was proposed as the most cost efficient scenario ***(IESO,2009)***

In 2009, Singer et al made a bibliographic review about energy audits' procedures and collected the basic information about the conduction of energy audits on hospitals. Information about data for HVAC, DHW and lighting systems, that are required in order for the energy audit to be conducted are provided. More specifically for space heating and cooling and DHW heating systems, supply and return temperatures of the heat transfer medium are required. Additionally for DHW the desired temperature and water's from the mains temperature are required. For ventilation systems the required air flow and air changes per unit time must be calculated. Efficiencies for HVAC and DHW systems must be calculated. The energy consumption, either it is final or primary must be provided in the form of kWh or kBTU per unit of hospital's useful area. For lighting systems, lighting power density is required for each space (in kW/m^2) and energy consumption per unit area (kWh/m^2) must be provided. Moreover the luminance level for each space is required. Finally internal temperature and relative humidity set points must be defined. Furthermore the energy auditing procedure of a medical unit is analytically described step by step with a methodology, called Energy Benchmarking Protocol. Finally the review contains information about energy consumption of HVAC, DHW, and lighting systems for California's coastal and inland hospitals. (derived from CEUS databases). ***(Singer et al, 2009)***

In 2009 Kerala State productivity council conducted an energy audit in one of the most known medical units of India, the 12 floors' Medical Trust Hospital. The annual power consumption of the medical unit was found to be equal to 2253 MWh/year. The energy consumption per floor was identified. Moreover the electricity consumption of each medical and non medical equipment was calculated with electricity flow meters' utilization. For example MRI panel was responsible for the 6,9 % of annual electricity's consumption. Additionally the daily energy demand chart for the medical unit was formed, with the peak hours for the energy demand being between 13:30 and 18:30. A proposal was explained to the medical staff, according to which a change of the demand chart (and movement of the higher energy consumption of the hospital in off peak hours) in order to reduce the annual cost for electricity. HVAC and refrigeration system was examined, with emphasis in the main parts, such as compressor, cooling tower, condensed water pump, chilled water pump and evaporator. A methodology of expressing the efficiency of the refrigeration system was analytically explained (in kW/TR). It was determined that with the increase of evaporator's temperature by 1 ^{o}C, energy conservation by 3% was achieved. Moreover by reducing the air intake temperature of the compressor by 4 ^{o}C, energy conservation equal to 1% was achieved. This could be combined with the pressure drop that was achieved in the compressor. The lower the pressure drop was, the lower was the required energy. Regarding the lighting systems, different types of lamps were tested like incandescent, fluorescent, compact fluorescent, high pressure mercury, high pressure sodium and low pressure sodium and their energy consumption was measured. The most efficient solution was found to be T5 efficient lighting system, which replaced the 40w fluorescent lamps, while incandescent lamps were replaced by compressed fluorescent lamps. Occupancy and movement sensors were installed, combining their energy saving potential with lighting voltage controllers implementation. The lighting power density was adjusted according to each space's needs and the proper according to each space's needs lamps' colors were proposed. A strategy to increase natural day lighting was proposed by keeping the transparent elements clean and installing on them a specially designed filter, in order to increase the amount of the transmitted through the window light, but at the same time reduce the solar heat gains. With the implementation of electronic ballasts 30 - 35% electricity savings were calculated to be achieved. An effort to improve insulation properties of the building envelope was done by installing on the roof and vertical walls, adjacent to external air, 50mm of extra insulation material. Special attention was paid to the reduction of air infiltration. Moreover the internal heat gains' producing medical equipment was decided to be turned off, when not needed, and the implementation of thermostats took place. For the HVAC system, regular maintenance of the compressing system was decided in order to reduce leakages and variable frequency control system was implemented in order to adjust the motor speed of the compressor in order to consume less energy when the compressor was not needed in full load mode. Finally the internal temperature set point was set equal to 25 ^{o}C and the relative humidity equal to 55%. With the implementation of these energy saving measures the energy saving potential was found to be equal to 19,4 % with positive implication in cost saving potential. ***(http://keralaenergy.gov.in), (Shanavaz et al, 2009)***

In 2009, Mavrotas et al developed a mathematical model, which had the ability to simulate energy performance of hospitals, with upper target the promotion of energy conservation and energy related cost reduction in hospitals. Moreover they utilized MONTE CARLO methodology on GAMS platform in order to perform sensitivity analysis in energy consumption and design, financial assessment of energy consuming systems in hospitals and optimize the energy behavior of medical units. Both the mathematical model and MONTE CARLO methodology took into consideration various factors such as fuels' and electricity's prices, energy consuming devices' efficiency, investment and operating cost. With the developed methodologies a 400 bed hospital in Athens, which was covering its energy needs with electricity and a natural gas boiler for heating and domestic hot water, was assessed. A framework according to which "model reduction process" can take place, assigning a typical day to a whole season in order to simulate the annual energy performance of a system with the utilization of only some selected days, and increase the response speed of the model was developed. Finally trigeneration of heating , electricity and space cooling was implemented and assessed with the developed methodologies for numerous hospitals. The results, showed that trigeneration or CHP is the ideal solution and the most appropriate energy saving measure for nearly every hospital or medical unit. ***(Mavrotas et al, 2009)***

Singer et al made a bibliographic review of the energy performance data that were available on online databases in order to research energy consumption in medical units. The databases, that were used were the following: California Commercial End Use Surveys (CEUS) databases, US Department of energy Commercial Building Energy Consumption Surveys (CBECS) databases and EIA databases. Furthermore energy performance was examined on sample hospitals with the Energy IQ Benchmarking tool (which can provide great information for the energy performance of a building, but it is not suitable for energy saving measure's proposal and simulation). CBES databases contained information about more than 217 hospitals and 144 examination centers and CEUS database contained information about more than 171 medical facilities. The general procedure for the determination of hospitals' energy performance that was used in all of these databases was the following: First of all research about general information about the buildings, such as location, orientation, useful floor area, number of beds, operational schedule etc was performed. Secondly information about building envelope's characteristics (both opaque and transparent elements) was collected. Furthermore efficiency and energy consumption for HVAC , DHW and lighting systems, medical and other equipment were calculated. Finally energy consumption's breakdown (to natural gas, oil, electricity and other energy carriers and to energy consumption's percentage for each energy consuming activity) was performed. The average energy consumption in US hospitals has been calculated to be as following: Space heating 28%, space cooling 10%, ventilation 10%, DHW preparation 17%, lighting 11 %, food preparation and cooking 4% and medical and general equipment 19%. Healthcare facilities were found to be the second biggest energy consumers in US territory only after food industry, with more than 1577 kWh/m^2/year energy consumed on annual basis. ***(Singer et al, 2009)***

Singer et al made a bibliographic review as well about guides that increase energy performance in hospitals. Guidelines that were published by ASHRAE, ASHE AIA, Energy Star, Hospitals energy alliance etc were reviewed. Great interest is presented in the "Prescriptive path to energy efficiency improvements in hospitals", which was published by Houghton and Guttmann in 2007. Singer et al synopsized the most important parts of this Guide which are: The average thermal transmittance of transparent elements must be equal to 0.4 W/m^{2}K ant their solar heat gain coefficient equal to 0,38. Moreover the average lighting power density of the building must be decreased by a percentage of 10% in comparison with ASHRAE's standard's 90.1-2004 specifications, while HVAC and DHW system's efficiency bust be at least equal to 90%. Finally efficient variable speed chillers and fans must be used. ***(Singer et al, 2009)***

In 2009 International Resource Group under the USAID ECO III program conducted energy audits in 35 public and 30 private Indian hospitals. First of all the annual energy consumption (by carrier) was calculated. Special attention was paid to the proposal of energy saving measures in order to reduce energy consumption and CO_2 emissions and increase energy efficiency of HVAC and lighting systems and medical appliances. More over an effort to reduce the energy related costs was done, in addition to a general increase of public awareness about energy efficiency increase in medical units and its positive results. The annual electricity consumption of the Indian health care sector, was equal to 1154 MWh/year and the annual cost for electricity was equal to 6500 RS. Electricity was consumed by HVAC (30-65%), lighting systems (30-40%) and water pumps (10-12%). The hospitals were found to consume on average for their energy needs electricity (91% of the overall energy use), oil (3 % of the overall energy use) and LPG (6% of the overall energy use). The annual energy consumption of each hospital was expressed either per bed or per unit of useful floor area. After the conduction of the energy audits, energy saving measures were proposed for each hospital, the majority of which refer to HVAC system, lighting system, compressed air for medical and HVAC relevant use, refrigerators, etc. Moreover an energy guide for the energy efficient operation of Indian medical units was written, the main points of which may be synopsized in the following: The ideal temperature was found to be after post occupancy evaluation equal to 24-26 ^oC (for recovery rooms 24- 26 ^oC, for operation rooms 17-27 ^oC and for patient hosting rooms 24-26 ^oC). For HVAC and domestic hot water systems, regular maintenance must take place and the system must be turned off when not needed. Heat recovery provisions must be installed which will be able to utilize waste heat from kitchens, sterilization areas and areas with high internal heat gains. Indoor air quality must be compatible with ASHRAE's standards' provisions. For lighting systems, compact fluorescent lamps must be used with T5 tubing systems. Magnetic ballasts must be replaced by electronic ones and occupancy sensors must be installed in order not to waste energy for lighting when it is not required**.** Office equipment must be turned off or in sleep mode when not needed. Energy Star and BEE labeled appliances must be utilized in order to improve energy efficiency. Medical equipment such as X-ray, MRI and Cat scanners must be energy star compatible. Regular maintenance must take place on them on a regular basis. Medical equipment that is not required in a continuous pattern must be placed together in order to be turned off when not needed, reducing energy consumption and creation of heat gains at the same time. Additionally when this equipment is in operation, the created internal heat gains may be utilized, in order to implement a heat recovery system in the hospital. Building envelope must be compatible with ASHRAE's and Indian government's standards. Windows must be double glazed with thermal bridges and low e coatings and opaque building elements must provide adequate insulation in order to reduce transmission and ventilation heat losses and diminish air infiltration. Hospitals are the ideal place for installation of CHP systems due to the continuous requirements in heat and power. The ideal time to install a cogeneration system is when the HVAC system and especially the heating system needs to be replaced. The CHP systems must be adequately sized in order to cover space heating, DHW heating and power requirements for the medical unit. This way a significant increase in efficiency is achieved not only because the equipment is utilized in a higher grade, but also because the transmission and distribution heat and power losses are reduced. CHP systems must undergo regular maintenance and their performance must be regularly measured . ***(International Resource Group, 2009)***

Some of the Indian hospitals, where energy saving measures were implemented during the conduction of the above energy audits were the following: In Apollo hospital in Chennai an efficient CHP system was installed and a new more efficient and less energy consuming elevator was implemented. Additionally waste steam from medical purposes was utilized for preheating purposes. In Batra hospital in New Delhi an economizer was installed on the boiler and energy efficient lighting systems replaced the old depreciated ones. In Jahangir hospital in Pune, timers on AHU systems were implemented and a solar collector for DHW heating was installed. Furthermore a biogas plant was created, which contributed in DHW preparation. In Kovai medical center in Coimbatore, a building energy management system was installed and solar collectors were implemented for DHW heating. Furthermore digital energy flow meters were installed in order to measure energy consumption in real time. In Ruby Hall clinic in Pune, efficient lighting systems were implemented and solar collectors for DHW heating were installed. Additionally a heat recovery system that utilized waste heat form kitchen and laundry room was installed. In Sterling hospital in Ahmedabad, efficient lighting systems and occupancy sensors were installed. Additionally all medical equipment that could be turned off due to its intermittent nature of requirements was placed together in the basement. This way the whole basement section, could be easily disconnected from heating and power connection, reducing drastically energy consumption when the equipment was not needed. Finally in Post graduate Institute for medical education and research in Chandigarh an energy efficient HVAC system with economizers was installed and the solar hot water heating system was renovated. Additionally energy efficient variable frequency drive elevator system was implemented in order to reduce energy consumption from elevator's operation. Finally chillers with variable velocity pumps were installed. ***(International Resource Group, 2009)***

The issuance of the most recent "advanced energy design guidelines for small hospitals and healthcare facilities", took place in 2010. The legislative aspect of these guidelines is presented in the legislation section. The main purpose of this issuance, was the provision of simple guidelines for small medical units, in order for them to achieve 30% energy conservation compared to the provisions of AHSRAE's standard, 90.1-1999. If this effort was successful then the next step was the issuance of 50% energy conservation guidelines in medical units and in the long term transition to nearly zero energy medical units. For this reason 2 prototype medical units were used, one surgery and one community hospital. The computerized building energy performance modeling platform DOE ENERGYPLUS 3,1 was used in order to run several simulations. The simulations were ran for these 2 specific buildings for all 8 climatic zones of ASHRAE's standards. The first category of simulations included the prototype surgery room and community hospitals, with all the ASHRAE's standard's 90.1-1999 guidelines applied on them. Information regarding, building envelope, transparent elements, lighting systems, HVAC and DHW systems were utilized. The second category of the simulation included the implementation of advanced energy design guidelines for small hospitals and health care facilities on the 2 prototypes for all climatic zones. Increased efficiency HVAC with heat recovery (by 15%) was used and high efficiency DHW preparation system was utilized. New guidelines about lighting power density (decreased by 37,5%) and occupancy controls' installation were implemented. Moreover the utilization of natural day lighting took place and increased thermal resistance and reduced infiltration glazed elements, with specially designed overhangs were installed. The two categories of simulations were compared between each other and indeed the achieved energy conservation, resulting from new guidelines' implementation was equal or higher to 30% in all of the climatic zones and both of the prototype medical units. The biggest contribution of this research in the energy audits' sector, was apart from the issuance of the guidelines, the performance of extended building energy performance simulations in electronic modeling equipment, without the need of actual measurements in real buildings. (***AEDG-SHC, 2010)***

Bonema et al created a technical support document, in 2010, the purpose of which was the provision of specific guidelines in order to reduce energy consumption and CO_2 emissions in hospitals by a percentage of 50%, compared with the standard AHSRAE 90.1-2004. The procedure of the research was the following: First of all creation of Baseline models took place. A prototype model whose characteristics were compatible with ASHRAE's standard 90.1-2004 was created. Building envelope (transparent and opaque elements), temperature and indoor air quality set points, ventilation rates, HVAC systems' efficiencies and lighting systems' efficiencies and power densities had the exact characteristics that were proposed by ASHRAE's standard. A typical 5 floor hospital, which contained a rehabilitation center and a surgery as well was designed. Next some baseline hospital models were designed, each fitted to the needs of each ASHRAE's climatic zone of the US territory. While implementing the standards of ASHRAE's 90.1-2004 on the hospitals a wide review of the standard 90.1.2004 takes place. For this reason a significant part of the information about Standard 90.1-2004 about medical units that is presented in the energy performance of medical units legislation section of the present thesis, has been extracted from this technical support document. The next step was the creation of low energy hospital models. In order to achieve this, various energy saving measures were implemented on prototype and baseline hospitals. The most important of them were the following: Increased efficiency of lighting systems (decreased lighting power density to a level of 0,88 w/m^2, installation of occupancy and movement sensors, utilization of natural day lighting), increased insulation in building envelope (Roofs with R25-R35, steel framed vertical walls, transparent elements with double glazing, maximum average U value of transparent elements equal to 0,2-0,43 W/m^2K, VLT 0,63-0,69 , SHGC 0,26-0,40 and the provision according to which the glazed area in vertical building elements is not more the 40% of the overall building element's area), maximum infiltration was set equal to 0,53 cfm/m^2, installation of overhangs on south facing windows (overhangs shading factor at least 0,5), increase of HVAC and DHW system's efficiency (cooling COP at least equal to 4,5 and heating COP at least equal to 5 and distribution system's efficiency at least equal to 55%, utilization of natural gas condensing boiler with 90% efficiency for heating and DHW etc) and utilization of an Automated Building energy management and recoding system. The energy performance for baseline models was simulated with the electronic modeling software NREL Opt-E-Plus and Energy plus Doe 2010. The energy performance of low energy hospitals was modeled with the same software. Data about building envelope, HVAC efficiency , lighting system's efficiency , DHW efficiency, outdoor temperature and relative humidity conditions and building's location and orientation were used as input for the simulations. A variety of simulations took place, until every low energy hospital had at least 50% energy conservation, compared with the prototype model, for the same climatic zone. Energy conservation 50% achieved for every climatic zone. The highest energy conservation was achieved in climatic zones 3C and 3 B in San Francisco and Los Angeles, California. ***(Bonnema et al, 2010)***

Saidur et al conducted an energy audit on a Malaysian 8 floor public hospital in 2010. Moreover Saidur et al performed a literature review in order to estimate the annual average electricity consumption of medical units around the world and compare it with findings in Malaysian medical units. USA medical units' average electricity consumption was equal to 320 kWh/m^2/year. The same number for Greece was equal to 200 kWh/m^2/year, for Malaysia 140 kWh/m^2/year and for Japan 120 kWh/m^2/year. Special attention was paid to building envelope , monthly electricity bills, internal temperature and RH set points and of course energy consumption of HVAC, lighting, DHW and medical systems. The overall energy consumption of the study hospital was equal to 19300 MWh. The electricity's consumption's breakdown for the under study hospital was found to be as following: Lighting systems were responsible for 36% and medical equipment for 34%, while office appliances for 8,9% and communications for 4% of overall electricity consumption. Their main conclusion of their literature review was that electric motors were responsible up to 75% of overall energy consumption of hospitals. For this reason they created the proper mathematical model for energy saving potential and CO_2 emissions' reduction potential calculation in hospitals from the installation of energy efficient motors and implementation of variable velocity drives, in order to reduce rotating speed when it is able. The main conclusion was the following: With the implementation of variable velocity motors and reduction of their rotational speed, energy conservation equal to 9% and CO_2 emissions' reduction equal to 654170 kg/year could be achieved with speed reduction equal to 20 %. For velocity reduction equal to 60 % the same numbers are equal to 33% energy conservation and 1529000 kg/year of CO_2 emissions. Significant energy saving potential and CO_2 emissions' reduction potential can be achieved with the implementation of energy efficient and low energy consumption motors in hospitals.

For 50 % load of energy efficient motors, the achieved energy conservation is equal to 1,1% and the CO_2 emissions' reduction potential equal to 85000 kg/year. For 100% load the same numbers are increased, with energy saving potential equal to 1,64 % and CO_2 emissions' reduction equal to 139000kg/year. ***(Saidur et al,2010)***

Ortiga et al developed in 2010 a graphic method, according to which an energy demand curve is designed, which characterizes the energy demand of a cogeneration of heat and power or trigeneration system. This method is used by the user, in order for him to be able to choose in the most objective way the typical days , during which the energy demand of a CHP or trigeneration system will be measured on a hourly basis. These days must include not only typical days with average demand, but also days with peak demand and must be representative for the whole year's energy performance of the CHP system. With this method and the typical days' utilization, the annual energy demand for space heating and cooling will be calculated (through software such as TRNSYS), the nominal capacity of CHP or trigeneration system will be estimated and an objective base for the optimization of CHP or trigeneration system will be created. Furthermore a mathematical model for CHP optimization with the utilization of typical days was developed, for both space heating and space cooling energy needs. Finally the model and the graphic method for the selection of typical days and optimization of CHP, was tested with the utilization of 5, 7 and 10 typical days. The results were compared with optimized models , which recorded energy demand on a hourly basis for all days around the year and in all 3 cases the relative error was less than 10%. Although this study may seem not relevant with medical units' energy performance, the truth is that that it is significantly important for their energy consumption, because medical units can be characterized as the ideal site for CHP or trigeneration systems' implementation. ***(Mavrotas et al, 2009), (Ortiga et al, 2010)***

In 2010 Dome-Tech, Inc conducted an energy audit on Hoboken University Medical Center which is located in New Jersey. First of all information about the building's size and its use patterns were collected. Secondly building envelope's insulation characteristics and constructional peculiarities were studied. Energy consuming equipment such as HVAC, DHW and lighting systems and medical and general equipment was recorded and their energy consumption was calculated. The medical unit's annual electricity consumption was equal to 7871940 kWh/year and its annual cost was equal to $1047913 per year, while its natural gas annual consumption was equal to 361500 therms/year with annual cost equal to $430390/year. Energy Saving measures were proposed in order to reduce annual energy consumption and CO_2 emissions and minimize annual operational energy related cost. The more important proposed ESMs were the replacement of lighting systems with more efficient ones, the maintenance and readjustment of automated building energy management system, the replacement of old DHW boiler with a new and more efficient one, the replacement of windows with new windows with lower U value and the implementation of a program whose purpose was to increase medical staff's awareness about energy conservation and its advantages, and practices to achieve it. With the implementation of the proposed energy saving measures 54% natural gas and 14% electricity conservation could be achieved on an annual basis. Moreover the annual cost reduction was calculated to be equal to 35% and the annual CO_2 emissions' reduction was calculated to be equal to 1485 tons/year. The payback period for the implementation of the above energy saving measures was equal to 10,1 years. Furthermore the implementation of 130 kW Photovoltaic installation of the medical center's roof was examined and 3 projects of wind turbine installation were technically and economically assessed , with the more appropriate solution being the implementation of a 50 kW wind turbine. Finally the implementation of CHP was not proposed due to the fact that the medical unit had low needs for thermal energy. ***(Dome-Tech, Inc, 2010)***

A significant study about hospitals' thermal comfort was performed in 2010 by Verheyen et al. They studied the thermal comfort in a Belgian medical unit. More specifically, they used objective measurements and subjective assessment of internal space temperature, relative humidity and indoor air quality. The subjective assessment was done by a sample of 100 different patients in different sections of the hospital, such as oncologic, gastroenterology, neurologic ant other sections of the hospital. The methodology intended to assess non only the physiological, but also the psychological response of the patients to the thermal comfort that was achieved in the hospital, including also their behavioral patterns, clothing insulation level and level of their activity. Methodologies such as predicted mean vote and percentage of dissatisfaction were utilized with the implementation of ISO 7730 and ISO 14415 standards for the conduction of the assessment of thermal comfort. The internal conditions were kept into steady state conditions, while measurements took place at 1 m above the floor and within 1 m of the patient's position. The main scope of the scientific team was to examine with objective and subjective (from patients' point of view) measurements if internal temperature, relative humidity and indoor air quality of the hospital complied with ASHRAE's and VIPA's standards and if patients felt comfortable with them. According to the objective measurements, hospital facilities complied with ASHRAE's standards in a percentage of 95% regarding internal temperature, relative humidity and indoor air quality levels. Finally the objective assessment that was done by patients, showed that 71% of patients were satisfied with ASHRAE's indoor air quality, and 70% with VIPA's standards. (***Verheyen et al, 2010)***

Bujak presented in 2010 a study, during which the thermal energy consumption for DHW preparation for two Polish hospitals was measured and analyzed. The hospitals were University Hospital of Bydgoszcz and Provincial Hospital. Measurements took place for a period of four years for each hospital. The measurements were done with the implementation of a specially designed device, Industrial Programmable Logic Controller. This device which is also used for industrial purposes, was able to measure and visualize the energy consumption for central space heating system, DHW preparation and for steam preparation on an annual, monthly, daily and hourly basis. Moreover average temperature and supply and return temperatures of DHW and systems' efficiency were measured. Finally the proper histograms were formed, the relative error was calculated and an objective basis for the forecast of DHW preparation system's energy consumption for an newly built hospital was formed. For University Hospital of Bydgoszcz a natural gas fueled system of 3 steam boilers had been utilized. Its efficiency was equal to 78,4% and the average DHW temperature was equal to 58,2^{o}C. The annual energy consumption for DHW and steam preparation was equal to 0,966 GJ/m^2/year. For Provincial Hospital, a natural gas boiler had been utilized. Its efficiency was equal to 79,7% and the average DHW temperature was equal to 57,5^{o}C. The annual energy consumption for DHW and steam preparation was equal to 1,178 GJ/m^2/year. For both hospitals the peak demand (for DHW) period was between 08:00 and 19:00. ***(Bujak,2010)***

Yau et al performed a bibliographic review in 2010 about the ventilation needs (one of the most energy intensive activities in hospitals) in large hospitals in the tropics. They concluded that the type of required ventilation (natural or mechanical) depends on type of hospital, type of building, desired internal temperature and relative humidity, indoor air quality and air change per unit time requirements. The main considerations during the construction of ventilation systems must be disease spread prevention and sensitive levels' of fresh air in the hospitals' interior maintenance. Judged from their form and their ventilation requirements, hospitals were classified into bay, nightingale , racetrack, hub and spoke buildings. The ideal indoor conditions for hospitals in tropics were found to be for temperature between 24-32 ^oC and for relative humidity equal to 50-90%. Finally a bibliographic research about the best method for assessing the performance of ventilation system in a hospital took place, with the most appropriate method being, computerized fluid dynamics airflow analysis, based on Navier Stokes equations. ***(Yau et al, 2010)***

Vanhoudt et al studied the installation of an Aquifer thermal energy storage system in Klinieken Noord Antwerpen hospital in Belgium. The system was operating with the operation of two heat pumps and a groundwater aquifer and it was intended to cover energy needs for the operation of HVAC system. The original HVAC system of the medical unit was parted from a natural gas fueled boiler for space heating and a water cooled device for space cooling and 40 air handling units for ventilation.. The ATES installation had 3 modes: Heating or winter mode, when heat was pumped from hot well and the cold water was extracted to the cold well, the cooling or summer mode, when hot water was injected to the warm well and cold water was extracted from the cold well and regeneration mode, which could be automatically be enabled when the ambient air temperature was equal to 4 ^oC, and according to which the cold intake air could be preheated, before entering the hospital's facilities. The change between winter and summer mode could be automatically done if the ambient air temperature was higher or lower than 14 ^oC. The ATES system's performance and contribution to HVAC needs was studied for a three year period. Space cooling utilized 81% of groundwater's thermal energy, while for space heating and ventilation direct utilization of 22% groundwater's heat took place. The heating's COP was equal to 5,6 and cooling's COP equal to 5. The primary energy conservation for HVAC needs was equal to 71 % and the CO_2 emissions' reduction 426000 kg/year or 73% reduction. Moreover the financial assessment presented annual cost savings equal to 54000 Euros. The payback period of the ATES implementation was found (without considering subsidies) equal to 8,4 years. ***(Vanhoudt et al, 2011)***

Ahmadzadehtalatapeh et al conducted an energy audit on the air conditioning system of Orthopedic section of Malaysian University Hospital in 2011. The purpose was to study the energy performance of air conditioning system and its capability of achieving the indoor air quality requirements of ASHRAE's standards. Although the desired temperature could be achieved, the internal air's relative humidity exceeded in a lot of cases the limit of 70%, making the air conditioning installation, not to comply with ASHRAE's standards. For this reason as a solution the implementation of heat pipe heat exchangers on air conditioning installation was proposed. The energy performance of 4, 6 and 8 heat pipe heat exchangers' implementation was simulated with the use of TRNSYS software and FORTRAN's code. Climatic data for Kuala Lumpur had been used for the simulation from TMY database. The energy consumption of the air conditioning system, the indoor dry bulb temperature, the indoor relative humidity and the system's efficiency wee simulated for the baseline air conditioning solution and for the implementation of 4, 6 and 8 rows of heat pipe heat exchangers. As a general rule it was found that with an increase of rows of heat pipe heat exchangers, the overall efficiency of the system, was increased. In all cases of heat pipe heat exchangers' implementation the relative humidity was always lower than 70%, complying with ASHRAE's standards. From energy performance and financial point of view the most efficient solution was found to be the implementation of 8 rows of heat pipe heat exchangers on the air conditioning system. The energy consumption of the air conditioning system was decreased by 455070 kWh/year and there were cost savings equal to 42277 $ per year. For this reason the implementation of heat pipe heat exchangers was found to be a feasible and attractive solution for a medical unit, in tropics, because this way it could easily reduce its energy consumption for air conditioning and comply easily with ASHRAE's standards. ***(Ahmadzadehtalatapeh et al, 2011)***

In 2011 a very interesting study was conducted on Municipal hospital of Vallejo, in Serbia. An energy audit was conducted on hospital facilities, which had as a purpose the replacement of current depreciated hospital's oil burner based space and DHW heating system with a well insulated pipeline which connects the hospital with the town's central heating system. This way the space heating needs would be covered. For DHW preparation, solar collectors were installed on hospital's roof in order to reduce pollution and final energy consumption. A financial and feasibility study was performed for this effort as well. ***(www.czda.cz)***, ***(MEVOS Ltd, 2011)***

In 2011 American Society for healthcare Engineering and American Hospital Association, conducted energy audits on 4865 US hospitals. Medical units with energy consumption less than 26,9$ per m^2 were 12% of the total number of participated medical units. The vast majority of hospitals (28%) consumed between 32,3-43 $/$m^2$, while a fair percentage (21%) consumed from 43 -53,8 $/$m^2$. Health care industry was found to be the second biggest energy consumer in US, behind food industry. Energy saving measures were implemented where it was necessary, with the most common of them being: Installation of energy efficient lighting systems in the 75% of hospitals, utilization of Energy Star Certified medical and common use equipment (in 55% of hospitals), installation of building energy management systems (in 53% of hospitals) , utilization of cogeneration of heat and power, onsite electricity generation with Photovolatics, utilization of natural daylight, implementation of south facing orientation of patients' rooms, improving the insulation efficiency of medical units' building envelope, installation of more efficient HVAC systems. The more efficient medical units within US were found to be Baptist Hospital in Nashville, St Francis Eastside Hospital and Memorial Hermann Hospital in Houston. Great interest is presented in Kadlecs Regional Medical Center, which installed a small scale wind turbine in order to generate on site RES based electricity, creating a new trend in the RES penetration in medical units. With the utilization of US's financial incentives the total cost for the installation of the wind turbine was equal to 80000$. The hospital achieved though with this measure and the simultaneous implementation of other relatively low cost energy saving measures annual savings of 50000$. Gunderson Luthhown medical unit in La Grosse, installed a cogeneration of heat and power provision, which was fueled by waste from a local brewery. The total electricity that was generated was 2 million kWh/year. Furthermore a solution for waste minimization and disposal strategies was presented with this innovative idea. ***(American Hospital Association, 2011)***

USAID sustainable development and policy center conducted an energy audit on Dusheti General Hospital, which is located in Georgia, in 2011. The energy consumption of the building on an annual base was calculated and energy saving measures were implemented. During the conduction of the energy audit and the implementation of ESMs, standard SNIP 2.04.05-86 for HVAC and Boiler and SNIP 11-3-79 for thermal properties of building envelope and sanitary spaces certification standards, were followed. The methodology of the project was the following: First of all general information about the building were collected such as useful floor and heated area (2250m^2). Secondly the thermal characteristics for the opaque and transparent elements of the building envelope were determined. For vertical walls adjacent to external air the average U value was found equal to 1,45 W/m^2K, for the roof 1 W/m^2K, for doors 2,91 W/m^2K and for windows the average U value was found to be equal to 3 W/m^2K. Then the characteristics for the HVAC, lighting and medical appliances were configured. For Space heating and DHW preparation electric heaters were used. DWH heater consumed 13176 kWh/year, while space heating energy consumption was equal to 303303 kWh/year. Lighting power density was equal to 5 W/m^2 and annual energy consumption was found equal to 49275 kWh/year. The installed power for medical equipment was 0,1 W/m^2 for PCs, for X-ray 4 W/m^2, for ultrasonography machinery 0,1 W/m^2, for centrifugal machine 0,1 W/m^2 and the total medical equipment installed power was equal to 7,9 W/m^2. Next some energy saving measures were proposed and implemented, the more important of which were: The application of more efficient building insulation on building envelope (vertical opaque building elements, roof , floor, ceiling) and implementation of double glazed windows, and installation of efficient lighting systems (fluorescent lamps). After the implementation of energy saving measures simulation with the pc software ENSI key number software was performed in order to demonstrate the new energy performance of the hospital. The auditing procedure was performed both with the simplified and detailed methodology. The electricity annual savings were equal to 32850 kWh/year due to the implementation of energy efficient lighting systems, while for space heating and DHW, the annual energy conservation was equal to 80771 kWh/year. Finally the CO_2 emissions that were saved were equal to 29468 tones/year. The financial assessment showed that the payback period for the implementation of ESMs was equal to 2,9 years. ***(USAID,2011)***

In 2011 Psaras et al conducted an energy audit on P. A. Kyriakou Children's hospital in Athens, Greece. First of all the general characteristics of the building were described and plans of each floor were designed. The hospital has 6 floors. Secondly the characteristics of the building envelope were calculated. The external part of walls was made from concrete (24 cm), with a layer of exp polystyrene and (or) from 20 cm of brick with a layer of exp polystyrene as an insulation material. The average U value for opaque building elements was found equal to 0,65 $W/m^2/k$, which did not qualify for TOTEE standards (0,5 W/m^2K). The total U value for transparent elements was found to be equal to 3,3 W/m^2K which did not qualify for TOTEE climatic B zone's standards (3 $W/m^2/K$). Next the internal temperature of each space was examined and possible heat losses from building elements were examined, through thermal camera viewing method. Moreover energy inspection for the boiler took place. The burner was found to have nominal power 140000 kcal/h. 2 boilers of 1000l each, were utilized and 2 oil burners, which had been constructed by Thermostahl, were used. The energy consuming devices were found to be the following: lighting systems, elevators, personal computers, pumps, fan coils, cooling tower and medical equipment and other electric appliances, which consumed electricity and of course the above mentioned heating system, which was fueled by oil. Apart from the annual electricity consumption , the annual cost for the operation of each energy consuming device was calculated as well. In order to estimate the exact energy and electricity consumption of each space, energy consuming devices were recognized in each space and their energy consumption, was recorded. The energy recording devices, showed that there was significant energy consumption, even when the hospital was not operating. The methods that were utilized during the conduction of the energy audit , were the following: First of all thermography was utilized. With the utilization of a thermal camera, the internal temperatures of the different spaces were identified. The cameras, that had been used were the FLIR B40 and FLIR B50. Secondly a boiler exhaust gas analyzer was used during the inspection of the boiler. This was the KANE 9000 Plus. Moreover specially designed electricity flow metering devises were used in order to estimate the daily electricity consumption in each plug. The device that was used was the Electricity Fluke 1735**.** Finally data from Public Power Corporation's bills were collected in order to find the monthly and annual overall electricity consumption of the hospital. The electricity consumption for lighting systems was found to be equal to 36481 kWh per year , being responsible for the 16 % of the total electricity consumption, for air conditioning 77290kWh/year (33 % of overall electricity consumption) and for electric appliances and medical equipment 117745 kWh/year (responsible for 51% of overall electricity consumption). The monthly average electricity consumption (around 250000kWh/year) presented an increase of

40000kWh during the summer months July and August, possibly due to the extended requirements for space cooling in Climatic zone B. The following saving measures were proposed and financially assessed, in order to reduce final and primary energy consumption and CO_2 emissions: First of all replacement of oil with natural gas fuel, for heating purposes was proposed. Secondly replacement of magnetic with electronic ballast for lighting in order to promote energy conservation was proposed. This measure led to 25% energy conservation. Its initial investment was equal to 6200 Euros and the annual savings due to its implementation were equal to 1052 Euros. Moreover replacement of T8 lighting systems with more efficient T5 was studied. This measure lead to 28% energy conservation. Its initial investment was equal to 15800 Euros and the annual savings due to its implementation were equal to 1178 Euros. Furthermore installation of occupancy sensors was implemented. The initial investment was equal to 1470 Euros and the savings were 315 Euros annually. Additionally installation of double glazed (air spaced 4-12-4) elements was implemented. The new overall U value for transparent elements was equal to 2,8 W/m^2k, complying with TOTEE standards. Installation of additional insulation on opaque building elements was found to be promising, in order for them to comply with Greek legislation for climatic zone B(0,5 W/m^2K). An interesting ESM was the installation of solar collectors for DHW preparation. This way 8% energy conservation was achieved. Moreover implementation of time sensors for space cooling systems and electronic appliances took place. This way the above devices stopped operating when the hospital was closed , reducing the energy consumption by 15%. This way 4074 Euros could be saved annually. Finally the installation of building integrated PVs was proposed with total installed power equal to 9,31 kW. The investment for their installation was equal to 35180 Euros and more than 13500 kWh could be generated annually, reducing the amount of electricity that had to be purchased from PPC's grid. ***(Psaras et al, 2011)***

In 2012 USAID Jordan Economic Development Program (SABEQ), in cooperation with Private Hospital Association, conducted energy audits on 8 public and private Jordanian Hospitals. Energy consumption was recorded and energy conservation measures were proposed in order to promote energy and water conservation, within hospital's facilities. The energy conservation measures that had been implemented were: Installation of energy efficient lamps (replacement of incandescent with fluorescent ones), maintenance and adjustment of heating systems in order to increase operational efficiency, installation of solar thermal collectors for hot water preparation, water conservation practices, such as cleaning and recycling grey waters with constructed wetlands and proper filters' utilization and waste minimization practices to promote a wider hospital's green operation**.** The cost of energy saving measures' implementation was estimated to reach JD 164000, while the annual savings were calculated to reach JD 100000 ***(www.poweringhealth.org), (USAID Jordan Economic Development Program, 2012)***

In 2012, Congradac et al made a research about energy consumption of heating and cooling systems in hospitals. First of all a bibliographic review about the energy consumption in hospitals, using the worldwide bibliography was made. According to it, energy is consumed in medical units in the following way (average energy consumption's breakdown of all sources): Lighting is responsible for the 21%, Cooling for 5%, DHW heating for 5%, Space Heating for 43%, cooking for 4% and medical and other equipment such as elevators for 19%. Moreover the same team created a mathematical model and a computer tool, which would be able to calculate and assess energy consumption data for medical units in real time. Moreover it could propose energy saving measures and calculate the resulted energy savings due to their implementation. This tool was named HOSPILOT and it was designed to assess the energy performance of a hospital room by room. For its creation dynamic mathematical models and linear equations for heat transfer, thermal storage and thermal mass capability within medical units, were utilized. The main concept was an evolution of heating and cooling degree day methodology. In order for the mathematical model to operate, the following variables had to be determined: General information about the building and climatic information, such as average temperature and relative humidity were collected. Location and orientation of each hospital's room was determined and information about hospital's building envelope was collected. Each room's occupancy patterns were estimated and heat losses by transmission and ventilation, internal heat gains due to lighting equipment and occupants and solar heat gains were calculated Finally the thermal energy stored in building's thermal mass was measured and variables such as desired internal temperature, air quality and lighting power density were determined. Last but not least the efficiency and type of HVAC, lighting, DHW and medical equipment were calculated. The next step was the calibration of the electronic tool. This took place with the conduction of energy audits in hospital rooms in 4 different areas, Athens, Logrono, Groningen and Helsinki. The collected data were assessed with the created tool and compared with 3 commercial tools RIUSKA, ENERGYPLUS and standard's 13790 results. Finally an energy audit was conducted on Emergency medical Center in Novisad, a complex medical building, with 5 floors, 7 HVAC systems and complex medical equipment. The model had significant accuracy , with +/- 7 % error, compared with conventional methods. This was characterized as more than acceptable, especially if the efficient and fast responding operation of the model is considered. ***(Congradac et al,2012)***

In 2012 Pagliarini et al studied the implementation of a gas fired cogeneration of heat and power system on Hospital Campus of Parma. An energy audit was conducted on all the medical units of the campus in order to calculate their electricity needs for medical equipment, lighting systems and DHW heating. The total heating and cooling loads of all medical buildings were calculated with the utilization of TRNSYS software. More specifically Multi Zone Building Subroutine was used. Additional information was needed, such as internal temperature and relative humidity set points, required air changes for each space and occupancy patterns for each space. Three scenarios were simulated: The base case scenario with the already existing system for space heating , the scenario of implementation of gas fuelled cogeneration of heat and power system and the scenario of the implementation of gas fuelled trigeneration of heat and power for space heating, electricity needs and space cooling. Furthermore an economic assessment of each scenario took place , taking into consideration initial investment for the implementation of CHP, operational and maintenance cost for natural gas fuel and electricity's unit's price in Italy. The most competitive and ideal solution from both energy consuming and economic view was found to be trigeneration of heating , cooling and power. Payback period for the implementation of trigeneration was found to be equal to 1,3 years. Moreover an optimization of the proposed trigeneration system was performed , with the optimum nominal capacity of the trigeneration system, being equal to 7 MW. ***(Pagliarini et al, 2012)***

Khodakarami et al performed a literature review regarding the designed indoor climate in medical units, and its correlation to patients' health and medical staff's productivity and to energy consumption of HVAC systems. They concluded that patients' and medical staff's health and the disease spread prevention priorities are achieved if a specific combination of relative humidity, internal temperature and indoor air quality standards are achieved. More specifically, internal temperature must be between 20-26^{o}C, relative humidity between 30-60 % and air changing speed equal to 0,1 m/s per patient. This more or less must be the set point of HVAC systems' operation in hospitals. (***Khodakarami et al, 2012)***

Adamu et al studied the implementation of 4 natural ventilation, buoyancy driven airflow techniques in Great Ormond Street Hospital in 2012. With the utilization of IES Dynamic thermal simulation modeling software and PHOENICS CDF modeling software, 4 different cases of natural ventilation were assessed regarding the achieved air movement, the additional energy consumption that was required for space heating and the achieved thermal comfort. The quality of the achieved thermal comfort was determined with the implementation of Predicted Mean Vote and Predicted Percentage of Dissatisfaction methodologies. The simulation was performed on a single bed hospital room. Case 1 examined the utilization of open window based ventilation, case 2 implemented two open windows on the same side, case 3 examined inlet and stack ventilation methodology and case 4 was a ceiling based natural ventilation concept. The higher achieved airflow rate was presented in case 2, followed by case 3, 4 and 1. In the majority of simulations, the achieved air flow rates were compatible with the ISO 7730 and WHO 60 standards' requirements with some exceptions in case one. The higher energy consumption for space heating was presented in case 2, followed by case 3, 4 and 1. Finally Predicted Mean Vote methodology showed that the preferred method regarding the achieved thermal comfort was method in case 2, followed by method in case 1. ***(Adamu et al, 2012)***

Short et al, in 2012, used dynamic models in order to simulate the energy performance of Addenbrooke's Hospital, which is a 10 floor medical unit, which is located in Cambridge, United Kingdom. An energy audit was conducted on this building, with special attention to opaque and transparent building elements' U value. For the opaque building elements the average U value was found equal to 1,2 W/m^{2}K, while the positive influence of the external selective shading devices and the specially designed polymer thin layers that had been installed on windows, limiting the creation of solar heat gains was recorded. The desired temperature of the hospital was 21,2-28^{o}C. The energy consumption and the created CO_2 emissions of the hospital for HVAC, lighting and DHW preparation systems' operation were calculated with the utilization of IES model. The building's energy consumption for ventilation and space heating was found to match the findings of the bibliographic review that had been performed by the same scientific team, with 44% of the overall energy consummation being utilized for this purpose. Apart from the calculation of the energy consumption of the hospital, the scope of the study was to research how resistant is the building to global warming phenomenon at that time and until 2030. This was simulated with IES dynamic model and it was found that the building had more than 16 h /day temperatures greater than 28^oC, which was the upper limit for indoor designed temperature. It was also found that this phenomenon was highly correlated with the outdoor climatic conditions and with the methodology that was used for building's ventilation. Five different scenarios with combinations of energy saving measures, efficient lighting systems, different ventilation methodologies, in order to increase building's resistance to the phenomenon of overheating at that time and until 2030 were simulated. These were the following: According to the first scenario the windows would not be open able, mechanical ventilation would be implemented and the application of Passivhaus standards would be utilized. The annual energy demand was forecasted to be equal to 59GJ/100m^3 and the CO_2 emissions equal to 137 kg CO_2/m^2. The second scenario used not open able windows, HVAC system with heat recovery provision and a ceiling heating or cooling system. The annual energy demand was forecasted to be equal to 46GJ/100m^3 and the CO_2 emissions equal to 102 kg CO_2/m^2. The third scenario implemented a combination of natural and mechanical ventilation with heat recovery provision and perimeter heating system. The annual energy demand was forecasted to be equal to 40GJ/100m^3 and the CO_2 emissions equal to 111 kg CO_2/m^2. The fourth scenario combined natural cross ventilation methodologies, with the implementation of perimeter heating systems. The annual energy demand was forecasted to be equal to 20GJ/100m^3 and the CO_2 emissions equal to 44 kg CO_2/m^2. Finally according to the fifth scenario perimeter heating systems would be combined with stack ventilation techniques. The annual energy demand was forecasted to be equal to 59GJ/100m^3 and the CO_2 emissions equal to 137 kg CO_2/m^2. Building's energy performance was simulated until 2080. Options 2 to 5 were found to be resistant against temperature increase and global warming until 2030, providing at the same time energy conservation and CO_2 emissions' reduction opportunities. ***(Short et al, 2012)***

3. Medical Units' energy performance Legislation and Standardization

In this section a review about legislation, regarding the energy performance of medical units and healthcare facilities around the world, takes place. The review starts from Greek legislation and K.E.ν.A.K and continues with the European Committee's Buildings Energy Performance Directive and its guidelines and accompanied Directives. Additionally energy performance legislation in United Kingdom is studied. Moreover ASHRAE's guidelines about healthcare facilities and their effect on U.S. and Canada's legislation are studied. Finally in order to monitor the condition in developing countries, the energy performance legislation, regarding medical units in Brazil is examined.

