Journal of Engineering and Architecture
December 2015, Vol. 3, No. 2, pp. 79-86
ISSN: 2334-2986 (Print), 2334-2994 (Online)

Published by American Research Institute for Policy Development
DOI: 10.15640/jea.v3n2a9
URL: http://dx.doi.org/10.15640/jea.v3n2a9

Creation of zero CO_2 Emissions Hospitals Due to Energy Use A Case Study in Crete-Greece

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Abstract

Hospitals consume a lot of energy for various operations compared with other buildings. They have complex energy systems and use conventional energy sources, mainly electricity, heating oil and natural gas. However various renewable energies can be used in order to cover their energy requirements resulting in low or zero CO_2 emissions from them. Solar energy, solid biomass and geothermal energy can be used for that generating electricity, heat and cooling. A case study of a hospital in Crete-Greece proves that the combined use of solar thermal, solar-PV, solid biomass and low enthalpy geothermal energy with heat pumps can cover all the energy needs of it resulting in zero CO_2 emissions. These renewable energy technologies are reliable, cost effective and present many environmental benefits. For a 300 beds hospital in Crete, Greece the investment cost for using solar thermal, solar PV and solid biomass in order to cover all its energy needs is estimated at 7, 434 € per bed and for using solar thermal, solar PV and low enthalpy geothermal energy with heat pumps 8, 679 € per bed. Annual CO_2 emissions savings due to use of the abovementioned renewable energies are estimated at 10.9 tons per bed.

Keywords: CO_2 emissions, Crete, energy, hospitals, renewable energies

1. Introduction

Promotion of low energy and low CO_2 emissions buildings is in the core of current EU energy policies. Although hospital's energy systems are very complex using conventional fuels, the use of renewable energies is very important for them. Recent advances in various renewable energy technologies have increased their reliability and their cost effectiveness allowing their broad applications in new fields. Innovative financial tools like third party financing allow the support of renewable energies investments by energy service companies (ESCOs). Changes in the legislative framework regarding the higher penetration of renewable energies in the electric system like attractive feed-in tariffs and net metering regulations facilitate and promote their applications in new fields. There are not currently many reports regarding the use of renewable energies in hospitals or reports related with hospitals with low or zero CO_2 emissions due to energy use. A report regarding the use of renewable energies in European hospitals has been presented in the framework of the implementation of an IEE project [Res-hospitals].

The use of geothermal energy in a hospital in New Zealand has been reported [Steins et. al., 2012]. High enthalpy steam is used for covering the heating needs of the hospital and it could be used also for covering its electricity requirements in the future. The design of a solar absorption cooling system in a Greek hospital combined with a case study in Crete-Greece has been reported [Tsoutsos et. al., 2010] and the cost effectiveness of the technology has been proved. An aquifer thermal storage system in a Belgian hospital has been reported [Vanhoudta et. al., 2011].

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The authors studied the system in combination with a heat pump for heating and cooling of the hospital. They found that the primary energy consumption of the heat pump was 71 % lower than the conventional system using gas-fired boilers and water cooling machines. The payback period of the investment without subsidies was estimated at 8.4 years. Energy consumption in Brazilian hospitals has been reported [Szklo et. al., 2004]. For a medium size hospital, annual energy consumption varied between 230-460 KWh/m^2 depending on the comfort level and more electricity than heating fuel was used in it. Energy performance and energy conservation in health care buildings in Hellas has been reported [Santamouris et. al., 1994]. The authors studied 30 health care buildings and they found that the energy consumption varied from 407 KWh/m^2.year in hospitals to 275 KWh/m^2 years in clinics. Space heating required 73.4 % of the total energy consumption in hospitals and 65.3 % in clinics. They concluded that proper energy saving measures could reduce overall energy consumption by 10 %. Energy conservation techniques for hospital buildings have been reported [Kolokotsa et. al., 2012]. The authors studied the state of the art technologies for energy efficiency in the hospital sector. They proposed that simple energy saving techniques can save up to 10 % of primary energy consumption. According to them a typical breakdown of energy use in a good practice hospital with 500 beds is fossil fuels for heating 34 %, fossil fuels for base load 14 %, lighting 14 % and the other electricity uses 38%. Use of renewable energies and energy conservation technologies for various buildings in Southern Europe has been reported [Santamouris et. al., 1994].

According to the authors energy consumption per sector in a typical Greek hospital is cooling 3 KWh/m^2 years, heating 299 KWh/m^2 year, lighting 52 KWh/m^2 year, equipment 53 KWh/m^2year, total 407 KWh/m^2year. Energy consumption in Greek hospitals has been reported [Sofronis et. al., 2000]. The authors found that energy consumption varies according to the climate zone from 270 KWh/m^2 years (south), to 438 KWh/m^2 years (north). The average consumption was 370 KWh/m^2 year, 290 KWh/m^2 years for heating and 80 KWh/m^2 year for electricity. A report for saving energy in hospitals has been published [CADDET, 1997]. According to it energy consumption in hospitals varies between 250-1, 000 KWh/m^2 years and energy savings of 20-44 % can be achieved in them. According to this report thermal energy consumption in Greek hospitals is estimated at 300 KWh/m^2 year and electricity consumption at 110 KWh/m^2 years. An optimal operation of a complex power plant in a hospital generating energy for heating, power and cooling which can be profitable has been reported [Van Schijndel, 2002]. Heat consumption for preparing domestic hot water in hospitals has been reported [Bujak, 2010]. The authors report that in Poland during 2003-2008 the energy consumption in large hospitals with over 600 beds varied between 250-333 KWh/m^2year. Use of new technologies for an effective retrofit in hospitals has been reported [Bizzari et. al., 2006].

The authors studied the use of a phosphoric acid fuel cell, a solar thermal and a solar PV system in a hospital and concluded that their use in hospitals during refurbishment can be profitable. Greenhouse gases reduction and primary energy savings via the adoption of a fuel cell hybrid plant in a hospital has been reported [Bizzari et. al., 2004]. The authors studied its use in a hospital in northern Italy and concluded that significant amounts of heat and electricity can be saved due to the operation of the fuel cell. A study of different cogeneration alternatives for a Spanish hospital has been reported [Renedo et. al., 2006]. The authors studied four cogeneration systems for providing heat, air conditioning and hot water in a large hospital in Spain and they concluded that all systems could be profitable and trigeneration in Southern Europe should be promoted. Economics of a trigeneration system in a hospital in Slovenia has been reported [Ziher et. al., 2006]. The authors studied the use of a trigeneration system with natural gas turbines and compression or absorption chillers for power, heat and cooling generation in a hospital and they concluded that the system can be profitable having low payback period and high NPV.

The potential for incorporating low energy ventilation and cooling strategies into the design of new hospitals has been studied proving that it will lower energy consumption and it could be profitable [Alan Short et. al., 2009]. A study concerning energy use in Malaysian hospitals has been published [Saidur et. al., 2010]. It was found that the use of high efficiency electric motors can decrease significantly energy consumption achieving payback periods less than a year. Application of pinch technology in a hospital has been presented [Herrera et. al., 2003] achieving power saving potential of 38 %. The energy consumption and the indoor air quality for office and hospital buildings in Athens have been reported [Argiriou et. al., 1994]. The authors found that the concentrations of NO_2 and SO_2 inside the hospital did not exceed the upper limits given by WHOM. A simple methodological tool for creation of building (hotels, dwellings) with zero CO_2 emissions due to energy use has been presented. [Vourdoubas, 2015, Vourdoubas, 2015] This approach allows the use of various renewable energies (solar thermal, solar PV, solid biomass, geothermal energy with heat pumps) in buildings in order to zero CO_2 emissions in them covering all their energy needs.