3.1. Legislation and Standardization in Greece

In Greece, the energy performance of hospitals and other public buildings is regulated by the Greek state's law ***ν. 3661/2008***, "Measures for the reduction of buildings' energy consumption and other provisions". According to the above Greek law a regulation regarding both minimum standards for energy performance of the buildings and the methodology regarding the conduction of an energy audit has been instituted. It is widely known as K.E.ν.A.K. (ΚΑΝΟΝΙΣΜΟΣ ΕΝΕΡΓΕΙΑΚΗΣ ΑΠΟΔΟΣΗΣ ΚΤΙΡΙΩΝ - GREEK REGULATION ON THE ENERGY EFFICIENCY OF BUILDINGS). During the conduction of an energy audit every an engineer uses these tools in the standardization of energy performance of buildings and the procedure that must be followed regarding the conduction of an energy audit. Both ***K.E.ν.A.K*** and Law ***ν. 3661/2008***, are harmonized with the European Directive ***2002/91/EC***, widely known as the European Union's "Energy Performance of Buildings directive" (EPBD). (http://portal.tee.gr)

According to the above legislative framework, technical guidelines have been published with ***7178/ΦΕΚ Β 1387-2010*** Decision, which have to be followed carefully by the engineers, members of TEE during the conduction of an energy audit. More specifically these guidelines are the following:

- TOTEE 20701−1/2010 " National specifications for the conduction of energy audits and the issuance of energy performance certificate for a building" (http://portal.tee.gr)
- TOTEE 20701−2/2010 " Thermo physical properties of building materials and control methodology for the adequacy of building insulating properties" (http://portal.tee.gr)
- TOTEE 20701−3/2010 " Climatic conditions in Greek climatic zones" (http://portal.tee.gr)
- TOTEE 20701−4/2010 " Guidelines and forms for building's energy audits and the inspection of Buildings, heating, cooling and ventilation" (http://portal.tee.gr)
- TOTEE 20701−5/2012 : "Cogeneration of Heating, Cooling and electricity in building installations" under ***1192/ΦΕΚ 1413-2012*** (http://portal.tee.gr)

Law ***ν. 3661/2008*** and K.E.ν.A.K focus in medical units as well. In the majority of the above mentioned legislative frameworks, hospitals are considered as public commercial buildings. For this reason their standardization and energy audit's details have similarities with other buildings such as residential buildings, either they are single or multifamily and commercial buildings such as educational buildings, offices, sports facilities and other commercial energy consuming buildings. The general part of the legislative framework such as the energy audit conduction procedure is the same for every category of a building, with some differences for each category. There are some sub categories though, such as the standardization in thermal comfort and energy consumption for different purposes, which are covered by legislation solely for every different type of the building. Of course hospitals are not an exception for this rule. (Law ***ν. 3661/2008)***

First of all there is a separation in the standardization of a newly constructed building and a renovated building that had been constructed previously. The energy audit procedure is more or less the same. The area that is covered by the Greek country is separated in 4 climatic zones. This takes place in order to configure in the most efficient way the outdoor temperatures and climatic conditions for each area. The above mentioned zones are called climatic zone A, B, C and D. Climatic zone A consists of the southern part of Greece such as Creta, Dodekanhssa, Argolida , Messhnia and Kyklades. Climatic Zone B is covering areas such as Attiki , Korinthia , Lefkada, Evoia and Preveza. Climatic Zone C is covering areas such as Thessaloniki. Chalkidiki, Serres Kavala and Larissa. Finally climatic Zone D is covering areas such as Grevena, Kozani, Florina and the rest northern part of Greece. Moving from climatic Zone A to climatic zone D the outdoor temperatures are considered to decrease, and for this reason the insulating and thermo physical properties of the buildings are properly adjusted. ***(Law v. 3661/2008)***

The energy audit procedure of a hospital and a common building is as following. A study of the energy performance of the building takes place. First of all the design and constructional details of the building are considered, including its orientation and location. Secondly the building's envelope is examined and its thermo physical and insulating properties are assessed. Electrical and mechanical installation are assessed and their energy consumption is examined. For hospitals, which are considered non residential buildings the energy consumption for space heating, space cooling, domestic hot water heating, ventilation and lighting must be calculated. This takes place as following: First of all the orientation of the building is considered. The outdoor and indoor space temperatures are calculated, followed by the insulating and heat conducting properties of transparent and opaque building elements. This way the heating and cooling load of the hospital is calculated. The optical comfort affects the energy need for lighting and the special indoor air quality for health care facilities forms the needs for ventilation. Special attention must be paid to the medical equipment not only because they require great amounts of energy but also because they produce great amount of internal heat gains, drastically affecting the indoor temperature and heating and cooling loads. The efficiency and type of heating, cooling, ventilation, lighting , domestic hot water and medical equipment is examined and this way the final energy consumption of the building is calculated separately for each purpose and each energy carrier. Depending on the type of each energy carrier the primary energy consumption and CO_2 emissions are calculated (Law ***v. 3661/2008)*** . In the following table, the final to primary energy conversion factor, regarding the type of energy carrier that is used is presented (Law ***v. 3661/2008)*** :

***Table 1: Final to primary energy conversion factor and Carbon Dioxide emissions regarding the type of energy carrier that is used** (**Law v. 3661/2008**)*

Energy Source	*Conversion Factor to Primary Energy*	*CO2 emissions ($kgCO_2/kWh$)*
Natural Gas	***1,05***	***0,196***
Oil	***1,10***	***0,264***
Electricity	***2,90***	***0,989***
Biomass	***1***	***0***
RES such as solar and wind	***0***	***0***

An energy performance certificate of the building is issued regarding the design and constructional details, its elements' insulating and thermo physical properties and the characteristics of its electric and mechanical equipment. Moreover a certification takes into consideration the final energy consumption of the building, the primary energy consumption and its CO_2 emissions. According to the assessment of the above elements an energy performance rating is given to the building. Public buildings such as hospitals are required to have an energy performance grade equal or greater than B. An energy performance certification of a hospital is required when the hospital is constructed or renovated, or when a medical construction is sold or rented . The rating of the building is held always in comparison to a reference building which undergoes the same use patterns. (Law ***v. 3661/2008)*** **.**

The methodology that is used during the conduction of an energy audit on the facilities of a hospital is configured by the following suggestions - standards:

***Table 2: Methodology for energy audit's conduction on a hospital's facilities suggestions - standards**(**Law v. 3661/2008**)*

ΕΛΟΤ EN ISO 13790 E2 (2009)	***Building's energy performance - Calculation of energy needs for space heating and cooling***
ΕΛΟΤ EN ISO 6946 E2 (2009)	***Calculation of Building's thermal transmittance and resistance***
ΕΛΟΤ EN ISO	***Calculation of heat transmission through ground***

13370 E2 (2009)	
EN ISO 10077-1 (2006)	*Simplified methodology for calculation of thermal transmittance trough windows and doors*
ΕΛΟΤ EN 13947 (2007)	*Thermal performance and thermal transmittance through walls*
ΕΛΟΤ EN 15241 (2008)	*Air ventilation in non residential buildings Heat losses due to air ventilation procedure.*
ΕΛΟΤ EN ISO 15927.01 (2004)	*Average monthly outdoor climatic and meteorological values*
ΕΛΟΤ EN 15193 (2008)	*Energy needs for lighting for non residential buildings*
ΕΛΟΤ EN 15316.01 (2008)	*Energy needs and efficiency of space heating systems*
ΕΛΟΤ EN 15316.02.01 (2008)	*Energy needs and efficiency of space heating systems- Emission system*
ΕΛΟΤ EN 15316.02.03 (2008)	*Energy needs and efficiency of space heating systems - Heat distribution system*
ΕΛΟΤ EN 15316.04.01 (2008)	*Energy needs and efficiency of space heating systems - Heat production Systems*
ΕΛΟΤ EN 15316.04.02 (2008)	*Energy needs and efficiency of space heating systems - Heat Pumps*
ΕΛΟΤ EN 15316.04.03 (2008)	*Energy needs and efficiency of space heating systems - Solar thermal heat production systems*
ΕΛΟΤ EN 15316.04.04 (2008)	*Energy needs and efficiency of space heating systems - Building Integrated cogeneration heat and power systems*
ΕΛΟΤ EN 15316.04.06 (2008)	*Energy need and efficiency of space heating systems - Photovoltaic installations*
ΕΛΟΤ EN 15316.04.07	*Energy needs and efficiency of space heating systems -*

(2010)	***Biomass burning Heat Producing systems***
ΕΛΟΤ EN 15243 (2008)	***Ventilation and Air conditioning of systems. Cooling load calculation and internal temperature set point estimation***
ΕΛΟΤ EN 15316.03.01 (2008)	***Domestic Hot Water Preparation Systems. Water needs***
ΕΛΟΤ EN 15316.03.02 (2008)	***Domestic Hot Water Preparation Systems - Distribution Systems***
ΕΛΟΤ EN 15316.03.03 (2008)	***Domestic Hot Water Preparation Systems - Production Systems***

Here it should be mentioned that these standards have value not only for energy audits in hospitals but more generally for the conduction of energy audits on non residential buildings (among them hospitals as well). This takes place because Greek legislation (Law **ν. 3661/2008** and K.E.ν.A.K.) considers hospitals in a more general legislative framework as non residential, tertiary buildings.

The energy rating of hospitals regarding the primary energy consumption is presented in the following table***:***

Table 3: Energy rating of hospitals regarding the primary energy consumption (Law ***ν. 3661/2008***)

Rating	***Rating Limits***	***Rating limits***
Α+	$EP \leq 0{,}33R_R$	$T \leq 0{,}33$
Α	$0{,}33R_R < EP \leq 0{,}50R_R$	$0{,}33 < T \leq 0{,}50$
Β+	$0{,}50R_R < EP \leq 0{,}75R_R$	$0{,}50 < T \leq 0{,}75$
Β	$0{,}75R_R < EP \leq 1{,}00R_R$	$0{,}75 < T \leq 1{,}00$
Γ	$1{,}00R_R < EP \leq 1{,}41R_R$	$1{,}00 < T \leq 1{,}41$
Δ	$1{,}41R_R < EP \leq 1{,}82R_R$	$1{,}41 < T \leq 1{,}82$
Ε	$1{,}82R_R < EP \leq 2{,}27R_R$	$1{,}82 < T \leq 2{,}27$
Ζ	$2{,}27R_R < EP \leq 2{,}73R_R$	$2{,}27 < T \leq 2{,}73$
Η	$2{,}73R_R < EP$	$2{,}73 < T$

where, EP is equal to the primary energy consumption of the assessed building, R_R is equal to the primary energy consumption of the reference building and T is the ratio of the primary energy consumption of the assessed building to the primary energy consumption of the reference building. consumption (Law ***v. 3661/2008)***

In the next table the maximum acceptable thermal transmittance U-value for different building elements and climatic zones is provided.

Table 4: Maximum thermal transmittance factor (Law v. 3661/2008)

		Climatic Zone			
Building Element	***U Value symbol***	***A (W/m²K)***	***B (W/m²K)***	***C (W/m²K)***	***D (W/m²K)***
Roof adjacent to external air	U_D	***0,50***	***0,45***	***0,40***	***0,35***
Vertical Walls adjacent to external air	U_W	***0,60***	***0,50***	***0,45***	***0,40***
Floor adjacent to external air (pilotis)	U_{DL}	***0,50***	***0,45***	***0,40***	***0,35***
Floor in contact with the ground	U_G	***1,20***	***0,90***	***0,75***	***0,70***
Vertical walls in contact with unconditioned space or ground	U_{WE}	***1,50***	***1***	***0,8***	***0,7***
Opening (windows- doors etc)	U_F	***3,2***	***3***	***2,80***	***2,60***
Glazed Facades of buildings	UG_F	***2,2***	***2***	***1,8***	***1,8***

In the next table the maximum mean thermal transmittance factor of a non residential building, always regarding the surface to volume ratio and the climatic zone is given.

Table 5: Maximum mean thermal transmittance factor of a non residential building, regarding the surface to volume ratio and the climatic zone (Law v. 3661/2008)

External Surface to volume ratio (m^{-1})	***Maximum mean U value (W/m^2K)***			
	Climatic Zone			
	A	***B***	***C***	***D***
Less than 0,2	***1,26***	***1,14***	***1,05***	***0,96***
0,3	***1,20***	***1,09***	***1***	***0,92***
0,4	***1,15***	***1,03***	***0,95***	***0,87***
0,5	***1,09***	***0,98***	***0,90***	***0,83***
0,6	***1,03***	***0,93***	***0,86***	***0,78***
0,7	***0,98***	***0,88***	***0,81***	***0,73***
0,8	***0,92***	***0,83***	***0,76***	***0,69***
0,9	***0,86***	***0,78***	***0,71***	***0,64***
Greater than 1	***0,81***	***0,73***	***0,66***	***0,60***

Some additional specifications about the building elements of hospitals (in the general framework of non residential buildings) is provided in the following paragraphs.

- A medical unit or tertiary building must successfully implement within its facilities at least one passive solar heating method, such as south facing orientation, thrombe wall, dethatched passive solar heated sunspace etc. in order to qualify for certification according to the criteria of Law v. 3661/2008. ***(Law v. 3661/2008)***
- Heat Distribution systems must be adequately insulated , complying with TOTEE standards. For external piping, insulation must be at least 19mm thick and have a maximum thermal conductivity equal to 0,040 W/mK. ***(Law v. 3661/2008)***
- Cooling Distribution systems must be adequately insulated , complying with TOTEE standards. For external piping, insulation must be at least 40mm thick

and have a maximum thermal conductivity equal to 0,040 W/mK. For internal piping, insulation must be at least 30mm thick ***(Law v. 3661/2008)***

- Domestic Hot water must be covered at least to a percentage of 15% by a solar thermal collector as a heat source ***(Law v. 3661/2008)***
- Lighting systems must have a minimum energy efficiency of 55 lumen/W ***(Law v. 3661/2008)***
- The absorption coefficient must be equal to 0,40 for walls and 0,60 for inclined roofs ***(Law v. 3661/2008)***
- External surfaces must have at least a shading factor of 0,70 for south facing orientation and 0,75 for east and west orientation. This can be achieved with the implementation of external shading devices and selective shading and light filtering constructions according to TOTEE standards. ***(Law v. 3661/2008)***
- Solar transmittance coefficient of transparent glazed elements must be at least equal to 0,76 ***(Law v. 3661/2008)***
- Shading factor for transparent vertical elements must be at least equal to 0,90***(Law v. 3661/2008)***
- Air infiltration through openings cracks must be equal to 5,5 $m^3/h/m^2$ of surface ***(Law v. 3661/2008)***
- *Building's Thermal mass must be at least equal to* 250 $kJ/(K.m^2)$ ***(Law v. 3661/2008)***
- The audited building must have a central heating system (oil fired or natural gas fired boiler) or a heat pump with COP equal to 3,2. Additionally thermostats must be installed. ***(Law v. 3661/2008)***
- The space cooling system must have a performance indicator EER at least equal to 3***(Law v. 3661/2008)***
- Cooling system is considered to cover an area equal to 50 % of the building's useful area. ***(Law v. 3661/2008)***
- For the distribution system of cooling systems the fans' power must be equal to at least 1,5kW/(m^3/s) ***(Law v. 3661/2008)***
- Heating ventilation air conditioning system with heat recovery equal to 50% (minimum value) must be utilized. ***(Law v. 3661/2008)***
- Natural day lighting must be utilized in order for energy conservation from lighting equal to 50% to be achieved***(Law v. 3661/2008)***

- Buildings and hospitals with total useful area greater than 3500 m^2 must have a building energy management system which will be able to automatically control the building's energy needs for heating cooling and domestic hot water and lighting in order to achieve energy conservation at least equal to 10%.***(Law v. 3661/2008)***
- Energy inspections for boilers must take place on a regular basis. This would be : Every five years for boilers with nominal power equal to 20-100 kW and liquid or solid fuel. Every 2 years for boilers with liquid or solid fuel and nominal power >100 kW. Every 4 years for boilers with gaseous fuels and nominal power greater than 100 kW. One energy inspection for boilers with nominal power smaller than 20kW and lifetime higher than 15 years. ***(Law v. 3661/2008)***
- The building must be separated into different thermal zones during the conduction of an energy audit if and only if: There are set point temperatures in mechanically heated or cooled spaces, with differences greater than 4 ^oC within the building. Different ventilation systems are used for different areas of the same buildings. There are areas within the same building that have significant differences of internal or solar heat gains. Air ventilation system covers less than 80% of the total useful building area. Doors between spaces of the building are frequently closed. ***(Law v. 3661/2008***

More specifically hospitals' standards are configured in the Greek State's legislation by the above mentioned TOTEE guidelines.

- According to TOTEE 20701−1/2010 a medical unit is considered to operate in a continuous operational schedule. In other words it is considered to operate 24 hours per day, 7 days per week and 12 months per year. (TOTEE 20701−1/2010)
- The thermal comfort and relative humidity standards for a medical unit are given in the following table:

Table 6: Internal Space Thermal comfort and relative humidity for medical units (TOTEE 20701−1/2010)

Thermal Zone or Room	***Temperature(C)***		***Relative humidity(%)***	
	Heating Period	***Cooling Period***	***Heating Period***	***Cooling Period***

General	***22***	***26***	***35***	***50***
Patient room	***22***	***25***	***35***	***50***
Surgery	***18***	***20***	***35***	***55***
External Medical Facilities	***20***	***26***	***35***	***50***
Waiting Rooms	***20***	***26***	***35***	***50***
Rural Medical Unit	***22***	***26***	***35***	***50***
Psychiatric Medical Facility	***22***	***26***	***40***	***45***

- The fresh air requirements for internal space of medical units are given in the following table**:**

Table 7: Fresh Air standards for medical units (TOTEE 20701−1/2010)

Thermal Zone or Room	***Persons / m^2***	***Fresh air $m^3/m^2/person$***	***Fresh air $m^3/h/m^2$***
General	***30***	***35***	***10,5***
Patient room	***22***	***25***	***5,5***
Surgery	***20***	***150***	***30***
External Medical Facilities	***10***	***50***	***5***
Waiting Rooms	***55***	***45***	***24,75***
Rural Medical Unit	***15***	***50***	***7,5***

Psychiatric Medical Facility	***15***	***25***	***3,75***

- The lighting standards for medical units are presented in the following table:

Table 8: Lighting standards for medical units(TOTEE 20701−1/2010)

Thermal Zone or Room	***Lighting lx***	***Power for reference building w/m^2***	***Measurement Reference Level m***
General	***300***	***9,6***	***0,8***
Patient room	***100***	***3,2***	***0,8***
Surgery	***1000***	***32***	***0,8***
External Medical Facilities	***500***	***16***	***0,8***
Waiting Rooms	***300***	***9,6***	***0,8***
Rural Medical Unit	***500***	***16***	***0,8***
Psychiatric Medical Facility	***300***	***9,6***	***0,8***

- The Domestic Hot Water standards are presented in the following table:

Table 9: Domestic Hot water Standards: (TOTEE 20701−1/2010)

Thermal Zone or Room	***L/person/day***	***$L/m^2/day$***	***L/bed/year***	***$m^3/m^2/year$***
Hospital for more than 500 persons	***80***	***-***	***29,2***	***-***

Hospital for less than 500 persons	***120***	***-***	***43.9***	***-***
Clinic	***60***	***-***	***22***	***-***
Rural Medical Unit	***5***	***0,75***	***-***	***0,2***
Psychiatric Medical Facility	***50***	***-***	***18,25***	***-***

- The internal heat gains due to occupants for medical units are calculated according to the following table:

Table 10: Internal heat gains due to occupants for medical units (TOTEE 20701−1/2010)

Thermal Zone or Room	***Thermal Power per person W***	***Thermal power per surface unit W/m²***	***Mean Presence factor***
General	***90***	***27***	***1***
Patient room	***70***	***15***	***0,75***
Surgery	***90***	***0***	***0,24***
External Medical Facilities	***90***	***9***	***0.24***
Waiting Rooms	***80***	***44***	***0,24***
Rural Medical Unit	***90***	***14***	***0,36***
Psychiatric Medical Facility	***80***	***12***	***1***

- In the following table the internal heat gains due to medical and general use equipment and appliances are standardized:

Table 11: Internal heat gains due to equipment and appliances standardization (TOTEE 20701−1/2010)

Thermal Zone or Room	***Equipment Power W***	***Mean Lag Factor***	***Lag Power of equipment***	***Mean operation factor***
General	***15***	***0,5***	***7,5***	***1***
Patient room	***8***	***0,5***	***4***	***0,75***
Surgery	***20***	***0,5***	***10***	***0,24***
External Medical Facilities	***15***	***0,5***	***7,5***	***0,24***
Waiting Rooms	***0***	***0***	***0***	***0,24***
Rural Medical Unit	***15***	***0,5***	***7,5***	***0,36***
Psychiatric Medical Facility	***10***	***0,5***	***5***	***1***

- Medical units, as they are considered as tertiary sector buildings, have a standardized operation factor for their auxiliary heating and cooling systems. This would be 80% for zones A and B and 100% for zones C and D for heating period and 80% for zones A and B and 50% for zones C and D for cooling period. ***(TOTEE 20701−1/2010)***
- Indoor air quality in a medical unit (and non residential buildings generally) must mandatorily be achieved with mechanical ventilation in order to maintain the increased air quality standards of indoor spaces. ***(TOTEE 20701−1/2010)***
- Auxiliary systems for heating domestic hot water are operating with a standardized operation factor, which would be equal to 10% for zones A and B and 15% for zones C and D between October and April and 7% for zones A

and B and 10 % for zones C and D between May and September for systems without recirculation. For systems with recirculation the operation factor would be equal to 12% for zones A and B and 17% for zones C and D between October and April and 8% for zones A and B and 12 % for zones C and D between May and September. ***(TOTEE 20701−1/2010)***

- In the next table the standardization of the operation schedule of a medical unit with respect to the availability of natural or artificial lighting is presented:

Table 12: Standardization of the operation schedule of a medical unit with respect to the availability of natural or artificial lighting(TOTEE 20701−1/2010)

Thermal Zone or Room	***Day operation h***	***Night operation h***	***Total Operation h***
General	***3276***	***4295***	***7571***
Patient room	***2912***	***3276***	***6188***
Surgery	***0***	***2080***	***2080***
External Medical Facilities	***1560***	***520***	***2080***
Waiting Rooms	***1560***	***520***	***2080***
Rural Medical Unit	***2340***	***780***	***3120***
Psychiatric Medical Facility	***3276***	***4295***	***7571***

- When a building energy management system is used, a correction factor must be used in order to correct the overall use of energy and electricity for space heating and cooling (the energy consumption may be increased or decreased). For overall energy use the correction factor for medical units is equal to 0,86 for climatic zone A, 0,91 for climatic zone B, 1 for climatic zone C and 1,31 for climatic zone D. For electricity the correction factor is equal to 0,96 for climatic zone A, 0,98 for climatic zone B, 1 for climatic zone C and 1,05 for climatic zone D***. (TOTEE 20701−1/2010)***

According to Greek state's guideline TOTEE 20701−5/2012 : "Cogeneration of Heating, Cooling and electricity in building installations" under 1192/ΦΕΚ 1413-2012, which is harmonized with the guideline of the European Union's guideline 2004/8/EC , the implementation of cogeneration of Heat and Power on the facilities of a hospital and more generally a tertiary building is significantly promoted. This takes place due to the fact that great amount (about 10%) of primary energy and CO_2 emissions can be conserved with the utilization of cogeneration. The term of cogeneration of heat and power refers to the production of thermal energy, which can be utilized for space heating, space cooling (with absorption or adsorption processes) and domestic hot water heating, and at the same time generation of power which can either be extracted to the grid or can be used on the facilities of the hospital for lighting and electric appliances. A basic characteristic of cogeneration is that heat and power are generated in one process. With the utilization of cogeneration of heat power and cooling effect (trigeneration) an increase in efficiency of the whole process over 40% is noticed, in comparison with the case that different devices are used for each purpose. ***(TOTEE 20701−5/2012)***

According to TOTEE 20701−5/2012, cogeneration of heat and power within the facilities of a hospital is the most efficient method for electricity production with the simultaneous production of heat. Great amount of greenhouse gases and more specifically CO_2 emissions are saved, and great amounts of primary energy resources are conserved. Additionally a cogeneration solution is economically attractive, especially in comparison with the production of heat and power within separate processes. It can be implemented more efficiently with the use of natural gas as feedstock. Moreover the implementation of cogeneration of heat and power promotes the security of supply and energy independency of decentralized medical units. Lower amount of fuel is used due to the reduced losses that occur at the transmission and distribution network, due to the onsite character of generation of electricity and heat. Finally the use of cogeneration of heat and power creates new opportunities for job creation and economic development within the nearby area of the medical facility. ***(TOTEE 20701−5/2012)***

The guideline TOTEE 20701−5/2012 sets the standards of for the cogeneration of heat and power installation and utilization in medical units and tertiary buildings. It sets the methodology for calculating the energy production and the capacity standards of the CHP units. The ideal cogeneration types which match each type of building are proposed and the operation modes are formulated: ***(TOTEE 20701−5/2012)***

The indicative by the legislation solutions for the implementation of heat and power solutions are the following:

- ***Otto Engines***: In these engines a gaseous fuel is utilized, while the power range is from 15 to 1300kW. The overall efficiency reaches a number of 85% and an average lifetime is about 10 years. ***(TOTEE 20701−5/2012)***
- ***Diesel engine with heat recovery system:*** The power range is from 100 to 20000kW. The efficiency is about 80% and the lifetime may reach 20 years.***(TOTEE 20701−5/2012)***
- ***Gas turbine with heat recovery at the exhaust area for steam generation:*** The generated power ranges from 100 to 30000kW , the overall efficiency is 80% and the lifetime 15-20 years. ***(TOTEE 20701−5/2012)***
- ***Micro turbine***: Ideal for low generated power, which ranges from 25-200kW. The overall efficiency reaches 80% and the lifetime may reach 15 years ***(TOTEE 20701−5/2012)***.
- ***Stirling Engine***: The generated power ranges from 3 to 100 kW and the efficiency is about 85%. The lifetime may reach several thousand hours but they need systematic maintenance. ***(TOTEE 20701−5/2012)***
- ***Fuel Cells:*** With this technology hydrogen is utilized as a fuel. The great advantages is the absolutely environmentally friendly operation, which complies with the high indoor air quality standards of a medical unit and the low produced noise. Great disadvantage is the high cost of the implementation of a fuel cell in a medical facility and the small lifetime (around five years). Only high temperature fuel cells are proposed by legislation for medical and tertiary buildings ***(TOTEE 20701−5/2012)***
- ***Abstraction Steam turbine:*** Ideal for wide ranges of power generation (500-100000) kW. The overall efficiency may reach 90% and the operational lifetime is equal to 30 years. ***(TOTEE 20701−5/2012)***

For medical units, legislation allows Otto engine, Diesel engine, Gas turbine and Steam turbine to be utilized as cogeneration engines. ***The allowed generated power ranges from 500 to 2000kW***. Trigeneration may be implemented on medical and tertiary units where the annual heat and power requirements are for more than 4500-5000 hours. Legislation promotes the implementation of cogeneration on tertiary buildings following the methodology of financial incentives' provision to medical units which utilize such a technology, and perennial agreements for the purchase of the generated power surplus (if any), on fixed favoring feed in tariffs. This way not only cogeneration is promoted, but also energy conservation within the medical unit's facilities. ***(TOTEE 20701−5/2012)***

3.2. Legislation and Standardization in European Union

European Commission sets the standards about energy performance of buildings with the Directive 2002/91/EC, regarding the energy performance of the buildings, widely known as Energy Performance of Buildings Directive (acronym EPBD). The spirit of the Directive is the implementation of a general legislative framework within the EU member States, according to which the energy performance of the buildings will be evaluated. The long term scope is the reduction of final and primary energy consumption within building facilities, the CO_2 emissions reduction from the operation of the buildings and the reduction of the negative impact of buildings on the environment. In the current legislation hospitals are considered as tertiary buildings. For this reason the general framework for the evaluation of energy performance for non residential tertiary buildings, is applied on hospitals and medical units. (***Directive 2002/91/EC)***

The basic purpose of the directive 2002/91/EC is the creation of a methodology for the certification of the buildings regarding their energy performance. If the building complies with the requirements of the directive, a certification will be issued for its energy class, which will be accompanied by proposals for the improvement of the energy performance of the building (reduction of final and primary energy and CO_2 emissions). A certificate will be valid for 10 years. In order to improve the energy performance of the building energy saving measures will be implemented if and only if they are financially and technically feasible. The Directive standardizes the minimum requirements for the energy performance of each type of building, among them, hospitals as well. Apart from the thermal characteristics and the envelope of the building, regular inspection on the heating and air conditioning systems shall take place. Boilers with a power range between 20 and 100 kW must be inspected on a regular basis. This takes place only for boilers which are non RES fuel fired. The spirit of the Directive is that hospitals, as public buildings must show the good example for the energy performance of every building. (***Directive 2002/91/EC)***

Directive 2002/91/EC proposes the implementation of energy saving measures for hospitals and tertiary buildings which have as a scope the reduction of the primary energy that is consumed and the CO_2 emissions. If such measures have already been utilized then they must be positively assessed. Such measures would be:

- High quality insulation of the building elements.
- High quality openings (transparent elements with reduced infiltration and radiative heat losses)
- Passive and active solar heating and cooling systems which utilize renewable energy sources (this type of heating and cooling systems have primary to final energy consumption factor equal to zero and almost zero CO_2 emissions)
- The implementation of cogeneration of heat and electricity within the facilities of a medical unit
- District heating systems
- Utilization of day lighting and reduction of use of artificial lighting. (***Directive 2002/91/EC)***

The general methodology for the energy certification of a building according to the European legislation is the following:

First of all the location and orientation and the thermal characteristics of the building are defined and assessed. The thermal conductivity, thermal transmittance and thermal resistance of each building element are examined and assessed. The infiltration and the solar absorbance and transmittance of transparent building elements is evaluated. The heat losses are calculated with respect to the outdoor conditions and the internal temperature set point and designed indoor climate, which is set by each country's legislation. The building energy needs for heating and for cooling, for domestic hot water preparation, for ventilation and for lighting are found for hospitals (which are considered non residential tertiary buildings). Then the efficiency of heating, cooling, ventilation, lighting provision and domestic hot water systems is calculated. The final energy consumption for each purpose and for each carrier is recorded. According to the type of fuel that is used for each purpose the primary energy consumption and the CO_2 emissions are calculated. An assessment of the energy performance of the building is done regarding all of the above information and a certification regarding the energy performance of the building is made. Promotion for the utilization of passive solar heating and cooling through favoring energy rating takes place. (***Directive 2002/91/EC)***

More specifically the energy assessment and certification of buildings is held by following a set of standards which have been issued by the European Committee for standardization. Directive 2002/91/EC operates in cooperation with these standards. Each country member state though, has different climate, different building types and different energy needs and sources. For this reason European Commission offers to the Member States the opportunity to adjust to these standards their local and national legislation in order to achieve the best possible result regarding the peculiarities of the climate and needs of each country. For this reason the best possible presentation of Directive 2002/91/EC is done on an applied way , when examined in cooperation with the national legislation of each Member State of the European Union. This has been done on the previous paragraph with the presentation of Greek State's law ***v. 3661/2008*** and ***K.E.v.A.K.*** . For this reason a reference for the European standards for buildings' and among them medical units' energy performance will take place, but an analytical presentation will not, as this has been done in the previous paragraph with Greek State's law ***v. 3661/2008*** and ***K.E.v.A.K.*** presentation. (***Directive 2002/91/EC)***

The most important European standards for the certification of energy performance of medical units and buildings are presented in the following table:

Table 13: European standards for the certification of energy performance of medical units and buildings(Anastaselos, 2012), (***Directive 2002/91/EC)***

Standard Name	***Description***
EN ISO 13790	***Energy requirements for space heating and cooling***
EN 15603	***Energy consumption for space heating, space cooling, DHW, Ventilation and lighting and expression of energy performance rating***
EN 15217	***Energy performance expression and certification and form of the energy performance certificate***
EN 15378	***Boiler Inspections***

EN 15240	*Air Conditioning Inspections*
EN 15429	*Economic evaluation of building energy systems*
EN 15316-1	*Space Heating - Efficiency and energy needs calculation*
EN 15316-2-1	*Space Heating - Efficiency and energy needs calculation - Emission System*
EN 15316-2-3	*Space Heating - Efficiency and energy needs calculation - Distribution System*
EN 15316-3	*Domestic hot water - Efficiency and energy needs calculation*
EN15243	*Indoor temperatures' calculation and indoor heating and cooling load calculation methodology*
EN15377	*Water based surface heating and cooling systems*
EN 15241	*Calculation of energy losses due to ventilation and infiltration*
EN 15232	*Energy efficiency improvements due to the implementation of Building integrated automation systems.*
EN 15193	*Energy Needs for lighting*
EN 15255	*Room Cooling load calculation*
EN 15265	*Heating and cooling energy consumption calculation*
EN ISO 13789	*Thermal Performance of buildings - Calculation methodology of transmission and heat transfer coefficients*
EN ISO 13786	*Thermal Performance of buildings - Dynamic Thermal Characteristics*
EN ISO 6946	*Thermal resistance and thermal transmittance of building elements calculation*
EN ISO 13370	*Thermal Performance of the buildings - Heat transfer through the ground*
EN ISO 10077-1	*Thermal Performance of windows doors and shutter s-Calculation of thermal transmittance*
EN ISO 1077-2/2003	*Thermal Performance of windows doors and shutters-Calculation of thermal transmittance - Numerical Methods for frames*
EN ISO 10211	*Thermal Bridges in building construction-Heat flows and surface temperatures calculation*
EN ISO 14683	*Thermal Bridges in building construction - Linear thermal*

	transmittance
EN 13465:2004	***Ventilation for buildings - calculation of airflow rates and infiltration***
EN 13779	***Ventilation for non residential buildings - Performance requirements for ventilation and air conditioning systems***
EN ISO 13791:2004	***Thermal performance of buildings - calculation of internal temperatures of a room in summer without mechanical cooling***
EN 13363-1:2003	***Solar protection devices and glazing calculation of solar and light transmittance***
CR 1752:1999	***Design criteria and the indoor environment***
EN 15251	***Indoor environment, thermal comfort, indoor air quality optical comfort(light) acoustic comfort(noise)***
EN ISO 15927-6	***Hygrothermal performance of buildings - Calculation and presentation of climatic data - Degree days method***
EN ISO 15927-1:2003	***Hygrothermal performance of buildings - Calculation and presentation of climatic data - Monthly and annual means of meteorological elements***
EN ISO 15927-2	***Hygrothermal performance of buildings - Calculation and presentation of climatic data - Hourly data for design cooling load***
EN ISO 15927-3	***Hygrothermal performance of buildings - Calculation and presentation of climatic data - Calculation of a driving rain index for vertical surfaces from hourly wind and rain data***
EN ISO 15927-4:2005	***Hygrothermal performance of buildings- Calculation and presentation of climatic data - Annual energy for heating and cooling assessment with hourly data***
EN ISO 15927-5:2005	***Hygrothermal performance of buildings - Calculation and presentation of climatic data - Design heat load for space heating***
EN ISO 9288:1996	***Thermal insulation and heat transfer by radiation***
EN ISO 7345:1996	***Thermal insulation***

EN 12599:2000	***Ventilation - Test and measurement methods for installed ventilation and air conditioning systems***
EN 13829:2001	***Thermal Performance of buildings - Fan pressurization method for permeability assessment of buildings***
EN ISO 12569: 2001	***Thermal Performance of buildings - tracer gas dilution method***
EN 13187:1999	***Thermal performance of buildings- thermal inconsistencies on buildings envelope and their infrared quality assessment***
EN 15239	***Methodology for the inspection of ventilation systems***

Special attention should be paid to Directive 2004/8/EC for the promotion of cogeneration in buildings. The main scope of this Directive is the promotion of cogeneration of heat and power within the facilities of medical units and other non residential buildings. This way, a significant increase in efficiency of heat and power generating devices and processes may be noticed, and great amounts of final, primary energy and CO_2 emissions can be conserved. The Directive sets the standards for cogeneration devices that can be utilized in hospitals and other tertiary buildings, and the methodology for the calculation of the generated heat and power and the achieved efficiency. This Directive again cannot be followed solely, but the local legislation of every State Member must be harmonized with it. For example in Greece, cogeneration of heat and power in tertiary buildings is standardized with the Greek State's guideline TOTEE 20701−5/2012, which is harmonized with the European Directive 2004/8/EC. The details of the Directive are explained in an applied way in the Greek state energy legislation about hospitals section. Directive 2004/8/EC establishes the implementation of a guarantee of origin for every kWh of produced heat and power from cogeneration, which will be able to prove that this amount of energy has been produced within the facilities of a tertiary building with high efficiency cogeneration processes, saving a certain amount of primary energy and CO_2 emissions. Annual targets for the potential amounts of heat and power that can be generated from cogeneration are set for every type of building and every country. Finally measures for the promotion of cogeneration of heat and power in tertiary buildings are implemented, such as the introduction of the feed in tariff for the surplus amount of energy that can be extracted to the grid. This is achieved in harmonization with European Union's Directives 2001/77/EC and 2003/54/EC***. (Directive 2004/8/EC)***

Directive 2002/91/EC "Energy Performance of Buildings" has been amended by the Directive 2010/31/EC. This directive implements the zero energy buildings concept. According to this, a zero energy building is a high energy performance building which is able to produce the same amount of energy that it consumes on an annual basis, with the onsite generation of energy based on renewable energy sources such as solar, solar thermal and wind energy. The target that is set is that by the end of 2018 every new public building, such as public hospitals, must be nearly zero energy building, and by the end of 2020 every new building must be nearly zero energy building. The Directive offers to Member States the opportunity to create their national plans in order to achieve these targets. Finally the Directive implements the obligation of every State Member to introduce financial incentives for the development of low and zero energy buildings, which will be flexible and dependent on each State's financial and climatic conditions and on its buildings' form and condition.***(Directive 2010/31/EC)***

Directive 2005/32/EC "Framework for the implementation of Eco design" sets the standards of energy efficiency and environmental impact of every product that uses energy during all the stages of its lifecycle. Its purpose is not only the energy conservation and reduction of CO_2 emissions, but the reduction of the environmental impact during the whole lifecycle of every energy consuming product (including medical equipment). Again this directive sets a general framework which has to be harmonized with the national legislation of each Member State***.(Directive 2005/32/EC)***

Directive 2006/32/EC promotes the improvement of end use efficiency in products and services of public sector (including public hospitals) by proposing optional annual and medium term targets for energy efficiency improvement. ***(Directive 2006/32/EC)***

Directive 2003/96/EC " Taxation of energy products" sets the standards for the taxation of energy consuming products within the Member States of European Unions, promoting the use of RES within services (including hospitals) by reduction and exemptions in taxation. The direct impact on medical facilities and tertiary buildings is the fact that hospitals' management have to pay more for the energy that they consume, except for the case that they use RES. For this reason with this directive extra financial incentives are offered to medical units in order for them to utilize solutions, such as renewable energy sources and cogeneration of heat and power, due to their favoring taxation. ***(Directive 2003/96/EC)***

The main disadvantage of both European and Greek legislation, regarding energy performance of buildings, at least for the time being, is the fact that that their provisions affect only public buildings. Under these circumstances private hospitals and medical units have the ability not to comply with the European legislation. This way the overall potential for final and primary energy conservation and CO_2 emissions' reduction within hospitals is significantly constrained.

3.3. Energy Performance of healthcare facilities legislation and standardization in U.S.- ASHRAE-HEA-Energy Star-AIE-ASHE

Energy legislation for medical units in U.S. is configured by the standards of ASHRAE, ASHE , Hospital Energy Alliance, Energy Star Certification's Standards and other relevant provisions of the U.S. Department of Energy.

ASHRAE is the acronym that stands for American Society for Heating, Refrigeration and Air conditioning Engineers and it was founded in 1894. It sets the standards for buildings’ HVAC, in order to achieve energy conservation, reduction of CO_2 emissions due to buildings’ operation and promote the sustainability in buildings’ construction and operation. Thousands of ASHRAE standards are applied in buildings around the world, among them in hospitals and medical units as well. ***(www.ashrae.org)***

ASHRAE standardizes the construction and operation of buildings with standards such 90.1-1999, which was amended by the standard 90.1-2004. These standards promote the energy efficiency within the facilities of a building by settings guidelines about the buildings elements' characteristics and selection. Furthermore they standardize the operation of HVAC in buildings. ***(www.ashrae.org)***

According to standard 90.1 minimum design requirements are set for the construction of building envelope and HVAC systems of residential and non residential buildings (among them hospitals). These requirements have as a purpose the promotion of energy conservation and CO_2 emissions' reduction within medical units' facilities.***(Standard 90.1,2004)***

More specifically minimum requirements are set for the following categories, regarding tertiary non residential buildings and medical units: ***(Standard, 90.1,2004)***

- ***Medical units' thermal comfort conditions.*** In the next table the internal spaces' thermal comfort conditions of medical units according to ASHRAE's standards are presented. ***(Standard 90.1,2004), (Standard 62.1,2010)***

  Table 14: ASHRAE's Internal space of medical units thermal comfort conditions(Standard 90.1,2004), (Standard 62.1,2010)

Type of space	*Temperature (^oC)*	*Relative Humidity (%)*	*Minimum total air changes per hour*
Patients' Rooms	*23-25*	*30-50 depending on orientation*	*6*
Newborn's facilities	*22-26*	*30-60*	*6*
Recovery room	*23-25*	*30-50 depending on orientation*	*6*
Surgery Room	*20-24*	*30-60*	*15*
Labor room	*23-25*	*30-50 depending on orientation*	*6*
Corridors	*-*	*-*	*4*

- ***Building envelope of non residential buildings and medical units.*** Maximum thermal transmittance and minimum thermal resistance values of building elements are set for opaque building elements. For transparent elements such as windows and doors, at least double glazed elements should be used. Minimum requirements or SHGH coefficient are set. Air infiltration is standardized and sunlight protection provisions' requirements are set. External doors which are on the 3_{rd} floor of a medical unit or above must be paired with a set of internal doors, in order to significantly constrain air infiltration. Maximum admissible values of moisture intrusion are set with standard ASTM 6272. Vertical external openings' area must be lower than the 50% of the overall vertical wall area, while skylight openings must be no more than 5% of the overall roof area. Opaque building elements' materials are standardized, with special attention to steel, wood, concrete, and brick. The orientation of the patients' rooms must be south facing in order to increase the solar heat gains in the winter and reduce them in the summer. ***(Standard 90.1,2004)***

Maximum U values of external walls' steel framed assembly of a medical unit complying with standard 90.1-2004 are presented in the following table:

Table 15: Maximum U values of external walls' steel framed assembly of a medical unit complying with standard 90.1-2004 (Bonnema et al, 2010)

Frame construction material	U value of Assembly ($W/m^{2o}C$)	Climatic zone
Steel	0,70	1, 2, 3, 4
Steel	0,476	5, 6
Steel	0,363	7, 8

In the next table maximum U values for medical units' roofs are presented:

Table 16: Maximum U values for medical units' roofs complying with standard 90.1-2004 (Bonnema et al, 2010)

U Factor ($W/m^{2o}C$)	Climatic zone
0,357	1, 2, 3, 4, 5, 6, 7
0,27	8

In the next table the maximum mean U value and solar heat gain coefficient for medical units' transparent elements complying with standard 90.1-2004 are presented:

Table 17: Maximum mean U value and solar heat gain coefficient for medical units' transparent elements complying with standard 90.1-2004(Bonnema et al, 2010)

Climatic Zone	*Solar heat gain coefficient*	*Visible light transmission coefficient*	*U Factor ($W/m^{2o}C$)*
1	***0,25***	***0,25***	***6,927***
2	***0,25***	***0,25***	***6,927***
3	***0,25***	***0,318***	***3,24***
4	***0,39***	***0,495***	***3,24***
5	***0,39***	***0,495***	***3,24***
6	***0,39***	***0,495***	***3,24***
7	***0,49***	***0,490***	***3,24***
8	***0,49***	***0,490***	***2,61***

- ***HVAC system and DHW Heating System.*** Requirements about space heating and space cooling systems are standardized. The ASHRAE compatible heating and cooling equipment is described with special attention to the peculiarities of boilers (natural gas and burners, heat pumps, heat rejection systems, desiccant wheels systems, absorption cycles, chillers and furnaces). A Building Energy Management system must be installed , with specially designed thermostats and thermostatic valves. This way heating and cooling systems are automatically turned on and off, according to the operational schedule of the hospital and the level of achievement of internal temperature set point. Heating systems may cover 100% of space heating and domestic hot water needs if and only if their energy requirement is lower than 43,961 kW and the set point temperature is lower than 18,28 ^{o}C. Additionally minimum requirements for the insulation of external and internal located distribution system (such as pipes) for both heating and cooling systems are provided . Indoor air quality and thermal comfort requirements are provided by AHSRAE's standard 62.1-2010 , which will be described later. Space heating provision's ASHRAE's requirements are the following: .***(Standard 90.1-2004)***

Table 18: ASHRAE's requirements for HVAC system.(Standard 90.1,2004)

Building's Useful Area (m^2)	Utilized HVAC system
<6968	Packaged rooftop constant volume HVAC system or heat pump with efficiency at least 80%
6968 - 13935	Packaged Rooftop Variable air volume HVAC system with heat recovery provision with efficiency at least 80%
>13935	Variable air volume HVAC system with reheat and chillers with efficiency at least 80%

In the next table, the domestic hot water flow rates of an ASHRAE compatible medical unit are presented:

Table 19: Domestic hot water flow rates of an ASHRAE compatible medical unit(Bonnema et al, 2010)

Facility Type	DHW flow rate (m^3/hour/person)
Examination Room	0,001434
Intensive Care	0,001434
Nurse Station	0,000719
Patient Room	0,069651
Physical Therapy	0,000719
Surgery	0,002869
Cafeteria	0,001434

In the next table DHW heating system's characteristics for ASHRAE compatible medical units are presented

Table 20: DHW heating system's characteristics for ASHRAE compatible medical units(Bonnema et al, 2010)

Characteristic	Value
Supply low temperature set point (^oC)	82,2
Outdoor low temperature (^oC)	-6,7
Supply high temperature set point	65,6

(°C)	
Outdoor high temperature (°C)	***10***
Heating system minimum efficiency	***0,8***
Distribution System minimum efficiency	***0,75***

In the next table ventilation needs for medical units' different spaces, according to ASHRAE standard 90.1-2004 and standard 62.1-2010 are presented.