1. Energy consumption in hospitals

Energy is consumed in hospitals in various sectors like:

- Space heating
- Space cooling
- Hot water production
- Lighting
- Operation of various electric equipment and apparatus

Hospitals are among the highest energy consuming buildings and the majority of them consume between 200-400 KWh/m^2 year. Various estimations concerning energy consumption in Greek hospitals (Santamouris et.al., 1994, Caddett, 1997) give values 407 and 410 KWh/m^2 year. Other estimations for energy consumption in Greek hospitals vary according to the climate zone that the hospital is located. The main energy sources which are consumed in hospitals are heating oil and natural gas for heat production and electricity for lighting, air conditioning and operation of various electric (equipment) devices. Distribution of energy consumption in a hospital per sector is presented in table 1

Table 1: Distribution of energy consumption in hospitals

Sector	Energy consumed (%)[1]	Energy consumed (%)[2]
Lighting	14	12.8
Other electricity uses	38	13.8
Heating	34	73.4
Other heat uses	14	
Total	100	100

([1]) Typical breakdown of energy use in a good practice hospital with 500 beds [Kolokotsa et.al., 2012]
([2]) Energy breakdown per sector in Greek hospitals [Santamouris et.al., 1994]

Energy consumption depends on the quality of the building construction and its thermal insulation, on the services offered as well as on the local climate. Average low and high air temperatures in Chania, Crete, Greece vary between 7.9-14.1 ^oC in January and 21.2-30.6 ^oC in July. Solar irradiance in Chania, Crete, Greece at tilt 30 degrees varies between 83 KWh/m^2 in January to 208 KWh /m^2 in July with monthly average 145 KWh /m^2

Fossil fuels and electricity used in hospitals can be easily replaced by renewable energies although there are not currently many of them using renewable energies in order to reduce fossil fuels consumption. Application of various simple energy conservation techniques can save up to 10 % of primary energy consumption and the use of more sophisticated technologies can result in higher energy savings.

2. Use of Renewable Energies in Hospitals

Although the energy system of a new hospital is extremely complex various renewable energies can be used in order to provide heat, cooling, electricity and vehicles fuels in it [Renewable energy guide for European hospitals]. Among them are a) various types of solid, liquid, or gaseous biomass, b) solar thermal energy, c) solar PV energy, d) geothermal energy with heat pumps, e) wind turbines and hydropower systems if the hospital is located nearby a river or a waterfall and if the annual average wind velocity nearby the hospital is satisfactory. Wind and hydropower can be used according to their availability on site or off site. Biomass which is produced elsewhere can be used for heat or/and power generation. Biofuels can also be used as fuels for the hospital vehicles. Biomass burning technology for the heat generation is a mature, reliable and cost effective technology which is used broadly today. Solar thermal energy can be used also for heat (and cooling) generation. Currently it is broadly used for hot water production in various buildings like residential buildings and hotels. Its effective use for space heating and cooling has been proved only in large systems. Solar photovoltaic energy is also used broadly for power generation. The last few year the sharp decrease in their prices has resulted in their increasing use for power generation mainly in grid connected systems.

Ground source heat pumps are used broadly for heat and cooling generation in buildings. Heat pumps use electricity for their operation but they are very energy efficient devices having C.O.P. in the range 3-4. The use of the abovementioned renewable energies in hospitals are influenced by various factors like a) Their availability on site or off site, b) The existence of governmental supporting policies, favourable regulations and ambitious targets set c) The existence of appropriate financial tools and mechanisms to support their investments, d) The maturity, reliability and the cost effectiveness of various renewable energy technologies which can be used in the hospitals, e) The possibility for grid connection of the electricity generation systems used in it.

A guide towards zero carbon hospitals using renewable energy systems has been presented during the implementation of an E.U. funded IEE project named Res-hospitals [http://www.res-hospitals.eu]. The case messages of this guide include the followings. Most European hospitals are embracing the need to reduce energy consumption but investments in renewable energies are less common and very few of them are demonstrating financial innovation to support investments in renewable energies. Current feasible options for onsite renewable energy production in European hospitals are situation dependent. However the most popular choices for onsite renewable energy generation are biomass systems and photovoltaic panels but there is also an increasing number of ground source heat pumps used in them. Finally offsite systems including hydropower and wind farms offer the best opportunities for hospitals to exploit the benefits of renewable energies and to cope with the problems of rising energy costs.