Table 21: Ventilation needs for medical units' different spaces, according to ASHRAE standard 90.1-2004 and standard 62.1-2010 (Bonnema et al, 2010)

Type of facility	***Ventilation per person (L/s person)***	***Ventilation per area unit(L/sm^2)***	***Total Air changes***
Examination Room	***2,4***	***0,31***	***6***
Nurse Station	***2,4***	***0,31***	***0***
Patient Room	***-***	***-***	***6***
Physical Therapy Room	***9,4***	***0,31***	***6***
Surgery	***-***	***-***	***15***
Recovery Room	***-***	***-***	***6***
Cafeteria	***3,5***	***0,91***	***0***
Emergency Room	***-***	***-***	***15***
Radiology Room	***2,4***	***0,31***	***6***

- ***Equipment medical or general.(Standard 90.1,2004)***

  In the next table the electric peak plug loads for an ASHRAE compatible medical unit are presented:

Table 22: Electric peak plug loads for an ASHRAE compatible medical unit(Bonnema et al, 2010)

Facility Type	***Electric peak plug load (W/m²)***
Examination Room	***10,76***
Intensive Care	***10,76***
Nurse Station	***2,69***
Patient Room	***10,76***
Physical Therapy	***10,76***
Surgery	***10,76***
Recovery Room	***10,76***
Cafeteria	***1,076***
Emergency Room	***10,76***

- ***Onsite power generation with RES and cogeneration of heat and power in the medical unit's facilities.(Standard 90.1,2004)***
- ***The separation of the building into different zones.(Standard 90.1,2004)***
- ***The separation of U.S. territory into different climatic zones according to the external conditions***. For the maximum achieved efficiency in evaluating buildings' energy performance, United States of America are separated in 8 climatic zones, depending on the climatic, temperature and relative humidity and outdoor conditions. These climatic zones are presented in the following figure .***(Standard 90.1,2004)***

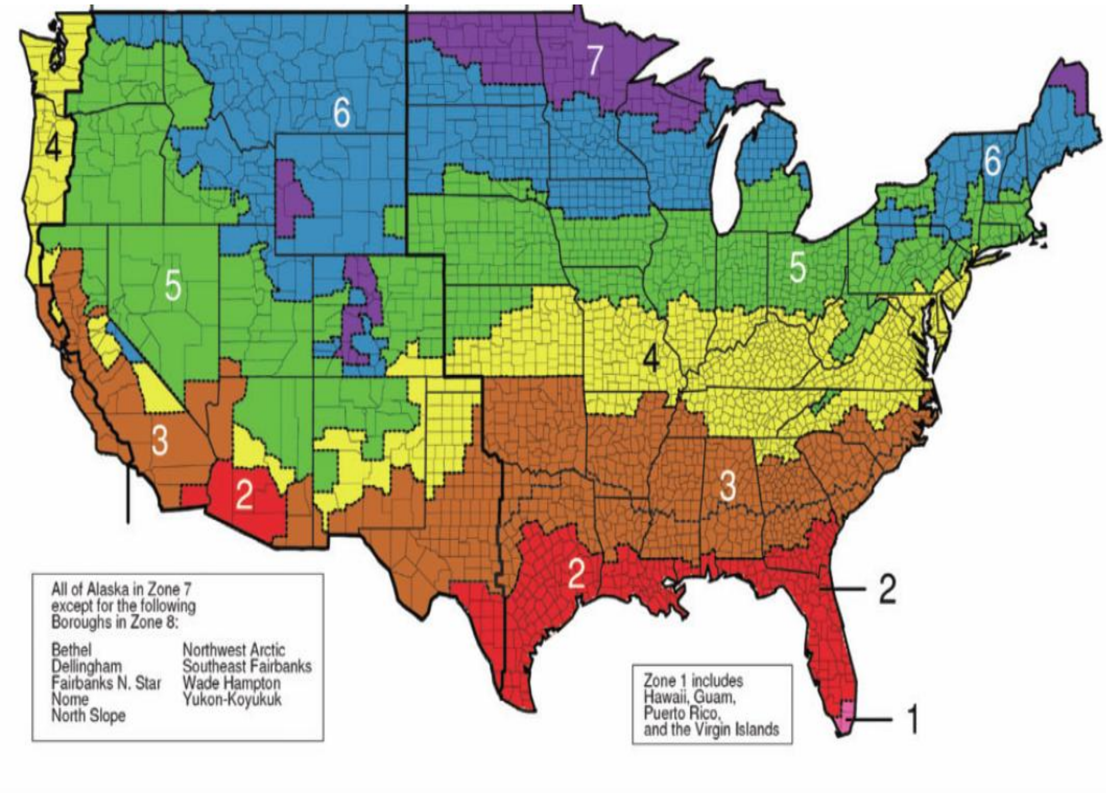

Figure 1: Separation of U.S. into climatic zones (Standard 90.1,2004)

- ***Conduction of Energy audit and certification.*** The procedures for the conduction of energy audit and certification of the building's energy performance are standardized. This takes into consideration the building envelope and the efficiency and energy consumption of HVAC and domestic hot water systems and the lighting systems. The energy consumption is the direct criterion of certification, while the CO_2 emissions are the indirect. The buildings' certification takes place with cooperation with LEED's requirements. The certification takes place as: ***LEED certified building*** if the energy consumption is reduced to a percentage of 25-35% in comparison with standard 90.1-2001 requirements, ***Silver LEED certification*** where the energy conservation reaches levels of 35-50% of standards 90.1-2001 requirements, ***Gold LEED certification*** for energy conservation 50-60 % and ***Platinum LEED certification*** for energy conservation higher than 60%. To gold and platinum certified buildings financial incentives such as tax reductions up to 50% are provided. ***(Standard 90.1,2004)***
- ***Implementation of Energy Saving Measures on Medical units.*** These could be the implementation of cogeneration of heat and power, south facing

orientation and overhangs above windows, installation of more efficient insulation and more efficient openings, utilization of natural day lighting and natural ventilation, installation of solar collectors for domestic hot water preparation etc**. *(Standard 90.1,2004)***

- ***Lighting Systems.*** The minimum requirements for lighting systems are provided. Lighting systems must have an occupancy control system installed and a movement sensor. When no movement is sensed for 30 minutes, lighting system must be turned off. Moreover time scheduling devises must be installed in order to turn off lighting systems in the morning and utilize them for optical comfort during night. Additionally emergency lights must be installed. Categorization of lights according to the area they are installed in is made and special attention is paid to their energy consumption and energy efficiency. Until September 2011 lamps of D, E, F, G energy class must be used while until the end of 2016 they must be replaced by higher energy class lamps (at least C), like Halogen lamps. Lamps' efficiency must be at least 60 lumen/watt. The lighting power density specifications for medical units are presented in the following table: ***(Standard 90.1,2004)***

Table 23: ASHRAE's requirements for medical unit's lighting systems(Standard 90.1-2004)

Space	*Lighting Power Density (W/m^2)*
Examination/Treatment room	***16,1***
Recovery Room	***8,61***
Whole medical facility average	***12,92***
Parking	***1,61***
External Stairway	***10,76***
Overhangs	***13,45***
Building facade	***2,15***
Nurse Station	***10,76***
Cafeteria	***9,69***
Radiology Room	***4,3***
Emergency Room	***29,06***
Physical Therapy Room	***9,69***

With the implementation of standard 62.1-2010 ASHRAE standardized the requirements for acceptable indoor space's air quality for residential and non residential (among them hospitals) buildings. The standard sets requirements for subjects of crucial importance for indoor comfort such as***:(Standard 62.1,2010)***

- Acceptable indoor air quality levels for medical units***(Standard 62.1,2010)***
- Moisture and humidity maintenance in acceptable levels***(Standard 62.1,2010)***
- Minimum ventilation rates ***(Standard 62.1,2010)***
- Requirements about the filtration of outdoor air. ***(Standard 62.1,2010)***
- HVAC system's constructional details***(Standard 62.1,2010)***
- Disease spread and microbial infection prevention strategies ***(Standard 62.1,2010)***

Some provisions about the operation of HVAC system on non residential, tertiary building and hospitals are: ***(Standard 62.1,2010)***

- HVAC systems and especially ventilation systems must be constructed from non corrosive and non toxic materials. They must have a double wall external insulation in order to reduce heat losses. ***(Standard 62.1,2010)***
- Exhaust system should be placed in a proper way with respect to the medical facility, in order for the exhaust air not to return in the sensitive indoor medical space. ***(Standard 62.1,2010)***
- Requirements for size and specifications for duct systems are given. ***(Standard 62.1,2010)***
- Indoor air quality is specified according to the type of the space, and number of total and outside air changes per hour is calculated according to the type of the space and the quality of the outdoor air. This happens according to the following methodology: First of all the quality and quantity of indoor air requirements are specified. Moreover the quality of outdoor air is specified. Finally the proper filters for incoming air that are utilized and the number of total and outdoor air changes per hour are specified. ***(Standard 62.1,2010)***
- Ventilation system's rate's control strategies are implemented. These could be: Ventilation control by digitalized controlling devises, building energy and ventilation automated management system and manual control of the

incoming air flow by adjusting the useful diameter of the air duct. ***(Standard 62.1,2010)***

- Single zone spaces may be ventilated by constant volume ventilation systems, while multiple zone spaces must be ventilated by variable volume ventilation systems. ***(Standard 62.1,2010)***
- Indoor air quality may be maintained by recirculating the air and filtering it, while incoming outdoor air quality standards are achieved by directly filtering the outdoor incoming air. Efficiency of the filtering devices is measured with the implementation of MERV system. For medical units the MERV efficiency must be at least equal or greater then 6***(Standard 62.1,2010)***
- Indoor spaces' pressure requirements are specified and buildings' pressure control strategies are proposed, in order to maintain the indoor pressure to the desired levels in comparison with the outdoor space pressure. ***(Standard 62.1,2010)***
- Occupancy patterns of medical units and their correlation with HVAC requirements are described. ***(Standard 62.1,2010)***
- The relative humidity standards for medical units are set for each type of space. As a general rule the acceptable range of indoor space relative humidity is 30-60%. This happens because bellow 30% a lot of people have respiratory problems such as sore and dry throats and above 60% a variety of pathogenic microorganisms may develop**. *(Standard 62.1,2010)***
- The indoor air quality requirements concerning some specific substances' and materials' concentration are standardized. Special attention is paid to indoor air's concentration in CO_2, volatile organic compounds and particulate matter**.** ***(Standard 62.1,2010)***
- Finally the requirements for cleaning and maintenance of HVAC systems in order to maintain the healthy indoor conditions and energy efficient operation are provided. The majority of devices undergo maintenance according to their manuals. For some devices though, such as cooling towers, ASHRAE proposes additional regular maintenance measures.***(Standard 62.1,2010)***

Additionally in regular basis, ASHRAE publishes guidelines about buildings' operation. For hospitals and medical units, of great importance is the issuance of guidelines for the design and construction of hospitals and healthcare facilities, which were published by ASHRAE and AIA in 2006, providing standards for the efficient operation of heating ventilation and air conditioning systems in hospitals. Finally in 2010 "Advanced Energy Design Guide for Small Hospitals and Healthcare Facilities" was published by the cooperation of ASHRAE, American Institute of Architects, U.S. Green Building Council and U.S. Department of Energy. Its scope is the provision of guidelines for not only energy conservation in hospitals, but also the reduction of negative environmental impact of medical units. ***(www.ashrae.org)***

Guidelines for design and construction of hospitals and healthcare facilities were issued by ASHRAE in cooperation with AIA (American Institute of Architects) in 2006 and set the standards for the operational conditions of Medical units within 42 States in U.S.. They are issued on a regular basis of 5 years, proposing new state of the art measures for the energy efficient operation of medical units, the prevention of disease and infection spread and promotion of safety provision in medical units . Apart from the general framework about the internal temperatures and indoor air quality, the requirements for ventilation and lighting needs are made available for hospitals' interior spaces. Original standard's 90.1-1999 requirements remain the same, with the addition of new standards in order for the legislative framework to be more complete. Special attention is paid to the categorization of a medical unit's internal spaces into: Biochemistry and Serology Laboratories, Laser Eye Room, X-Ray room and surgery room, Gastrointestinal Endoscopy Room, Endoscopic Instrument Processing Room and waiting room . Additionally to hospitals, guidelines for the design and operation of intermediate Care centers are provided. For each room separately, the indoor space design temperature is specified, the lighting and ventilation needs are provided, the cooling and heating loads are standardized and the energy consumption of medical equipment per m^2 of medical unit area is designed. ***(AIA,2006), (ASHRAE,2006)***

For general medical spaces the ideal internal space thermal comfort is achieved when the relative humidity is in the range between 30% and 60%, and the internal temperature is between 20-23 ^{o}C. Infection Control Risk Assessment (ICRA) has been implemented in order to reduce the risk for disease spreading and avoid patients' contact with hazardous exhausts of HVAC systems. It standardizes the operation of HVAC systems in order not only to achieve energy conservation and increase in energy efficiency, but also maintain the high quality health standards inside hospitals. This provision is more complete with the implementation of MERV ratings

(ANSI/ASHRAE Standard 52.2-1999, "Method of Testing General Ventilation Air Cleaning Devices for Removal by Particle Size") and Standard 52.1-1992, "Gravimetric and Dust-Spot Procedures for Testing Air-Cleaning Devices Used in General Ventilation for Removing Particulate Matter". (AIA,2006) (ASHRAE,2006)

Of great importance is the implementation of heating systems' operating standards. More specifically the boilers must be adjusted to the desired thermal comfort of the conditioned spaces and must be able to cover the energy needs for space heating, hot water preparation, preparation of steam for sterilizing and water heating needs for food preparation. ***(AIA, 2006), (ASHRAE,2006)***

Special attention is paid to the ventilation and indoor air quality requirements within the internal spaces of the medical units. The indoor air quality needs of the most important spaces of a medical unit according to ASHRAE are presented in the following table:

Table 24: AIA and ASHRAE indoor air quality needs for medical units(Addition to standard 90.1-2004)(AIA, 2006), (ASHRAE,2006)

Room	***Minimum Air changes of outdoor air per hour***	***Minimum Total Air changes per hour***
Intermediate Care	***2***	***6***
Gastrointestinal Endoscopy Room	***2***	***6***
Endoscopic Instrument Processing room	***-***	***10***
Laser Eye room	***3***	***15***
X- Ray- Surgical Room	***3***	***15***
Biochemistry Lab	***-***	***6***
Serology Lab	***-***	***6***

The indoor space relative humidly for a medical unit correlated with internal space temperature is presented in the following graph.

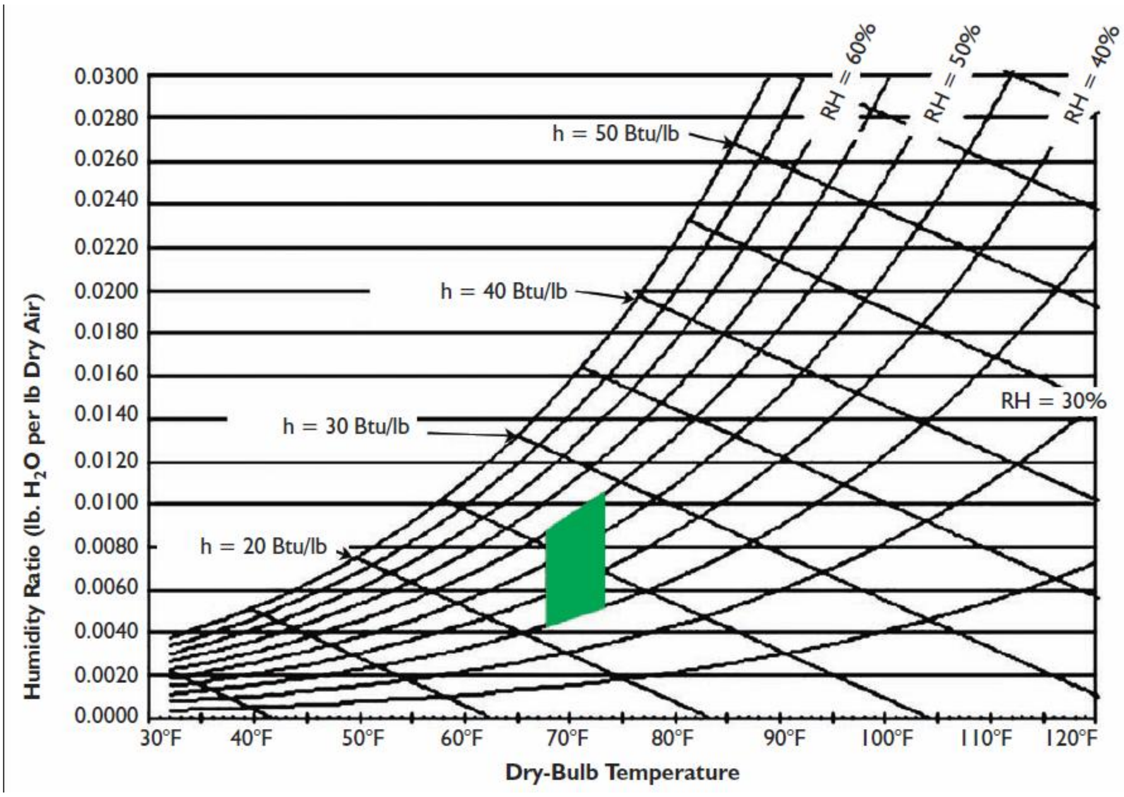

Figure 2: Correlation between relative humidity and internal space temperatures for medical units and thermal comfort area (AIA,2006), (ASHRAE,2006)

Finally a distinction between heating and cooling loads, internal spaces' comfort and health requirements in new and renovated medical units is made. Furthermore the methodology, according to which the non renovated parts of a medical unit operate during the renovation of other parts of the same medical unit and how a gradual renovation of a medical unit shall proceed is provided***. (AIA,200), (ASHRAE,2006)***

Advanced Energy design guide for small hospitals and healthcare facilities is a co operational effort from ASHRAE, American Institute of Architects, U.S. Green Building Council and U.S. Department of Energy. It has as a scope to offer the ability to small size medical units to reduce their energy consumption by a percentage of 30% in comparison with the provisions of the standard 90.1-1999 which has been issued by ASHRAE. ***(AEDG-SHC,2010)***

The guidelines are applied to the medical unit, following a 4 step adaptation program. Pre-design, design, construction and operation. During the pre-design and construction steps the location of the medical unit is selected and the climatic conditions according to the climatic zone are examined. During the design of the medical unit, the orientation of the building is selected in order to maximize solar heat gains in winter and reduce them during summer and increase natural day lighting .

High insulating quality building materials are selected and low infiltration and heat loses' transparent elements are selected. During the construction step, high efficiency, low energy consumption and compatible with energy star standard space heating and cooling, domestic hot water heating, lighting and ventilation systems are installed. ***(AEDG-SHC,2010)***

In order to demonstrate the proposals of the guideline, two prototype medical units had been utilized. Their specificities are presented in the following table.

Table 25: Characteristics of prototype medical units(AEDG-SHC,2010)

Medical Unit's characteristics	***Community Hospital***	***Surgery Center***
Size	***6039 m^2***	***3809 m^2***
Floor number	***1***	***3***
Occupancy	***100% during daytime, partial occupancy during night***	***100% during day time, 0 % during night***
Average Peak plug loads	***22,6 W/m^2***	***19,38 W/m^2***
Percentage of useful floor area that is heated or cooled	***100%***	***100%***
Heating Ventilation and Air-conditioning Systems	***Packaged variable air volume system with direct expansion cooling, air or water cooled chiller and water boiler heating***	***Packaged variable air volume system with direct expansion cooling, air or water cooled chiller and water boiler heating***

The proposals that must be followed by medical units in order to reduce their energy consumption by a percentage of 30 % are the following ***(AEDG-SHC,2010)***:

- Installation of high quality insulating materials on building envelope (opaque building elements) ***(AEDG-SHC,2010)***
- Installation of high quality, low infiltration, low radiative heat losses', at least double glazed and with thermal bridge transparent elements***(AEDG-SHC,2010)***
- Decreased light power density and implementation of sensors and occupancy controls***(AEDG-SHC,2010)***

- Implementation of natural day lighting in public areas, waiting rooms and medical staff's offices***(AEDG-SHC,2010)***
- Installation of high efficiency heating ventilation and air-conditioning systems with heat recovery***(AEDG-SHC,2010)***
- High quality roof insulation, reflective roof implementation and implementation of vegetation on roof for the effect of evaporative cooling ***(AEDG-SHC,2010)***
- Implementation of steel framed walls ***(AEDG-SHC,2010)***
- Adaptation of the medical unit's design to the climatic zone's climatic and environmental peculiarities***(AEDG-SHC,2010)***
- South orientation of the medical unit and installation of overhangs and shading devices on every side of the hospital, always taking into consideration the orientation of the side***(AEDG-SHC,2010)***
- Addition of skylight on the surgery center in order to reduce the internal heat gains from artificial lighting. ***(AEDG-SHC,2010)***
- Reduction of fan pressure drop(***AEDG-SHC,2010)***
- Installation of high efficiency and low energy consuming space heating and cooling systems. Selection of fuel that minimizes the primary energy consumption and CO_2 emissions. Utilization of renewable energy sources. ***(AEDG-SHC,2010)***

Energy Star Certification System

Energy Star Certification System is the result of a voluntary partnership between several tertiary buildings' owners in US, such as schools, hospitals and industrial buildings and the environmental Protection Agency of United States. Energy Star has as a scope the implementation of energy saving measures in order to promote energy conservation at tertiary buildings, even up to a 50% percentage. ***(Reed,2005)***

Energy Star rating system for hospitals assesses from an energetic point of view all the cooperated hospitals and medical units within United States and ranks their energy consumption in a ranking scale from 0 to 100. The highest the ranking of a hospital is, the more efficient energy performance it has. In order to assess the energy consumption of a hospital, a variety of factors are considered: ***(Reed,2005)***

- Size of the hospital***(Reed,2005)***
- Number of floors of the hospital***(Reed,2005)***
- Number of buildings that the healthcare facility has***(Reed,2005)***
- Opaque building elements' thermal transmittance***(Reed,2005)***
- Transparent building elements' quality***(Reed,2005)***
- Energy consumption and efficiency of HVAC system***(Reed,2005)***
- Energy consumption for lighting***(Reed,2005)***
- Energy consumption and efficiency for electric appliances and medical equipment***(Reed,2005)***
- The overall energy consumption on an annual or multiannual basis (through electric utility's bills, or Building energy management system if any) ***(Reed,2005)***

After the assessment of all the cooperated hospitals there is a ranking for every medical unit. For example if a healthcare facility scores an energy Star score 67, it means that it operates more efficiently and consumes less energy per m^2 than the 67% of the cooperated with energy star medical facilities. There are 3 categories for energy star rating: ***(Reed,2005)***

- ***Low Score Hospitals (1-49)*** : Great investments for renovation are required in order for the medical unit to comply with ASHRAE's guidelines***(Reed,2005)***
- ***Medium Score Hospitals(50-74):*** There is no requirement for extra investments but a readjustment of the energy operational schedule according to the ASHRAE's guideline is required. ***(Reed,2005)***
- ***High score Hospitals (75-100):*** These hospitals have the best possible energy efficient operation. An ***Energy Star compliance label*** is awarder to them in order to demonstrate their efficient operation, and set the good example for other facilities. ***(Reed,2005)***

Hospital Energy Alliance (HEA)

Hospital Energy Alliance is a national mechanism that was issued by US building Technology section of US Department of Energy in 2009. It is a program, according to which public and private medical facilities cooperate with US government in order to achieve energy conservation and pollution's reduction within the healthcare facilities. ***(US Department of energy,2009).***

The primary targets of HEA program are the following:

- Primary and final energy conservation within medical units' facilities***(US Department of energy,2009)***
- Greenhouse gas reduction from medical units' operation***(US Department of energy,2009)***
- RES Penetration, as an efficient and environmentally friendly energy source for medical units' HVAC system and medical equipment***(US Department of energy,2009)***
- Job creation and economic development through RES penetration ***(US Department of energy,2009)***
- Improvement of energy efficiency in HVAC system, lighting systems, and medical equipment***(US Department of energy,2009)***
- Provision of support schemes and financial incentives for the implementation of these measures ***(US Department of energy,2009)***
- Provision of high quality and affordable healthcare services for every citizen***(US Department of energy,2009)***

HEA has as a scope the application on medical units of Energy Independence and Security Act which was issued by US Department of Energy in 2007. According to it every newly constructed non residential building must be nearly net zero energy building until the end of 2030. Until the end of 2040 half of the existing and newly constructed non residential buildings must be net zero energy building and until the end of 2050 every non residential public or private building, including hospitals must be net zero energy buildings. ***(US Department of energy,2009)***

American Society for Healthcare Engineering (ASHE)

ASHE's scope is the monitoring and improvement of medical facilities' service quality and environment. American Society for Healthcare Engineering Issues on regular basis guidelines about design and construction, energy management, medical equipment and engineering and maintenance of the high quality health standards within healthcare facilities. ASHE has issued the Green Healthcare Guidance

Statement and the healthcare energy guidebook, which with cooperation with ASHRAE's and Energy Stars standards provide the required guidelines for the environmentally friendly and safe operation of medical units within United States of America. ***(Singer B. C. et al, 2009)***

3.4. Hospitals' energy consumption standards in United Kingdom

In United Kingdom the public organism, that is responsible for the efficient and smooth operation of the public health provision mechanism, is the widely known National Health Service. NHS operates in compliance with the EPBD (Buildings Energy Performance Directive) Directive , which is known as: Directive 2002/91/EC, and have as a common goal the reduction of final and primary energy consumption within healthcare facilities and the decrease of the total CO_2 emissions from hospitals' operation. ***(Aspinall,2004)***

For the period 2000-2010, National Health Service had as a target the achievement of 15% conservation of energy within healthcare facilities and a reduction of 15 M kg in CO_2 emissions. Furthermore, for the time period 2010-2020 the target has been set equal to 20% energy conservation through medical units' and hospitals' operation. For this reason NHS has set a mandatory target for the energy consumption due to the operation of the existing medical units (hospitals) which must be between 0,55 and 0,65 GJ / m^3. Moreover newly constructed hospitals must have an upper limit of energy consumption equal to 0,55 GJ / m^3. For the needs of these calculations an average floor height equal to 3 m is used. ***(Aspinall,2004)***

The targets of UK's National Health Service may be achieved with the following measures/proposals:

- Construction of the medical units with a methodology, and utilization of building materials which comply with Directive 2002/91/EC. ***(Aspinall,2004)***
- Careful selection of fuel carrier for heating , cooling, ventilation, domestic hot water and lighting, in order to achieve the minimum possible primary to final energy conversion factor. This way the primary energy that is consumed within the medical unit's facilities and CO_2 emissions will be minimized. ***(Aspinall,2004)***

- Efficient devices for space heating and cooling, domestic hot water preparation, ventilation and lighting ***(Aspinall,2004).***
- Passive solar heating design with south facing orientation ***(Aspinall,2004)***
- Utilization of daylight, with daylight sensors, occupancy and movement controls and low energy consumption lamps. ***(Aspinall,2004)***
- HVAC systems with heat recovery implementation. ***(Aspinall,2004)***
- Low energy consuming medical equipment and electric appliances. The energy consumption assessment must be done not only during operation, but also during the whole lifecycle of the medical equipment, including construction and die out cost. ***(Aspinall,2004)***
- Implementation of building energy management system ***(Aspinall,2004)***
- Utilization of cogeneration of heat and power (CHP) within the healthcare facilities. This way higher efficiencies are achieved, with minimum primary energy consumption and CO_2 emissions' creation ***(Aspinall,2004)***
- Reduction of energy transmission and distribution losses with the use of efficient pumps and fans and other distribution and storage equipment. ***(Aspinall,2004)***
- Waste to energy plant implementation. With this method medical waste are treated and incinerated. With the produced heat's proper utilization significant parts of the medical unit's thermal loads for space heating and domestic hot water preparation are covered. ***(Aspinall,2004)***

Aspinall et al made a research within UK's medical facilities and categorized hospitals and medical units according to their level of compliance to the UK's National Health Service Standards. The categorization was "good practice hospitals" for hospitals that have energy consumption that complies with NHS's standards (equal or lower) and "typical hospitals", as the representation of the average hospital of United Kingdom. This way the required energy consumption of a medical unit that complies with NHS standards in every energy consuming activity is presented. The standards are presented in the next tables ***(Aspinall,2004):***

Table 26: UK NHS energy consumption standards for health care facilities (Aspinall,2004)

Medical unit's category	***Annual energy consumption kWh/m^2***	***Annual Energy consumption GJ/m^3***
Good Practice(NHS standards)	***459***	***0,55***
Typical (Average UK's hospital	***550***	***0,66***

In the next table the required energy consumption of a hospital in all energy consuming activities, in order for it to comply with NHS standards is presented ***(Aspinall,2004)***

Table 27: Required energy consumption of a hospital in all energy consuming activities, in order to comply with NHS standards (Aspinall,2004)

Energy consuming Activity	***Good Practice hospitals (In compliance with NHS standards)***	***Typical UK hospitals (Average UK hospitals)***
	Annual Energy Consumption (kWh/m^2/year)	***Annual Energy Consumption (kWh/m^2/year)***
	Fossil Fuels	
Heating	***215***	***260***
Non Heating	***124***	***185***
Total	***339***	***445***
	Electricity	
Lighting	***20***	***35***
HVAC	***22***	***54***
Other	***9***	***14***
Heating	***0***	***0***
Medical Equipment	***15***	***17***
IT Systems	***6***	***7***
Small power	***11***	***14***

Generation		
Food refrigeration/ cooling	***0,9***	***0,9***
Food Preparation/Heating	***0,3***	***0,3***
Total	***103***	***160***

The main problem of compliance with UK National Health Service energy consumption standards is the fact that the implementation of the required measures in order to achieve the energy conservation results is financially intensive. For this reason United Kingdom's government offers the financial support to the cooperated healthcare facilities with the mechanisms of Public Private Partnership (PPP) and Private Finance Initiative (PFI). These two mechanisms offer a percentage of the required financial funds to both public and private hospitals, that achieve the compliance with NHS standards for the implementation of energy saving measures such as: Building Energy Management systems, CHP installation, efficient lighting and occupancy sensors, efficient HVAC system with heat recovery, installation of energy efficient electrical mechanical and medical equipment and implementation of medical waste to energy plant operation within the healthcare facility. The main advantage of the UK's legislation is that contrary to the wider European and Greek legislation, the financial incentives cover hospitals that belong both to the public and private sector. This way the achieved result in medical unit's energy conservation may be as efficient as possible. ***(Aspinall,2004)***

In Ireland, the European Building Energy Performance Directive is applied with the implementation of S.I. No. 666 of 2006, which had been issued in 2006 by the Irish Ministry of Environment, Heritage and Local Government. According to it every building must be accompanied with a first or second schedule BER certificate, which proves that its energy performance is compatible with the EU standards. A BER certificate must be issued when a building is constructed, sold or rented and it ranks the energy performance of the building regarding the thermal characteristics of its building elements and the energy consumption of space heating and cooling, ventilation, domestic hot water preparation and lighting. Lack of the appropriate BER certificate of a building is an offence for the building owner. The main target is the energy conservation and environmental protection regarding the operation of buildings, among them medical units. This can be achieved with the provided guidelines and with utilization of cogeneration of heat and power within a hospital's facilities, efficient heat pumps, district heating and cooling systems and decentralized RES based systems. ***(S.I. No. 666,2006)***

3.5.Canadian hospital's energy performance standardization

In Canada the energy performance of healthcare facilities is standardized by a specially designed standard which had been issued by the Canadian Standards Association in the beginning of 2010. ***(CSA Z317.2, 2010)***

The standard is named CSA Z317.2-10 " Special requirements for Heating, Ventilation and Air-conditioning systems in healthcare facilities". This standard sets the minimum requirements for HVAC system in order for it to comply with the strict indoor space quality standards for healthcare facilities. It standardizes the design, construction and operation and maintenance of HVAC systems in medical units. Minimum values for indoor space thermal and air quality comfort are standardized and guidelines for the construction and operation conditions of HVAC systems are provided. The standard does not provide guidelines for the selection of building elements, building envelope properties and lighting system's characteristics. Legislation and standardization about these items can be extracted by ASHRAE's guidelines and standard 90.1-1999 and the general Canada's legislative framework about buildings. ***(CSA Z317.2, 2010)***

The standard provides guidelines about the operation, design and construction of HVAC in medical units systems, taking into consideration issues such as:

- Final and Primary Energy Conservation in medical units***(CSA Z317.2, 2010)***
- Increased lifetime of HVAC systems and reduced maintenance requirements***(CSA Z317.2, 2010)***
- Increase of energy efficiency of HVAC system's operation***(CSA Z317.2, 2010)***
- Reduction of The medical unit's negative environmental impact***(CSA Z317.2, 2010)***

- Compliance with the strict and sensitive indoor conditions of a healthcare facility and disease spread prevention***(CSA Z317.2, 2010)***
- Sustainable operation of HVAC and medical unit with as low CO_2 emissions as possible ***(CSA Z317.2, 2010)***

This can be achieved with standardization in some operational HVAC variables such as:

- Indoor Space's Relative Humidity***(CSA Z317.2, 2010)***
- Indoor Space's Temperature***(CSA Z317.2, 2010)***
- Indoor air quality***(CSA Z317.2, 2010)***
- Air movement ***(CSA Z317.2, 2010)***
- Noise Level ***(CSA Z317.2, 2010)***

The heating ventilation and Air-conditioning Systems, serving medical facilities must be in compliance with the National Canadian law for buildings and the ASHRAE's standard 90.1**.** This takes place either for new or for renovated medical units. In other words both categories of medical units must comply with these 2 requirements. ***(CSA Z317.2, 2010)***

Space heating may be achieved by boilers and burners (either oil or natural gas), district space heating or heat pumps. Moreover space cooling may be achieved by electricity fueled air-conditioning systems, district space cooling systems and natural gas, oil or RES based absorption or adsorption space cooling systems. In both cases emergency operation mode, in case of loss of electric power must be installed. Ventilation providing systems must be able to provide the required indoor air quality , depending on the place where ventilation system is installed. Ventilation systems may be constructed by materials such as stainless steel, copper and aluminum. Air filters must be installed in order to protect the indoor spaces from the intrusion of hazardous materials, while exhaust systems must be placed in spaces where the indoor air quality of patient involving areas is not affected. Indoor space temperature controls and humidity controls must be installed inside the indoor areas of medical units. In unoccupied periods, HVAC systems may operate with the specially designed indoor quality minimum standards, in order to promote energy conservation and greenhouse gas reduction. HVAC systems must have a heat recovery provision installed, while solar heat gains must be utilized as efficiently as possible with the implementation of proper glazed transparent elements, of course in correlation with the outdoor environment. Renewable energy sources and cogeneration of heat and power must be used in order to promote the general sustainable operation. Finally apart from the standardization of pre design, design, construction and installation, performance testing, and operation stages, regular maintenance should take place on the HVAC system in order to maintain the efficient operation and post occupancy evaluation should be made from patients, visitors and medical staff, not only to instantaneously find remedy for the possible design inconsistencies, but also provide knowledge for the future promotion of sustainability of health care facilities' operation and construction. ***(CSA Z317.2, 2010), (Meir,2012)***

In the next table the minimum requirements for temperature, relative humidity, indoor air quality etc are presented , depending on the use of medical facility's space. ***(CSA Z317.2, 2010)***

Table 28: Minimum requirements for temperature, relative humidity, indoor air quality (CSA Z317.2, 2010)

Type of room	Minimum Outdoor Air changes/h	Minimum total air changes/h	Temperature °C	Relative Humidity
Ambulatory care clinic areas	2	9	20-24	30-60
Anesthetic storage room	-	8	20-24	30-60
Animal Research-Induction room	3	12	20-24	30-60
Animal Research-Surgery room	15	20	20-24	30-60
Autopsy	3	20	18-20	30-60
Cardiac Catheterization	6	20	20-24	30-60
Medication room	2	6	22-24	30-60
Corridors	1	3	20-24	30-60
Critical Care-Nursery	3	9	24-27	30-60
Intensive care	3	9	22-24	30-60
Coronary care	3	9	20-24	30-60
Dental Treatment-Clinic	2	6	20-24	30-60
Dental Treatment-Minor procedures room	3	9	20-24	30-60
Detoxification room	2	6	20-24	30-60
Kitchen	2	10	20-24	30-60
Dishwashing Room	2	10	20-24	-

Meal room	*2*	*6*	*20-24*	*30-60*
X-ray, MRI ,CT room	*3*	*9*	*20-24*	*30-60*
Nuclear medicine room	*3*	*9*	*20-24*	*30-60*
Angiography Room	*6*	*20*	*20-24*	*30-60*
Film Storage Room	*-*	*4*	*20-24*	*30-60*
Dialysis Unit	*3*	*9*	*22-24*	*30-60*
Emergencies-General	*4*	*12*	*22-24*	*30-60*
Emergencies-Examination room	*4*	*12*	*22-24*	*30-60*
Emergencies-Fracture Treatment room	*4*	*12*	*22-24*	*30-60*
Emergencies-life support	*5*	*15*	*22-24*	*30-60*
Emergencies-decontamination space	*-*	*15*	*22-24*	*30-60*
Examinations-General	*2*	*6*	*22-24*	*30-60*
Examinations-Storage Room	*-*	*2*	*20-24*	*30-60*
Examinations-Conference Room	*20 cfm/person*	*10*	*20-24*	*30-60*
Examinations-Offices	*2*	*6*	*20-24*	*30-60*
Examinations-Lockers room	*2*	*6*	*20-24*	*30-60*
Examinations-Admitting	*2*	*6*	*20-24*	*30-60*
Hydrotherapy room	*3*	*9*	*24-27*	*30-60*
Laboratories-General	*3*	*12*	*22-24*	*30-60*
Laboratories-Media Preparation	*3*	*12*	*22-24*	*30-60*
Laundry	3	12	22-23	30-60
Nursing Station	*2*	*6*	*20-24*	*30-60*
Newborns' sector- Birth room	*3*	*9*	*22-24*	*30-60*
Newborn sector-Caesarean delivery area	*6*	*20*	*20-24*	*40-60*
Newborn sector-Nursery	*2*	*6*	*24-27*	*30-60*
Decontamination soiled	*2*	*10*	*18-20*	*30-60*
Ethylene Oxide sterilizing room	*-*	*10*	*22-24*	*30-60*
Packaging room	*3*	*10*	*18-23*	*30-60*
Sterile storage	*-*	*4*	*20-23*	*30-60*
Sterilizing Equipment room	*-*	*10*	*20-23*	*30-60*
Endoscopy	*5*	*15*	*18-22*	*30-60*
Bronchoscopy	*5*	*20*	*18-22*	*30-60*
Cytoscopy	*5*	*15*	*18-22*	*30-60*
Large Urban Medical Unit	*2*	*6*	*20-24*	*30-60*
Mid Size Rural Medical Unit	*2*	*4*	*20-24*	*30-60*
Patient waiting room	*4*	*12*	*22-24*	*30-60*

Washroom and toilet rooms for patients	-	*9*	*22-24*	-
Pharmacy	*3*	*9*	*24*	*30-60*
Physiotherapy room	*3*	*9*	*22-24*	*30-60*
Radiation Treatment Room	*4*	*12*	*20-24*	*30-60*
Respiratory treatment-Clinic	*3*	*9*	*22-24*	*30-60*
Respiratory treatment-Workroom	*3*	*10*	*22-24*	*30-60*
Special precautions-Anteroom	*3*	*9*	*22-24*	*30-60*
Special precautions-Burning Unit	*5*	*15*	*24-30*	*30-60*
Special precautions-Protective environment Room	*3*	*12*	*22-24*	*30-60*
Special precautions-Infected patients' isolation room	*3*	*12*	*22-24*	*30-60*
Surgery- Sterilized Corridors	*2*	*6*	*22-24*	*30-60*
Surgery-Day Surgery	*3*	*9*	*22-24*	*30-60*
Surgery-Operating room	*6*	*20*	*18-23*	*40-60*
Surgery-Pre operation waiting room	*2*	*6*	*22-24*	*30-60*
Surgery-Preparation room	*3*	*9*	*22-24*	*30-60*
Surgery-Recovery Room	*6*	*20*	*22-24*	*30-60*
Surgery-Scrub room	*2*	*6*	*22-24*	*30-60*
Surgery-Sterile Core	*3*	*9*	*22-24*	*30-60*
Surgery-Sub sterilization Room	*3*	*10*	*22-24*	*30-60*
Waste Storage and Processing space	-	*10*	-	-

The great advantage of the present standard is that like UK's National Health Service's requirements for medical units, guidelines are provided not only for public, but also for private medical units, maximizing the potential for energy conservation and environmental protection from the healthcare sector's operation. ***(CSA Z317.2, 2010)***

3.6. Energy performance indicators in Brazil as an indication of developing countries

Brazil is one of the more fast paced developing countries. For this reason reviewing the healthcare units' energy performance legislation within it, may provide a quite indicative idea about the energy legislation for medical units in developing countries. Brazilian hospitals are built following the Brazilian legislation about buildings, which until the recent years did not pay too much attention in energy conservation and environmental protection. During the last years though more and more hospitals are built according to ASHRAE standard 90.1.1999 trying to implement provisions and solutions about the environmental protection ***(Szklo et al,2003)***

The energy performance indicators for medical units in Brazil for space heating and cooling, domestic hot water preparation, lighting and ventilation and of course medical equipment are set by the Brazilian National Health System (SUS). In the next table the standard for energy performance of medical units, which has been provided by SUS (Brazilian Government Health System) is presented.***(Szklo et al,2003)***

Table 29: Standards for energy performance of medical units by SUS (Szklo et al,2003)

Type of energy related activity	***SUS standard***
Monthly energy intensity (kWh/bed)	***248***
Share of energy mix held per electricity (%)	***71,5***
Power load factor	***40***
Lighting energy consumption (W/m^2)	***3,30***
Air-Conditioning ($TR/100\ m^2$)	***0,31***
Domestic hot water (m^3/bed/month)	***0,93***

Here it should be mentioned that for the time being there are not standards for the energy efficiency of heating systems and covered area percentage for air-conditioned system. ***(Szklo et al,2003)***

The SUS standards are implemented in the public hospitals and medical units. Unfortunately these standards are not obligatory for privately owned hospitals, as it has been described in the energy audit review section**. *(Szklo et al,2003)***

SUS makes efforts for the promotion of cogeneration of heat and power within the facilities of medical units. These will have as a result increased efficiency of energy performance of CHP process and significant conservation of energy resources and reduction in CO_2 emissions. CHP must be fueled with natural gas in order to increase the overall efficiency of the process while, biothenol based CHP concepts, which is abundant in brazil are allowed as well. CHP is promoted for large and medium sized hospitals. The generated heat is intended to cover the space heating and domestic hot water demand for hospitals, while the generated power must be able to cover energy needs for ventilation, lighting, and of course medical equipment and production of steam and medical purpose oxygen. Additionally, produced heat will be utilized with specially designed absorption cooling cycles in order to efficiently cover the cooling loads, which are significant for a warm country such as Brazil. ***(Szklo et al,2003)***

4. Green Hospital

4.1. Green Buildings

Before starting the discussion about the concept of green hospitals, the term of green buildings should be defined and their differences with low energy buildings should be explained.

The greatest similarity between green buildings and low energy buildings is that both of the concepts have as a major target the reduction of final and primary energy consumption during the operation of the building, always in compliance with the CO_2 emissions reduction target. This is the sole target of a low energy building. A green building pays great attention to the above mentioned target. The main difference though is the fact that a green building considers more widely the concept of sustainability, having as additional targets the reduction of waste, the reduction of water use, the utilization of recycled materials, the reduction of negative influence on the environment and the efficient use of resources during construction and operation stages. According to these definitions a low or zero energy building may not always be characterized as a green building as it may succeed in the completion of the reduction of primary and final energy consumption, but it may fail in reducing the total negative impact of the building on the environment, such as the waste reduction, the use of recycled building elements and the reduction of used raw materials. ***(Anastaselos, 2012)***

The greatest advantage of a green building versus a low energy building is that it takes into consideration a greater sustainability and environmental protection criteria. Its main disadvantage though, is the fact that the cost for its construction may be higher, and the implementation of green building target around European Union may not be a realistic and achievable target. ***(Anastaselos, 2012)***

The green building concept may not always be economically feasible. For this reason it may need political promotion and financial support such as legislative schemes, tax reductions and subsidies in order for every family, businessman or government to be able to construct their residential, commercial or industrial building with the green building targets. Around the world numerous green building certification programs can be found; the most important and widely used are the following:

- United States' Leadership in Energy and Environmental design standards
- Canada's Leadership in energy and Environmental design standards
- Japan's CASBEE 16 standardization system
- United Kingdom's code for sustainable homes and buildings. ***(Anastaselos, 2012)***

The modeling of a green building concept is presented in the following figure:

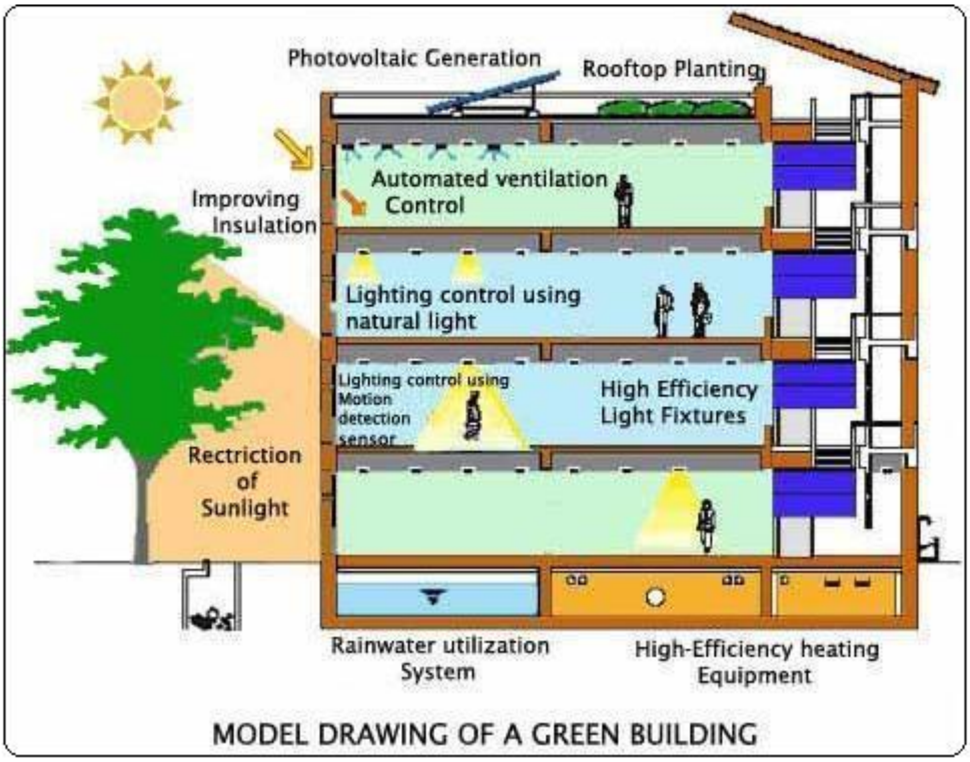

Figure 3: Model drawing of a green building. (http://greenbuildings-in-the-world.blogspot.gr)

4.2. Green Hospital

Green hospital concept was firstly promoted by Leadership in Energy and Environmental design (LEED) by the U.S. Green Building Council (USGBC). The initial cost for the construction of a green hospital is relatively high in comparison with an ordinary medical facility. In the long term though there is a significant reduction in the energy consumption and the cost for energy generation and transmission. Moreover the waste production, pollution and more generally the hospital's negative impact on the environment is drastically reduced in the mid and long term. Both medical and non medical staff and patients characterize the environmental conditions in a green hospital as the ideal healthy environmental conditions. ***(http://greenhospitals.net), (http://hospital2020.org), (Hospital 2020 Organization, 2011), (Karliner et al, 2011)***

During the last years a significant number of hospitals were built from scratch or renovated , receiving the (USGBC)'s certification as green medical units. In order for a hospital to be considered as green a lot of criteria must be fulfilled from the stage before its construction , until the stage to its operation and health services provision.