3. Creation of hospitals with zero CO_2 emissions due to energy use

In order to zero CO_2 emissions due to energy use from hospitals the following two criteria must be fulfilled.

- Fossil fuels must not be used and
- Electricity used from the existing electric grid must be offset by electricity generated by renewable energies i.e. solar P-V.

In such a case CO_2 emissions due to operating energy use (but not the construction or the demolition energy) in the hospital will be zero.

Assuming that fuels used in hospitals vehicles will be based in biofuels it can be considered that they have zero CO_2 emissions. Therefore the hospitals can

Produce heat using solar thermal energy and solid biomass

- Produce heat and cooling using ground source (low enthalpy geothermal) heat pumps
- Generate electricity with solar- PV panels which will be fed into the electric grid (with net metering regulations) which will be equal with the annually consumed electricity from the grid.

The combination of the abovementioned sustainable energy technologies can be used in order to accomplish the target of zero CO_2 emissions due to energy use. The following two cases will be examined for a hospital located in Chania-Crete-Greece.

3.1 Use of solar energy and solid biomass for covering all the energy needs of the hospital in Crete-Greece

In this case the hospital will generate a) hot water mainly with solar thermal systems and additionally with solid biomass burning, b) space heating with solid biomass burning, c) Electricity with solar PV panels. Electricity will be used for lighting, for space cooling and for the operation of various equipment and machineries (pumps, valves, lifts, aerators, refrigerators, surgical tools and equipment etc.)

The combined use of solar thermal energy, solar PV and solid biomass in hospitals can result in zeroing their CO_2 emissions due to energy use in them. In order to estimate the size of the necessary renewable energy systems the following assumptions are made:

a) The hospital has 300 beds and covered area 15, 000 m^2 (50 m^2/bed)
b) It will utilize biofuels instead of fossil fuels in its vehicles and renewable energies for heating, cooling and power generation.
c) A grid connected solar PV will generate annually the same amount of electricity that the hospital consumes from the grid (based on the net-metering regulations)

d) The hospital will reduce by 10 % its initial energy consumption (407 KWh/m^2 year) to 366 KWh/ m^2 year by implementing various energy saving techniques
e) The breakdown per sector of energy use in the hospital is 42% for electricity 36% for space heating and other heat uses, 22% for hot water production
f) The annual generated electricity from the solar PV system in Crete is 1, 500 KWh/ KWp
g) The annual generated heat from the solar thermal system with flat plate collectors is 1, 800 KWh /KW (1m^2 of flat plate solar collector is equivalent to 0.7 KW)
h) The heat content of solid biomass is 4, 000 kcal/ kg and the efficiency of the burning system is 0.75. Its net heating value is 3, 000 kcal/kg (3.48 KWh/kg)
i) The flat plate collectors will produced 75% of the required energy for hot water production (906 MWh)
j) Solid biomass burning will produced all the energy used for space heating and other heat uses plus 25% of the required energy for hot water production
(1, 976 + 302 =2, 278 MWh)
k) The power of the solid biomass burning system will be double than the average power estimated from annual needs (2, 278, 000 KWh/24X365 =260 X2=520 KW) in order to cover the peak loads.