First of all an environmentally friendly site must be selected for the construction of the medical unit. During the construction step environmentally friendly, recycled and with low embodied energy materials and building elements must be selected, and the selected design must be compact, efficient and sustainable. During its operation energy, water and resources conservation, recycling and waste minimization concepts must be applied. ***(http://hospital2020.org), (Hospital 2020 Organization, 2011)***

Green hospital concept is globally promoted by Green hospital Initiative (GHI). Green Hospital initiative is a movement operating globally that has as a purpose the setting of the quality set point for hospitals starting from 2020. In order to achieve this, newly constructed and renovated hospitals must fulfill 4 basic criteria. They must be innovative, green, global and safe. The main target of the GHI is the promotion of construction and operating designs and practices in order to diminish the negative impact of medical units on the environment. It has as a target also the provision of examples and case studies of successfully implemented green hospital measures on hospitals within Europe, United States and Canada. Finally it promotes the waste minimization concept and demonstrates alternative methodologies for waste incineration for the treatment of waste. ***(http://hospital2020.org), (Hospital 2020 Organization, 2011)***

Green hospital is a medical facility that promotes sustainability in healthcare provision, by successfully accomplishing 3 basic criteria: Efficiency, green construction and operation and quality of services. ***(http://www.medical.siemens.com), (Siemens Healthcare Department, 2012)***

Green construction and operation refers to the reduction of final and primary energy consumption during operation and construction, reduction of greenhouse gas and CO_2 emissions, waste minimization and conservation in water and resources. ***(http://www.medical.siemens.com) , (Siemens Healthcare Department, 2012)***

Quality of services refers to the creation of health supporting environmental conditions and secure provision of high quality health services. ***(http://www.medical.siemens.com) , (Siemens Healthcare Department, 2012)***

Efficiency refers to the optimization of medical and non medical processes within the medical unit, and the efficient allocation of cost and time. ***(http://www.medical.siemens.com) , (Siemens Healthcare Department, 2012)***

The promotion of the above mentioned targets takes place within different areas of the medical unit's operation: Energy generation and transmission, site selection, building construction, building automation, telecommunication and networking and medical and non medical equipment. ***(http://www.medical.siemens.com) , (Siemens Healthcare Department, 2012)***

Green hospital concept pays great attention in the reduction of electronic, medical and non medical waste, the followed chemical policy and the reduction of pollutants such as: Volatile organic compounds, lead, mercury, polyvinyl chloride and brominated flame retardants. Great emphasis is given on the selection of recycled and environmentally friendly building materials, energy and water conservation, recycling and waste minimization, medical waste treatment in an environmental gentle way, green electronics, efficient pest management and pharmaceuticals efficient management procedure. The methodology for constructing a green hospital or for converting an ordinary hospital to a green one is presented in the following paragraphs. ***(http://hospital2020.org), (Hospital 2020 Organization, 2011)***

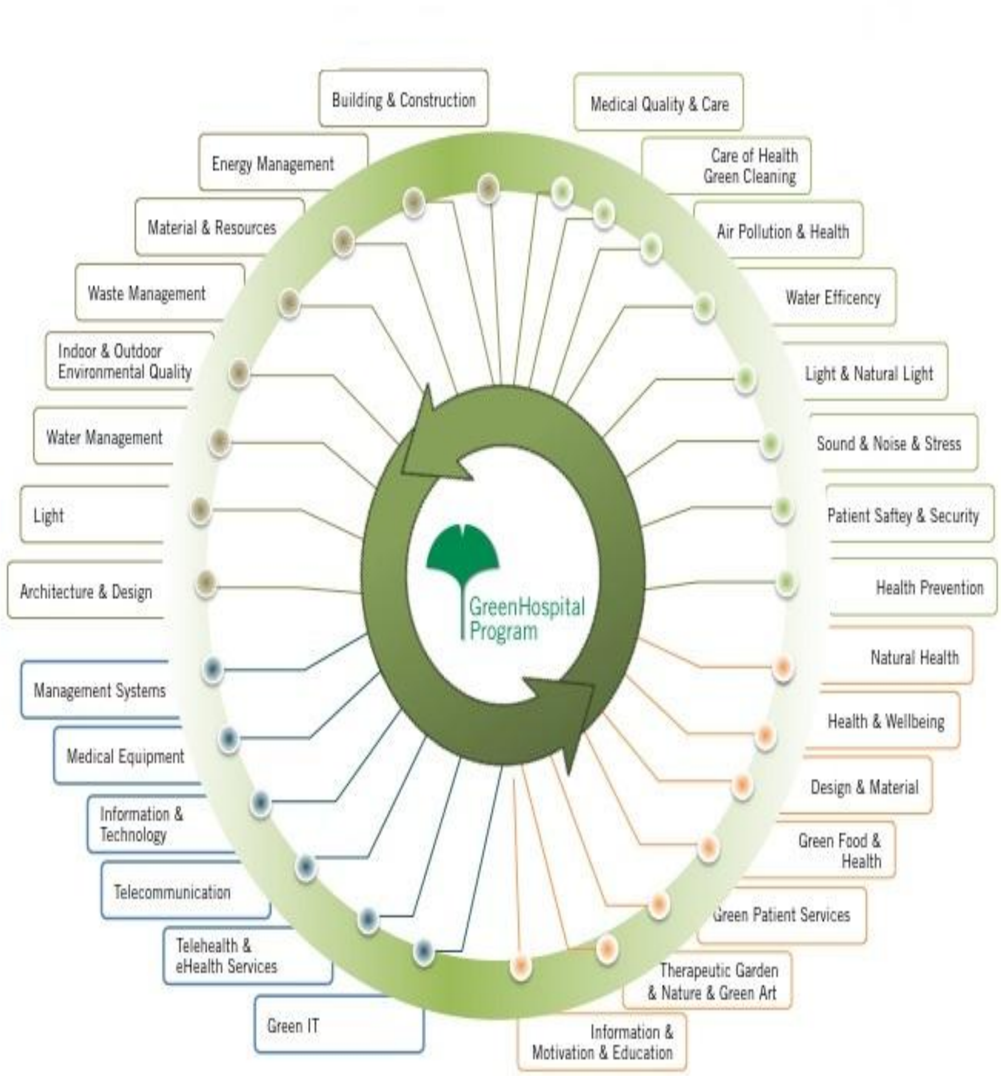

Figure 4: Key factors in a green hospital (http://greenhospital.blogspot.com)

First of all an environmentally friendly construction site should be selected. Wetlands and farmlands, lands with high biodiversity and rare and protected kinds of flora and fauna or with high concentration in pollutants should be avoided. According to estimations of United Kingdom's National Health Service, CO_2 emissions which are produced by the transportation of patients and medical staff from or to the hospital are equal to the 18% of the total medical unit's CO_2 emissions. For this reason parking facilities and transportation infrastructure should be shared with other local, private or public companies and the use of the public dense transportation grid or pedestrian streets and bicycle roots should be promoted. Ambulances and medical vehicles should utilize hybrid and electric alternative technologies. The problem here though, is the fact that for the time being these technologies are very expensive and cost inefficient. Medicines and medical equipment should be purchased from local suppliers, reducing this way their carbon footprint. Strategies such as telemedicine, or smart email communication between medical staff and patients must substitute actual transportation of patients to the hospital where it is possible. This way not only a significant amount of energy is conserved, but also there is a great reduction in the production of CO_2 emissions (which contribute to the greenhouse effect), CO, NO_2 and SO_2 (which are responsible for a variety of respiratory malfunctions and lungs' diseases). Moreover a green construction should reduce, as efficiently as possible, the urban heat island. In other words an ideal location should not be in the center of a city or downtown, but in the city's suburbs. Finally the already existing water and energy transmission infrastructure should be utilized and there is no need for the creation of a new one because it would significantly cost in environmental resources. ***(http://hospital2020.org), (Hospital 2020 Organization, 2011)***

Sustainable design and construction processes should be chosen, promoting the efficient operation and energy performance of the building. Hospitals and medical units as public buildings, should provide the best example in areas such as environmental protection, energy conservation, and innovation. Moreover there is a proven correlation between therapeutic efficiency and building environment. Green covered areas around the hospital should be constructed promoting the evaporative cooling and shadowing effect. Technologies such as reflective and green roofs should be used, in order to reduce urban heat island and facilitate the collection of rainwater. The form and design of the building, should be harmonized with the form of the rest nearby community's buildings and environment. The building materials that will be utilized for the construction of the building should be recycled or recyclable, and with low embodied energy. Special attention should be paid to the promotion of the transportation to or from hospital of the working staff with bicycles, by constructing bicycle paths and showers and changing rooms. The lifecycle and durability of building elements shall be as long as possible in order to reduce the waste creation from building elements. The orientation of patient rooms should be south facing in order to increase the heat and solar gains during the winter and reduce them during the summer. This way the heating and cooling load can be drastically reduced. Additionally the natural lighting and day lighting should be promoted in order to reduce the energy consumption for lighting. High quality insulation on walls and windows (low e coatings double glazing) should be chosen in order to reduce air infiltration and heat losses. Building materials that are produced and are available locally must be chosen in order to reduce the transportation energy and cost. The selected building materials should also be easily adaptable into environmental changes. The recycling should be promoted by creating recycling spaces and offering incentives for staff and patients to recycle, Special attention must be paid into the indoor air quality in order to achieve the ideal healthy conditions with low CO_2 concentrations. This can be achieved by special sensors and automated indoor air quality management and ventilation system. ***(http://greenhospitals.net), (http://hospital2020.org), (Hospital 2020 Organization, 2011), (Karliner et al, 2011)***

Energy conservation during the operation of the building is the most important factor of the green hospital concept. This way not only great amount of final and primary energy are conserved but also the overall amounts of CO_2 emissions due to the building's operation are drastically reduced. Passive solar heating and cooling methodologies and natural day lighting processes should be selected in order to reduce the overall amount of energy that is consumed. Additionally high efficiency heating ventilation and air conditioning systems with heat recovery systems must be chosen in order to maintain the high indoor air quality and contribute to the coverage of heating and cooling loads. High efficiency heating and cooling equipment must be chosen in order to reduce the overall energy consumption. Additionally energy balance and management automated system must be utilized. High efficiency electric appliances (compatible with energy star and environmental choice standards) must be selected. Moreover high efficiency lighting systems must be used with automated movement sensors and timers. Additionally the lighting systems must be carefully and cleverly designed in order to achieve the maximum optical comfort with the least possible lighting equipment. This way not only great amounts of energy are conserved, but also great amounts of cost. Where possible, natural ventilation in order to maintain indoor air quality with low energy consumption and low cost should be utilized. Finally an energy, water consumption and temperature and humidity monitoring automated system must be utilized in order to record and maintain the indoor comfort, with the lowest energy consumption and the highest efficiency. Insulation on vertical building elements floor and ceilings must be in compliance with the U.S. Energy Department, or the legislation for green buildings within European Union. ***(http://hospital2020.org), (Hospital 2020 Organization, 2011)***

For an existing medical unit the most proper solution is the implementation of energy saving measures for the reduction of energy consumption. A target of at least 10% of energy conservation within a 5 year period is indicative. For new buildings of green medical units the energy performance must be less than 320kWh/m^2 per year. Energy audits must be conducted on a regular annual or 2 year basis. The utilization of onsite energy generation based on renewable energy sources is the key component of energy conservation. This way not only primary energy consumption is drastically reduced, but also CO_2 emissions are diminished. Moreover if energy is generated onsite, the transmission and distribution of energy cost and energy consumption is significantly lower. Where an automated energy control system or thermostats are available and the internal spaces are mechanically conditioned, thermostats can be set slightly lower from the comfort temperature in the winter and slightly higher in the summer. Of course this measure can be implemented mainly on offices and places, where thermal comfort is not too important and not into patient rooms and surgery rooms. ***(http://greenhospitals.net), (Karliner et al, 2011)***

Another significant criterion for green building is the conservation of water. This is even more important in regions where there is water scarcity and lack of municipal water network or water treatment facilities. In these areas a significant number of people do not have access to water and a great percentage suffers due to disease spreading through potable water. When the medical facility is located on an area where municipal water treatment and sewage systems are not available, an affordable onsite water (both potable and waste) treatment system should be utilized. Biodigestion may be an efficient technology, which may use waste water as a feedstock in order to produce biogas and biomethane, which is an alternative fuel to natural gas. This way not only the waste water is minimized but there is also further contribution in the indirect CO_2 reduction in the transportation sector. In developing countries, where lack of potable water treatment municipal system may be presented, the medical facility can provide potable water to the nearby communities, contributing this way to the maintenance of community's health and quality of life and preventing disease spreading and fighting drastically the phenomenon of water scarcity. Water in a hospital is used for process use (70%) and for drinking, food preparation and showers and cleaning (30%). For the promotion of water conservation, water efficient showers, toilets and urinals must be utilized. Moreover gray water (used water from showers, washing machines and sinks) or wastewater (used water from toilets and dish washing machines) should be recycled and reused, with the utilization of natural and constructed vertical flow or horizontal flow wetlands. Rainwater must be collected in specially designed spaces and used in operative purposes such as irrigation, steam creation, cleaning etc. A great idea for water conservation is the substitution of film based imaging radiological technology (which requires water for the preparation of film) with digital visualizing methods. Finally drought resistant deciduous plants must be utilized in order to allow the building utilize the surrounding vegetation. Water quality should be tested on a regular basis. ***(http://hospital2020.org), (Hospital 2020 Organization, 2011)***

Medical waste have severe toxic and infectious properties. For the time being medical waste management is not efficiently implemented. Health care waste is estimated to put in danger more than the half of global population. Waste minimization strategies should be followed in order to reduce the negative impact on the environment. First of all building elements, chemicals and medicines that are subject to create great amount of waste should not be used. An adequate and properly designed space for waste collection should be created. Recyclable waste must be recycled and reused, while hazardous waste such as chemicals, radioactive or biomedical waste must be safely disposed. The used building and medical materials should be specially designed in order not to create waste that cause pollution to forests and wetlands. For this reason they must be in compliance with Forest Stewardship Council Principles and Criteria. Two significant routes in medical waste minimization strategies are the composting and recycling of anesthetic gases and the reduction of packaging. Moreover the transportation stage in waste management should be as minor as possible, reducing the energy consumed, cost and of course the danger of disease spreading. Plastic waste should be recycled and not incinerated, as incineration creates toxic chemicals such as dioxins, furans and greenhouse gases. A good alternative to incineration would be the implementation of autoclaving, which is a cheap, safe and efficient process. A specially designed waste management advising team for each hospital must be created and a fixed amount of the medical unit's overall budget should be dedicated to medical waste treatment and minimization strategies. Injectable medicines should be avoided where it is possible, in order to reduce disease spreading through medical waste. Finally it should be mentioned that a green hospital must support and contribute in the growing of a zero waste policy in order to reduce the amount of waste which is generated on a local, national and global scale. ***(http://greenhospitals.net), (http://hospital2020.org), (Karliner et al, 2011)***

Figure 5: Medical waste collection space (http://greenhospitals.net), (Karliner et al, 2011)

The main portion of a hospital related waste is pharmaceutical waste. This kind of waste can be significantly reduced if a proper strategy is followed. First of all every medicine should be provided only with a prescription, while only small quantities and where it is only necessary must be provided. Medicine's samples' provision should be avoided, while the packaging of medicines should be as low as possible. Educational seminars for doctors and prescribers must be done in order for the medical staff to be able to follow efficiently the above directions. A cooperation between hospitals and pharmaceutical producers in the sector of research and development in order to improve the quality of medicines and reduce their waste creating potential must take place. The most efficient way of collecting medical waste is their collection on the hospital's central facilities and either dispose them , or return them to the producer. The disposal of a pharmaceutical waste must be done in compliance of WHO guidelines. Incineration should be avoided, and proper chemical treatment must be used. ***(http://greenhospitals.net), (Karliner et al, 2011)***

Indoor and outdoor air quality should be maintained in the acceptable environmentally friendly criteria with the least possible pollutants. Chemicals with ozone depleting capability such as refrigerants including CFCs should not be used in building materials and mechanical and medical equipment. Solvent-based finishes, adhesives and particleboards, which are responsible for the release of formaldehyde should be avoided. Fire fighting systems which use HCFC's should strictly be avoided. Materials , either building elements or medical equipment or medicines which contain or release to the environment toxic, non biodegradable or carcinogenic chemicals should not be used. Special attention should be paid to the avoidance of arsenic, PVC and mercury. Glutaraldehyde, DEHP and BPA based chemicals must be strictly prohibited. Every mercury based thermometer and blood pressure measurement instrument must be replaced with safe, accurate and cost efficient alternative devices. Every chemical that is used, must have undergone a strict toxicity testing procedure, in order to avoid the use of carcinogenic toxic and hazardous chemicals. A specially designed action plan for every medical unit and for each kind of health service must be followed in order to protect patients, medical (or non medical staff), local community and environment from hazardous chemicals. This can be achieved either by promoting the safe use and disposal of chemicals, or by replacing the dangerous chemicals with proper and cost efficient alternatives. Indoor air quality must be maintained into high standards. For this reason air intakes must be placed away from spaces, where vehicles are moving and indoor air quality automated management system must be installed. Pesticides should be strictly avoided . ***(http://greenhospitals.net), (http://hospital2020.org), (Hospital 2020 Organization, 2011), (Karliner et al, 2011)***

The provision of food for patients and visitors is a very important factor, which must promote sustainability. Food in western and developed countries is responsible for numerous deaths due to obesity, while in developing countries a variety of diseases are spreading through the consumption of food. A green hospital should provide the good example by providing to visitors, patients and staff healthy food, which has been produced with sustainable methods. Sugar based soft drinks and junk food should not be served and the overall percentage of meat that is served should be minimized. The raw materials that are used for food preparation should be purchased by the local producers, reducing this way the food's carbon footprint (due to reduced transportation needs) and at the same time, supporting the local economy. The raw materials and meat that will be used must be produced in sustainable way, without synthetic pesticides and hormones. Moreover the animals must be tested on a regular basis for diseases. The promotion of healthy food such as fruit and vegetable must take place within the hospital's facilities. Educational procedures and an effort to increase the awareness about the advantages of following a healthy diet, should take place for the staff , patients and visitors. Food remains must be recycled in order to reduce waste, while proper waste treatment methods must be applied in order to maintain sustainability. ***(http://greenhospitals.net), (Karliner et al, 2011)***

A medical unit has significant needs regarding the purchase of a variety of products. These would be: chemicals and medicines, raw material for foods, electrical and medical equipment, computing equipment and the initial purchase of building materials. Every product that is purchased by a green medical unit should comply with certain specifications, in order to prove that it promotes environmental protection, general sustainability and conservation of energy and resources. Moreover is should be produced with procedures which are ethically responsible and respect the human and labor rights. The purchase of products and materials must be done from local producers and markets, not only to reduce energy consumption and CO_2 emissions for transportation needs, but also in order to financially support the local community and markets. ***(http://greenhospitals.net), (Karliner et al, 2011)***

Pre and post occupancy building evaluation should take place. Before occupancy, at least a two or three week evaluation of the building operation must take place. This way the energy consumption of the building, the CO_2 emission indicators and the indoor concentration of contaminants can be monitored and recorded, allowing the adjustment of heating and cooling systems, ventilation system, lighting and domestic hot water preparation system in order to achieve the target in energy conservation , waste minimization and reduction in CO_2 emissions. This way electric plumbing and medical equipment can be properly calibrated in order to be able to achieve the high quality oriented services of the medical unit. Post occupancy evaluation of the building may not only contribute in the remedy of operative problems of the hospital but also offer knowledge in the future investments in the sector of the green hospitals, variously contributing into the environmental protection. Educational seminars about greening the hospital processes for the staff and clients should be organized on an annual basis. The central point of the educational procedure, will be the explanation of the correlation between disease prevention, environmental protection and quality of life. This way not only the working staff will acquire the required knowledge for the operation of a green medical unit, but also the patients and common people will increase their awareness about the significance of an investment such as a green hospital and its benefits, and acquire extra motives to support such an investment. Finally the target and achieved results in the sector of energy conservation, CO_2 emissions' reduction, pollutants' reduction, financial benefits from the reduction of consumed energy, water and resources should be recorded on an annual basis and monitored by an environmental coordination chief , who will as well be responsible for the implementation of new measures that are to be taken in order to achieve a further promotion the green policy of the medical unit. Significant investments must be made for each hospital in order to promote the creation of a research and development team, which will have as a purpose the implementation and further development of green measures, in order to achieve the best possible greening results. This team must work in cooperation with the local community and government in order to promote the green favoring policy. Local networks with other green or ordinary hospitals must be made. Debates, dialogues and discussions between the different hospitals, people and the local government have to be made with main subject the targets and achievements of each hospital in the environmental protection sector. Bilateral and multilateral agreements between the hospital's stakeholders' and various public or private counter parts have to be made in order to financially support the cost intensive green investments on the hospital facilities. ***(http://greenhospitals.net), (http://hospital2020.org), (Hospital 2020 Organization, 2011), (Karliner et al, 2011), (Meir, 2012)***

4.3. Case Study: Northumberland Health Care Centre

Northumberland Health Care Centre is an effort that had started in Canada back in 2001. It refers to the creation of a state of the art green hospital and rehabilitation centre, taking into consideration a wider sustainability and environmental protection. It focuses mainly in energy conservation and CO_2 emissions' reduction, paying at the same time great attention in objects such as water and resources management, utilization of recycled building elements and reduction of waste. It considers the environmental impact of the medical facility, not only during its operation but attempts a life cycle analysis of the medical centre. This refers to building elements, medical equipment, medication and even transportation of patients and staff. Of course energy conservation remains one of the major targets of the effort. Northumberland health care centre started its operation as a pilot green medical unit in 2003. Since then it has continuously being improving and making steps towards a total green operation. ***(Vosburgh, 2001)***

The scope of the creation of the current green medical unit is the improvement of the working quality of the hospital's staff and the provision of quality medical care to patients. Common axis of these two targets is the promotion of environmental protection, providing a clean and safe environment not only for patients and staff, but also for the nearby areas' habitats. The creation of the green medical unit as a target is promoted by the hospital's staff operational methodology. This would be holistic thinking, post occupancy evaluation from both working staff of all levels (medical or not) and patients, promotion of the co operational spirit, front loaded design and environmental consideration behind every decision, operational or constructional. All in all the effort's philosophy is apart from the provision of quality medical services, a significant contribution in the reduction of the hospital's negative impact on the environment. In order to achieve this purpose a significant number of issues had been considered. These issues are presented in the following paragraphs, accompanied by comments regarding the status and the financial and environmental feasibility of their implementation. ***(Vosburgh, 2001)***

- ***Public education and awareness***

One of the main problems regarding the development of not only green hospitals and buildings , but also green economy's is the lack of knowledge and awareness of people about the advantages of such an effort. The first step is to make a systematic effort to educate and increase public awareness of green economy, not only for staff, but also for the nearby area's habitats. This way possible workers (medical and hospital staff or not) will acquire the required technical skills about the implementation of green measures to the hospital. Moreover people will learn about the advantages of supporting an effort such as a green hospital. Seminars providing the required knowledge in all sectors were held before even the construction of the hospital. Communication strategies and policies had been used in order to promote the environmental awareness of people and educate them for the importance of recycling and waste minimization processes. ***(Vosburgh, 2001)***

- ***Creation of a dense public transportation grid***

With this step the total CO_2 emissions and the overall negative impact due to transportation of patients and staff from their residences to the hospital have been reduced. The objective was the creation of a dense public transportation grid through bus routes , pedestrian paths and bicycle routes in order to reduce the transportation by private cars. Of course special routes for cars and ambulances had been created for emergencies. ***(Vosburgh, 2001)***

- ***Creation of underground parking spaces and greening of the hospital's surrounding area.***

In order to reduce the amount of cars around the hospital and create additional green areas, underground parking areas had been created. This way in the available space trees and deciduous, drought resistant and native perennial plants had been planted. This way, not only an evaporative cooling effect and natural shading effect had been created, but also a psychological effect, easing the difficult conditions during the hot summer days, had been implemented. Additionally a wind protection for the walls of the facility had been created. ***(Vosburgh, 2001), (Meir,2012)***

- ***South orientation of windows in patients' rooms and increase of natural day lighting***.

This step is one of the most significant steps that had been implemented in the facility. With the south orientation of windows the amount of solar heat gains in the summer is drastically reduced, reducing the required cooling load for the air-conditioning system. Additionally the amount of solar heat gains during the winter is increased reducing the heating load of the heating systems in the winter. Special large windows and skylights had been implemented in order to increase the natural day lighting, reducing the amount of energy consumption for lighting. In order to control the amount of solar heat gains in the summer an additional measure had been implemented. External shading devices had been installed on the windows, allowing only the required amount of solar radiation to enter the patients' rooms. Office rooms that do not require so sensitive internal conditions had been placed on north and east walls. ***(Vosburgh, 2001)***

- ***High insulation on walls and transparent elements***

High insulation materials had been unitized on walls in order to reduce energy demand for space heating and cooling, by reducing the heat losses from the internal to the external space. Additionally the openings (windows and glazed doors) had been designed with high insulation materials. All of them are double glazed, with aluminum frame with thermal bridges and low e-coatings in order to reduce the radiative heat losses. This way air infiltration had been reduced and heat losses had been diminished, allowing the required amount of sunlight to enter into the rooms. All building elements, either transparent or opaque had been designed with respect to the ASHRAE standards. ***(Vosburgh, 2001)***

- ***Compact Design***

With the implementation of compact design and avoidance of structural overdesign in the medical facilities the amount of heat losses and heat interaction within the surrounding environment had been reduced. Additionally conservation in the materials that had been used had been achieved. ***(Vosburgh, 2001)***

- ***Utilization of RES***

With the utilization of renewable energy sources such as passive solar heating and solar cooling, natural ventilation cooling and day lighting the primary energy consumption and CO_2 emissions had been drastically reduced. The use of photovoltaics had been proposed . It was rejected though, for the time being due to the high cost of such an installation. PV's utilization though will be a perfect solution for the near future were PV cells' prices are expected to drastically be reduced. ***(Vosburgh, 2001), (Anastaselos, 2012)***

- ***Utilization of recycled building elements' materials***

With the use of recycled materials as building elements, where it was feasible, significant contribution to the target of resource management and raw materials' conservation had been achieved. The cost of recycled building elements had been slightly higher but this was compensated not only by the reduction of building's negative environmental impact, but also with the compliance with future obligatory standards of buildings' legislation. The same philosophy exists with electric and medical equipment with utilization of materials such as copper and steel. ***(Vosburgh, 2001)***

- ***Increased durability of the building materials, electric and medical equipment***

With this step the life of the building had been significantly increased, reducing the needs of future reconstructing needs. This way future conservation in raw materials and resources is achieved, and less waste is created, not only protecting the environment but also reducing the cost of waste disposal (die out cost). This is promoted with the use of recycled/recyclable materials. The same philosophy exists in the use of medical equipment and electric facilities expanding their lifetime more than 50 years.***(Vosburgh, 2001)***

- ***Reduction of radon moisture and pesticides***

Transport of radon from the ground to the hospital is achieved by the fact that there is no basement in the hospital, but underground parking. Additionally insect screens and filters had been utilized in order to reduce the building's needs for pesticides.

Polyethylene vapour layers on the walls had been reducing the intrusion of moisture into the building. ***(Vosburgh, 2001)***

- ***Onsite water management and rain water absorb system***

With these 2 measures there will not be need for transportation of rain water in the sewage systems. Rainwater will be absorbed by the plantation ,stored for further use with cooling towers, or with proper canal systems will be driven into the sea. ***(Vosburgh, 2001)***

- ***Building orientation with respect to solar and wind rights.***

The medical facilities had been constructed in a way to achieve access to the solar radiation in the winter and cool wind breezes in the summer nights. This way and with the contribution of vegetation's evaporative cooling and shading effect, the heating load in the winter and the cooling load in the summer had been significantly reduced. ***(Vosburgh, 2001)***

- ***Avoidance of the use of ozone depleting chemicals and materials***

This way the negative environmental impacts on the atmospheric ozone is drastically reduced. ***(Vosburgh, 2001)***

- ***Minimization of waste strategies***

The materials that may wear off releasing amounts of pollutants such as formaldehyde had been avoided. Additionally minimization of packaging waste strategies were implemented. For example electrical cables were constructed by recycled materials, which at the same time are biodegradable and recyclable. ***(Vosburgh, 2001)***

- ***High efficiency heating and cooling equipment***

High efficiency heating natural gas boilers and chillers had been utilized. Cooling towers, which use the concentrated rainwater (as mentioned above) are used in order to reduce the water consumption. The energy needs had already been reduced due to the high insulation materials. With increased efficiency of heating and cooling equipment the amount of final and primary energy consumption is drastically reduced. Additionally there is a reduction in pollutants and greenhouse gases such as NOX and CO_2. ***(Vosburgh, 2001)***

- ***High efficiency lighting and appliances***

First of all natural day lighting had been utilized. High efficiency lamps had been used such as fluorescent lamps with high efficiency electronic ballasts and halogen lamps. For the exterior spaces metal halide lamps had been utilized again with the use of timers and photocells. The interior lighting had been controlled automatically with sensors and timers but there were internal switchers as well. ***(Vosburgh, 2001)***

- ***Water efficient equipment***

With the utilization of equipment with low water needs such as low flush toilets and water efficient showers the amount of water that is used had been drastically reduced. ***(Vosburgh, 2001)***

- ***High efficiency HVAC system***

With the implementation of high efficiency heating ventilation air conditioning system the amount of energy consumption for mechanical ventilation is drastically reduced. Additionally an automated energy management control system is utilized in order to reduce the energy use. Every HVAC installation was in compliance with the CSA Z317.2 standard (Special Requirements for HVAC systems in Health Care Facilities). Additionally HVAC with heat recovery system is planned to be utilized in the near future in order to further reduce the used energy for ventilation, heating and cooling needs. ***(Vosburgh, 2001)***

- ***Recycling policy***

An efficient programme for recycling was used. According to it every waste such as plastic, steel, copper, medicine residues etc was to be recycled, contributing in the resources conservation and management and avoiding waste disposal cost and negative impact on the environment as well. ***(Vosburgh, 2001)***

- ***Energy conservation in offices***

Offices do not require such sensitive thermal, optical and air quality comfort like medical spaces (with patients). For this reason there is greater potential for energy conservation, not only for the heating and cooling loads but also for ventilation and lighting sector. ***(Vosburgh, 2001)***

- ***Utilization of Gray and Waste water***

With the utilization of gray water (water from sinks, washing machines and shower) with vertical flow constructed wetlands and the recycling of wastewater (toilet and dishwasher water) with horizontal flow constructed wetlands great contribution in water conservation can be achieved. This methods though, are cost and land intensive and are expected to contribute further in the near future, when technology will be improved and cost will be reduced. ***(Vosburgh, 2001), (Meir,2012)***

- ***Building materials with low embodied energy***

With the utilization of low embodied energy building materials such as fly ash and stabilized soil block, the building materials' energy consumption is considered during their whole life cycle, achieving a more efficient result regarding energy conservation. The main disadvantage of this method is that it is cost intensive in comparison with ordinary building materials. It is expected to be utilized in the near future. ***(Vosburgh, 2001), (Meir,2012)***

- ***Use of locally produced building materials***

With the use of locally produced building materials, great amount of cost, energy and CO_2 emissions are saved due to the reduced needs of transportation. This strategy had been successfully used from the beginning of the green medical unit's construction. ***(Vosburgh, 2001)***

4.4. GREEN@Hospital: A program with Greek interest

GREEN@Hospital is a European pilot program with Greek interest due to the participation of the General Hospital of Chania, Crete and the Engineering faculty of Crete. GREEN@Hospital started its operation on the 1st of March 2012. It is cofinanced by the ICT Policy Support Programme and the Competitiveness and Innovation framework Programme. On every hospital that participates into the above programme an innovative and revolutionary electronic computer system will monitor on a 24 hour base the energy consumption and will automatically take the required actions in order to optimize the energy consumption on a daily basis. ***(http://www.cretalive.gr/), (Cristalli, 2012), (http://www.greenhospital-project.eu/)***

The importance of this programme lies in the fact that hospitals are the most energy intensive buildings due to their increased needs in heating and cooling and due to their continuous operation nature. This means that if energy conservation measures are successfully implemented in buildings such as medical units, the overall energy conservation target will be significantly promoted. ***(http://www.cretalive.gr/), (Cristalli, 2012), (http://www.greenhospital-project.eu/)***

GREEN@Hospitals automated installations observe the energy demand and consumption of hospitals and monitor and record the correlation between heating and cooling loads and thermal comfort, lighting needs and the optical comfort, and ventilation (either natural or mechanical) needs and the indoor air quality requirements. The next step is the automated adjustment of the energy consumption and appliances' performance in order for the optimized result to be achieved and the balance between the lowest possible energy consumption and an acceptable for the sensitive hospital levels indoor comfort to be maintained. Of course the internal temperature set point will be able to be adjusted manually as well for security reasons. In order for the pre mentioned result to be achieved state of the art computing and telecommunication technologies will be utilized. ***(http://www.cretalive.gr/), (Cristalli, 2012), (http://www.greenhospital-project.eu/)***

The GREEN@Hospital effort's main scope is the creation of a central control system within Europe, having as an upper target, not only energy conservation, but also CO_2 emissions' reduction, resources and water management and reduction of energy consumption cost.

GREEN@Hospital pilot programme has 11 participants which are the following:

- Engineering Faculty of Crete
- AEA-Loccioni Group (Italy)

- Schneider Electric Italia Spa (Italy)
- Fundacio Insititut de Recerca de L'Energia de Catalunya (Spain)
- Agefred Servicio, S.A. (Spain)
- IF Technology B.V. (Netherlands)
- Deerns Raadgevende Ingenieurs B.V. (Netherlands) ***(http://www.cretalive.gr/), (Cristalli, 2012), (http://www.greenhospital-project.eu/)***

The 4 hospitals, where the pilot application of GREEN@Hospital programme takes place are the following:

- Virgen de las Nieves Granada Hospital (Spain)
- Angona Hospital (Italy)
- General Hospital of Chania (Greece)
- De Mollet General Hospital of Barcelona (Spain) ***(http://www.cretalive.gr/), (Cristalli, 2012), (http://www.greenhospital-project.eu/)***
- The GREEN@Hospital programme is successfully applied on the general hospital of Chania. The outside appearance of this hospital has no difference with the appearance of an ordinary hospital. The utilization of the present programme though, offers great hope and opportunity in the reduction of hospital building's negative impact on the environment not only in the future but also in the present as well. ***(http://www.cretalive.gr/), (Cristalli, 2012), (http://www.greenhospital-project.eu/)***

Figure 6: General hospital of Chania, Crete, where the GREEN@Hospital programme is successfully applied. (http://www.cretalive.gr/)

4.5. The future of green hospitals

From what has been mentioned during the green hospital concept analysis a conclusion that green hospitals contribute to energy and resource conservation can be made. For the time being the short and long term, the target of a green hospital is the conservation of energy, water and resources and the reduction of negative impact on the environment. There is a big question though. Is this enough? What about the environmental damage that has been occurred from medical units and ordinary buildings until now? The answer is the creation of the regenerative design of medical units concept. As the technology progresses and the cost of such a concept is becoming lower the scope of the state of the art medical units will stop being the reduction of negative impact on the environment, but the correction of environmental problems that have been caused until know and the creation of a positive impact on the environment. A state of the art green regenerative hospital will be able to produce more energy that it consumes with the utilization of RES and provide it to the world for other than medical everyday purposes, replacing fossil fuels. The advanced water treatment system of a medical unit will be able to recycle waste and grey water and provide the communities with clean, disease free potable and other use water. This way the valuable and reducing resources will be protected and conserved in a global level and a correction to the environmental damage that has been occurred until that time will take place. Of course as it has been mentioned above in order for this to take place, significant technological progress and cost reduction must occur. In other words the concept of regenerative design green hospital will be available only in the long term. ***(http://greenhospitals.net), (Karliner et al, 2011)***

In the next figure the comparison between green and regenerative buildings takes place:

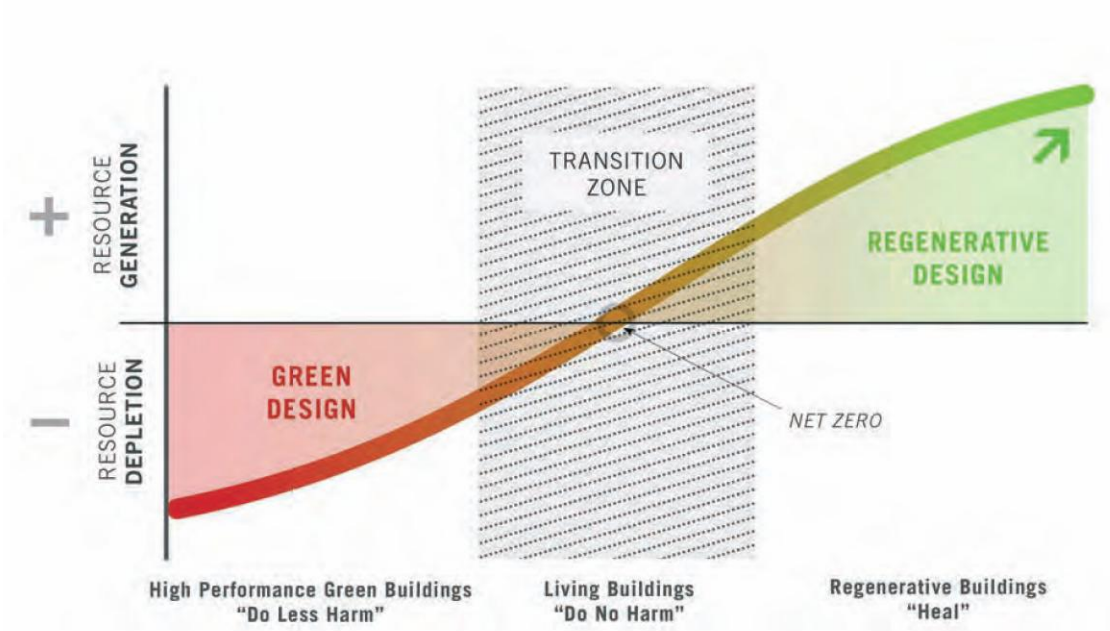

Figure 7: Comparison of Green buildings' and Regenerative building's effect on the environment (http://greenhospitals.net), (Karliner et al, 2011)

B. EXPERIMENTAL PART

5. Preliminary energy audit of a medical unit – The case of Arogi Euromedica Rehabilitation Center

5.1. Introduction

As a practical implementation of the knowledge that has been acquired during the bibliographic part of the thesis, a preliminary energy audit has been conducted on the facilities of Euromedica Arogi, a rehabilitation center that is Located in Pylaia, in the Eastern part of Thessaloniki, Greece, during August and September of 2012. First of all the location and the orientation of the building has been studied. The preliminary audit was selected over a complete energy audit to be conducted mainly due to the small time period that was available for the completion of the dissertation and the lack of the required measuring infrastructure, such as energy flow meters etc. Additionally the collection of the required data and the inspection of the energy consuming devices had to be done in the less possible visits due to the fact that a medical unit has restricted access and strict schedule in order to maintain the high quality of medical services that it offers to its patients. A complete energy audit would require 6 months - 1 year in order to be successfully completed, in order to cover energy consumption and energy performance of the building during both heating and cooling periods. Furthermore the object of the experimental part is a practical utilization of the knowledge that had been acquired during the bibliographic part. It has been judged by the writers of the dissertation that a preliminary energy audit can successfully achieve this scope, fulfilling at the same time successfully the time limits and given deadlines for the completion of the dissertation. Some data about the climatic conditions of the location, such as outdoor mean monthly temperatures and solar radiation have been collected. Additionally a walkthrough energy audit around the facilities of Euromedica Arogi has been conducted, during which general inspection of the energy consuming devices and thermal zones took place. Moreover the architectural drawings of the healthcare facilities have been studied, assessed and redesigned on computer based software, such as AutoCAD. Then data about the building elements' ability to conduct heat have been collected. A special classification has been made between transparent and opaque building elements. The most important energy consuming devices for space heating, cooling and ventilation, domestic and swimming pool hot water have been inspected. Their operational characteristics have been analytically studied. Every lighting system, that is used in the medical unit has been analytically inspected and recorded, with special attention to its operational characteristics and schedule. Furthermore data about the achieved illuminance in each space have been collected and presented. A subject of special importance was the internal gains and the solar gains of the building. The main difference between the medical units and ordinary buildings is the fact that the internal gains in medical units are really greater due to the existence of heat producing medical equipment. The internal gains contain heat gains from lighting, people and medical and ordinary equipment. The next step was the calculation of the heating and cooling loads in order to achieve and maintain the thermal comfort which is suitable for patients and people under rehabilitation. Moreover data about internal space temperature and relative humidity and indoor air quality have been collected and presented in order to assess the medical unit's thermal comfort and examine if it is compatible with ASHRAE's or EPBD's standards. Additionally the energy performance of the building was calculated with the utilization of TEE-KENAK's (ΕΛΟΤ EN ISO 13790) software. The energy demand and final energy consumption for space heating and cooling, domestic hot water preparation, ventilation and lighting was calculated, followed by the calculation of the total primary energy consumption and the total CO_2 emissions that occur from the operation of the building. The electricity consumption of medical equipment has been measured with the utilization of PPC bills for the last two years due to the preliminary nature of the energy audit. Finally Energy Saving Measures in order to reduce primary and final energy consumption and CO_2 emissions have been proposed and financially and technically assessed.

5.2. Selection and general description of the audited medical unit - Arogi Euromedica Rehabilitation Center

The reason that a rehabilitation center was selected instead of a hospital was that during the bibliographic research numerous scientific articles about energy audits on hospitals and clinics were identified, while the scientific references about energy audits on rehabilitation centers were very few. This phenomenon is even more visible in Greek scientific references, where articles about energy audits on Greek rehabilitation centers can be met very rarely. In order to maintain and promote the innovative character of the present thesis and achieve the highest possible contribution in a scientific area that has not been researched so much, at least until the present day , a rehabilitation center was selected to be studied over a common hospital. Furthermore with this choice a stable basis for the conduction of energy audits on rehabilitation centers will be created offering the opportunity for future research to be conducted on this area by future possible researchers.

Euromedica Arogi is located in Pylaia, Thessaloniki as it has been mentioned above and has been constructed in 2009-2010. It is a state of the art rehabilitation center that consists of some of the most modern and extended rehabilitation facilities among Balkans. Arogi is located on a 3 floor 14500 m^2 building that has more than 200 beds. It has 4 swimming pools and other specialized equipment that can promote the main scope of the present medical unit, which is the rehabilitation of the patients that are in the recovering stages of a psychological or physiological trauma or illness. It has physiatrist , physician and neurology sectors, while special attention is paid on the physiotherapy, speech therapy and psychological services' provision to the patients.

The general procedure for the conduction of the energy audit on the facilities of the rehabilitation center is more or less the same with the process that is followed for a hospital, medical unit, or more generally non residential buildings. The main target for the conduction of the energy audit is the calculation of the annual primary and final energy consumption for space heating and cooling, domestic hot water preparation, lighting and ventilation. The main difference between a hospital and a rehabilitation center is that the second does not have a surgery room and so complex and energy intensive medical equipment. The thermal comfort and indoor air quality requirements are not so sensitive as the requirements of a surgery room that is contained on a hospital. On the other hand though, a rehabilitation center and more specifically Arogi has the sensitive requirements of the swimming pools' water thermal comfort and sterilization standards. This is the main thermal load and amount of consumed energy that exists within the rehabilitation center. For this reason great attention will be paid on the swimming pools' thermal loads, water's temperature and surrounding space's thermal comfort and air quality requirements. Furthermore energy saving measures will be implemented for the reduction of final and primary energy consumption and CO_2 emissions of the medical unit with special attention on the energy conservation and CO_2 emissions' reduction regarding the swimming pools' water preparation procedures. All in all the thermal and energy performance of Arogi and more generally a rehabilitation center can be described as a medium behavior between a hospital and an energy intensive high quality services' hotel.

5.3. Topographic and Climatic Data of Arogi Euromedica Rehabilitation Center

The first step of the conduction of the energy audit is the collection of some topographic and climatic data about the rehabilitation center's location. The topographic data are necessary in order to calculate the exact location of the assessed medical unit on earth and determine the climatic zone that it belongs to. Climatic conditions not only affect drastically the indoor desired temperature set point and thermal comfort, but also determine the amount of energy that is required in order to achieve and maintain these indoor desired conditions. Furthermore according to these climatic data the legislative framework of each country, regarding the desired internal temperature, relative humidity and indoor air quality set points is determined. This data may provide valuable information about transmission and distribution losses of each internal space, let alone the solar heat gains, which exist in each room depending on its orientation. Finally crucial information about the implementation of Energy Saving Measures such as installation of solar collectors, PV cells or even a wind turbine may be extracted from these data. The climatic and topographic data have been collected with the utilization of computer based software RETSCREEN 4. In the next two tables the climatic and topographic data about the location of Euromedica Arogi are collected. The collection of the climatic and topographic data has been done with the utilization (by the RETSCREEN software) of a metering station which is located in International Airport of Thessaloniki "Makedonia" in Mikra, Thessaloniki. This metering station is the nearest possible metering station to the assessed medical unit.

Table 30: Topographic data for Euromedica Arogi (www.retscreen.net)

Characteristic	***Value***
Latitude (^{o}N)	***40,5***
Longitude (˚E)	***23***

Elevation (m)	***4***
Earth Temperature Amplitude (°C)	***22,7***

According to KAPE Euromedica Arogi's location belongs to Climatic Zone C.

Table 31: Climatic Characteristics for Euromedica Arogi's location on a monthly and annual base (www.retscreen.net), (http://re.jrc.ec.europa.eu/pvgis)

Month	*Ambient air temperature*	*Relative humidity*	*Solar radiation on horizontal surface and daily basis*	*Atmospheric Pressure*	*Wind Speed at height of 10 m*	*Earth Temperature at height of 0 m*
Measuring Unit	°C	%	Wh/m²/d	kPa	m/s	°C
January	4,4	74,4%	1600	96,6	2,9	1,5
February	6	69,8%	2250	96,4	3,3	3,3
March	9	69,5%	3270	96,3	3,1	8,0
April	13,3	68,2%	4730	96,0	2,9	14,1
May	18,9	65,4%	5600	96,1	2,7	20,6
June	23,6	57,8%	6640	96,1	3,4	26,1
July	25,9	55,5%	6470	96,1	3,4	28,9
August	25,6	57,0%	5670	96,1	3,1	28,3
September	20,8	62,8%	4380	96,3	2,9	23,2
October	16	70,9%	3110	96,6	2,5	15,9
November	10,2	75,6%	1900	96,5	2,7	8,2
December	5,7	77,3%	1170	96,6	2,8	2,5
Average value on an annual basis	14,9	67,0%	3910	96,3	3,0	15,1

In the next picture, a satellite photography of Euromedica Arogi Rehabilitation Center is presented with the utilization of Google Earth PC software.

Figure 8: Satellite photography of Euromedica Arogi Rehabilitation Center

The main sides of the building are sides A and B. Azimuth Angle of A side was found to be equal to 315 and its orientation can be characterized as northwest. For B side the azimuth angle was found to be equal to 135 and the orientation is found to be southeast. Orientation for side C and D is considered to be Northeast (45 azimuth angle) and Southwest (225 azimuth angle) in respect. The orientation of the building can be characterized as northwest.

Figure 9: Northwest side A of Euromedica Arogi (www.euromedica-arogi.gr)

Figure 10: Southeast side B or Euromedica Arogi (www.euromedica-arogi.gr)

Towards the north west, northeast and southwest sides of Euromedica Arogi there are no other buildings that provide a shading effect on the studied rehabilitation center. Towards the southeast side a midwifery clinic , named Genesis is located, but it is not considered to affect significantly the incoming solar radiation on Euromedica Arogi.

(the parts where it affects are going to be calculated with the implementation of horizon shading factor feature)

5.4. Walkthrough energy audit

The second step of the energy audit that has been conducted on Euromedica Arogi was a walkthrough energy audit, which was performed on 23/8/2012, with the guidance of the technical manager of the rehabilitation center, Mr. Zachopoulos. A tour around the energy consuming devices and conditioned spaces of the rehabilitation center was performed in order to get familiar with the space heating and cooling and ventilation system, lighting system and domestic hot water and hot swimming pool's water's preparation system. Some general notes about the characteristics of each system and conditioned spaces were held. The spaces where access was allowed for inspection were the following:

5.4.1. Domestic hot water and swimming pool water preparation room

This space contains the DHW and swimming pools' water pretreatment system. Water is pumped from the mains and it is preheated though a heat exchanger until the temperature of 85^{o}C, mainly for sterilization and disease spread prevention reasons. Then the required amount of Cl_2 is added and water is driven to the secondary natural gas boilers' room, in order to be prepared either for DHW use, or for swimming pool and space heating use,

5.4.2. Boilers' room

In this space there are 3 natural gas boilers. 2 of them are responsible for space heating and one of them is responsible for domestic hot water and swimming pools' water preparation. Water which is utilized for bathrooms is pumped from DHW room's preheating system with a temperature, which is equal to 45^{o}C. Water, which is used for kitchen/cooking purposes, must have temperature equal to 70^{o}C. During the summer months, when the cooling needs are significant, a heat recovery system for the heat that is rejected from the coolers is utilized. With this methodology, the rejected heat from coolers is utilized in order to heat DHW and swimming pools' water during the cooling period. The boilers' efficiency has been calculated equal to 92% from the technical service of the medical unit.

Figure 11: Boiler room with the 3 utilized natural gas boilers

Figure 12: Boiler room's pumping system and heat exchanger

5.4.3. BEMS control room

Euromedica Arogi has installed a state of the art automated building energy management system. The control of this system takes place in the BEMS control room. The BEMS system is responsible for the monitoring and automatic or manual adjustment of space heating and cooling system, DHW and swimming pool's water's temperature and Cl_2 concentration, desired water flow rate, lighting systems' operational schedule and illuminance, ventilation of internal spaces and indoor air quality, elevators , auxiliary systems and internal spaces' temperature and relative humidity. For the ventilation system's operation there are two sensors, one internal and one external. Depending on the relative humidity of internal and external spaces and the desired RH set point, BEMS system automatically selects the intake of external clean air, or the filtering and recirculation of internal air.

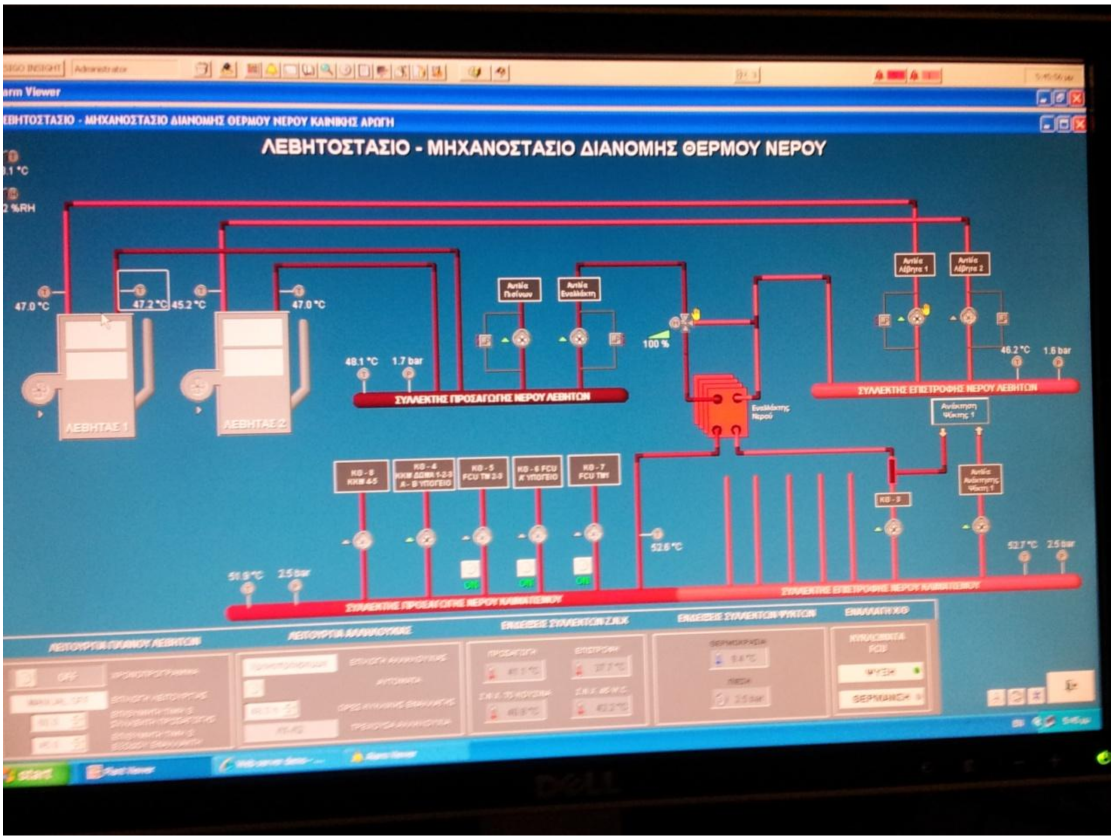

Figure 13: Interface of the BEMS system

In the same room the security cameras' based monitoring systems of the hospital are installed as well. This room is observed in a 24 h basis every day.

5.4.4. Medical Gases room

This room contains the necessary infrastructure for O_2 distribution for medical purposes in the medical unit. There is a central tank that contains liquid oxygen. The oxygen is turned into gaseous phase with the implementation of a heat exchanger. Then with a specially designed distribution system it is distributed into patients' rooms and medical appliances. Of course there is a second tank and a secondary distribution system for the case of emergency,

5.4.5. Lighting systems

Lighting systems of various spaces of the medical unit were inspected and assessed. Their analytical presentation will take place in a following section. Manual use of lights is allowed for the users only in patients' rooms. Every other lighting system is either automatically adjusted by the BEMS system, or automatically controlled with the implementation of occupancy and movement sensors. The implementation of LED lights has been assessed in the past by the medical units' management team but it was rejected due to the high cost of the implementation of such an idea.

5.4.6. Swimming pools

There are 4 swimming pools in the rehabilitation center. Rehabilitation activities take place until 8 o clock in the evening. After that time an economy mode is automatically set by the BEMS system, where energy conservation is promoted. The central swimming pool's water's temperature set point is equal to 33 ^{o}C, the desired pH is equal to 7,30 and water's Cl_2 concentration is equal to 0,58 mg/l. The second swimming pool's water's temperature set point is equal to 31,8 ^{o}C, the desired pH is equal to 7,47 and water's Cl_2 concentration is equal to 0,55 mg/l. The third swimming pool's water's temperature set point is equal to 30,9 ^{o}C, the desired pH is equal to 7,40 and water's Cl_2 concentration is equal to 0,50 mg/l. The fourth swimming pool is used for special purposes. It is the smallest one and its characteristics are adjusted according to the user's preferences and medical condition. For the central swimming pool's space and for the period when the energy audit had been conducted the internal temperature set point was equal to 28,5^{o}C. Above this point cooling mode is automatically enabled, while for temperatures bellow this point. heating mode is automatically enabled. For relative humidity above 59% dehumidification mode is enabled, while for relative humidity bellow 20% humidification mode is enabled.

Figure 14: Euromedica Arogi's Central Swimming pool (www.euromedica-arogi.gr)

Figure 15: Swimming pools 2 and 3 (www.euromedica-arogi.gr)

5.4.7 . Emergency energy system room

This room contains an oil burner and a generator in order to cover the electricity and space heating, cooling, domestic hot water, lighting and ventilation needs of the medical unit in case of power loss or natural gas boilers' malfunction.

5.4.8.Overflow system room

The central swimming pool has an overflow system. Water that overflows is automatically driven in the overflow tank. Then it is pumped to specially designed devices that monitor and adjust its pH, Cl_2 content and the required chemicals are added. Then water is filtered and pumped through heat enhancers in order to acquire the desired temperature. Finally it is pumped again in the swimming pool.

5.4.9.Space cooling systems.

There are 2 water coolers which are located on the buildings terrace. These coolers operate at 11,5 and 8,5 ^oC in respect. In the nearby terrace area free and available space equal to more than 1000m^2 has been identified for the implementation of energy saving measures such as for the installation of photovoltaics or solar thermal collectors or a cogeneration system.

Figure 16: Water chiller installed on the terrace of the rehabilitation center

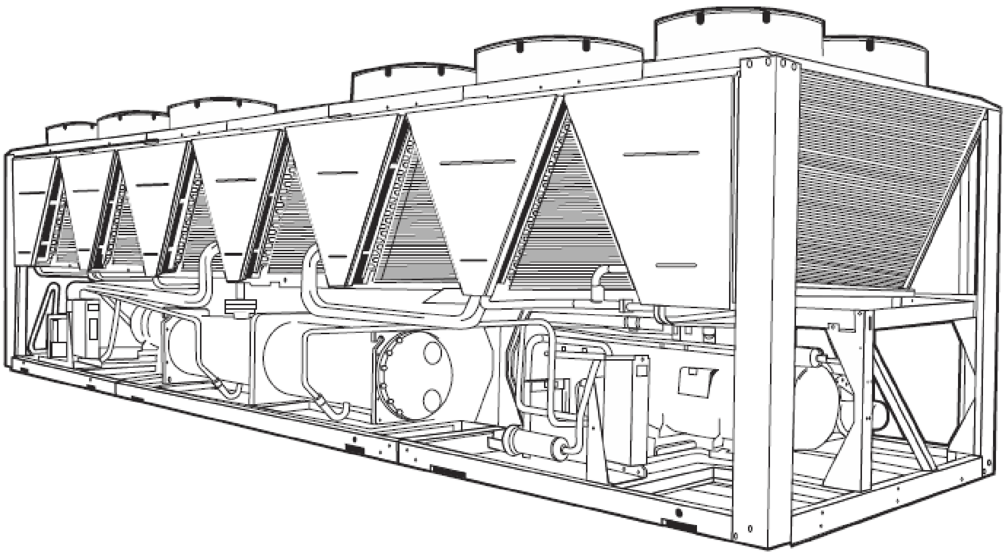

Figure 17: Utilized Chiller's Sketch

Figure 18: Heat recovery system for the utilization of rejected heat from the water chillers

5.4.10. Operational schedule and Number of medical and office staff

During the conduction of the walkthrough energy audit, a discussion with Arogi's manager about operational schedule and number of workers was made. The information that was extracted can be considered valuable, regarding the operational schedule and the energy consumption of space heating, cooling, DHW, ventilation and lighting systems. Additionally the information about the number of medical and general staff can be crucial regarding the production of occupants' internal heat gains and their effect on the internal temperature set point.

The operational schedule of the medical units is presented in the next lines:

- Swimming pools: 08:00-19:00
- Examination Rooms- Labs- Physiotherapy Spaces 08:00-19:00
- Cafeteria- Restaurant: 08:00-19:00
- Patients' rooms: 24h/day
- Intensive Care: 24h/day

- Doctors', general staff's and management board's offices: 08:00-15:00

The number of medical staff that works in the rehabilitation center is equal to 180 persons, while the same number for general staff is equal to 50 persons.

5.4.11. Unified operation of space heating, cooling and DHW preparation system

The whole operation of the space heating , cooling and domestic hot or cold water preparation system can be simply described in the following lines. From the walkthrough energy audit about 10 thermal zones had been identified in the rehabilitation center. Domestic and swimming pool hot water can be prepared with the utilization of natural gas boilers that are located in the boiler's room. This water can be alternatively pumped in 10 air conditioning units (AHU) that are installed in the medical center and utilized in order to heat the air which is circulated through the thermal zones of the medical unit. This way space heating needs are covered. Cool water is prepared in the chillers and can be used when it is needed. For space cooling the cold water from the chillers is pumped to the air conditioning units. Then the air is cooled and circulated through the thermal zones. This way space cooling is achieved. During the cooling period the cooling needs are significant. For this reason the 2 coolers that are installed in the rehabilitation center are significantly heated. With a piping-heat exchangers' network this rejected heat can be recovered in order to be utilized in order to preheat DHW and pools' water until the temperature of 55^{o}C. This way not only the coolers are efficiently cooled, increasing significantly their efficiency, but also the rejected heat is utilized in order to reduce the consumed energy for DHW and pools' water preparation. This methodology provides a remarkable example of final and primary energy conservation, CO_2 emissions' reduction and cost savings.

The conclusion of the walkthrough energy audit was that the average monthly electricity's cost is equal to 15000 Euros /month, while the monthly cost for natural gas utilization is equal to 11000 Euros/month. The implementation of the heat recovery for the utilization of chiller's rejected heat is found to be very energy and cost efficient, let alone the environmentally friendly character that it gives to the rehabilitation center. One disadvantage that has been found was the lack of utilization of renewable energy sources within the medical unit's facilities. More than 1000 m^2 of available area has been identified on the roof of the medical unit for the implementation of a RES solution. An ideal solution could be the implementation of hybrid photovoltaics, with the combination of an absorption chiller. This way a 100% renewable based solution can be created for the trigeneration of heat for space heating and DHW preparation, space cooling and cold water preparation and power for electricity needs. As it has been extracted from the bibliographic review that had been conducted during the bibliographic part, cogeneration or trigeneration is an ideal solution for medical units.

5.5. Achieved Indoor Comfort - Thermal comfort - Relative Humidity - Indoor Air Quality

After measurements that were held and observation of BEMS system a variety of data were collected about the achieved internal comfort of different spaces within the medical unit. The results are presented in the following table:

Table 32: Internal Spaces' Temperature Set point, Relative Humidity, Air quality and Conditioning method

Type of Space	Temperature Set point Cooling Period (^oC)	Temperature Set point Heating Period (^oC)	Relative Humidity Cooling Period (%)	Relative Humidity Heating Period (%)	Indoor air Quality	Conditioning Method
Lab	26	20-22	50	40	30 m^3/h/person	FCU with integrated economy mode
Patients' Rooms	26	22	50	40	30 m^3/h/person	FCU with integrated economy mode
Medical Staff's Offices	26	22	50	40	30 m^3/h/person	FCU with integrated economy mode

Management team's Offices	***26***	***22***	***50***	***40***	***30 m^3/h/person***	***FCU with integrated economy mode***
Waiting Rooms	***26***	***22***	***50***	***40***	***30 m^3/h/person***	***FCU with integrated economy mode***
Patients' WC	***-***	***22***	***-***	***-***	***60 m^3/h/person***	***FCU with integrated economy mode***
Swimming Pools' Spaces	***28***	***28***	***NA***	***NA***	***7 changes/ hour***	***Independent Air Handling/Conditioning Unit***
Non Conditioned Spaces	***-***	***-***	***-***	***-***	***2-6 air changes / hour***	***-***
Examination Rooms	***26***	***20-22***	***50***	***40***	***30 m^3/h/person***	***FCU with integrated economy mode***
Physiotherapy Rooms	***26***	***20-22***	***50***	***50***	***30 m^3/h/person***	***FCU with integrated economy mode***
Common Use Spaces	***26***	***22***	***50***	***40***	***2-6 air changes / hour***	***FCU with integrated economy mode***
Bar Restaurant	***NA***	***NA***	***NA***	***NA***	***NA***	***Independent Air Handling/Conditioning Unit***
Control Room	***NA***	***NA***	***NA***	***NA***	***NA***	***Split unit***

The internal temperature and relative humidity set points have been adjusted from the medical unit's technical team according to the external climatic conditions. For cooling period the external temperature is considered to be equal to 37 ^{o}C and the relative humidity equal to 45%. For the heating period the external temperature is considered to be equal to -5 ^{o}C and the relative humidity equal to 80%. According to these climatic conditions, which have been extracted from the average outside climatic conditions for Pylaia, Thessaloniki, the internal thermal comfort and air quality set points have been selected in order to be compatible with Greek and European legislation.

Data that have been collected showed that the rehabilitation center's internal temperature, relative humidity and indoor air quality are compatible with both EPBD's and ASHRAE's regulations about medical units, with variations less than +/-5%.

5.6. Medical unit's plans' presentation and separation into thermal zones

The original architectural plans have been acquired from the constructional team of Euromedica Arogi and studied and processed . These are presented in the following figures:

Figure 19: General plan of Euromedica Arogi

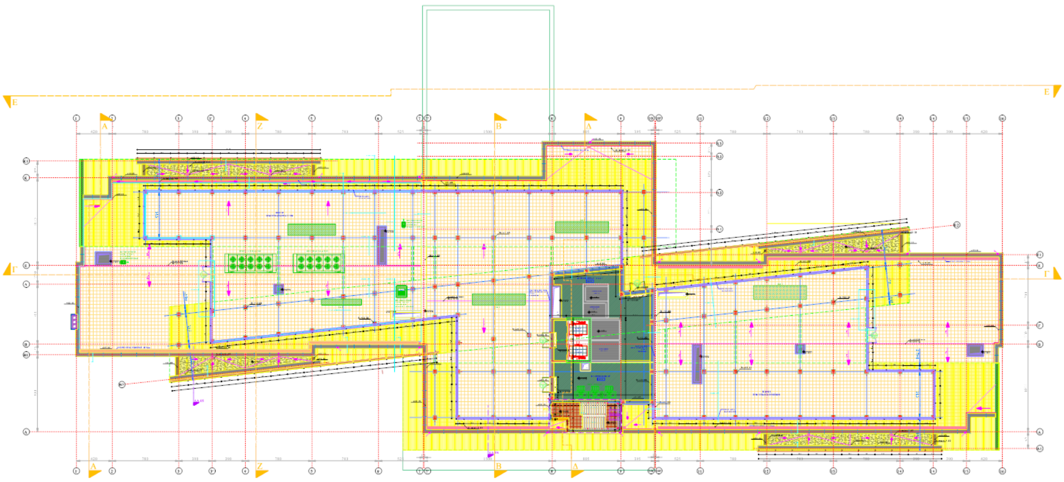

Figure 20: Terrace with AHU and coolers installed plan

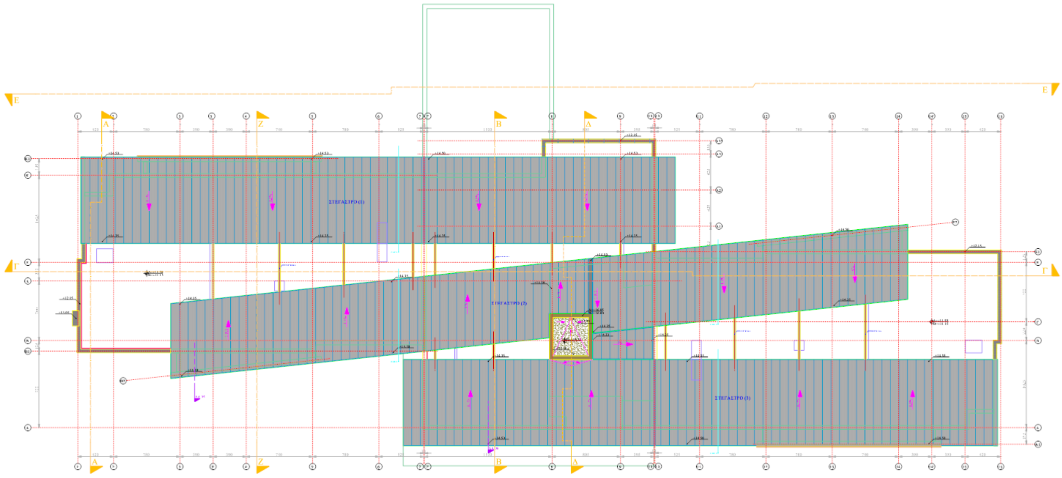

Figure 21: Plan of Shelter on the roof, where there is available space for future RES installations

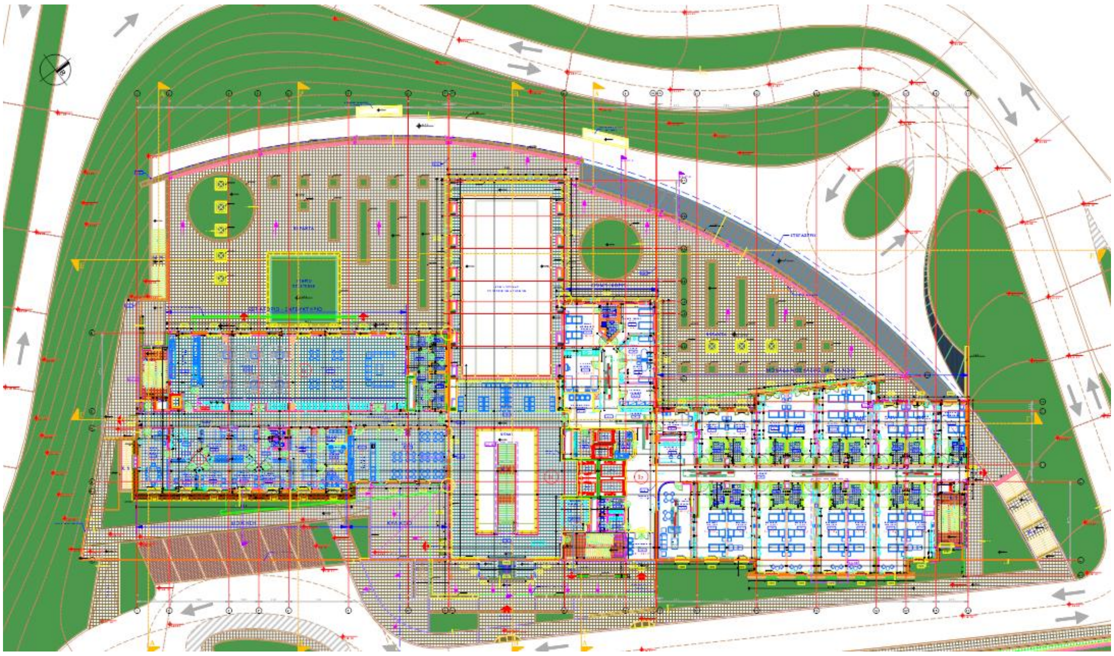

Figure 22: Zero Floor Plan

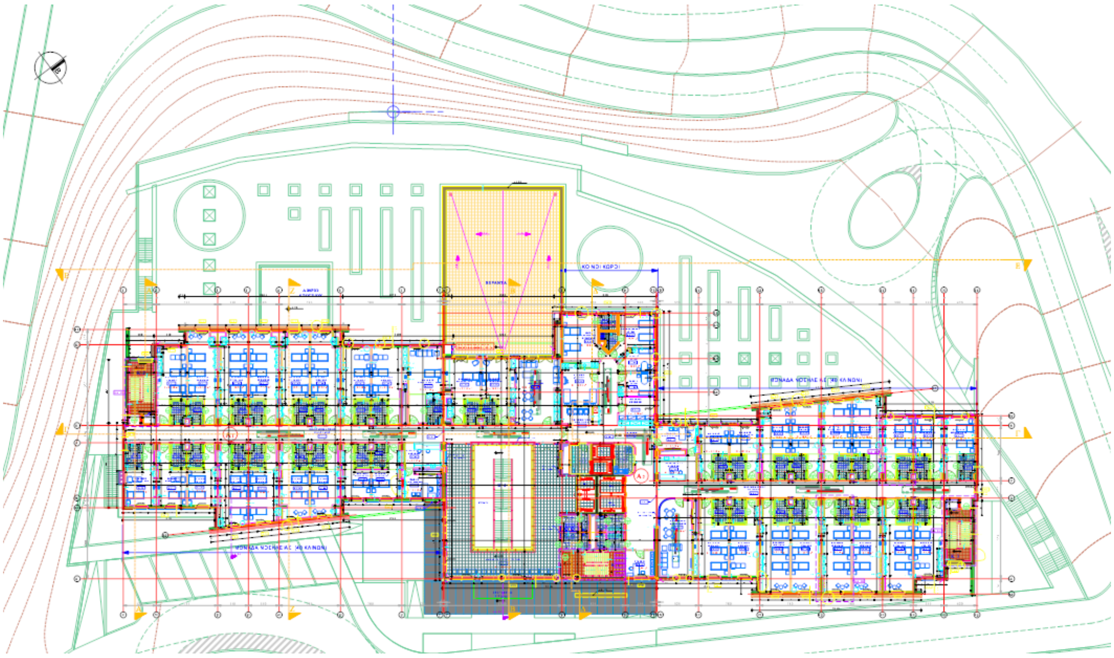

Figure 23: First Floor Plan

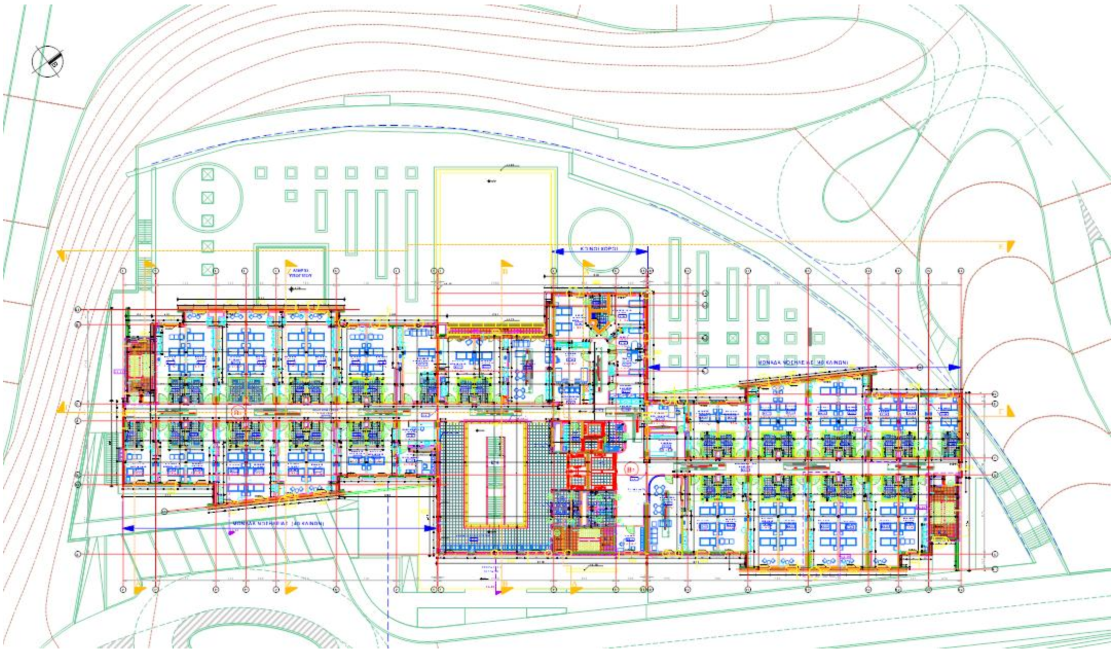

Figure 24: Second floor Plan

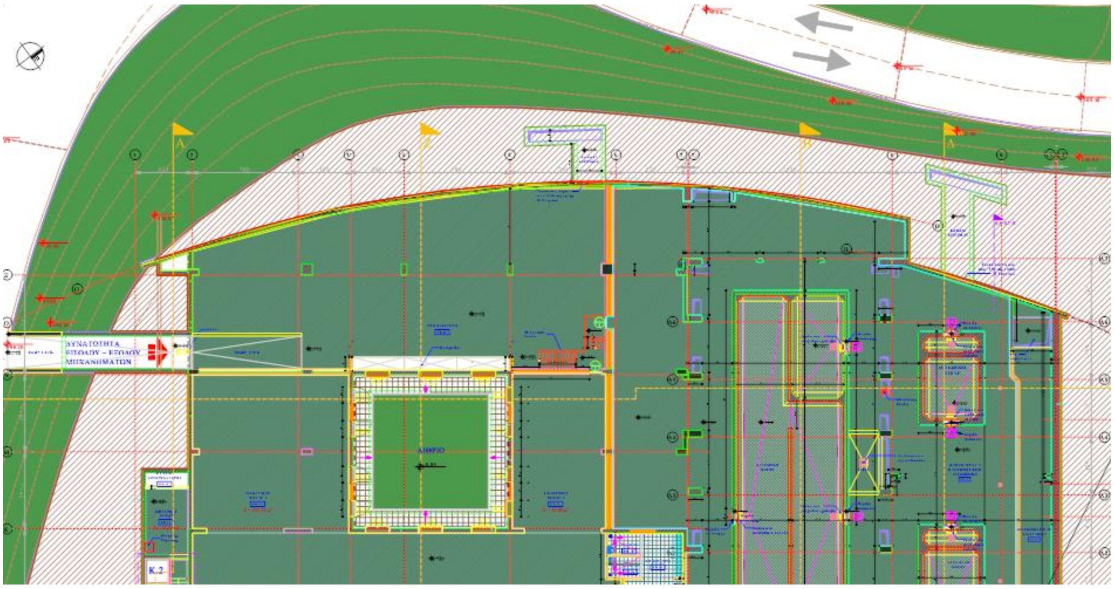

Figure 25: Basement B 1/2 plans

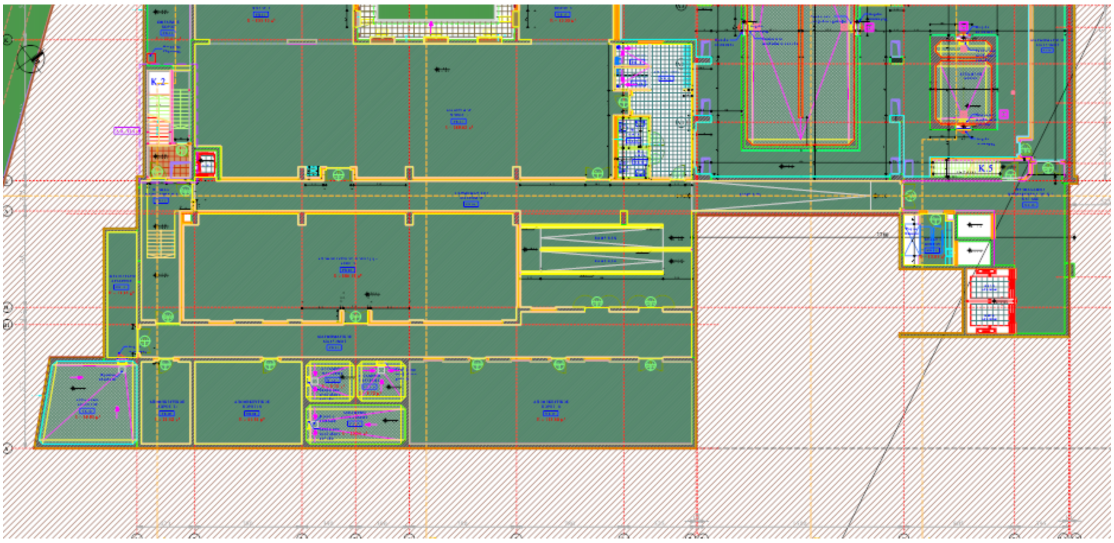

Figure 26: Basement B 2/2 plans

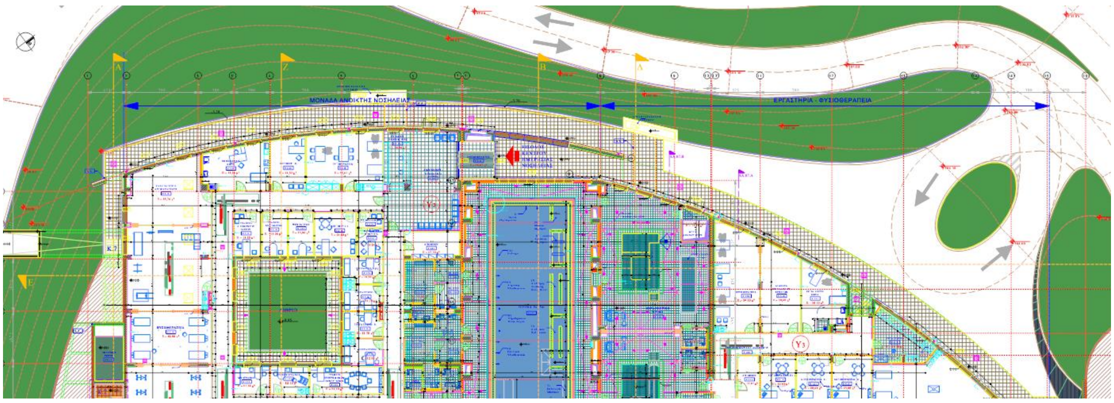

Figure 27: Basement A 1/2 Plans

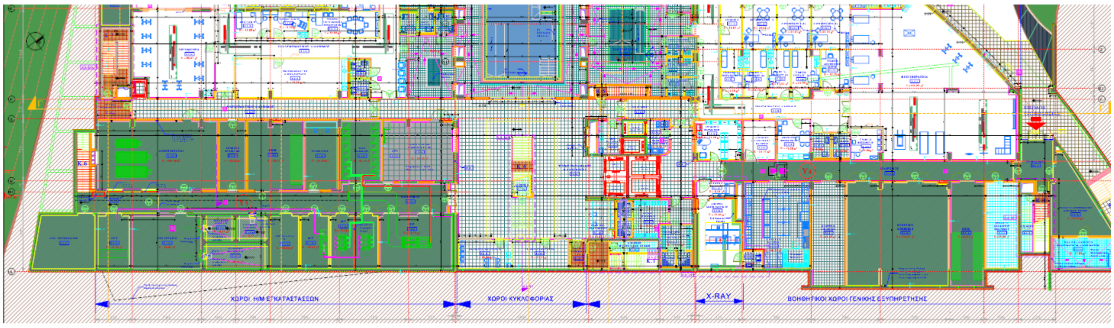

Figure 28: Basement A 2/2 Plans

5.6.1.Definition of thermal zones

The separation and definition of thermal zones had taken place according to the purpose of use of each space. If two nearby thermal zones have similar (less than 4^{o}C difference) temperature, then during the separation procedure an assumption that no heat transfer between the two zones takes place is done. In other words for simplification reasons an assumption is made that heat transfer takes place only between conditioned and unconditioned spaces and between conditioned spaces and external air spaces. The temperature, relative humidity and air quality set points of each thermal zone (where they are available) are presented in the previous section.

In the following figures the thermal zones of the medical unit are presented.

- ***Basement B*** is considered to be an unconditioned space. It is adjacent to the ground. It contains swimming pools' water's tanks and natural gas and oil storage tanks. Its total area is equal to 3055 m^2 and its height equal to 3 m.

Operational Schedule: 24 h/day

Lighting systems: Occupancy Sensors

- Basement A part where, boiler room, substation, medical gases room, BEMS control room and swimming pools water control room are located is considered to be an unconditioned space. Its total area is equal to 714 m^2 and its height equal to 3,5 m.

Operational Schedule: 24/day

Lighting systems: Occupancy Sensors

Number of occupants: 3

- ***Thermal Zone 1-Basement A Examination - Physiotherapy and doctor's and general staff's offices***

  This thermal zone is adjacent on its southwest side with external air, on its southeast with unconditioned space of boiler room, substation and BMS control room. on its northwest side with external air. On its north east side it is adjacent to the conditioned space of the swimming pools. A part of it is adjacent to external air, as it encloses an open space. Its floor is considered adjacent to unconditioned space.

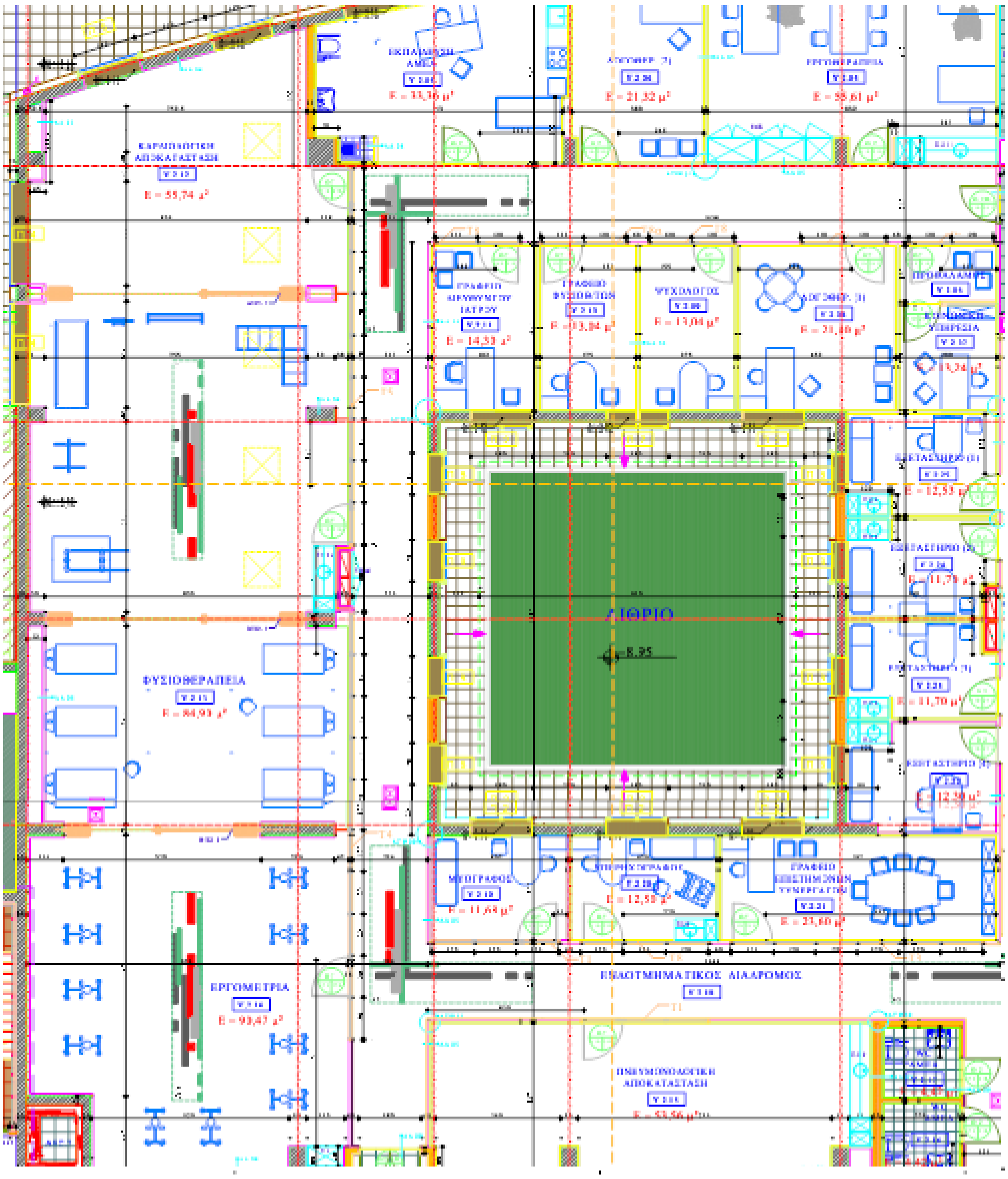

Figure 29: Basement A Examination - Physiotherapy and doctor rooms

Operational Schedule: 08:00-19:00 (for offices 08:00-15:00)

Lighting systems: Occupancy Sensors

Occupants :87

Total Area: 1439 m^2

Total Height 3,5 m

Figure 30: Physiotherapy and rehabilitation practices' room (www.euromedica-arogi.gr)

- ***Thermal Zone 2-Basement A small swimming pools' space***
  This conditioned space is adjacent on its south west with conditioned space on its northwest with external air, on its northeast with conditioned space and on its south west with conditioned space. Its floor is adjacent to unconditioned space.

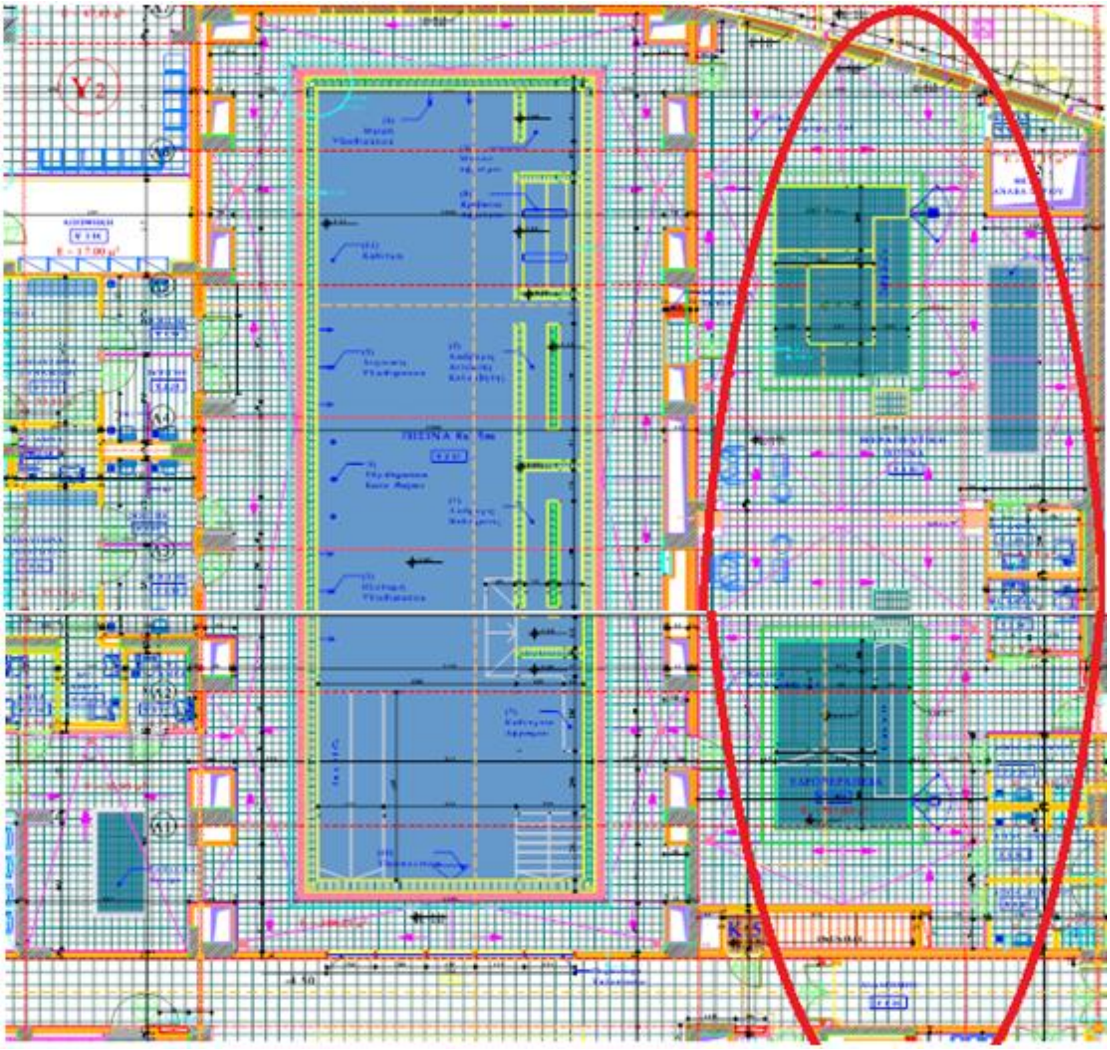

Figure 31: Basement A small swimming pools' space

Operational Schedule: 08:00-19:00

Lighting systems: Occupancy Sensors

Occupants :10

Total Area: 348 m^2

Total Height 3,5 m

- ***Thermal Zone 3-Basement A Main Entrance- Waiting and common space room***

This space is adjacent on its southeast with external air and its floor is adjacent to unconditioned space. Its height covers all of basement, zero floor, floor one and two with total height equal to 14m. Its roof is adjacent to external air.

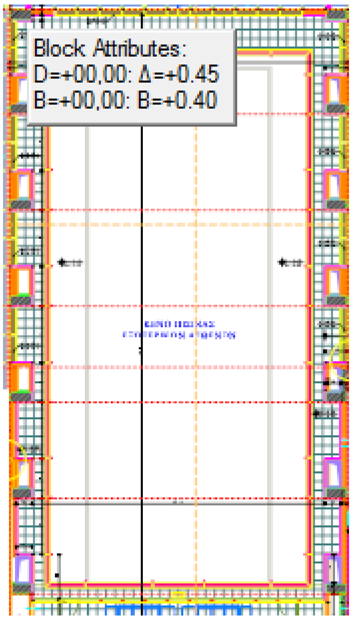

Figure 32: Basement A Main Entrance- Waiting and common space room

Operational Schedule: 24h/day

Lighting systems: Occupancy Sensors and Timers

Occupants :10 (Only the working Staff)

Total Area: 411 m^2

Total Height 14 m

Figure 33: Common Space-Entrance Space (www.euromedica-arogi.gr)

- ***Thermal Zone 4-Basement A main swimming pool's space***

This space contains the main swimming pool and basement A and zero floor of the medical unit. On its northwest side it is adjacent to external air, while its floor is adjacent to unconditioned space and its roof adjacent to external air.

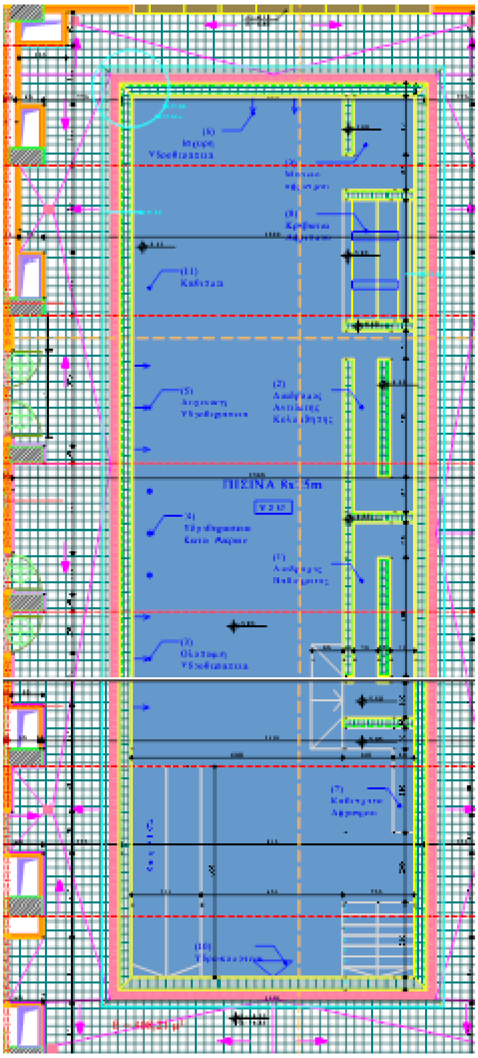

Figure 34: Basement A main swimming pool's space

Operational Schedule: 08:00-19:00

Lighting systems: Occupancy Sensors

Occupants :30

Total Area: 502 m^2

Total Height 7 m

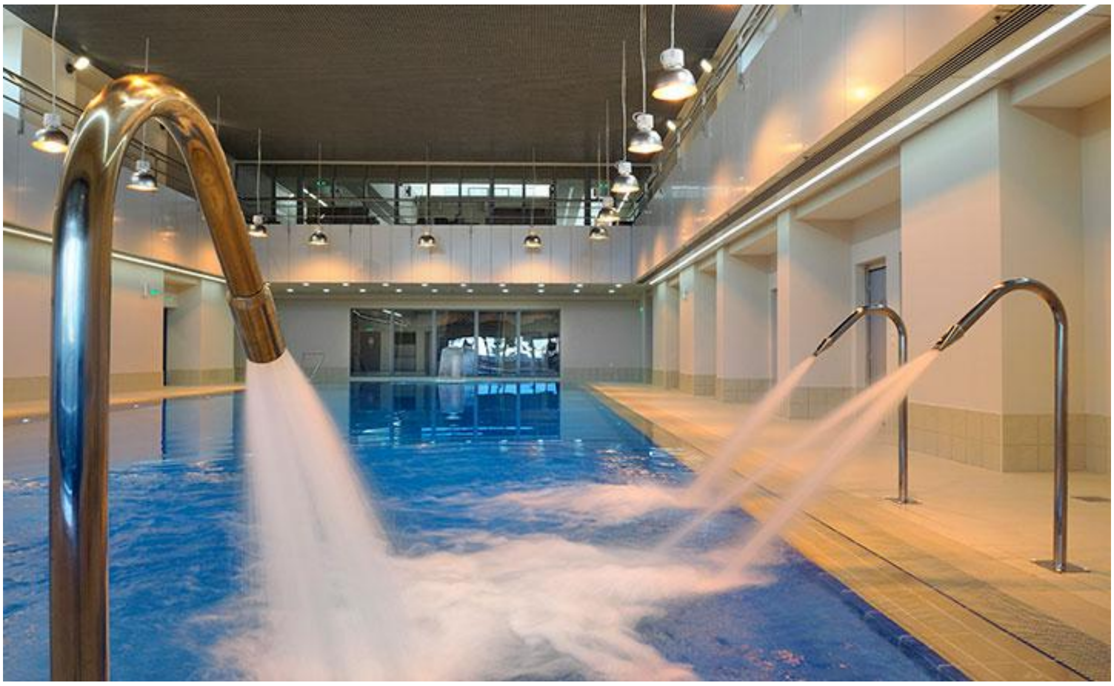

Figure 35: Main swimming pool's thermal zone (www.euromedica-arogi.gr)

- ***Thermal Zone 5-Basement examination rooms***

This space is adjacent on its northwest, southwest and northeast side with external air. Its floor is adjacent to unconditioned space.

Figure 36: Basement Examination Rooms

Operational Schedule: 08:00-19:00

Lighting systems: Occupancy Sensors

Occupants :30

Total Area: 1565 m^2

Total Height 3,5 m

- ***Thermal Zone 6-Zero Floor Restaurant and Cafeteria room***

This space is adjacent on its southwest , north west and southeast side adjacent to external air.

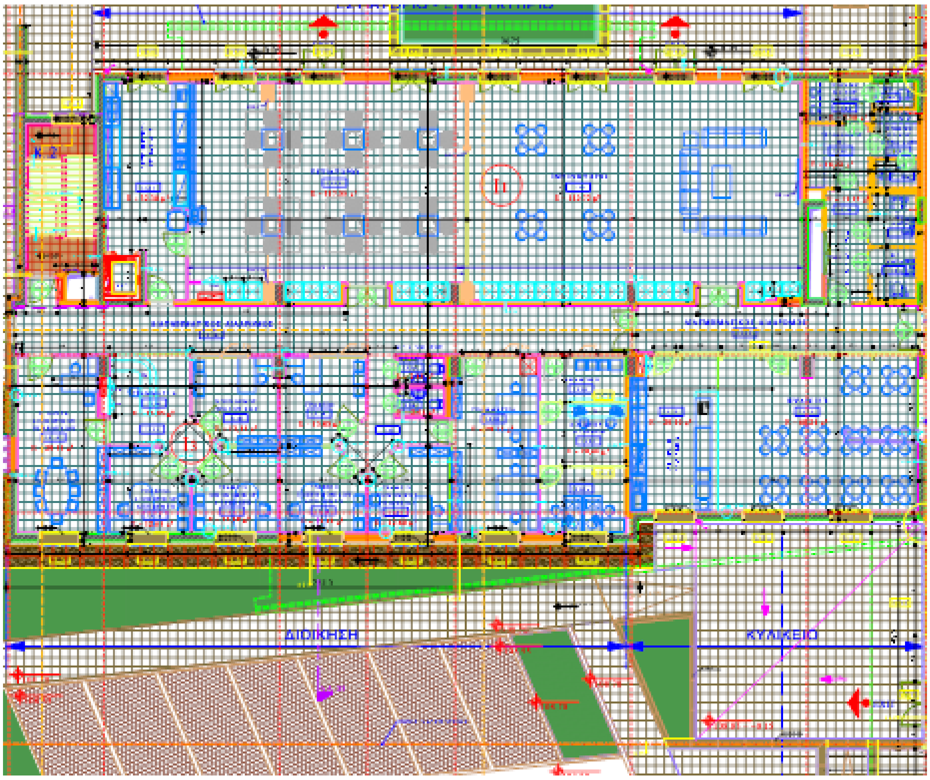

Figure 37: Zero Floor Restaurant and Cafeteria room

Operational Schedule: 08:00-19:00

Lighting systems: Occupancy Sensors

Occupants :30

Total Area: 787 m^2

Total Height 3,5 m

- ***Thermal Zone 7-Zero Floor 40 bed clinic-patient rooms***

This space is adjacent on its north west, north east and southwest side with external air.

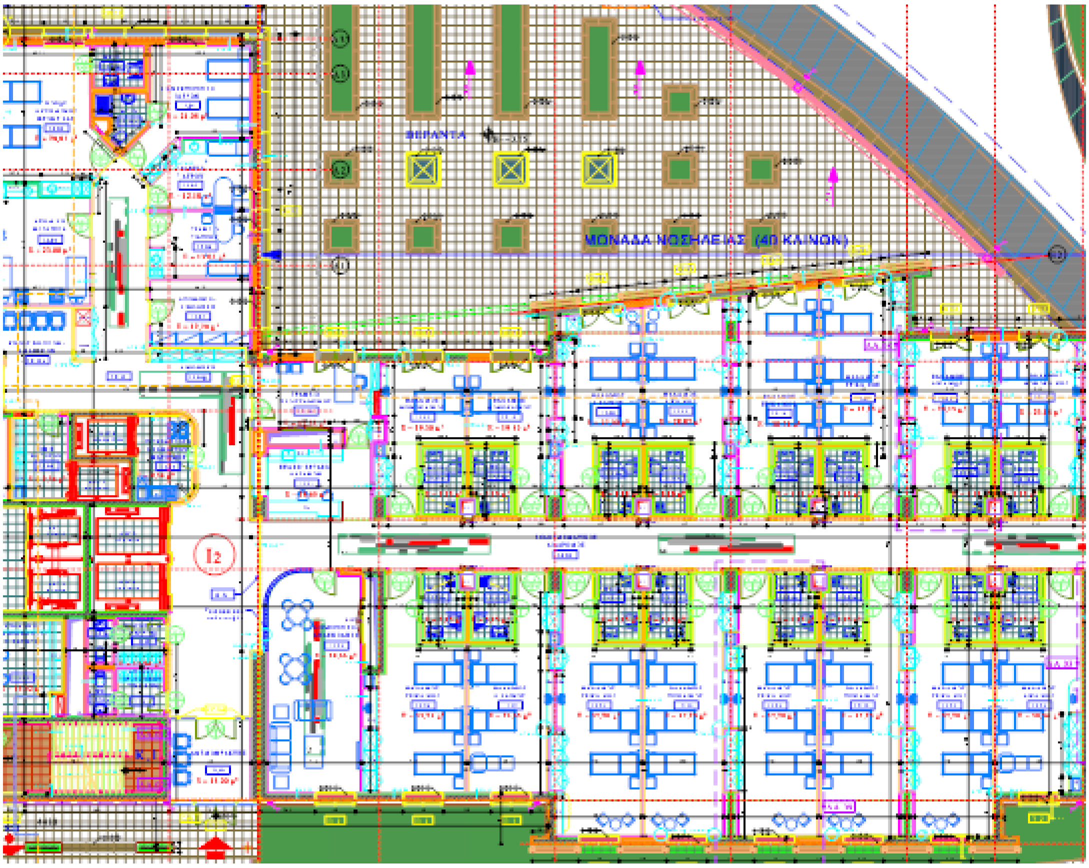

Figure 38: Zero Floor 40 bed clinic-patient rooms

Figure 39: Zero Floor 40 patient room (www.euromedica-arogi.gr)

Operational Schedule: 24h/day

Lighting systems: Occupancy Sensors and manual switchers

Occupants :70 (0,5 visitor per patient)

Total Area: 1097 m^2

Total Height 3,5 m

- ***Thermal Zone 8-1st floor clinic- patient rooms a***

This space is adjacent on its southwest , north west and southeast side adjacent to external air.

Figure 40: First Floor clinic-patient rooms a

Figure 41: First Floor Patient's room (www.euromedica-arogi.gr)

Operational Schedule: 24h/day

Lighting systems: Occupancy Sensors and manual switchers

Occupants :70 (0,5 visitor per patient)

Total Area: 837 m^2

Total Height 3,5 m

- ***Thermal Zone 9-1st floor clinic- patient rooms b***

This space is adjacent on its north west, north east and southeast side to external air.

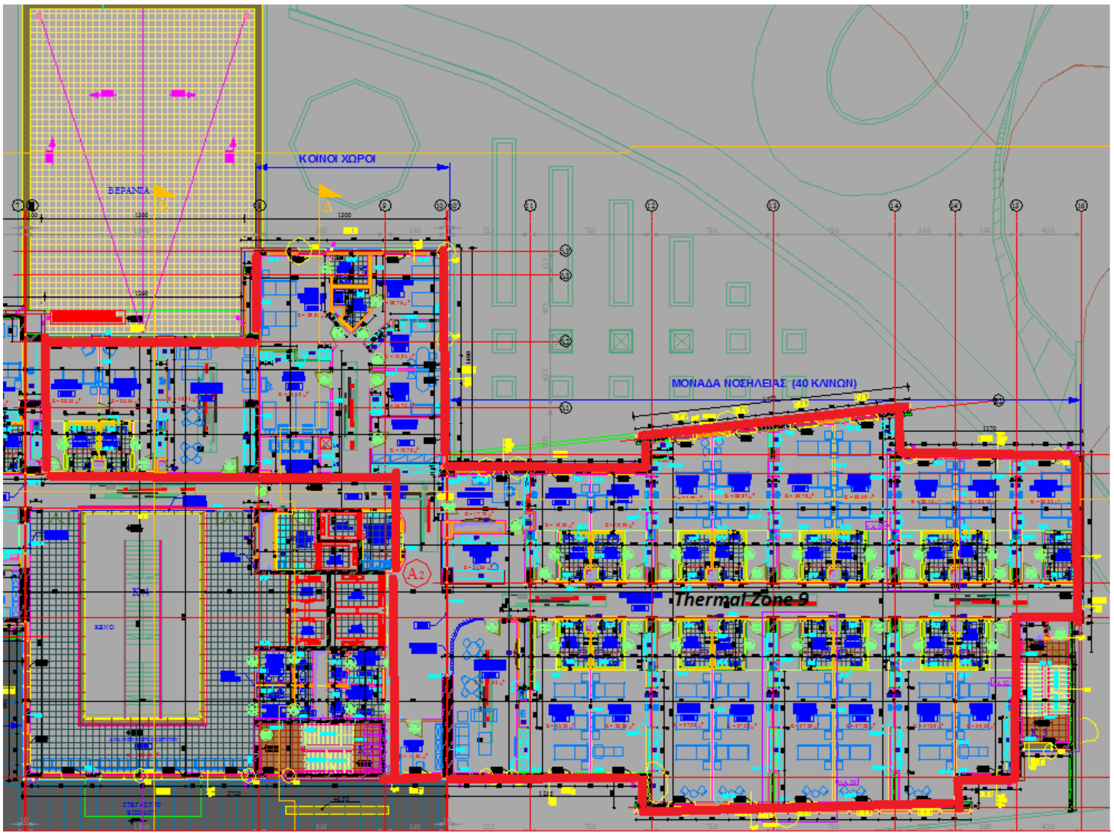

Figure 42: 1st floor clinic - patient rooms b

Operational Schedule: 24h/day

Lighting systems: Occupancy Sensors and manual switchers

Occupants :70 (0,5 visitor per patient)

Total Area: 1279 m^2

Total Height 3,5 m

- ***Thermal Zone 10-2nd floor clinic- patient rooms a***

This space is adjacent on its southwest, northwest and southeast side adjacent to external air. Its roof is adjacent to external air as well.

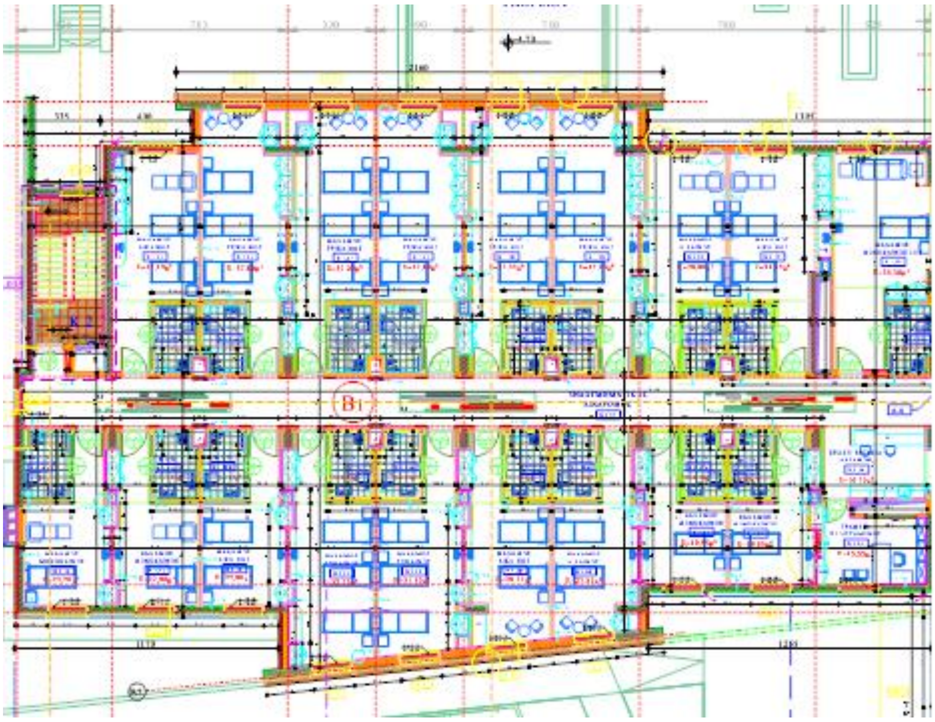

Figure 43: 2nd floor clinic- patient rooms a

Operational Schedule: 24h/day

Lighting systems: Occupancy Sensors and manual switchers

Occupants :70 (0,5 visitor per patient)

Total Area: 847 m^2

Total Height 3,5 m

- ***Thermal Zone 11-2nd floor clinic- patient rooms b***

This space is adjacent on its north west, north east and southeast side to external air. Its roof is adjacent to external air as well.

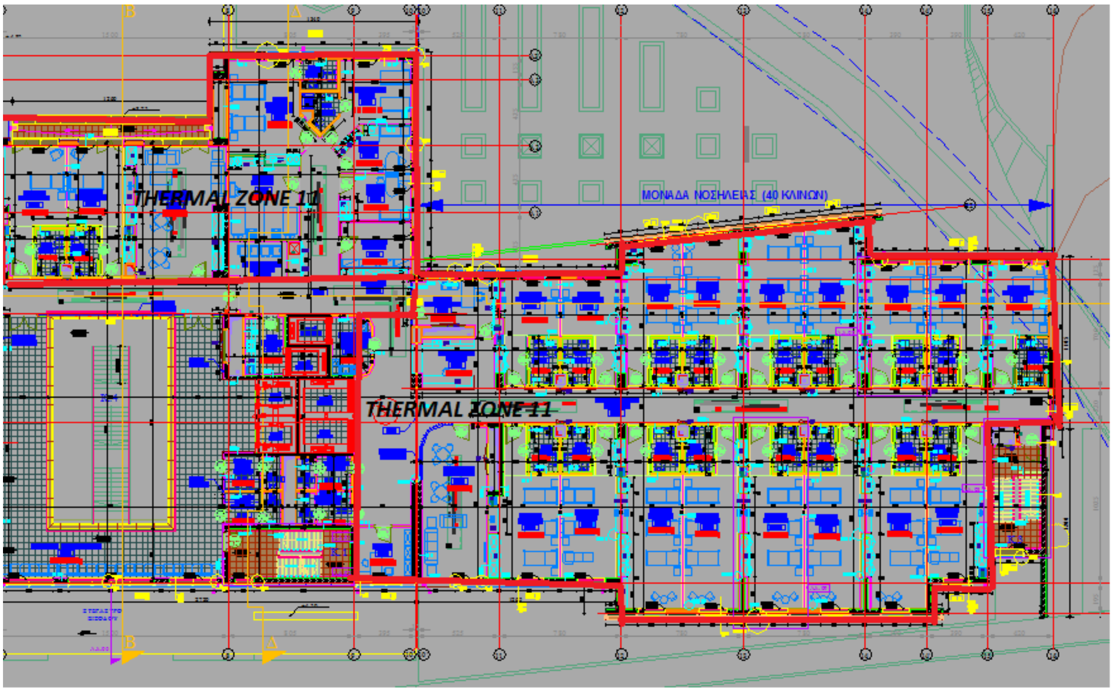

Figure 44: 2nd floor clinic- patient rooms b

Figure 45: 2nd floor patient's room (www.euromedica-arogi.gr)

Operational Schedule: 24h/day

Lighting systems: Occupancy Sensors and manual switchers

Occupants :70 (0,5 visitor per patient)

Total Area: 1304 m^2

Total Height 3,5 m

5.7. Building Envelope

The procedure that must be used in a complete energy audit for the assessment of the building envelope is the following: First of all sampling holes must be made on different building elements in order to identify the materials and layers of each building element. Then the thermal conductivity of each building element must be found from bibliographic sources. By dividing the thickness of each layer with its conductivity, each layer's thermal resistance is found. If the thermal resistance of all layers that form the building element are added then the total thermal resistance of the building element Rt is calculated. Each building element's thermal transmittance is equal to 1/Rt. ***(Anastaselos, 2012)***

In the present case there was no permission by the management of the hospital to make sampling holes on the building elements of the medical unit. Additionally the study about the installation of the building elements was not available to the writers. The writers were reassured by the technical management of the medical unit that opaque building and transparent building elements were compatible with the Greek and European legislation that existed during the construction of the rehabilitation center. Additionally they were informed that opaque elements were insulated with adequate amount of extruded and expanded polystyrene. For this reason the building elements were considered to be compatible with Greek (Law **ν. 3661/2008** and K.E.ν.A.K.) and European (Directive 2002/91/EC) legislation and maximum acceptable values for thermal transmittance that existed until 2010, according to K.E.ν.A.K..

The medical unit's building's elements' thermal conductivities are considered to be compatible with the suggested ones by European and Greek legislation. The main opaque elements that are comprised in the building are concrete, bricks, steel, insulation materials and steel frames. The brick based building elements that have been identified, had a total thickness of 0,3 m. Two types of concrete based building elements have been identified. The first type was placed on vertical walls and had a total thickness equal to 0,3 m, while the second type was used in the corners as a structural reinforcement and had a total thickens equal to 0,5 m. As transparent building elements, a complex combination between double glazed aluminum windows without low e coatings and glazed facades is utilized, with thermal transmittance values equal to 2,8 W/m^{2}K and 1,8 W/m^{2}K in respect. Their total thermal transmittance is considered to be equal to 2,5 W/m^{2}K. For opaque building elements U value for vertical walls, adjacent to external air is considered to be equal to 0,4 W/m^{2}K, for roofs adjacent to external air 0,4 W/m^{2}K and for floors adjacent to the ground 0,75 W/m^{2}K. For vertical walls that are adjacent to unconditioned space the overall thermal transmittance is considered to be equal to 0,8 W/m^{2}K. Additional information about proposed maximum U value of the building's elements by the Greek and European legislative framework is provided in the Appendix.

In the next table, the total area of each building element for each thermal zone, which was calculated after inspection of the rehabilitation center's drawings is presented. Building elements with no comment refer to separating areas of conditioned spaces with external air or ground. If a building element refers to a separating area between conditioned - unconditioned space, then it is marked with a comment on the next table. Building elements, which separate a conditioned space from another conditioned one, are not mentioned in the next table, as it is considered that no heat transfer takes place between 2 different conditioned spaces with temperature difference lower than 4 ^{o}C:

Table 33: Characteristics of building envelope for each thermal zone

Total Area of each building element (m^2)	***Brick (m^2)***	***Brick To not Conditioned Space (m^2)***	***Concrete (m^2)***	***Concrete To not Conditioned Space (m^2)***	***Double Glazed Aluminum Windows - Glazed Facade Transparent Elements' combination (m^2)***	***Roof (m^2)***	***Floor(m^2)***	***Floor To not Conditioned Space (m^2)***
Thermal Zone								
1	***19,5***	***104,1***	***286,7***	***7***	***174,3***	***652***	***-***	***1439***
2	***-***	***-***	***19,25***	***-***	***25,2***	***-***	***-***	***348***
3	***24,7***	***4,03***	***100,1***	***30,8***	***178,5***	***411***	***-***	***411***
4	***35***	***-***	***12,6***	***-***	***59,5***	***502***	***-***	***502***

5	*8,4*	-	*400,2*	-	*88,2*	*468*	-	*1565*
6	*51,5*	-	*166,6*	-	*119,7*	-	-	-
7	*104,1*	-	*207,8*	-	*156,5*	-	-	-
8	*91,4*	-	*159,95*	-	*136,5*	-	-	-
9	*143,15*	-	*188,5*	-	*175,35*	-	-	-
10	*108,7*	-	*173,6*	-	*166,25*	*847*	-	-
11	*125,83*	-	*166,43*	-	*190,05*	*1304*	-	-

Note: Only building elements for areas that are separating conditioned spaces with external air or conditioned and unconditioned spaces are recorded.

5.8. Analytical recording of energy consuming devices for space heating, cooling, DHW preparation, ventilation and lighting

After the walkthrough energy audit, an analytical energy audit has been conducted. Every energy consuming device responsible for space heating, cooling, ventilation, DHW and swimming pool water preparation and lighting was inspected and recorded.

5.8.1.Lighting Systems

The lighting systems that are installed in Euromedica Arogi rehabilitation center are parted from cabling systems, switchers and the actual lighting systems. The actual lighting systems can be classified into common lighting systems, emergency lighting systems, safety/security lighting systems and night lighting systems. In the next table the recorded illuminance of different spaces of the medical unit are presented.

Table 34: Illuminance of different spaces

Space	*Lighting Power (lux)*
Patients' rooms	*200*
Corridors	*150-250*
Examination rooms	*300-400*
Labs	*300-400*
Storehouse	*150*
Restaurant	*300*
X-Ray room	*150-250*
Kitchen	*400-500*
Laundry room	*400*

The illuminance of each space was designed to be in compliance with EPBD and ASHRAE's standard 90.1.2004. The reflecting coefficient is calculated to be equal to 0,7 for roof, 0,5 for walls and 0,5 for floors in respect. It should be mentioned that switchers for the operation of lighting systems are placed only in patients' rooms. Every other lighting system is either automatically or manually controlled by the BEMS system, or automatically turned on and off with the implementation of timers, and occupancy or movement sensors. Lighting systems in the corridors outside the patients' rooms can be manually controlled with switchers as well, the access to which is only available to medical staff.

Each patient room has 1 36 W lamp and 2 18w reading lamps which can be operated manually by the user. Patients' room's WC has 2 13 W lamps. Additionally 3 bed patients' rooms have 1 26 W fluorescent lamp. Labs have lighting systems of type IP 40. Waiting rooms have 35 W halogen lamps, while common WCs have fluorescent lamps. Swimming pools' spaces have IP 40 fluorescent type lamps and 150 W metal halide, bell type lamps. Offices have IP 20 type lamps and each office has 4 18 W fluorescent lamps. At the main and emergency exits IP 54 type 8 W fluorescent lighting systems have been installed, while in the entrance of X-ray room a red light 5W/220W lamp is installed.

From the combination of information regarding the description of lighting systems for each space, that was collected and the operational schedule of each space, an effort to extract information about the operational schedule of each type of lighting systems was made , in order for the estimation of energy consumption for lighting systems to become more efficient.

The analytical recording of the lighting systems that have been identified in the rehabilitation center are presented in the following table:

Table 35: Euromedica Arogi's lighting systems' list

Number	*Type*	*Number of Units*	*Operational Schedule*	*Type of Control*	*Annual Energy Consumption (kWh/year)*
1	*Suspended Ceiling Type*	*163*	*08:00-19:00*	*Occupancy*	*30983*

	Fluorescent Lighting system with 4 18 W lamps and type DISANO 873 type blinds			***Sensors - Timers***	
2	***Fluorescent Lighting system with cover 2 X 18 W IP 54 DISANO 827 type***	***15***	***08:00-19:00***	***Occupancy Sensors - Timers***	***1425***
3	***Fluorescent Lighting system with cover 4 X 18 W IP 54 DISANO 827 type***	***28***	***08:00-19:00***	***Occupancy Sensors - Timers***	***5322***
4	***Fluorescent Lighting system with cover 2 X 36 W IP 54 DISANO 827 type***	***13***	***08:00-19:00***	***Occupancy Sensors - Timers***	***2471***
5	***Fluorescent Lighting system with cover 2 X 18 W IP 40 DISANO 825 type***	***3***	***08:00-19:00***	***Occupancy Sensors - Timers***	***285***
6	***Fluorescent Lighting system with cover 4 X 18 W IP 40 DISANO 825 type***	***161***	***08:00-15:00***	***Occupancy Sensors - Timers***	***19474***
7	***Fluorescent Lighting system with cover 2X 36 W IP 40 DISANO 825 type***	***42***	***08:00-19:00***	***Occupancy Sensors - Timers***	***7983***
8	***Fluorescent roof lighting system IP 65 type 2 X 58 W of type DISANO ECHO 930***	***169***	***08:00-19:00***	***Occupancy Sensors - Timers***	***51754***
9	***Fluorescent industrial type lighting system IP 65 type 2 X 58 W of type***	***18***	***08:00-19:00***	***Occupancy Sensors - Timers***	***5512***

	DISANO ECHO 930				
10	***Suspended ceiling lighting system with 2 compact fluorescent lamps X 26 W of type FOSNOVA ENERGY 8***	***718***	***24***	***Occupancy Sensors and manual switches***	***161291***
11	***Suspended ceiling lighting system with 1 compact fluorescent lamp X 26 W of type FOSNOVA ENERGY 8***	***213***	***24***	***Occupancy Sensors and manual switches***	***23924***
12	***Suspended ceiling lighting system with 2 compact fluorescent lamps X 13 W of type FOSNOVA ENERGY BIS with reflector***	***270***	***24***	***Occupancy Sensors and manual switches***	***30326***
13	***Suspended ceiling lighting system with incandescent lamp of 35 W of type FOSNOVA CRISTAL 2 60610***	***94***	***08:00-19:00***	***Occupancy Sensors - Timers***	***8685***
14	***Suspended ceiling lighting system with Halogen lamp 12V/35 W of type FOSNOVA SIRIO 64116***	***39***	***08:00-19:00***	***Occupancy Sensors - Timers***	***3603***
15	***Turtle type lighting system with fluorescent lamp 18 W of type SIMES PLAFONIERE OVAL WITH CAGE S.359/G***	***150***	***08:00-19:00***	***Occupancy Sensors - Timers***	***7128***
16	***Safety Provision lighting system with***	***147***	***24h***	***Occupancy Sensors -***	***10160***

	batteries Ni-Cd 90min 8W			***Timers***	
17	***DISANO Box type night operation lighting systems for rooms***	***147***	***19:00-07:00***	***Occupancy Sensors - Timers***	***5080***
18	***Linestra type lighting system***	***18***	***08:00-19:00***	***Occupancy Sensors - Timers***	***855***
19	***Medical equipment operation indication lamp***	***1***	***08:00-19:00***	***Occupancy Sensors - Timers***	***47***
20	***Spot type Lighting System with 2 fluorescent type lamps X 26 W of IP 44 DISANO Energy 2 type***	***68***	***08:00-19:00***	***Occupancy Sensors - Timers***	***9335***
21	***Linear type lighting system with linear fluorescent type lamps***	***500***	***24h***	***Occupancy Sensors and manual switches***	***38880***
22	***Spot type Lighting System with 2 fluorescent type lamps X 26 W of IP 44 DISANO SHELL3 WITH GLASS type with glass cover***	***41***	***08:00-19:00***	***Occupancy Sensors - Timers***	***5628***
23	***Bell type metal halide 150 W lighting system of DISANO GHOST 3215 type***	***20***	***08:00-19:00***	***Occupancy Sensors - Timers***	***7920***
24	***Roof projection type lighting system with metal halide lamp of type SIMES WIP***	***10***	***08:00-19:00***	***Occupancy Sensors - Timers***	***475***

	FLOODLIGHT S.4318				
25	***Bollard type low height lighting system with 70 W HIT-CE lamp of type SIMES COLUMN Φ200mm ROUNDED HEAD S. 4186 type***	***26***	***08:00-19:00***	***Occupancy Sensors - Timers***	***4804***
26	***Wall mounted up down lighting system with HIT-CRI 70W lamp of type SIMES SLOT WALL UP-DOWNS.3947***	***16***	***08:00-19:00***	***Occupancy Sensors - Timers***	***2957***
27	***Patient bed console with direct and indirect lighting provision (2x18W and 1x36W in respect), 1 double receiver RJ45 (THA-DATA), 2 plug inputs, 2 medical gases outputs of type DISANO SERENA 7205***	***228***	***24 h***	***Occupancy Sensors and manual switches***	***35458***
28	***Arm type lighting system with Hg 250 W lamp of type PHILIPS SRP***	***26***	***08:00-19:00***	***Occupancy Sensors - Timers***	***17160***
29	***Summit type lighting system with Hg 124 W Lamp of type DISANO VISTA 1595***	***6***	***08:00-19:00***	***Occupancy Sensors - Timers***	***1964***
Total		***3350***			
Installed total Power		***147647 W***			

Patients' rooms are considered to operate 360 days per year, while examination centers, labs, doctors' offices, swimming pools etc are considered to operate 240 days per year. Lighting systems that are available 24h per day like those in patients' rooms are considered to be in operation 12 from 24 hours per day. The annual electricity consumption for lighting systems is equal to 500889 kWh/year. This stands for the 23,37% of the total annual electricity consumption of the medical unit.(Judged from data for 2011)

5.8.2.BEMS System

Euromedica Arogi has an integrated building management system. This system is a combination of an Ethernet/LAN Network, Personal Computers and PC software, alarm system and sensors. Its priority is to monitor and automatically adjust according to the desired set points the energetic performance of the systems that are responsible for space heating and cooling, Domestic Hot Water preparation, ventilation and lighting. Additionally it controls the internal temperature and relative humidity set points' monitoring and adjustment, let alone the observation of air quality and air changes frequency. Last but not least it can automatically or manually adjust conditioning of swimming pools. Different sensors collect and record data such as temperature, relative humidity, water level of swimming pools, pressure, voltage, engines' rotational speed, water's temperature at different internal and external spaces of the medical unit. Cold and hot water temperatures and circulation or recirculation flow rates for heating or cooling systems are monitored and adjusted and rotational speed of fans is selected. Furthermore the quantity of available natural gas and petrol (for the emergency unit) is monitored. Finally UPS system's and substation's is monitored and adjusted. BEMS system is observed on a 24 hour basis. If a value of the monitored variables is different than the desired ones then an alarm system is enabled, giving the signal to the technical team to examine the possible problem/ malfunction. During the assessment of the whole building the existence of the BEMS system will be taken into consideration affecting positively the whole energy performance ranking.

5.8.3.Electric appliances

Every patient's room is equipped with a small refrigerator and a small TV. Additionally 3-5 electricity plugs are provided per room. Assuming that at the same time the TV and refrigerator are operating and a mobile phone charger and a small laptop are connected and making the hypothesis that the laptop has power equal to 40 W , a the refrigerator power equal to 90W, the TV equal to 120 Wand the mobile phone charger equal to 2 W, the installed power for a single bed room can be considered equal to 252 W per single bed room for electric appliances only.

Finally the labs and examination rooms have 3 electrical plugs per working bench or 2-6 plugs per examination table . The corridors have one electrical plug per 15-30 m. The assessment of the more complex and electric general and medical equipment will take place through the utilization of PPC'c bills which are available for the last 1,5 years.

The electricity feed of the buildings is done through PPC's medium voltage network at 20 kV, 250 MVA and 50 HZ.

5.8.4.Space heating - Space cooling - Domestic Hot Water and Swimming pools' hot water preparation systems

Euromedica Arogi rehabilitation center presents a unified operation of space heating, space cooling, DHW and Swimming pools' water preparation and cool water systems. Water is pumped from the mains to a heat exchanger and it is preheated. Then it is pumped through 3 natural gas boilers. The first two heat water for space heating purposes and their type is ACV Jumbo 1000 with power equal to 650 MCal/h. The third natural gas boiler has power equal to 350 MCal/h and it is responsible for DHW preparation. Water which is used for kitchen/ cooking purposes has a desired temperature equal to 70^{o}C, while DHW which is utilized in showers and bathrooms has a desired temperature equal to 45 ^{o}C. The desired temperature for swimming pools' water is equal to 33, 31,8 and 30,9 ^{o}C for the main , second and third swimming pool in respect. The total installed power of the boiler room is equal to 1860 kW. There are 2 boiler circuits installed. The primary circuit is able to achieve water temperatures equal to 85^{o}C and the secondary circuit is adjusted to achieve water with temperature equal to 55 ^{o}C and it is connected to a heat exchanger with power equal to 800 kW. Hot water is driven to 10 Air Handling Units , which are installed on the roof of the medical unit. There air is heated. Finally heated air is distributed to the emission systems and fan coils and space heating is achieved. The Space Heating , space cooling and DHW preparation distribution systems are considered to be adequately insulated with Polypropylene and ARMAPLEX insulating materials. For the production of cold water, two 500 kW chillers have been installed on the roof of the building. Their type is Carrier 30 X A 502. The produced cool water can be directly used for medical or general purposes, or utilized for space cooling during the cooling period. This is achieved in the following way. Cold water which has been cooled in the chillers is pumped to the air handling units. There through a complex heat exchanging procedure air is pumped through the AHU units and cooled. The next step is the emission of the cooled air through a fan coil- emission system's combination. The main advantage of such a solution is that due to the higher specific heat and density of water (compared to air) lower pipes' diameter is required, compared with the diameter of air ducts that would be utilized if space heating and cooling was covered by a completely air based solution. Consequently space requirements are significantly lower and the pumping systems must have significantly lower power than the power that would be required in the case of air distribution network. All of those have as a result a significantly reduced cost.

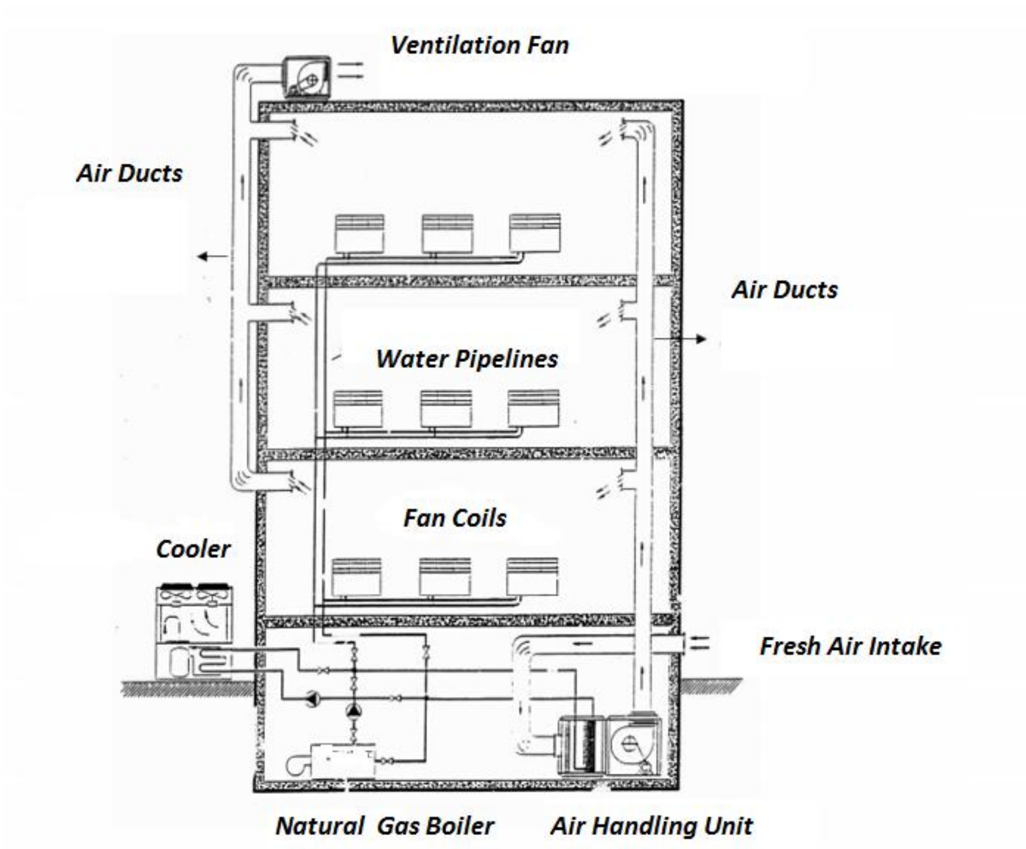

Figure 46: Space heating and cooling systems' presentation (Psaras et al, 2011)

A heat exchanging system is installed on the coolers. The rejected heat from the coolers during the cooling period is recovered, achieving efficient cooling of the cooler and increased efficiency of the cooling system and at the same time utilizing the rejected heat for hot water preparation. With this provision water can be heated until 55°C, significantly relieving the thermal load from natural gas boilers and reducing the energy consumption for space heating and DHW and swimming pools' water preparation during the cooling period.

In the next tables the characteristics of the 10 Air Handling Units are presented.

Table 36: Air Handling Units' 1-5 Characteristics

AHU		AHU 1	AHU 2	AHU 3	AHU 4	AHU 5
Characteristic	Input Fan Speed (m^3/h)	10000	15000	11700	7000	1700
	Output Fan Speed (m^3/h)	10000	15000	11000	62000	1700
Cooling Mode	Input Dry Bulb Temperature (°C)	37	37	37	33,5	37
	Output Dry bulb Temperature (°C)	24	24	24	15,6	24
	Water Flow Rate (L/s)	5,56	8,34	6,51	3,96	0,95
	Thermal Load for Cooling (W)	117000	175000	137000	83000	20000
Heating Mode	Input Dry Bulb Temperature (°C)	8,5	8,5	7,7	6,3	8,5
	Output Dry bulb Temperature (°C)	24	24	24	25,3	24
	Water Flow Rate (L/s)	2,3	3,44	2,86	1,5	0,39
	Thermal Load for heating (W)	52000	78000	63000	34000	11000
	Air to Air Heat exchanger efficiency	0,55	0,55	0,55	0,55	0,55

Table 37: Air Handling Units' 6-10 Characteristics

AHU		AHU 6	AHU 7	AHU 8	AHU 9	AHU 10
Characteristic	Input Fan Speed (m^3/h)	7200	6400	15000	6000	4800
	Output Fan Speed (m^3/h)	7500	6300	16000	7000	4300
Cooling Mode	Input Dry Bulb Temperature (°C)	37	37	31,9	31,4	31,5
	Output Dry bulb Temperature (°C)	24	24	17	18,4	16,3
	Water Flow Rate (L/s)	4	3,6	8,1	3,12	2,11

	Thermal Load for Cooling (W)	***85000***	***75000***	***170000***	***65000***	***45000***
Heating	***Input Dry Bulb Temperature (^oC)***	***9***	***8,3***	***12,2***	***13,85***	***5,7***
	Output Dry bulb Temperature (^oC)	***24***	***24***	***36***	***36***	***28,3***
Mode	***Water Flow Rate (L/s)***	***1,58***	***1,5***	***4,93***	***1,67***	***1***
	Thermal Load for heating (W)	***36000***	***35000***	***120000***	***37000***	***25000***
	Air to Air Heat exchanger efficiency	***0,55***	***0,55***	***0,55***	***0,55***	***0,55***

Here it should be mentioned that every AHU's main body is properly insulated, with maximum thermal conductivity equal to 0,72 W/m^2K.

Figure 47: Air Handling Unit 1

Figure 48: Air Handling Unit's technical specifications

For both space heating and space cooling systems fan coils are utilized as emission systems.

For water cooling 2 coolers with power equal to 500 kW each are utilized. Their characteristics are presented in the following table.

Table 38: Carrier 30 X A 502 Coolers' Characteristics.

Characteristic	*Value*
Model Type	*Carrier 30 X A 502*
Power	*500 kW*
Number of units installed	*2*
Full load EER	*10,2*
Full Load COP	*3*
Integrated Part Load EER	*14,8*
Integrated Part Load COP	*4,3*

Fuel	***Electricity***

Distribution system is considered to have state of the art insulation. Furthermore the transferred power is more than 400 kW(500 kW for each cooler) and the supply temperature is considered to be within the limits of 7-12 ^{o}C (11,5 and 8,5 ^{o}C as it had been extracted during the walkthrough energy audit) . The pipes are considered to rout through internal spaces. The pumping system for space cooling has total power equal to 3 kW.

For DHW preparation a central boiler with power equal to 350 Mcal/h is used. This value is approximately equivalent to 407 kW. The efficiency of the production system has been found to be equal to 92%.

For Space heating and swimming pools' hot water preparation systems 2 ACV Jumbo 1000 natural gas boilers with power equal to 650 mCal/h or 755 kW each are utilized. Their characteristics are presented in the following table:

Table 39: ACV Jumbo 1000 natural gas boiler's characteristics

Characteristic	***Value***
Model Type	***ACV Jumbo 1000***
Power	***755 kW***
Number of units installed	***2***
Minimum Supply Temperature	***10 ^{o}C***
Maximum Return Temperature	***90 ^{o}C***
Capacity	***1000 L***
Achieved efficiency	***92%***
Pressure Drop	***101 mbar***
Primary Flow	***7800 L/h***
Fuel	***Natural Gas***

The above boilers are considered to be well insulated. The distribution system is routing through internal spaces and the pipelines are considered to have excellent insulation. Their pumping system can achieve maximum volumetric flow rate equal to 46 m^3/h. The total power of the space heating and DHW preparation pumping and distribution system is considered to be equal to 4,5 kW.

The daily DHW demand can be found if the total number of patients (200) is multiplied by the legislation provided for a medical unit number of 120 L/person/day. The total daily DHW demand is equal to 24 m^3/day. DHW's desired temperature set point must be 45^oC for bathroom use and 70^oC for kitchen use , as it has already been mentioned. Additionally swimming pools' water's preparation system must provide enough hot water in order to cover 300m^3 of 33^oc water for the big swimming pool, 48 m^3 of 31,8^oC water for the second swimming pool, 48 m^3 of 30,9 ^oC water for the third swimming pool and 18 m^3 of water for the additional swimming pool.

The air that is heated or cooled in the utilized Air handling units is emitted through fan coils in the conditioned spaces of the medical unit. More than 195 fan coils with power 80W each are utilized for space heating and cooling. All of them have air filters and provide the choice of filtering and recirculating the internal air, or filtering and providing fresh outside air according to internal and external spaces' relative humidity and temperature.

Swimming pools' and bar restaurant's spaces are covered by dedicated AHUs which cover only these spaces. Their technical characteristics have been described above.

Control room is covered by a split air-conditioning unit, which has been manufactured by Carrier. Its technical characteristics are provided in the following table:

Table 40: Technical characteristics of control room's split air conditioning unit (Anastaselos, 2012),(www.carrier.gr)

Characteristic	***Value***
Manufacturer	***Carrier***
Cooling Capacity	***2,9 kW***
Heating Capacity	***4 kW***
Heating COP	***3,63***
Cooling EER	***3,25***

Inverter	***YES***
Refrigerant	***R 410 A***
Compressor type	***DC Rotary Type***
Distribution's system's efficiency	***100%, (Anastaselos, 2012)***
Production's system's efficiency	***1, (Anastaselos, 2012)***
Emission's System's efficiency	***96% (Heat pump with inverter), (Anastaselos, 2012)***

For ventilation and feed of the internal spaces with hot cold or fresh air the following settings are used.

Table 41: Ventilation ducts' air's speed

Ventilation Network Part	***Air's Speed (m/s)***
Fan's Exit	***8***
Central Duct	***7***
Secondary Ducts	***6***
Ducts with nozzles	***4***

5.8.5. Elevators

In Euromedica Arogi's facilities 6 elevators are utilized. 2 of them are for public use, 2 for patients' and medical staff's transportation, 1 for food transportation and 1 for laundry transportation. Elevators that are responsible for public transportation are moved by an electricity fueled system, which has power equal to 3 kW each (6 kW total). Elevators that are responsible for patients' transportation are powered by an electricity based motor with power equal to 6 kW each (12 kW total). Finally the laundry elevator has power equal to 2 kW and the food transportation elevator has power equal to 3 kW. The total installed power for the elevator motors is equal to 23 kW.

5.9. Inspection of Natural Gas and Electricity Bills

As it has been mentioned above, due to the short time that the writers had in their availability to conduct an energy audit in a complex medical unit and the lack of the available infrastructure , such as energy flow and electricity flow meters, the collection and assessment of electricity and natural gas bills becomes a subject of crucial importance for the energy audit.

Electricity and natural gas bills have been collected and studied for the time period of January 2011 , until July 2012. Electricity bills provide an indication for the energy consumption for lighting systems, coolers, air handling units, ventilation systems, split units, fan coils and of course energy intensive medical equipment and general use equipment. Natural gas bills can provide an indicative idea about the energy consumption of the medical unit for domestic hot water and swimming pools' water preparation and for the boilers' and space heating system's energy consumption. As it has been mentioned above there is a backup oil boiler and a generator system that may cover electricity and thermal loads for the case of an emergency. As this system is not a part of the ordinary operation of the medical units it is not a subject of this dissertation. The data that occurred from the collection and assessment of electricity and natural gas bills are presented in the following tables.

Table 42: Euromedica Arogi's electricity consumption

Month	*Power Units (kW)*	*Power Cost (Euros)*	*Electricity Units (kWh)*	*Electricity Cost (Euros)*	*Total Cost with public benefit's charges*
January 2011	*191,80*	*508,27*	*165.600,00*	*9.378,19*	*13.688,74*
February 2011	*144,00*	*381,60*	*136.800,00*	*7.803,20*	*11.282,56*
March 2011	*233,00*	*617,45*	*144.000,00*	*8.147,94*	*12.119,63*
April 2011	*191,60*	*507,74*	*156.000,00*	*8.800,07*	*12.860,06*
May 2011	*196,40*	*520,46*	*172.800,00*	*9.824,21*	*14.341,01*
June 2011	*182,70*	*1.107,16*	*218.400,00*	*12.453,57*	*18.490,54*
July 2011	*296,20*	*1.794,97*	*237.600,00*	*13.442,80*	*20.723,12*
August 2011	*279,70*	*1.694,98*	*235.200,00*	*13.378,83*	*20.478,64*
September 2011	*256,90*	*1.556,81*	*216.000,00*	*12.306,76*	*18.733,55*
October 2011	*301,20*	*798,18*	*158.400,00*	*8.930,82*	*13.516,27*
November 2011	*124,20*	*329,13*	*146.400,00*	*8.334,56*	*11.921,65*
December 2011	*137,40*	*364,11*	*156.000,00*	*8.819,20*	*12.672,78*
January 2012	*120,60*	*319,59*	*163.200,00*	*9.225,25*	*14.852,15*

February 2012	***274,50***	***1.990,13***	***153.600,00***	***8.796,53***	***15.820,47***
March 2012	***421,60***	***3.056,60***	***170.400,00***	***9.804,51***	***18.824,04***
April 2012	***345,00***	***2.501,25***	***175.200,00***	***9.954,84***	***18.300,82***
May 2012	***402,00***	***2.914,50***	***201.600,00***	***11.605,63***	***21.221,52***
June 2012	***471,00***	***3.414,75***	***232.800,00***	***13.328,29***	***24.462,65***
July 2012	***540,40***	***3.917,90***	***268.800,00***	***15.408,79***	***28.293,08***

Electricity consumption is higher in months where cooling requirements are higher. This happens due to the fact that outdoor temperature and water's from the mains temperature are significantly higher. For this reason during the cooling period and especially from June until September, electricity consumption is higher, compared with the rest of the year.

Table 43: Euromedica Arogi's Natural Gas consumption

Month	***Natural Gas Consumption (kWh)***	***Natural Gas Unit price (Euro)***	***Natural Gas Cost (Euro)***
January 2011	***370.445,5788***	***0,0503***	***18.636,21***
February 2011	***381.162,0540***	***0,0497***	***18.954,13***
March 2011	***332.764,5398***	***0,0494***	***16.459,41***
April 2011	***293.466,2000***	***0,0479***	***14.067,79***
May 2011	***184.252,9216***	***0,0519***	***9.563,81***
June 2011	***3.747,2128***	***0,0532***	***199,51***
July 2011	***0,0000***	***0,0000***	***0,00***
August 2011	***14.433,5055***	***0,0608***	***877,32***
September 2011	***2.634,2100***	***0,0639***	***168,41***
October 2011	***164.817,1200***	***0,0495***	***8.160,27***
November 2011	***292.115,4500***	***0,0511***	***14.945,41***
December 2011	***352.707,0900***	***0,0575***	***20.281,82***
January 2012	***411.215,7700***	***0,0618***	***25.449,82***
February 2012	***395.014,4400***	***0,0600***	***23.704,09***
March 2012	***324.468,7100***	***0,0599***	***19.440,25***
April 2012	***223.707,0500***	***0,0602***	***13.471,54***
May 2012	***83.961,4900***	***0,0593***	***4.983,79***
June 2012	***23.180,9700***	***0,0607***	***1.408,72***

July 2012	***2.087,8900***	***0,0673***	***140,52***

As it was expected natural gas consumption is higher when the requirements for space heating and domestic hot water and swimming pools' water heating are higher. This takes place in the heating period and especially from December, until March. This happens because the outdoor temperature is low and significant transmission and ventilation heat losses occur from the medical unit to the environment. Additionally the water that is received from the mains, has remarkably low temperature, leading to higher energy consumption for DHW and space heating systems in order to heat the water until the desired temperature. Finally great interest is presented in the fact that during July 2011 all the space heating and DHW and swimming pools' water heating requirements are covered by the heat recovery system that is installed on the coolers. This, combined with the low requirements of space heating during the summer months and the high temperature of water in the mains leads to zero natural gas consumption in that month. As it has been mentioned previously, the heat recovery provision keeps the efficiency of the coolers in high levels, by avoiding their overheating, utilizes their rejected heat, increasing the overall medical unit's efficiency and reduces the final, primary energy consumption and CO_2 emissions due to natural gas utilization for space, DHW and swimming pools' water's heating during the summer months (June-September).

In the next figure the monthly electricity and natural gas consumption are compared.

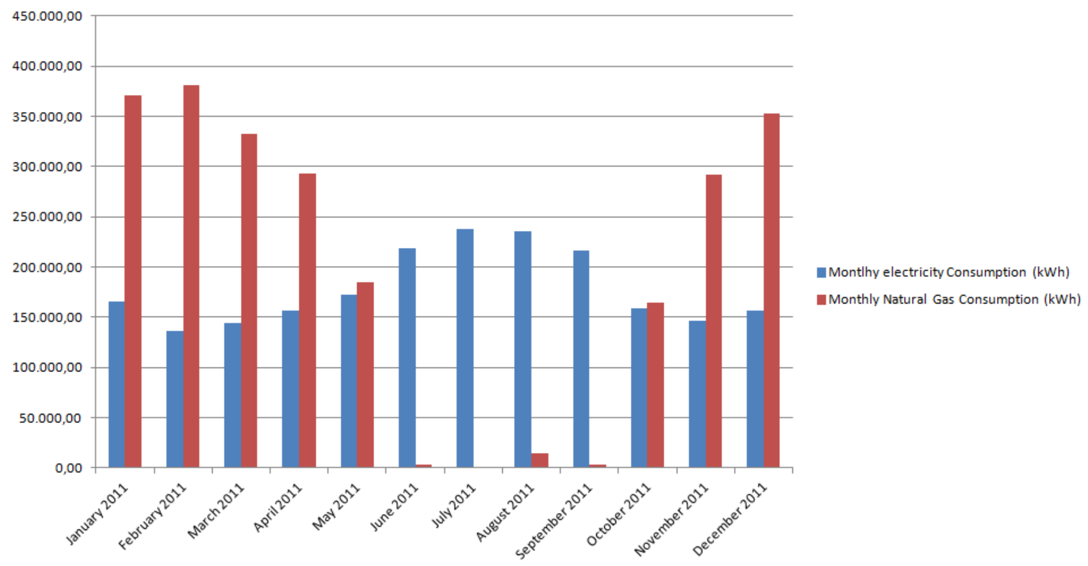

Figure 49: Monthly Electricity and Natural gas consumption's comparison for 2011

The average monthly and annual electricity and natural gas consumption and cost are presented in the following table. Data from 2012 were omitted on purpose in order to avoid having a biased image of electricity and natural gas consumption due to the lack of cold months like December.

Table 44: Average monthly and annual electricity and natural gas consumption and cost

Fuel	Average Monthly Consumption (kWh/month)	Annual Consumption (kWh/year)	Average monthly cost (Euros/month)	Annual cost (Euros/year)
Electricity	178600	2143200	15069,05	180828,55
Natural Gas	199378,8	2392545,9	10192,8	122314,09

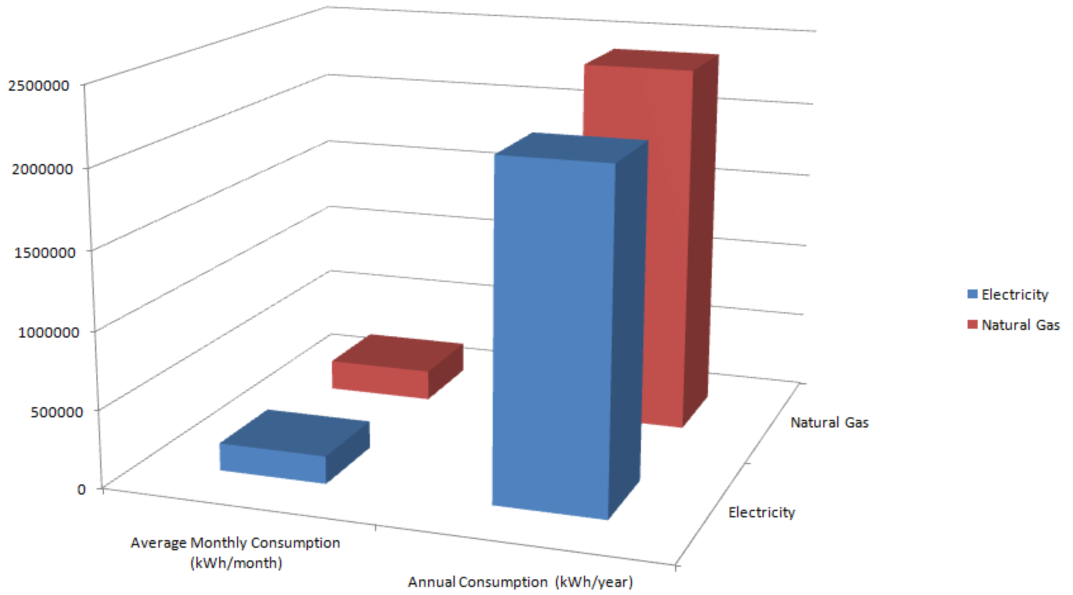

Figure 50: Average/monthly and annual Electricity and Natural gas consumption's comparison for 2011

As it can be extracted by both the graphs and the tables, electricity is responsible for the 47,25% of the total final energy consumption, while natural gas is accounted to 52,75% of the total final energy consumption. (as it can be extracted from the 2011 data).

The annual electricity's consumption is equal to 151 kWh/m^2, while the annual natural gas consumption is equal to 168,7 kWh/m^2. The total final annual energy consumption for the medical unit is equal to 319,7 kWh/m^2. The energy performance of the medical unit has been found to be more than satisfying, if it is compared with the average energy consumption of a Greek medical unit, which was found to be 370-426 kWh/m^2/year. ***(Balaras et al, 2006)***

From the inspection of the national water service bills it occurs that the average monthly DHW and swimming pools' water consumption for 2011 is equal to 1212 m^3. The annual DHW and Swimming pools' water consumption is equal to 14548 m^3.

Law 3661/2008 provides information for the conversion of each type of final energy to primary energy for Greek country. For electricity, the conversion factor is equal to

2,90 and for natural gas 1,05. CO_2 emissions for natural gas can be calculated if the number of total consumed energy is multiplied with the number 0,196 kg CO_2/kWh. For electricity the same number is equal to 0,989 CO_2/kWh. ***(Law 3661/2008)***

In the next tables the primary energy consumption and CO_2 emissions of the rehabilitation center are presented:

Table 45: Primary energy consumption for 2011

Month	***Primary Energy Consumption for Electricity (kWh)***	***Primary Energy Consumption for natural gas (kWh)***	***Total Primary Energy Consumption (kWh)***
January 2011	***480240***	***388967,9***	***869207,9***
February 2011	***396720***	***400220,2***	***796940,2***
March 2011	***417600***	***349402,8***	***767002,8***
April 2011	***452400***	***308139,5***	***760539,5***
May 2011	***501120***	***193465,6***	***694585,6***
June 2011	***633360***	***3934,573***	***637294,6***
July 2011	***689040***	***0***	***689040***
August 2011	***682080***	***15155,18***	***697235,2***
September 2011	***626400***	***2765,921***	***629165,9***
October 2011	***459360***	***173058***	***632418***
November 2011	***424560***	***306721,2***	***731281,2***
December 2011	***452400***	***370342,4***	***822742,4***
Average	***517940***	***209347,8***	***727287,8***
Annual 2011	***6215280***	***2512173***	***8727453***

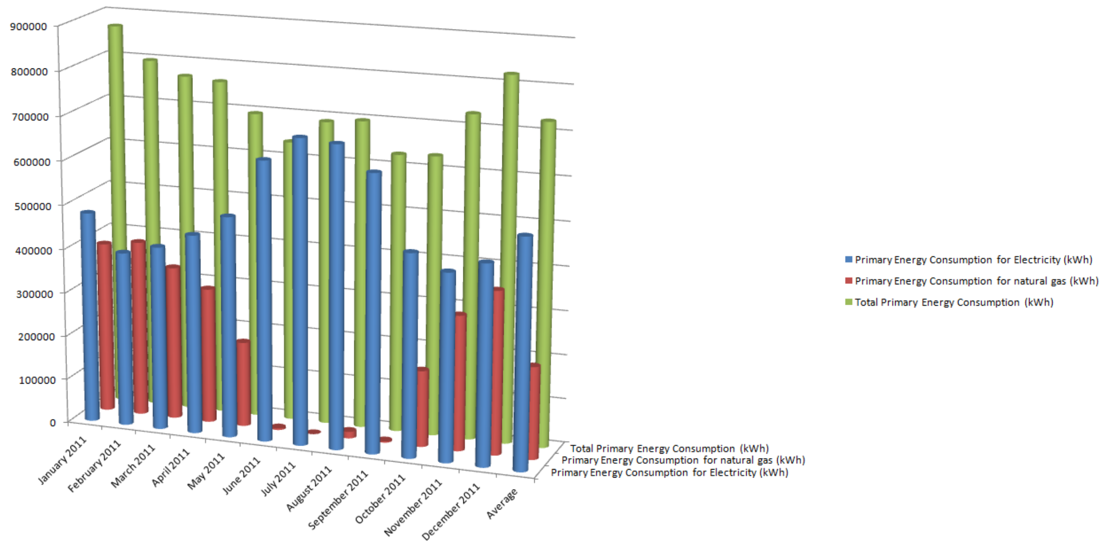

Figure 51: Monthly Primary energy consumption for electricity and natural gas comparison

Table 46: CO_2 emissions for 2011

Month	CO_2 emissions for Electricity (kg CO_2)	CO_2 emissions for natural gas (kg CO_2)	Total CO_2 emissions (kg CO_2)
January 2011	163778,4	72607,33	236385,7
February 2011	135295,2	74707,76	210003
March 2011	142416	65221,85	207637,8
April 2011	154284	57519,38	211803,4
May 2011	170899,2	36113,57	207012,8
June 2011	215997,6	734,4537	216732,1
July 2011	234986,4	0	234986,4
August 2011	232612,8	2828,967	235441,8
September 2011	213624	516,3052	214140,3
October 2011	156657,6	32304,16	188961,8
November 2011	144789,6	57254,63	202044,2
December 2011	154284	69130,59	223414,6
Average	176635,4	39078,25	215713,6
Annual 2011	2119625	468939	2588564

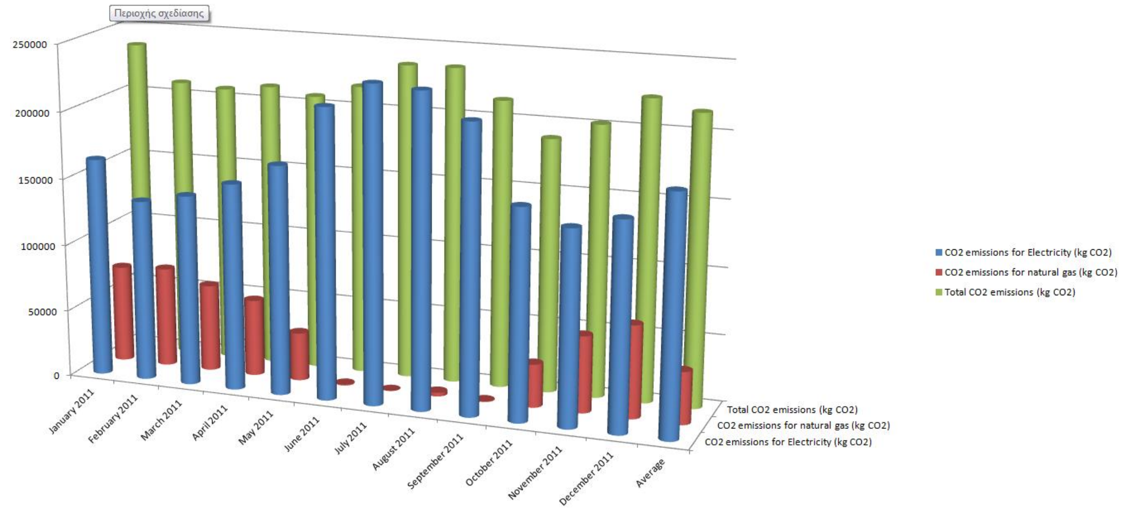

Figure 52: Monthly CO_2 emissions for electricity and natural gas comparison

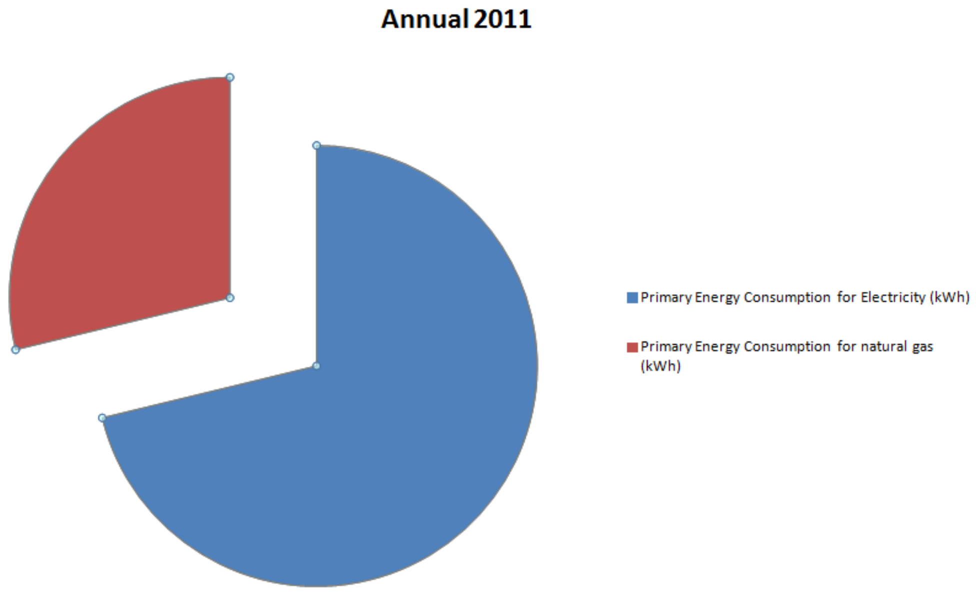

Figure 53: Annual Primary energy consumption's comparison due to electricity and natural gas fuels for Euromedica Arogi

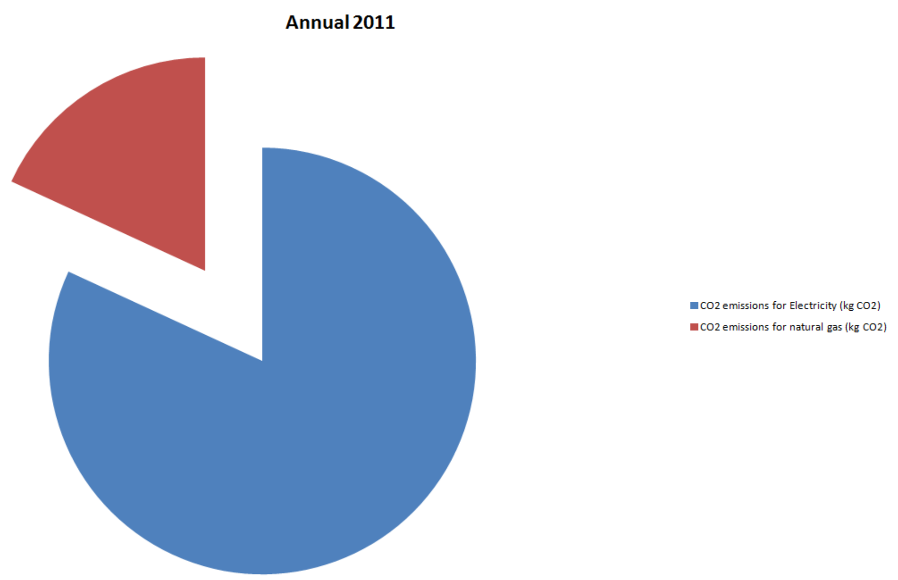

Figure 54: Annual CO_2 emissions' comparison due to electricity and natural gas fuels for Euromedica Arogi

The annual primary energy consumption that occurs due to electricity is equal to 438,1 kWh/m^2, while for natural gas the same number is equal to 177,1 kWh/m^2. The total primary energy consumption of the medical unit is equal to 615,2 kWh/m^2. Primary energy consumption that results from electricity's utilization is equal to 71,22% of the total primary energy consumption, while the same percentage for natural gas is equal to 28,78%. Judging from the data that have been collected from 2011. Primary energy consumption and CO_2 emissions occur mainly due to electricity. This can be attributed to the fact that electricity fuels not only space cooling system (AHU, fan coils and coolers), but also energy intensive medical equipment and elevators. From financial point of view cost for electricity is by far larger than cost for natural gas on an annual base. For this reason from both from environmental and economical point of view, the energy efficiency measures should have as a target to reduce the amount of fossil fuel based electricity. The natural gas consumption may be smaller than electricity but it is not negligible at all. For this reason, the most ideal ESM must combine a major reduction in the PPC's grid extracted electricity's amount, and a brave reduction in natural gas consumption as well.

5.10.Medical Unit's Energy Performance Simulation

The energy performance of the rehabilitation center was simulated with the utilization of TEE-KENAK's (ΕΛΟΤ EN ISO 13790) software. The software version that was used was version v 1.29.1.19_20_5_12. During the simulations, monthly calculation method (quasi-steady state) was utilized, known as ΕΛΟΤ EN ISO 13790. Data that have been collected during the previous sections of the experimental part were used as an input in the software. More specifically, data about medical unit's location and orientation, outdoor climatic conditions and indoor space's desired temperature and relative humidity set points were used. Data about most important energy consuming devices such as HVAC , DHW and swimming pools' water preparation systems, lighting systems and medical equipment were collected and utilized. Furthermore data about the daily DHW demand and its desired temperature set point that have been described above, where used as well. The efficiency of energy consuming devices and the type and requirement of fuel (electricity or natural gas) were utilized as well. Finally the building envelope's opaque and transparent elements' characteristics (total area, U value, orientation, infiltration etc), that have been described in the Building Envelope section were assessed by the pre mentioned software. In the next tables the results of the Energy performance simulation of Euromedica Arogi rehabilitation center, as they occurred by the utilized TEE-KENAK's software are presented.

Table 47: Final Energy Consumption for Space Heating , Cooling and DHW (including swimming pools' water)

Final Energy Consumption (kWh/m^2)	*Jan*	*Feb*	*Mar*	*Apr*	*May*	*June*	*July*	*Aug*	*Sep*	*Oct*	*Nov*	*Dec*	*Annual*
Heating	*8,00*	*6,50*	*5,90*	*4,60*	*0,00*	*0,00*	*0,00*	*0,00*	*0,00*	*2,40*	*5,40*	*7,20*	*40,10*
Cooling	*0,00*	*0,00*	*0,00*	*0,00*	*1,60*	*5,20*	*5,90*	*5,70*	*1,60*	*0,00*	*0,00*	*0,00*	*20,10*
DHW	*24,1*	*21,3*	*22,3*	*19,3*	*17,2*	*14,0*	*13,0*	*12,8*	*14,0*	*17,1*	*19,6*	*22,8*	*217,5*
Total	*41,2*	*36,1*	*37,4*	*32,7*	*27,9*	*28,1*	*28,0*	*27,7*	*24,3*	*28,6*	*33,8*	*39,2*	*385,0*

Table 48: Final Energy Consumption by Fuel and CO_2 Emissions

Energy Source	Fuel Consumption (kWh/m^2)	CO2 emissions (kg/m^2)
Electricity	159,10	157,30
Oil	0,00	0,00
Natural Gas	229,00	44,90
Other Fossil Fuels	0,00	0,00
Solar	0,00	0,00
Biomass	0,00	0,00
Geothermal	0,00	0,00
Other RES	0,00	0,00
Total	385,00	202,20

Table 49: Primary Energy Consumption and Energy Performance Ranking

Primary Energy Consumption (kWh/m^2)	Reference Building	Building	Percentage (%)
Heating	111,00	95,10	14,2
Cooling	67,90	58,60	8,76
Domestic (and Swimming pools') Hot Water	125,70	204,10	30,53
Lighting and electric equipment (medical and general)	88,10	310,70	46,4
Renewable Energy Sources	0,00	0,00	0
Total	392,70	668,50	100
Ranking (Energy Class)	-	C	

In the next figure the primary energy consumption breakdown is presented:

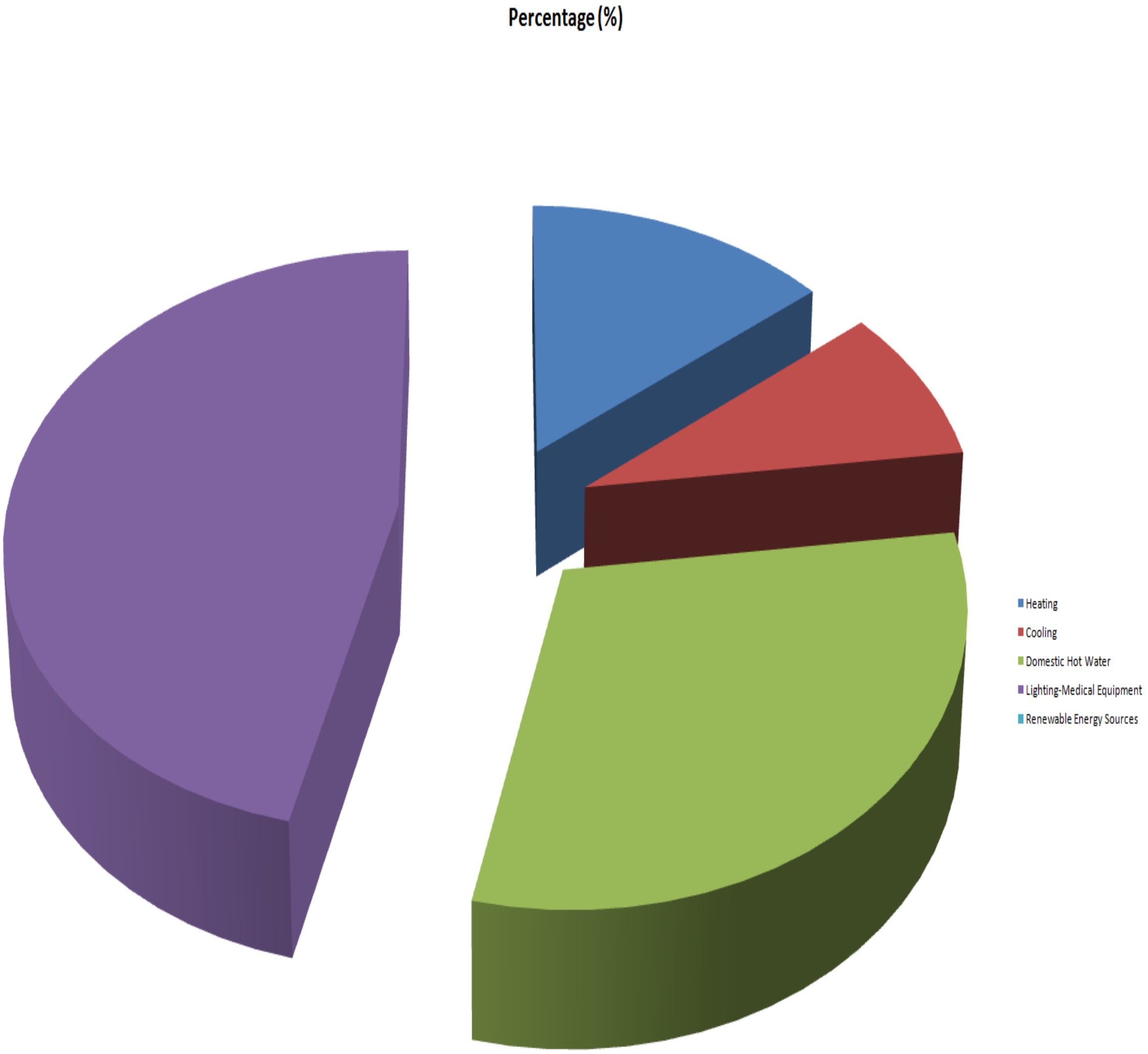

Figure 55: Primary Energy Consumption Breakdown

More or less, the simulation of the energy performance of the rehabilitation center, matches with the findings from the electricity and natural gas bills' assessment. If the inspection of the bills had data from more than one years (it has only for the one operating year of 2011, when the medical unit was in operation) then probably the results between the two methods of assessment would be identical. Another factor that may causes differences, between the results of the two methods is the fact, that actual data about the building envelope were not available to the auditors. For this reason building envelope was considered to be compatible with K.E.ν.A.K.'s indicative U values, which were collected by bibliographic research.

The most important result is the energy ranking of the rehabilitation center, which was found to have ***energy class equal to C***. This takes place, despite the fact that the medical unit was constructed in 2009-2010 and its energy performance is better in comparison to the energy performance of the average Greek medical unit (370-426 kWh/m^2/year) and reflects the total absence of renewable energy sources' utilization within the building's facilities. For this reason the Energy Saving Measures that will be proposed will be focused on this disadvantage.

Note: The energy performance of the medical unit was simulated with the cooperation of the dissertation's supervisor Dr D. Anastaselos.

5.11.Energy Saving Measures

As it was expected the energy performance of the building was found to be more than satisfying. The combination of the building envelope's characteristics and the newly purchased HVAC, DHW and lighting systems has as a result a conservative energy consumption performance of the building and reduced CO_2 emissions.

One great disadvantage that can be concluded through both the walkthrough energy audit, that has been conducted and the inspection and assessment of energy consuming devices is the lack of utilization of renewable energy sources from the building. Utilization of RES could promote further energy conservation within the building's facilities and CO_2 emissions' reduction and in the medium and long term significant cost savings.

During the walkthrough energy audit and analytical study of the plans it had been concluded that above the space where AHUs and coolers have been installed there is available space (1420 m^2) for the installation of a renewable energy source solution. This space is the shelter, which according to the technical management of the medical unit has been constructed by the appropriate materials and undergone the required studies, regarding the required mechanical strength and technical and legal suitability for installation of RES structures such as solar thermal collectors or phototovoltaics. It had been included before the beginning of the construction of the medical unit in the plans as a blank area which will be available for future installations- upgrades.

Arogi rehabilitation center, as every medical unit, has increased electricity needs and energy requirements for space heating and cooling and DHW preparation. In the case of Euromedica Arogi, the existence of 3 swimming pools increase significantly the thermal loads. For this reason cogeneration of heat and power or trigeneration of heat, power and space cooling is ideal for such a facility. This has been extracted from previous researches as well. ***(Mavrotas et al, 2009), (Pagliarini et al, 2012)***

In the next paragraphs some energy saving solutions are proposed for the medical unit. Due to the preliminary nature of this energy audit, the majority of energy saving measures will be proposed, creating the base for furtherer technical and financial assessment of this propositions. The propositions that have to do with the available space in the building's terrace - shelter will be assessed as well in order to provide an idea about the implementation of energy saving measures. The most important energy saving measures that have been identified and proposed are the following:

- Replacement of transparent elements with triple glazed windows, with aluminum frames, thermal bridges and low e-coatings. The gap between the layers of the glasses will be equal to 24 mm and the filling gas will be crypton. This way the convection, conduction and radiation heat losses will be drastically reduced. The thermal transmittance of the windows' glass part will be equal to 0,6 W/m^2K and the total thermal transmittance of the window will be equal to 0,8 W/m^2K.
- Installation on the available space in the roof of PV systems. The medical unit has an available space on the roof-shelter, which is equal to more than 1400 m^2. On this space PV cells can be installed, providing the ability to generate great amounts of CO_2 free electricity, which will be extracted to the grid. Furthermore, the rehabilitation center, will have significantly reduced annual electricity expenses, as long as the annual income that will derive from the PV electricity, that is extracted to the grid, will be subtracted. from the PPC bills, that are paid for the significant electricity requirements.
- Regarding the operation of lighting systems, it has been found to be more than satisfying, due to the implementation of occupancy sensors and timers and the high efficiency of the majority of lighting systems that are utilized. Replacement of T8 with more efficient T5 or LED lamps can be proposed. With the implementation of T5 or LED lighting systems, the electricity consumption and CO_2 emissions for the operation of lighting systems will be

reduced to a percentage equal to even 25%, with no or non significant reduction of lighting power and illuminance. A disadvantage regarding this proposition is the increased price of T5 and especially LED systems.

- Implementation of a cogeneration or trigeneration solution. As it has been mentioned above natural gas based cogeneration or trigenration systems for space heating, cooling and power generation have been proven to be ideal for a medical unit.
- Reduction of the desired temperature set point of swimming pools' water or DHW by 1 or 2 degrees ^{o}C. This measure has been experimentally implemented in the past with swimming pools' water's temperature reduction by 1 ^{o}C, but after complaints of the patients it was rejected.
- During low traffic hours like 20:00 until 07:00 one of two public elevators and one of two patients' elevators and laundry elevator may be turned off. Emergency cases will be covered by the second patients' elevator, while 1 elevator for public use during that time will be more than adequate.
- Installation of a geothermal solution for space heating and cooling. This solution can be ideal if the ideal geothermal potential of Macedonia, is taken into consideration. Furthermore, this solution presents the advantage of the direct utilization of the hot or cold water than can be extracted from relatively shallow depths of earth's crust for medical unit's space heating or cooling systems. As it had been described in a previous section, the rehabilitation center uses three natural gas boilers in order to heat water which will be used either for DHW heating, or space heating . Additionally 2 chillers cool the water in order for it to be used in the AHUs for space cooling. The geothermal system will be parted from an injection and a production well. A combination of heat exchangers and heat pumps is utilizing the earth's shallow layers' constant and relatively high temperature in order to extract hot water in the winter and cold water in the summer. In the winter hot water is extracted from the production well and cold water is driven to a storage space in the ground for use in the summer. This way water of a temperature until 37^{o}C can be extracted, significantly relieving the natural gas boilers from their thermal loads. In the summer cold water is extracted from the cold storage space and driven to the coolers, significantly reducing their energy consumption for cold

water preparation. This way primary and final energy consumption , CO_2 emissions and cost for space heating and cooling are significantly reduced. ***(Giannakidis, 2012)***

- Implementation of solar thermal collectors. As it has been extracted from the energy audit the rehabilitation center has increased energy requirements for hot water, which is utilized for space heating, DHW preparation and swimming pools' water heating. This water can be heated with the utilization of south facing solar collectors, which are going to be installed on the roof of the medical unit. Additionally with the installation of an absorption chiller and the simultaneous switching off for permanent or temporary time periods of one from two electricity fueled chillers, that are utilized at the time being, great amounts of energy financial resources and CO_2 emissions can be saved. Furthermore this idea can have an innovative character by creating a modern and different than the conventional ones type of cogeneration of space heating and cooling.
- Installation of a hybrid PV solution on the available space on the building's roof-shelter. This way both electricity and thermal energy can be generated, achieving a RES fueled cogeneration system. Additionally with the simultaneous implementation of an absorption chiller, trigeneration of power , space heating, DHW heating and space cooling can be achieved. This can be an ideal solution due to its innovative character and due to the fact that it is a combination of a RES based solution and a trigeneration system.

The proposition of energy saving measures follows the logic that first of all thermal and energy losses must be reduced, then efficiency of energy consuming devices must be maximized and finally Renewable Energy Sources must be utilized. Due to the fact that Euromedica Arogi is a medical unit, that has been constructed in the end of 2009, building envelope and energy consuming devices are considered to have efficient operation. This can be demonstrated by the fact that all of the energy consuming devices and building envelope have been designed according to Greek and European legislation about energy performance of a medical unit or a tertiary building, let alone the utilization of an automated building energy management system, which monitors and adjusts the energy performance of the building (a little more attention could have been paid on the transparent elements during the construction stages; thus new transparent elements are proposed for the medical unit). For this reason and after the building envelope's and energy consuming devices' recent construction (they are not depreciated yet) has been considered, propositions about these areas do not take place. For this reason the propositions of energy saving measures are concentrated on the utilization of RES, the lack of which has been identified as the medical unit's major disadvantage, regarding its energy performance. In the present thesis three energy saving measures that exploit the free and abundant source of sun are researched in a prefeasibility study level. Comments are made about each ESM and a base for future research is created (for instance their combination with an absorption or adsorption chiller in order to create a trigeneration system).

5.11.1.ESM 1- Installation of Mono Si PV modules on the roof

As it has been mentioned above on the building's terrace, adequate area has been identified (about 1420 m^2) for the implementation of RES energy saving measures. Moreover the shelter- roof's mechanical strength has been qualified (by previous civil engineering studies) for the implementation of PV modules. From the inspection of electricity and natural gas bills during the year 2011, it has been concluded that electricity is the main fuel that is used for the operation of the medical unit. Furthermore it is responsible, not only for the greatest amount of primary energy that is consumed and CO_2 emissions that are emitted, but also for the greatest portion of the operating cost of the medical unit (always from energetic point of view). For this reason the implementation of a PV installation on the roof of the building (until 100kW, as it is allowed by European legislation-***see note***) was found to be the most suitable for the needs of the rehabilitation center.

The climate of Greece can be characterized as one of the most ideal climates for PV or PV/T solutions within Europe. This can be explained due to the fact that solar radiation is constant and available around the whole year, powering the PV system with sufficient energy to cover electricity needs. Moreover Euromedica Arogi presents an ideal free space for the utilization of solar energy with clear access to the sun and no or negligible shading effect from nearby buildings or environmental elements.

In the next figure the solar potential of Greece and Europe is presented.

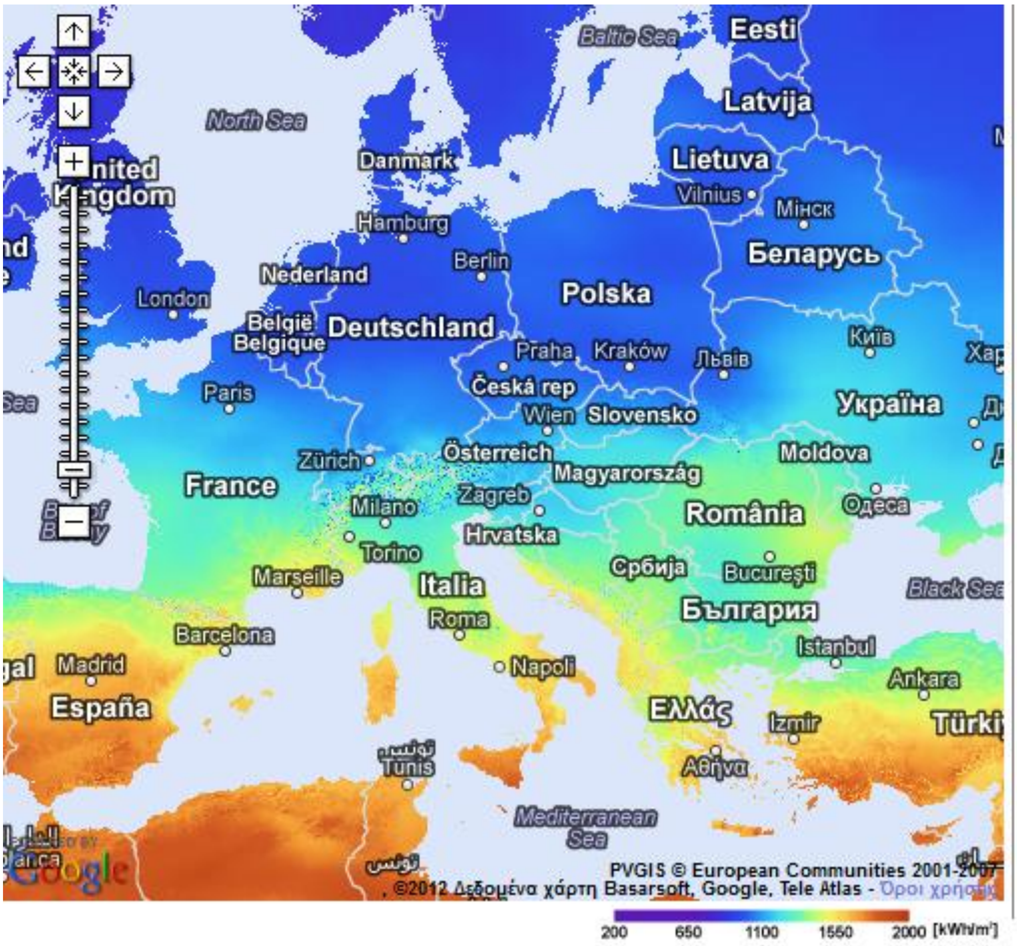

Figure 56: Solar potential of European countries (http://re.jrc.ec.europa.eu/pvgis)

In the following table the available radiation characteristics of the location of Euromedica Arogi are presented as they are provided by the widely known PVGIS application. Additionally information about the average daytime temperature (only for daytime, when sun is available) is provided. The average optimal inclination of a PV installation is equal to 31 degrees.

Table 50: Euromedica Arogi's location's optimal inclination, solar irradiation, average daytime temperature, diffuse to global radiation ratio characteristics(http://re.jrc.ec.europa.eu/pvgis)

Month	*Irradiation on Horizontal Surface (Wh/m²/day)*	*Irradiation on optimal inclination (Wh/m²/day)*	*Irradiation on 90 degrees inclination (Wh/m²/day)*	*Optimal Inclination (degrees)*	*Diffuse to global radiation ration*	*Average Daytime Temperature (°C)*
January	***1710***	***2490***	***2430***	***59***	***0.60***	***4.2***

February	***2390***	***3160***	***2740***	***51***	***0.57***	***6.0***
March	***3450***	***4070***	***2950***	***39***	***0.55***	***9.0***
April	***4890***	***5260***	***3060***	***26***	***0.48***	***13.3***
May	***5700***	***5650***	***2680***	***14***	***0.49***	***19.1***
June	***6730***	***6380***	***2590***	***7***	***0.42***	***23.8***
July	***6560***	***6380***	***2730***	***11***	***0.41***	***26.0***
August	***5800***	***6050***	***3170***	***22***	***0.43***	***25.7***
September	***4520***	***5300***	***3590***	***37***	***0.44***	***20.9***
October	***3200***	***4280***	***3600***	***50***	***0.46***	***16.2***
November	***1970***	***2880***	***2760***	***58***	***0.55***	***10.3***
December	***1230***	***1700***	***1600***	***56***	***0.69***	***5.2***
Yearly Average	***4020***	***4470***	***2820***	***31***	***0.47***	***15.0***

The PV modules that have been selected for installation are the model HIT-240HDC4, which have been constructed by Sanyo. They utilize Mono Si technology. Their selection took place, mainly due to their high efficiency (and generally every Mono Si PV cell's efficiency). Their technical characteristics are presented in the following table:

Table 51: Utilized PV modules' technical characteristics (www.helacpo.gr)

Manufacturer	***Sanyo***
Model	***HIT-240HDC4***
Type	***Mono Si***
Number of Units	***416***
Maximum power	***240 W***
Total Power	***99840 W***
Maximum voltage	***35,5V***
Open circuit voltage	***43,6 V***
Short circuit current	***7,37 A***
Dimensions	***0,861X1,6X0,035m***
Module Efficiency	***17,3%***
Cost of Unit	***410,00 euro /module***
Total Cost	***170560 euro***

In the next table the characteristics of the utilized inverters are presented

Table 52: Technical characteristics of the inverters (www.hotwater-shop.gr), (www.sma-hellas.com)

Manufacturer	***SMA***
Model	***Sunny Tripower 20000TL***
Number of Units	***5***
Input Maximum Power	***20450 W***
Maximum Input voltage	***1000 V***
Input Voltage Range	***580-800 V***
Input Nominal Voltage	***580V***
Maximum input current	***36A***
Output Nominal power at 230V and 50 Hz	***20000W***
Output Range of nominal voltage	***160-280V***
Output Network frequency	***50Hz - 60 HZ***
Maximum output current	***29 A***
Maximum Efficiency	***98,5 %***
Operation Temperature range	***-25-60 ^{o}C***
Dimensions	***0,665X0,69X0,265 m***
Total Output Power	***100 kW***
Cost of Unit	***4800 euro***
Total Cost	***24000 euro***

A subject of major importance is the positioning of the PV systems during their installation on the terrace of the rehabilitation center. As it has already been mentioned the optimum inclination of the PV systems is 31 degrees and the optimum orientation is south, due to the fact that Greece is in the northern hemisphere. Special attention must be paid during the installation of PV modules that are placed in the same row, facing towards the south direction. This happens in order to avoid the phenomenon, during which the first PV module, towards the south direction, shades part of the second. In order to avoid such a phenomenon two consecutive PV modules, that are installed in the same row facing south, must have a specific distance, between each other. This distance can be calculated from the following figure: ***(Giannakidis, 2012)***

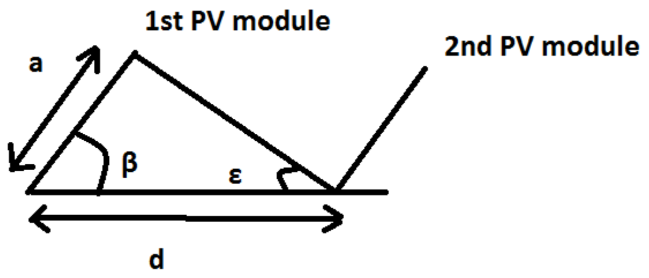

Figure 57: Distance between two consecutive PV modules (Giannakidis, 2012)

where a is the length of the PV module and d is the distance between two consecutive modules. d/a ratio is called normalized distance and it can be calculated by the formula

$d/a=\cos\beta = \sin\beta/\tan\varepsilon$,where φ symbolizes the latitude of the location and δ stands for the declination angle . ε is equal to $\delta - \varphi$, ***(Giannakidis, 2012)***

Alternatively, normalized distance can be directly calculated from empirical tables, which provide information for normalized distance for different latitudes. For Thessaloniki, where the medical center is located, an indicative normalized distance is equal to d/a=2 ***(Giannakidis, 2012)***

The length a of the utilized PV modules is equal to 1,6 m. For this reason distance d must be equal to 3,2 m. According to this standard the virtual installation of the PV modules on the AutoCAD drawing takes place.

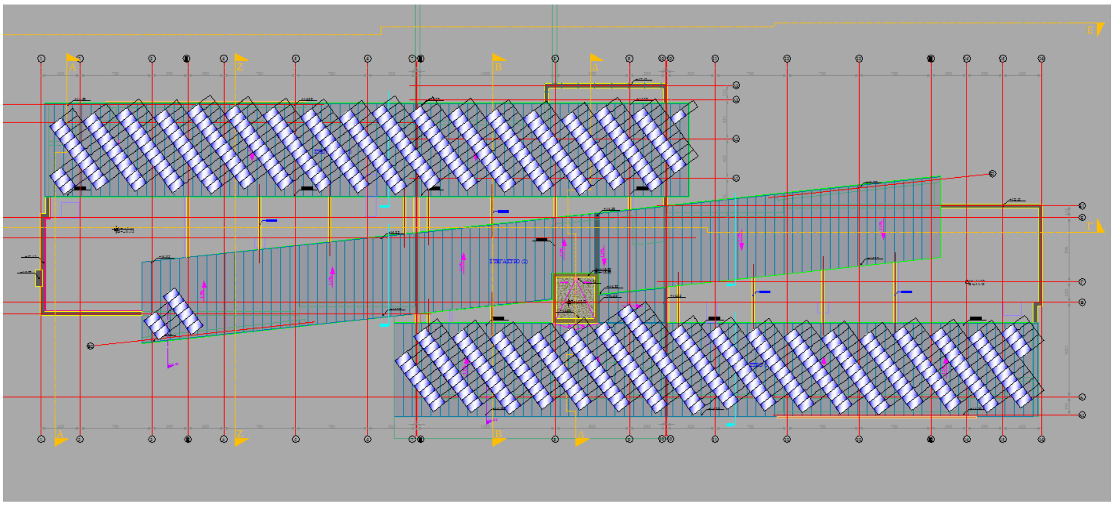

Figure 58: PV installation on Euromedica Arogi's Roof

As it can be extracted, 416 panels can be installed on the medical unit's roof with total power equal to 99840 kW. For this reason five 20 kW output inverters will be utilized, with total power output equal to 100kW. For the financial assessment of the energy saving measure the following assumptions are made:

Table 53: Financial assumptions about the installation of the PV panels

Stainless Steel Support Structure's Cost	*20000 Euros*
Cables' Cost	*1000 Euros*
Installation Cost	*4000 Euros*
Maintenance Cost	*1% of the initial investment and 2500 Euros at the end of the 15th year for a major inverter's maintenance*
Engineers' Compensation	*2000 Euros*
Administration Costs	*500 Euros upfront and 50 Euros annually*
Inflation	*3%(www.naftemporiki.gr)*
Discount Rate	*7% (www.naftemporiki.gr)*
Debt Interest Rate	*7%*
Financing that will be covered with debt	*50%*
Feed in tariff for installations until 100 kW	*252,62 Euros/MWh (www.ypeka.gr)*

The assessment of the energy saving measure is done with the utilization of RETSCREEN 4 software and PVGIS application. Data about the electricity's consumption and installed power for each month and the price of each kWh for each month have been utilized as well. This information has been presented in section 5.8.6 and electricity's consumption table.

In the next table the results of the simulations are presented. The produced electricity is extracted to the grid, with the fixed feed in tariff for every unit of electricity. The annual income will be subtracted by the PPC bills that the rehabilitation center pays due to its electricity requirements, drastically reducing the electricity related expenses of the medical unit. Additionally significant amounts of primary energy and CO_2 emissions are conserved.

Table 54: PV installation technical and financial assessment(www. retscreen.net)

Annual Income			
Electricity exported to grid	***MWh***		***156***
Electricity Export Rate	***€/MWh***		***252,6***
Electricity Export Income	***€***		***39428***
Annual Savings from generated electricity(cash flows not paid to PPC)	***€***		***39428***
Initial Costs			
Feasibility Study	***0,2%***	***€***	***500***
Development	***1,8%***	***€***	***4000***
Engineering	***0,9%***	***€***	***2000***
Power System	***97%***	***€***	***213312***
Total Initial Costs	***100,0%***	***€***	***219812***
Annual Costs and Debt Payments			
O&M		***€***	***300***
Debt Payment for 15 years		***€***	***12067***
Total Annual Costs		***€***	***12367***
Periodic costs			
Inverter major maintenance - 15 years		***€***	***2.500***
Annual cash flows			
Year	***Pre-tax***	***After Tax***	***Cumulative***
#	***€***	***€***	***€***
0	***-109.906***	***-109.906***	***-109.906***
1	***27.052***	***27.052***	***-82.854***
2	***27.043***	***27.043***	***-55.811***
3	***27.033***	***27.033***	***-28.777***
4	***27.024***	***27.024***	***-1.754***
5	***27.013***	***27.013***	***25.260***
6	***27.003***	***27.003***	***52.262***
7	***26.992***	***26.992***	***79.255***
8	***26.981***	***26.981***	***106.236***

9	*26.970*	*26.970*	*133.206*
10	*26.958*	*26.958*	*160.164*
11	*26.946*	*26.946*	*187.109*
12	*26.933*	*26.933*	*214.043*
13	*26.921*	*26.921*	*240.964*
14	*26.907*	*26.907*	*267.871*
15	*22.999*	*22.999*	*290.870*
16	*38.947*	*38.947*	*329.817*
17	*38.932*	*38.932*	*368.749*
18	*38.918*	*38.918*	*407.667*
19	*38.902*	*38.902*	*446.569*
20	*38.886*	*38.886*	*485.455*
21	*38.870*	*38.870*	*524.325*
22	*38.853*	*38.853*	*563.179*
23	*38.836*	*38.836*	*602.015*
24	*38.818*	*38.818*	*640.833*
25	*38.800*	*38.800*	*679.633*

Financial Viability criteria		
Pre-tax IRR - equay	*%*	*24,8%*
Pre-tax IRR - assets	*%*	*12,2%*
After-tax IRR - equity	*%*	*24,8%*
After-tax IRR - assets	*%*	*12,2%*
Simple Payback	*years*	*5,6*
Equity Payback	*years*	*4,1*
Net Present Value (NPV)	*€*	*233.512*
Annual Life cycle savings	*€/ years*	*20.038*
Benefit-Cost (B-C) ratio		*3,12*
Debt Service Coverage		*3,24*

Environmental Assessment	
Electricity to tones of CO_2 conversion factor (produced from coal in Greece) (t CO2/MWh)	*0.989*
Annual CO_2 Emissions' Savings (t CO_2)	*154,3*
Primary Energy Savings (MWh)	*452,4*

The implementation of a 100 kW PV installation can be characterized as a promising energy saving measure. All financial indicators, such as Simple payback period (5,6 years), Net Present Value and IRR suggest that the implementation of such an energy saving measure must qualify for further research, as from financial point of view it can be considered as more than attractive. The annual CO_2 emissions' reduction will be equal to 154,3 tones CO_2 per year, let alone that primary energy conservation equal to 452,4 MWh can be achieved.

Note: For PV and PV/T installations, the maximum available theoretical capacity that can be installed on a non residential tertiary building, like a medical unit, is considered to be equal to 1 MW according to the Greek legislation (so the maximum achievable capacity is the maximum capacity that can be installed, satisfying the space restrictions). For the present thesis the maximum acceptable installed power is considered to be equal to 100 kW. This takes place in order to achieve a favoring guaranteed feed in tariff (feed in tariff for installations above 100 kW is significantly lower) and at the same time, for the installation to be able to be characterized as low voltage system and keep the initial investment into reasonable levels. During the assessment of the implementation of the present energy saving measures, there was a discussion about changing the Greek legislation about PV and PV/T installations. These possible changes were not taken into consideration.

5.11.2.ESM 2 - Installation of solar collectors on the roof in order to heat main swimming pool's water

The second energy saving measure that is proposed is the implementation of solar collectors on the building's roof. The solar collectors will be utilized in order to heat main swimming pool's water. The area that is covered by water is 200 m^2. The average depth of the pool is equal to 1,5 m.

For the implementation of the present energy saving measure, solar collectors which have been manufactured by Enerworks are utilized. Their type is COL-4x8-NL-SG1-SH10 and it was proposed by the RETSCREEN's software project database. ***(www. retscreen.net)***

In the next figure the installation of 250 solar collectors on the building's terrace-shelter is presented. The dimensions of each solar collector are presented in the solar collectors' technical characteristics table. On each metallic base that is presented on the graph, 2 solar collectors are placed (due to the constructive properties of the utilized bases). The climatic and solar radiation characteristics of the installation location have been presented in the previous section. For the positioning of the solar collectors, the same empirical rule that was used in the previous section is utilized.

The slope of the solar collectors is equal to 31 degrees and their orientation is south facing.

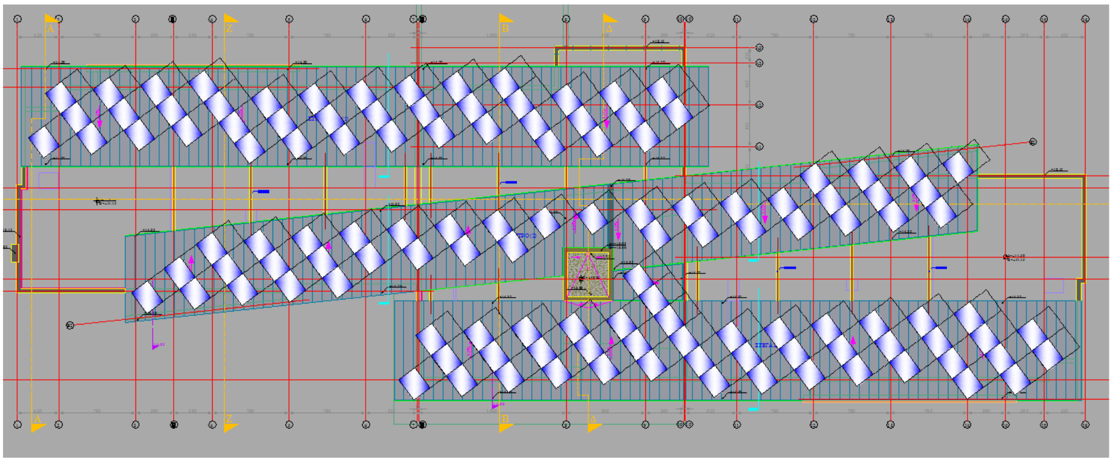

Figure 59: Solar Collectors' Installation on the building's terrace

For the calculation of the produced thermal energy for the coverage of swimming pool's water's needs, data about water's temperature from the mains have been utilized for the area of Thessaloniki.

The technical characteristics of the ESM are presented in the following table:

Table 55: Technical assessment of the solar collectors' implementation (www. retscreen.net)

Characteristic	***Value***
Type of swimming pool	***Indoor***
Total Area covered by water	***200 m^2***
Daily Use	***11 h/day (08:00-19:00)***
Desired Temperature	***33 ^oC***
Type of Solar Collector	***Glazed***
Manufacturer	***EnerWorks***
Model	***COL-4x8-NL-SG1-SH10***
Gross Solar collector's Area	***2,87 m^2***
Aperture Solar Collector's Area	***2,69 m^2***
Fr (tau alpha) coefficient	***0,7***
Fr UL coefficient	***4,04 $(W/m^2)/°C$***
Number of Units	***250***
Total Solar Collectors' Area	***717,50 m^2***

Total Capacity	***470,75 kW***
Losses	***4%***
Pump Required Power per solar collector area	***10 W/m²***
Annual Thermal energy produced	***407,2 MWh***
Solar Fraction Captured	***87%***
Natural Gas Used Before the implementation of ESM	***64.341,1 m^3 or 670 MWh***
Cost	***39.505 €***
Natural Gas used after the implementation of ESM	***8.478,1 m^3***
Cost	***5.206 €***
Electricity used for water's pumping	***13,0 MWh per year***
Fuel Mix For Swimming pool's water heating after the implementation of ESM	***Solar Energy 80,1%, Natural Gas17,4%, Electricity for Pumping 2,5%***
Annual Consumption in Natural Gas	***88 MWh***
Annual Consumption in solar energy	***407,2 MWh***
Annual Consumption in Electricity	***13 MWh***
Base Case GHG emissions	***131,3 tCO_2/year***
ESM Case GHG emissions	***30,1 tCO_2/year***
GHG emissions savings	***101,2 tCO_2/year***
Primary Energy Consumption reduction with the implementation of ESM(including the aggregation of electricity that is implemented for pumping)	***573,4 MWh/year.***

In the next table the financial assessment of the installation of the solar collectors is presented.

Table 56: Financial Assessment of Solar collectors' ESM(www. retscreen.net)

Initial Costs			
Feasibility Study	***0,1%***	***€***	***500***
Development	***0,6%***	***€***	***2000***
Engineering	***0,4%***	***€***	***1500***
Heating System	***98,9%***	***€***	***358.750***
Total Initial Costs	***100,0%***	***€***	***362.750***
Annual Costs and Debt Payments			

O&M	*€*	*300*
Debt Payment for 15 years	*€*	*19.914*
Fuel Annual Cost	*€*	*5.944*
Total Annual Costs	*€*	*25.858*
Periodic costs		
Major maintenance - 15 years	*€*	*1.500*

Annual cash flows			
Year	*Pre-tax*	*After Tax*	*Cumulative*
#	*€*	*€*	*€*
0	*-181.375*	*-181.375*	*-181.375*
1	*14.319*	*14.319*	*-167.056*
2	*15.003*	*15.003*	*-152.053*
3	*15.702*	*15.702*	*-136.352*
4	*16.414*	*16.414*	*-119.938*
5	*17.140*	*17.140*	*-102.798*
6	*17.881*	*17.881*	*-84.916*
7	*18.637*	*18.637*	*-66.279*
8	*19.408*	*19.408*	*-46.870*
9	*20.195*	*20.195*	*-26.676*
10	*20.997*	*20.997*	*-5.679*
11	*21.815*	*21.815*	*16.137*
12	*22.650*	*22.650*	*38.787*
13	*23.501*	*23.501*	*62.288*
14	*24.369*	*24.369*	*86.657*
15	*22.918*	*22.918*	*109.575*
16	*46.072*	*46.072*	*155.648*
17	*46.994*	*46.994*	*202.642*
18	*47.934*	*47.934*	*250.575*
19	*48.892*	*48.892*	*299.468*
20	*49.870*	*49.870*	*349.338*
21	*50.868*	*50.868*	*400.206*
22	*51.885*	*51.885*	*452.091*
23	*52.923*	*52.923*	*505.014*
24	*53.981*	*53.981*	*558.995*
25	*55.061*	*55.061*	*614.056*

Financial Viability criteria		
Pre-tax IRR - equay	*%*	*11,5%*
Pre-tax IRR - assets	*%*	*5,4%*
After-tax IRR - equity	*%*	*11,5%*
After-tax IRR - assets	*%*	*5,4%*
Simple Payback	*years*	*10,8*
Equity Payback	*years*	*10,3*
Net Present Value (NPV)	*€*	*114.097*
Annual Life cycle savings	*€/ years*	*9.791*
Benefit-Cost (B-C) ratio		*1,63*
Debt Service Coverage		*1,72*

From environmental point of view the installation of solar collectors for the main swimming pool's water's preparation can achieve significant CO_2 emissions' reduction (101,2 tCO_2/year) and primary energy consumption's savings (573,4 MWh/year). For this reason such an energy saving measure should qualify for further study and implementation. From financial point of view all financial indicators are attractive (all of NPV, IRR and simple payback period). This shows that the ESM could be profitable for the rehabilitation center. In comparison with the implementation of PV installation though, NPV and IRR are significantly lower. Additionally payback period is equal to 10,8 years, a time period which is significantly higher than the PV ESM's implementation (5,6 years). This acquires even more importance if the uncertainty of the present time and economic recession in Greece is considered. For this reason the implementation of solar collector's may be an attractive investment, but the implementation of the PV installation should be preferred.

Note: The preparation of main swimming pool's water in summer months takes place with the utilization of the heat recovery system that is installed on the coolers. This was not taken into account during the study of the solar collectors' ESM in order to have a more spherical image about the potential of this energy saving measure. The coverage of thermal loads for the other three swimming pools' water's and domestic hot water's preparation and possible heating during summer months, will continue to take place with the utilization of the heat recovery provision.

5.11.3.ESM 3 - Installation of PV/T modules on the roof

The third proposition of the writers of the present thesis is the implementation of a hybrid photovoltaics' installation on the roof of the building. Photovoltaics will be responsible for onsite electricity generation , while thermal energy will be produced as well. Generated power will be extracted to the grid and generate income, which will be subtracted from the annual PPC bills, while the produced heat will be used again to heat the main swimming pool's water until 33 ^oC, which is the desired temperature set point. In other words the present energy saving measure will be a combination between the first and second ESMs. Another interesting idea for future research could be the combination of the present ESM with an absorption cooler, and the simultaneous turning off of one of the two existing coolers. With the combination of an absorption or adsorption cooling system, which will be able to cover the cooling needs of the medical unit, a trigeneration solution can be successfully implemented. Hybrid Photovoltaics will promote the innovative character of the present dissertation, with an implementation of a solution with finite and rare utilization in Greece and set at the same time an ideal base for further research and study. Finally the relative high temperatures which exist in Greece and would be a clear disadvantage in the case of a simple PV system can be balanced with the increased heat that will be rejected from the PV cell and transferred to the working fluid.

Hybrid organic solar cells, or PV thermal systems, or PV/T systems have the ability to generate power and thermal energy at the same time. Generation of Power is the main result of a hybrid PV cell. It has been proven that PV cells' efficiency is reduced with the increase of temperature. For every degree that temperature increases, the efficiency of a PV installation is reduced by 0,45%. PV thermal systems utilize a working fluid, which can be water , air, glycerol or other in order to cool the heated operating PV system. With this procedure the temperatures of PV/T systems can be maintained in low levels and their efficiency can be ranged in the highest possible level. Additionally PV/T systems' lifetime is significantly increased as long as they are not thermally stressed, at least not to the same level that common PV systems are. At the same time the working fluid acquires and transfers the rejected temperature from the PV cell. This heat can be utilized for various purposes such as space heating or water heating. This can be achieved with the implementation of a heat exchanger-pipe - tube combination, which are installed on the back side of the PV cell. A PV thermal system has many visual similarities with an ordinary solar flat plate collector. If water is used as a working fluid, then it can be directly fed into the already installed AHU units or circulated through the natural gas boiler, if additional heating is required in order to be utilized for space heating. Moreover it can be directly fed into an absorption or adsorption unit in order to provide space cooling, If the working fluid is a liquid, different than water, then through the heat exchanger , it can transfer its acquired heat to the space heating's or absorption chiller's utilized water. Air cooled PV/T have significantly lower price and are ideal for use in cooler climate countries. Water cooled PV/T systems though, are ideal for warmer countries, like Greece. Another advantage in favor of the utilization of water cooled PV/T is the easy combination of the water working fluid, with the existing piping- boiler-AHU installation. For these reasons a water cooled PV thermal installation is selected. ***(Giannakidis, 2012)***

The PV/T panels that were utilized , were the Volther Power Volt Model, which have been manufactured by Solimpeks. Its type is MWPVT-1414. Their technical characteristics are presented in the following table:

Table 57: Technical characteristics of utilized PV/T systems(www.solimpeks.com)

Manufacturer	***Volther***
Model	***Power Volt MWPVT-1414***
Type	***Mono Si Hybrid PV Module***
Number of Units	***526***
Maximum power	***190 W***
Total Power	***99940 W***
Maximum voltage	***36,5V***
Open circuit voltage	***45,2 V***
Short circuit current	***5,6 A***
Dimensions	***0,828X1,655X0,09m***
Module Efficiency	***22,8%***
Cost of Unit	***760 euro /module***
Total Cost	***399760 euro***
Maximum Thermal Power	***460 W***
Absorber Piping Material	***Copper***
Internal Piping Material	***Copper***
Sealing	***Silicone +EPDM***
Liquid Content	***1,2 Lt***
Flow	***65Lt/h***
Thermal Efficiency for 80^{o}C Supply temperature	***46%***
Thermal Efficiency for 60^{o}C Supply temperature	***58%***
Thermal Efficiency for 10^{o}C Supply temperature	***82%***

In the next table the characteristics of the utilized inverters are presented

Table 58: Technical characteristics of the inverters (www.hotwater-shop.gr), (www.sma-hellas.com)

Manufacturer	***SMA***
Model	***Sunny Tripower 20000TL***
Number of Units	***5***
Input Maximum Power	***20450 W***
Maximum Input voltage	***1000 V***

Input Voltage Range	***580-800 V***
Input Nominal Voltage	***580V***
Maximum input current	***36A***
Output Nominal power at 230V and 50 Hz	***20000W***
Output Range of nominal voltage	***160-280V***
Output Network frequency	***50Hz - 60 HZ***
Maximum output current	***29 A***
Maximum Efficiency	***98,5 %***
Operation Temperature range	***-25-60 ^{o}C***
Dimensions	***0,665X0,69X0,265 m***
Total Output Power	***100 kW***
Cost of Unit	***4800 euro***
Total Cost	***24000 euro***

In the next figure the installation of the PV/T systems on the building's roof-shelter is presented:

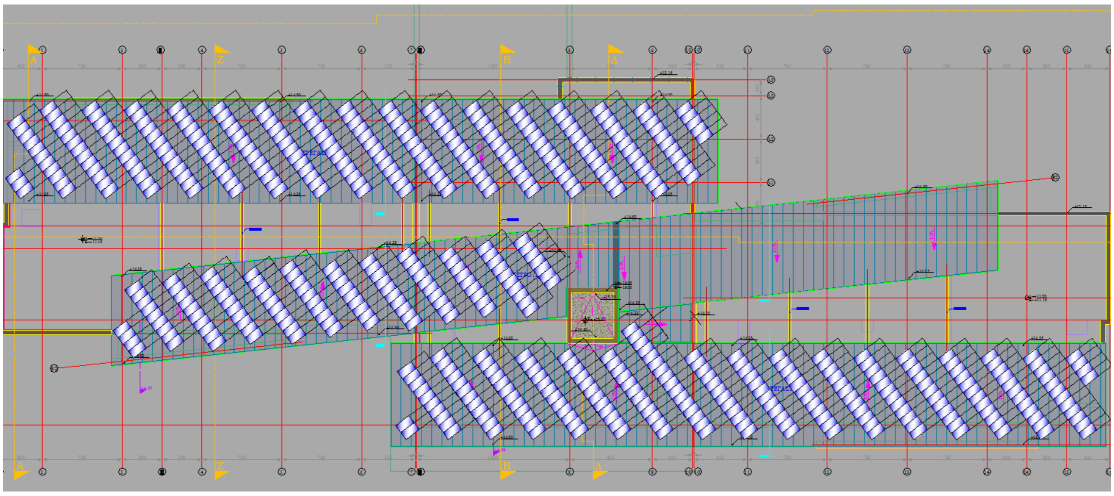

Figure 60: Installation of Hybrid PV systems on the medical unit's roof

Again the slope of the PV/T systems is equal to 31 degrees and their orientation is south facing as this way the exploitation of the available solar radiation is maximized. The same empirical rule that was used for simple PV systems' positioning is used. It has been described in the relevant figure in the ESM 1 section. As the length a of each PV/T system is equal to 1,655 m, the distance d is equal to 3,31 m. As it has been found, 526 panels can be placed on the roof, satisfying at the same time the limitation of 100 kW maximum of total installed electric power. The total nominal power is equal to 99940 W.

More or less the same financial assumptions with the PV ESM exist.

Table 59: Financial assumptions about the installation of the PV/T panels

Stainless Steel Support Structure's Cost	*22000 Euros*
Cables' Cost	*1000 Euros*
Installation Cost	*4000 Euros*
Maintenance Cost	*1% of the initial investment and 2500 Euros at the end of the 15th year for a major inverter's maintenance*
Engineers' Compensation	*2000 Euros*
Administration Costs	*500 Euros upfront and 50 Euros annually*
Inflation	*3%(www.naftemporiki.gr)*
Discount Rate	*7% (www.naftemporiki.gr)*
Financing that will be covered with debt	*50%*
Debt interest rate	*7%*
Feed in tariff for installations until 100 kW	*252,62 Euros/MWh (www.ypeka.gr)*

Again the thermal energy that will be produced, will be used for heating of a 200m^2 area swimming pool. The average depth of the swimming pool is equal to 1,5 m. Again the assumption that the swimming pool will be heated by the PV/T produced heat for every month is made (although for the time being this is achieved with the heat recovery from coolers during June, July and August). The technical and financial assessments are presented in the following table:

Table 60: PV/T installation's technical and financial assessment(www. retscreen.net)

Annual Income			
Electricity exported to grid		*MWh*	*156*
Electricity Export Rate		*€/MWh*	*252,6*
Electricity Export Income		*€*	*39468*
Annual Savings from generated electricity(cash flows not paid to PPC)		*€*	*39468*
Natural gas savings per year		*m^3*	*54110*
Natural Gas Cost Savings per year		*€*	*32539*
Initial Costs			
Feasibility Study	*0,1%*	*€*	*500*
Development	*0,9%*	*€*	*4000*

Engineering	0,4%	€	2000
Power System	98,6%	€	444.512
Total Initial Costs	100,0%	€	451.012
Annual Costs and Debt Payments			
O&M		€	300
Debt Payment for 15 years		€	24.759
Total Annual Costs		€	25.157
Periodic costs			
Inverter major maintenance - 15 years		€	2.500
Annual cash flows			
Year	Pre-tax	After Tax	Cumulative
#	€	€	€
0	-225.506	-225.506	-225.506
1	47.915	47.915	-177.591
2	48.911	48.911	-128.681
3	49.937	49.937	-78.744
4	50.994	50.994	-27.750
5	52.082	52.082	24.332
6	53.203	53.203	77.535
7	54.358	54.358	131.894
8	55.548	55.548	187.442
9	56.773	56.773	244.214
10	58.035	58.035	302.249
11	59.335	59.335	361.584
12	60.673	60.673	422.258
13	62.052	62.052	484.310
14	63.473	63.473	547.783
15	61.041	61.041	608.824
16	91.202	91.202	700.025
17	92.754	92.754	792.779
18	94.352	94.352	887.132
19	95.999	95.999	983.131
20	97.695	97.695	1.080.826
21	99.442	99.442	1.180.268
22	101.241	101.241	1.281.509
23	103.094	103.094	1.384.603
24	105.003	105.003	1.489.606
25	106.969	106.969	1.596.575

Financial Viability criteria		
Pre-tax IRR - equay	%	23,6%
Pre-tax IRR - assets	%	12,3%
After-tax IRR - equity	%	23,6%
After-tax IRR - assets	%	12,3%
Simple Payback	years	6,3

Equity Payback	***years***	***4,5***
Net Present Value (NPV)	***€***	***517.417***
Annual Life cycle savings	***€/ years***	***44.400***
Benefit-Cost (B-C) ratio		***3,29***
Debt Service Coverage		***2,94***
Environmental Assessment		
Annual CO_2 Emissions' Savings (t CO_2) due to electricity conservation	***154,3***	
Primary Energy Savings (MWh) due to electricity conservation per year	***452,4***	
Annual CO_2 Emissions' Savings (t CO_2) due to natural gas conservation (including pumping system's electricity)	***98,48***	
Primary Energy Savings (MWh) due to natural gas conservation per year (including pumping system's electricity)	***556,4***	
Total annual CO_2 Emissions' Savings (tCO_2)	***252,8***	
Total Primary Energy Savings (MWh)	***1008,8***	

The implementation of the present ESM can be characterized as the best from environmental point of view because with its implementation, the greatest possible amount of CO_2 emissions' and final and primary energy consumption's reduction is achieved. From financial point of view all financial indicators show that it is an attractive project. The 6,3 years payback period may insert a little more risk in the investment in comparison with the simple PV installation. NPV though indicates that in the long term the PV/T may be a more profitable investment. All in all the implementation of the PV/T energy saving measure, is an innovative investment, at least for Greek standards; it is by far the most promising investment, as soon as technological development takes place regarding the efficiency of PV/T technologies, and commercialization of this solution occurs, leading to reduction of PV/T panels' prices in the near future. Further research and development must take place on its implementation , not only on medical units, but also generally on tertiary sector's buildings, with special attention to its combination with an absorption cooler, in order to achieve a totally RES fueled cogeneration of heating, cooling and power (trigeneration).

Note: For PV and PV/T installations, the maximum available theoretical capacity that can be installed on a non residential tertiary building, like a medical unit, is considered to be equal to 1 MW according to the Greek legislation (so the maximum achievable capacity is the maximum capacity that can be installed, satisfying the space restrictions). For the present thesis the maximum acceptable installed power is considered to be equal to 100 kW. This takes place in order to achieve a favoring guaranteed feed in tariff (feed in tariff for installations above 100 kW is significantly lower) and at the same time, for the installation to be able to be characterized as low voltage system and keep the initial investment into reasonable levels. During the assessment of the implementation of the present energy saving measures, there was a discussion about changing the Greek legislation about PV and PV/T installations. These possible changes were not taken into consideration.

6. Conclusions

The main purpose of the present master Thesis was a conduction of a research, regarding the energy efficiency in every kind of medical units. The research took place in both a bibliographic and an experimental level.

The literature review that took place regarding the conduction of energy audits in medical units can demonstrate the technological and methodology progress that has been noticed in these sector. Useful conclusions can be extracted about the average energy consumption of a medical unit, the energy consumption's break down and the fuels that are utilized for the operation of medical units. Furthermore all the methodologies that have been used until the present day are mentioned or briefly described. The interested reader may search the initial provided bibliography and find additional information, such as advantages and disadvantages about the methods that can be used for the conduction of energy audits. Finally a very interesting collection of the possible energy saving measures that can be implemented on a medical unit has been created. The interested reader may find information about every energy saving measure that has been implemented until the present day on hospitals and healthcare facilities, with short comments about their technical and financial feasibility.

As it can be extracted from the literature review, an organized effort for assessing the energy performance of medical units started in the mid 1960s in US. The first steps in the sector were done in the US territory, with Europe having an active role in this sector, in the mid 1980s. In the first energy audits single energy consuming devices, such as boilers, or air conditioning units were inspected. With the progress of time there was presented a trend within energy audits, according to which the energy performance of the whole building is examined, giving to the energy audits a more holistic approach. The main incentive behind the first energy audits is an effort to promote cost savings regarding the operation of medical units. As the recent times are approached the main incentives are energy conservation and CO_2 emissions' reduction, reflecting the scientific community's considerations about resources' conservation and slowing the pace of the global warming phenomenon and climatic change. Of course the financial factor keeps its significant importance. The main energy consumers in a medical unit are considered to be space heating, cooling and ventilation systems with energy consumption of more than 45% of the overall energy consumption, domestic hot water preparation system with energy consumption equal to 17% of the overall energy consumption and lighting systems with 11% of the overall energy consumption. Special attention should be paid to medical equipment's energy consumption. In the first chronologically energy audits, medical equipment's energy consumption is not so significant, being responsible for about 4-5 % of overall energy consumption. From the more resent energy audits though, it can be extracted that medical equipment, which becomes more and more complex, is becoming responsible for 19% of the overall energy consumption in a medical unit. Every energy audit is finished with the proposal and the assessment of energy saving measures in order to reduce energy consumption and CO_2 emissions. In the first energy audits energy saving measures had been firstly implemented and then assessed. As technology and time progressed the trend in energy audits was the implementation of simulation software such as TRNSYS and Energy Plus. These computer programs accept data about the building's energy consuming devices such as HVAC and DHW system, lighting and medical equipment and the implementation of energy saving measures is virtually assessed. If an energy saving measure is found to be efficient, then it qualifies for implementation. The most popular energy saving measures refer to the replacement, adjustment or maintenance of HVAC and DHW systems, the implementation of solar collectors, the replacement of the lighting systems with more efficient ones and the installation of occupancy or movement sensors and the implementation of more efficient operating schedule for the energy consuming devices, such as medical equipment and elevators. More recently the implementation of waste management in order to recover heat from them and safely dispose them has been studied leading to a more green approach in the medical units' energy performance assessment. The key behind the implementation of every energy saving measure, is an effort to increase patients' and medical staff's awareness, about energy conservation and CO_2 emissions' reduction.

The energy performance legislation for medical units section, is maybe the first organized effort to concentrate on a single project healthcare facilities' energy performance legislation on a worldwide level. Information about energy performance legislation for medical units has been collected for Greece, Europe, United States of America, United Kingdom, Canada and Brazil. The interested reader may find information about standardization of energy consuming devices in medical units around the world and examine if a healthcare related activity that is studied by him is compatible with national and international legislation or not.

Concluding the energy performance legislation and standardization for medical units, it can be extracted as a result that in European Union energy performance is controlled by the Energy performance of buildings directive. On the contrary in American (both north and south) countries energy performance of medical units is controlled by ASHRAE's legislative framework such as standard 90.1-1999, and the local legislation of each country about energy consumption within tertiary buildings. The best way to assess these two frameworks is in the way they cooperate with each country's national legislation and not solely. This way these two frameworks are adjusted to the energy needs, buildings' forms and climate of each country, and only with the national peculiarities' adjustment to the general EC's and ASHRAE's framework, the best energy conservation result can be achieved. The main disadvantage of European legislation and European countries' national legislation and developing countries' national legislation is that the legislative framework is obligatory only for public hospitals. On the contrary ASHRAE's, U.S.'s, Canada's and UK's legislation has power not only on public medical units but also on private as well, increasing significantly the energy conservation potential.

Finally with the description of the green hospital's concept, the next level of low energy and energy efficient hospital is described. With this section environmental protection is considered in a more holistic approach with the implementation of terms, such as water's and resources' conservation and waste minimization. A very stable and promising base for future research - maybe with future MSc dissertations- has been created on a subject, that is going to be studied a lot in the short and medium term.

The experimental part of the present dissertation, is the practical implementation of knowledge that has been acquired during the bibliographic part. A preliminary energy audit was conducted on Euromedica Arogi rehabilitation center, which is located in Pylaia, Thessaloniki, Greece , with latitude 40,5 and longitude 23. The orientation of the medical unit was found to be northwest. The study of a rehabilitation center, was preferred over the study of a usual hospital, in order to promote the innovative character of the present thesis. Few or no energy audits on rehabilitation centers in Greece have been recorded until the present day.

First of all a walkthrough energy audit was conducted, with the inspection of the rehabilitation center's spaces and most important energy consuming devices. The second step was the performance of the actual energy audit. The energy audit is characterized as a preliminary one, due to the fact that in order for a complete energy audit to be conducted, both heating and cooling periods must be covered. This means that about a year is needed, while in the specific case the available time was about 4 months, a period during which, only a part of the cooling period could be covered with the utilization of actual measurements. This is the reason that the medical unit's energy performance was estimated with the utilization of collected data and not by actual measurements; thus the energy audit acquires a more preliminary character. Measurements about the thermal comfort in the medical unit were performed, with the internal temperature set point being between 20-26 ^{o}C and the relative humidity between 40-50%, achieving more than sufficient compliance with EPBD's and ASHRAE's standards. In comparison to a hospital, the rehabilitation center, may have not such complex and energy intensive medical equipment and the ultra-sensitive environment of the surgery room. On the other hand, it has 4 swimming pools, the water of which must be maintained in temperatures' range from 31 to 33 ^{o}C requiring great amounts of primary and final energy. Three natural gas boilers are responsible for the heating of water that is pumped from the mains. This water can be directly utilized in swimming pools, kitchens, and bathrooms, or it can be pumped in 10 air handling units, where it exchanges heat with fresh air. The heated air is emitted in spaces of the rehabilitation center, with the utilization of fan coils, achieving at the same time, space heating and ventilation. Two 500 kW coolers are responsible for cooling the water that is needed for medical uses. The same water can be driven in the 10 air handling units and cool the incoming air. The cool air is again driven in the internal spaces , with the implementation of fan coils, achieving space cooling and ventilation at the same time. Great interest is presented in the installed heat recovery system on the coolers, which utilizes their rejected heat in order to cover the required thermal loads for space heating and DHW and swimming pools' water's heating during summer months. An analytical inspection and recording of the lighting systems was performed and data about the illuminance of each space of the medical unit were collected as well. The total installed lighting systems' power was equal to 147647W and lighting systems were found to be responsible for the 23,39% of overall electricity's consumption and around 11% of the overall final energy's consumption of the rehabilitation center for 2011. Despite the fact that their overall installed power was significantly high, if the large area of the medical unit and the implementation of timers and occupancy sensors are considered, their operation can be characterized as more than satisfying. Electricity was responsible for the 47,25% of the final energy consumption and for the 71,22% of the primary energy consumption. On the other hand natural gas (fueling the 3 boilers for water heating) was found to be responsible for the 52,75% of overall final energy and for the 28,78% of the primary energy consumption of the medical unit for 2011. The annual electricity consumption was equal to 151 kWh/m^2, while the annual natural gas consumption was equal to 168,7 kWh/m^2. The total final annual energy consumption for the medical unit was equal to 319,7 kWh/m^2. During the summer months, natural gas consumption is kept into zero, or very low levels. This takes place due to the fact that space heating and DHW and swimming pools' water's heating during cooling period is covered by the heat recovery provision, that is installed on the coolers. The total primary energy consumption of the medical unit was found to be equal to 8.727.453 kWh/year or 615,2 kWh/m^2/year and the total CO_2 emissions of the medical unit were found to be equal to 2.588.564 kg CO_2/year. The energy performance of the rehabilitation center was found to be more than satisfying, in comparison with the average Greek medical unit's energy consumption, something which was expected due to the fact that it was constructed in 2009-2010. For this reason its energy consuming devices' efficiency was at high levels and its building envelope was compatible with EPBD's and K.E.ν.A.K.'s specifications. The main disadvantage that was identified, was the lack of renewable energy sources' utilization. This was reflected on the energy performance ranking of the medical unit which was assessed with the utilization of TEE-KENAK's (ΕΛΟΤ ΕΝ ISO 13790) software. The energy performance of the rehabilitation center was ranked as Energy Class C. A variety of RES based energy saving measures were proposed, in addition to the utilization of more efficient transparent elements. A pre-feasibility study about the implementation of solar collectors, PV and hybrid PV thermal installations took place. From environmental point of view PV/T systems were found to have the best result in reducing the primary energy consumption and CO_2 emissions of the medical unit. From financial point of view, the implementation of PV installation was found to be the less riskier investment, with the lowest payback period. PV/T investment though, had the highest Net Present Value, leading to the conclusion that it may be the most profitable investment in the long term and the most promising one, as PV/T technology is rapidly developing and their price will rapidly drop as they will be widely commercialized in the next years. A subject that is proposed for future research -why not by a dissertation of the present MSc programme- is the combination of the PV/T systems that were studied, with an absorption or adsorption cooler. This way the implementation of a 100% RES fueled trigeneration of space heating, cooling and power may be achieved, adding to a methodology that has been proven to be ideal for medical units an environmentally friendly and innovative character.

7. Bibliography-References

1. ***Adamu Z.A. et al, (2012), "Performance evaluation of natural ventilation strategies for hospital wards - A case study of Great Ormond Street Hospital", School of Civil and Building Engineering, Loughborough University, Loughborough, , United Kingdom***
2. ***Adderley et al, (1987), "Prospects for energy thrift in Welsh Hospitals", Cranfield Institute of Technology, Bedford, United Kingdom***
3. ***Adderley et al, (1989), "Energy-Signature Characteristic of a Hospital", Cranfield Institute of Technology, Bedford, United Kingdom***

4. *AEDG-SHC,(2010), "Advanced Energy Design Guide for Small Hospitals and Healthcare Facilities", ASHRAE journal, United States of America*
5. *Ahmadzadehtalatapeh et al, (2011), "The application of heat pipe heat exchangers to improve the air quality and reduce the energy consumption of the air conditioning system in a hospital ward - A full year model simulation", Department of Mechanical Engineering, University of Malaya, Kuala Lumpur, Malaysia*
6. *American Hospital Association, (2011), "Hospital Energy Management Survey", Health Facilities Management, AHA, Chicago, Illinois, United States of America*
7. *Anastaselos D., (2012), "Notes for Energy efficiency and savings", International Hellenic University, Thessaloniki, Greece*
8. *Argiriou et al, (1993), "On the energy consumption and indoor air quality in office and hospital buildings in Athens, Hellas", Chemical engineering department, National Technical University, Athens, Greece*
9. *Aspinall P., (2004), " Benchmarking and Best Practice - Energy management for healthcare in United Kingdom", Dalkia, Houston, Texas, United States of America*
10. *ASHRAE, (2006), " Guidelines for design and construction of hospitals and healthcare facilities" ASHRAE journal, United States of America*
11. *ASHRAE, (2010), "Standard 62.1-2010 - Indoor Air quality" ASHRAE journal, United States of America*
12. *ASHRAE, (2004), "Standard 90.1-2004 - Amendment of Standard 90.1-1999" ASHRAE journal, United States of America*
13. *Balaras C. A. et al, (2006), "HVAC and indoor thermal conditions in hospital operating rooms", Institute for Environmental Research and Sustainable Development, National Observatory of Athens, Athens, Greece*
14. *Benatech, (1987), "Energy audit for Moncrief army community hospital, Oliver dental clinic, Caldwell dental clinic and Hagen dental clinic", Savannah District Corps of Engineers, Georgia, United States of America*
15. *Bonnema et al, (2010), "Large Hospital 50% Energy Savings: Support Document", National Renewable Energy Laboratory, U.S. Department of Energy, Washington, United States of America*

16. *Bujak J., (2010), "Heat consumption for preparing domestic hot water in hospitals", Polish Association of Sanitary Engineers, Division Bydgoszcz, Ruminskiego, Poland*
17. *Canadian Standards Association, (2010), CSA Z317.2-10 " Special requirements for Heating, Ventilation and Air-conditioning systems in healthcare facilities", Ontario, Canada*
18. *Carpenter et al, (2006), "In Search of Efficiency", Health Facilities Management, American Hospital Association, Chicago, Illinois, United States of America*
19. *Chinese et al, (2006), "From hospital to municipal cogeneration systems: An Italian case study", University of Udine, Udine, Italy*
20. *Chirarattananon et al, (1993), "Energy Conservation Promotion Act's impact on new buildings", Division of Energy Technology, Asian Institute of Technology, Bangkok, Thailand*
21. *Congradac et al, (2012), "Assessing the energy consumption for heating and cooling in hospitals", Faculty of Technical Sciences, Novi Sad, Serbia*
22. *Cristalli C., (2012), "GREEN@Hospital Web based Energy Management System for the optimization of energy consumption in hospitals project", Loccioni AEA, Ancona, Italy*
23. *Dascalaki et al, (2007), "Air quality in hospital operating rooms", Institute for Environmental Research and Sustainable Development", National Observatory of Athens, Athens, Greece*
24. *Directive 2002/91/EC "Energy Performance of Buildings", (2002), Official Journal of the European Communities, Brussels, Belgium*
25. *Directive 2003/96/EC " Taxation of energy products",(2003), Official Journal of the European Communities, Brussels, Belgium*
26. *Directive 2004/8/EC " Promotion of the cogeneration based on useful heat demand and amending Directive 92/42/EEC",(2004), Official Journal of the European Communities, Brussels, Belgium*
27. *Directive 2005/32/EC "Framework for the implementation of Eco design",(2005), Official Journal of the European Communities, Brussels, Belgium*

28. *Directive 2006/32/EC "Promotion of the end use efficiency of energy services",(2006), Official Journal of the European Communities, Brussels, Belgium*
29. *Directive 2010/31/EC "Energy Performance of Buildings amending 2002/91/EC", (2010), Official Journal of the European Communities, Brussels, Belgium*
30. *Dome-Tech Inc., (2010), "Hoboken University Medical Center Energy Audit", Hoboken, New Jersey, United States of America*
31. *Exergy Development Group, (2012), "Online undertaken Project Description Brochure", Boise, United States of America*
32. *Giannakidis G., (2012), "Notes for Renewable Energy Sources 2", International Hellenic University, Thessaloniki, Greece*
33. *Greentech, (2007), " Energy Audits and implementation of Energy management system on Malaysian hospitals", Malaysia*
34. *Herrera et al, (2001), "Pinch Technology Application in a hospital", Centro de Investigacion en Energia, Morelos, Mexico*
35. *Hirst et al, (1982), " Analysis of hospital energy audits", Oak Ridge National Laboratory, Oak Ridge, United Stated of America.*
36. *Hospital 2020 Organization, (2011), "Building a Green Hospital Checklist", Chicago , Illinois, United States of America*
37. *International Resource Group, (2009), "Energy efficiency in hospitals - Best practice guide", USAID ECO III Program, Bureau of energy efficiency, India*
38. *IESO, (2009), "Analysis of energy use for Ontario Hospitals", Finn Projects, Toronto, Canada*
39. *Karliner et al, (2011), "A Comprehensive Environmental Health Agenda for Hospitals and Health Systems Around the World", HCWH Europe, Brussels, Belgium*
40. *Khodakarami et al, (2012), "Thermal comfort in hospitals – A literature review", Ilam University, Ilam, Iran*
41. *Kumar et al, (2004), "Energy conservation measures on Sir J. J. Hospital", Promoting Energy Efficient Public Sector Act, Mumbai, India*
42. *Law v. 3661/2008, (2008), National Press of Greece, Athens, Greece*

43. *Mavrotas et al, (2009), "Energy planning of a hospital using Mathematical Programming and Monte Carlo simulation for dealing with uncertainty in the economic parameters", School of Chemical Engineering, National Technical University of Athens, Athens, Greece*
44. *Meir I. A., (2012), "Notes for Urban Energy Systems", International Hellenic University, Thessaloniki, Greece*
45. *MEVOS Ltd, (2011), "Enhancement of energy effectiveness in heating system of hospital in the city of Valjevo", Valjevo, Serbia*
46. *Natural Resources Canada, (1998), "Energy Audit on Kingston General Hospital", Buildings' Division, Office of Energy Efficiency, Natural Resources Canada, Ottawa, Canada*
47. *Ortiga et al, (2010), " Selection of typical days for the characterization of energy demand in cogeneration and trigeneration optimization models for buildings", Universitat Rovira i Virgili, Tarragona, Spain*
48. *Pagliarini G. et al, (2012), "Hospital CHCP system optimization assisted by TRNSYS building energy simulation tool", University of Parma, Italy*
49. *Paksoy et al, (2000), " Heating and cooling of a hospital using solar energy coupled with seasonal thermal energy storage in an aquifer", University of Cukurova, Adana, Turkey*
50. *Pollack R. I., (1979), "Hospital Energy Audits, A bibliography", Lawrence Berkeley National Laboratory, California, United States of America*
51. *Psaras et al, (2011), " Energy audit on P. and A. Kyriakou children's hospital, as a thesis of student Papastamatiou for electrical engineering degree", National Technical University, Athens, Greece*
52. *Reed C. A., (2005), "Increasing Hospital Energy Performance with Energy Star®",US Environmental Protection Agency, United States of America*
53. *Regulation For Energy Performance Of The Buildings- K.E.v.A.K., (2008), National Press of Greece, Athens, Greece*
54. *Saidur et al, (2010), "An end use energy analysis in a Malaysian public hospital", College of Engineering Universiti Tenaga Nasional, Selangor, Malaysia*
55. *Santamouris et al, (1993), "Energy Performance and Energy Conservation in healthcare buildings in Hellas", University of Athens, Athens, Greece*

56. *Shanavaz et al, (2009), "Energy Audit Methodology in Hospitals and Medical Trust Hospital Case Study", Kerala State Productivity Council, Kalamassery, India*
57. *Short C.A. et al, (2012), "Building resilience to overheating into 1960's UK hospital buildings within the constraint of the national carbon reduction target: Adaptive strategies", Department of Architecture, University of Cambridge, Cambridge, United Kingdom*
58. *S.I. No. 666 of 2006, (2006), "Energy performance of Buildings regulations" , Government's Publications Office, Dublin, Ireland*
59. *Siemens Healthcare Department, (2012), "Green + Hospitals - Sustainable Healthcare Infrastructure. More than just Green", Siemens AG, Erlangen, Germany*
60. *Singer B. C. et al, (2009), "Hospital Energy Benchmarking Guidance - Version 1.0" Berkeley National Laboratory, California, United States of America*
61. *Singer B. C. et al, (2009), "Summary of Information and Resources Related to Energy Use in Hospitals" Berkeley National Laboratory, California, United States of America*
62. *Sofronis et al, (1994), "Energy consumption in Greek public hospitals", KAPE, Athens, Greece*
63. *Szklo A. S. et al, (2003), "Energy consumption indicators and CHP technical potential in the Brazilian hospital sector", Federal University of Rio de Janeiro, Rio de Janeiro, Brazil*
64. *Tadonnio et al, (2008), "Energy conservation project for University of Pittsburg Medical Center", US Department of Energy, Washington, United States of America*
65. *TOTEE 20701−1/2010, "National specifications for the conduction of energy audits and the issuance of energy performance certificate for a building", (2010), National Press of Greece, Athens, Greece*
66. *TOTEE 20701−5/2012 : "Cogeneration of Heating, Cooling and electricity in building installations" under 1192/ΦΕΚ 1413-2012 , (2012), National Press of Greece, Athens, Greece*

67. *Tudor et al, (2006), "Towards the development of a standardized measurement unit for health care waste generation", University of Exeter, Exeter, United Kingdom*
68. *USAID Jordan Economic Development Program, (2012), "Energy and Water Audits on Jordanian Hospitals", SABEQ Program, USAID Asia, Jordan*
69. *USAID Sustainable development and policy center, (2011), "Energy audit report on the Dusheti general hospital", USAID Caucasus, Georgia*
70. *US Department of energy, (2009), "Hospital Energy Alliance (HEA) Executive Roundtable", Us Department of Energy, Washington, United States of America*
71. *United States Army Corps of Engineers, (1981), "Kimborough Hospital Energy Audit", US Army facilities Engineering Support Agency, Virginia, United States of America*
72. *Vanhoudt et al, (2011), "An aquifer thermal storage system in a Belgian hospital: Long-term experimental evaluation of energy and cost savings", Flemish Institute for Technological Research, Mol, Belgium*
73. *Verheyen et al, (2010), "Thermal comfort of patients: Objective and subjective measurements in patient rooms of a Belgian healthcare facility", University College of Antwerp, Antwerp, Belgium*
74. *Vosburgh E. J.,(2001), "Northumberland Green health care center analysis" Human Resources and Risk Management Department, Northumberland Health Care Corporation, Canada*
75. *Wastren Energy Services, (2000), "Online Project Description Brochure", Wastren Advantage, Piketon, United States of America*
76. *Williams et al, (1998), "Hospital energy performance: New indicators for UK National Health Service Estate", Cardiff School of Engineering, Cardiff, United Kingdom*
77. *Yau et al, (2010), "The ventilation of multiple bed hospital wards in the tropics: A review", University of Malaya, Kuala Lumpur, Malaysia*

Internet Sources

1. ***http://www.ashrae.org (accessed on 30-6-2012)***
2. ***http://www.carrier.gr (accessed on 7-9-2012)***
3. ***http://www. cretalive.gr (accessed on 19-6-2012)***
4. ***http://www.czda.cz (accessed on 8-7-2012)***
5. ***http://www.exergydevelopment.com (accessed on 8-7-2012)***
6. ***http://www.euromedica-arogi.gr (accessed on 25-8-2012)***
7. ***http://greenbuildings-in-the-world.blogspot.gr (accessed on 19-6-2012)***
8. ***http://greenhospital.blogspot.com (accessed on 21-6-2012)***
9. ***http://www.greenhospitals.net (accessed on 22-6-2012)***
10. ***http://www.greenhospital-project.eu (accessed on 1-8-2012)***
11. ***http://harvard.edu (accessed on 8-7-2012)***
12. ***http://www.helacpo.gr (accessed on 10-9-2012)***
13. ***http://www.hospital2020.org (accessed on 21-6-2012)***
14. ***http://www.hotwater-shop.gr (accessed on 10-9-2012)***
15. ***http://www.keralaenergy.gov.in (accessed on 13-7-2012)***
16. ***http://kgh.on.ca (accessed on 8-7-2012)***
17. ***http://medical.siemens.com (accessed on 21-6-2012)***
18. ***http://www.naftemporiki.gr (accessed on 10-9-2012)***
19. ***http://portal.tee.gr (accessed on 26-6-2012)***
20. ***http://www.poweringhealth.org (accessed on 8-7-2012)***
21. ***http://re.jrc.ec.europa.eu/pvgis (accessed on 23-8-2012)***
22. ***http://www.retscreen.net (accessed on 23-8-2012)***
23. ***http://www.sma-hellas.com (accessed on 10-9-2012)***
24. ***http://www.solimpeks.com(accessed on 12-9-2012)***
25. ***http://www.ypeka.gr (accessed on 10-9-2012)***
26. ***http://www.wastrenadvantage.com (accessed on 22-7-2012)***

Acknowledgments

I would like to personally thank Dr. D Anastaselos, supervisor of the Thesis for his guidance and crucial contribution to the completion of the present dissertation. Furthermore, I would like to thank Mr. Zachopoulos, technical manager of Euromedica Arogi, for his cooperation and provision of the required data for the completion of the dissertation. Finally I would like to attribute special thanks to my father, Nikolaos, mother, Eleni and my fiancée, Foteini for their unconditional support, during the whole duration of my studies.

Appendix

In the next table information about maximum U value for various building elements and for climatic zone C, as it is provided by Greek and European legislation is provided . This information was used in building envelope section of the experimental part.

***Table A1: Maximum thermal transmittance factor** (**Law v. 3661/2008**)*

		Climatic Zone C
Building Element	***U Value symbol***	***(W/m^2K)***
Roof adjacent to external air	U_D	***0,40***
Vertical Walls adjacent to external air	U_W	***0,45***
Floor adjacent to external air (pilotis)	U_{DL}	***0,40***
Floor in contact with the ground	U_G	***0,75***
Vertical walls in contact with unconditioned	U_{WE}	***0,8***

space or ground		
Opening (windows- doors etc)	***U_F***	***2,80***
Glazed Facades of buildings	***UG_F***	***1,8***

In the next table information about the conversion factor of each type of fuel to primary energy and CO_2 emissions is provided. This information was utilized during the calculation of primary energy and GHG emissions of the medical unit.

Table A2: Final to primary energy conversion factor and Carbon Dioxide emissions regarding the type of energy carrier that is used (***Law v. 3661/2008***)

Energy Source	***Conversion Factor to Primary Energy***	***CO2 emissions ($kgCO_2/kWh$)***
Natural Gas	***1,05***	***0,196***
Oil	***1,10***	***0,264***
Electricity	***2,90***	***0,989***
Biomass	***1***	***0***
RES such as solar and wind	***0***	***0***

The calculation of daily DHW demand was based on the following table:

Table A3: Domestic Hot water Standards: (TOTEE 20701−1/2010)

Thermal Zone or Room	***L/person/day***	***$L/m^2/day$***	***L/bed/year***	***$m^3/m^2/year$***
Hospital for more than 500 persons	***80***	-	***29,2***	-
Hospital for less than 500	***120***	-	***43.9***	-

persons				
Clinic	***60***	***-***	***22***	***-***
Rural Medical Unit	***5***	***0,75***	***-***	***0,2***
Psychiatric Medical Facility	***50***	***-***	***18,25***	***-***

The calculation of Internal Heat gains from occupants was based on the following table:

Table A4: Internal heat gains due to occupants for medical units (TOTEE 20701−1/2010)

Thermal Zone or Room	***Thermal Power per person W***	***Thermal power per surface unit W/m²***	***Mean Presence factor***
General	***90***	***27***	***1***
Patient room	***70***	***15***	***0,75***
External Medical Facilities	***90***	***9***	***0.24***
Waiting Rooms	***80***	***44***	***0,24***
Rural Medical Unit	***90***	***14***	***0,36***
Psychiatric Medical Facility	***80***	***12***	***1***

Information about water's from the mains temperature that was utilized for ESM 2 and DHW's thermal load for climatic zone C is provided in the following table:

Table A5: Water's from the mains temperature for climatic zone C (Law v. 3661/2008)

Month	*Jan*	*Feb*	*Mar*	*Apr*	*May*	*June*	*July*	*Aug*	*Sep*	*Oct*	*Nov*	*Dec*
Temperature °C	*6,5*	*7,3*	*9,4*	*13,2*	*17,6*	*21,9*	*24,3*	*24,6*	*22*	*17.7*	*12,7*	*8,6*