The energy consumption of the hospital is presented in table 2

Table 2: Energy consumption in the hospital

Number of beds	300
Covered area	15, 000 m^2
Specific annual energy consumption	366 KWh/m^2
Total annual energy consumption	5, 490 MWh
Electricity Consumption	2, 306 MWh
Energy used for hot water production	1, 208 MWh
Energy used for space heating and other heat uses	1, 976 MWh

The sizes of the solar thermal, solar PV and solid biomass burning system are presented in table 3

Table 3: Size of various renewable energy systems covering all the energy needs of the hospital

Energy system	Size or Quantity consumed	Energy generated (MWh)
Nominal power of solar-PV	1, 537 KW	2, 306
Area of flat plate collectors	503 m^2	906
Power of flat plate collectors	352 KW	-
Power of solid biomass burning system	520 KW	2, 278
Annual consumption of solid biomass	655 tons	-
Total		5, 490

3.2 Use of solar energy and low enthalpy geothermal energy with heat pumps for covering all the energy needs of the hospital in Crete-Greece

In this case the hospital will generate

a) Hot water mainly with solar thermal systems and additionally with ground source heat pumps
b) Space heating and cooling with ground source heat pumps
c) Electricity with a solar-PV system which will be used for lighting and for the operation of various equipment and machineries (pumps, valves, lifts, aerators, refrigerators, surgical tools and equipment etc.). Additionally electricity will be also used for the operation of the ground source heat pumps.

The solar thermal, the solar PV systems and the low enthalpy geothermal heat pump will utilize the in-situ renewable energies. With reference to the same hospital described previously the followings assumptions are made in order to estimate the size of the renewable energy systems

a) The grid connected solar PV will generate annually the same amount of electricity that the hospital consumes from the electric grid.
b) The solar thermal system will produced 75% of hot water requirements (906 MWh).
c) The heat pump will cover all the space heating and other heating needs and it will produce also the 25% of the hot water needed (302 MWh). It will cover also the cooling loads of the hospital and it is assumed that the energy required for that is 15 % of the initial electricity consumption which corresponds to 346 MWh (1, 976+302+346=2, 624 MWh).
d) The C.O.P. of the heat pump is 3.5. Therefore it will consume 750 MWH annually. It is assumed that it will operate 8, 760 hours annually and its power will be double than the average estimated in order to cover peak loads. Therefore the power of the heat pump is 750, 000/8, 760=86X2= 172 KW.
e) Grid electricity consumption will be equal with the initial consumption minus the electricity used for cooling which will be covered from the heat pump plus the electricity consumption of the heat pump (2, 306-346+750 =2, 710 MWh).

The size of the renewable energy systems used in the hospital are presented in table 4

Table 4: Size of various renewable energy systems which can cover all the energy needs of the hospital

Energy system	Size	Energy generation (MWh)
Area of flat plate collectors	503 m^2	906
Power of flat plate collectors	352 KW	
Power of heat pump	172 KW	2, 624
Nominal power of solar PV system	1, 807 KW	2, 710
Total		6, 240

4. Economic Considerations

Use of the abovementioned renewable energy technologies in the hospital requires new investments. In order to estimate the necessary investment capital the following assumptions are made.

a) The cost of solar thermal system is 250 €/m^2
b) The cost of solar PV system is 1, 200 €/KWp
c) The cost of solid biomass burning system is 500 €/ KW_{th}
d) The cost of ground source geothermal heat pump is 1, 800 €/KW

In table 5 the capital cost of the renewable energy systems which can generate all the required energy in the abovementioned hospital in Crete-Greece is presented

Table 5: Capital cost of various renewable energy systems which can generate all the required energy in the hospital in Crete-Greece

Energy system	Use of solar energy and solid biomass Capital cost (€)	Use of solar energy and geothermal energy with heat pumps Capital cost (€)
Solar thermal	125, 750	125, 750
Solar PV	1, 844, 400	2, 168, 400
Solid biomass burning	260, 000	
Geothermal heat pump		309, 600
Total	2, 230, 150	2, 603, 750
Total per bed	7, 434	8, 679

It is obvious that the use of the abovementioned renewable energies in the hospital significantly reduces the conventional fuels costs which are required in order to cover all its energy needs. However in order to assess the profitability of the proposed renewable energy systems their maintenance and depreciation costs must be taken also into account. The costs of solar and geothermal energy are zero and the only fuel cost is due to solid biomass use. In table 6 the annual costs of conventional fuels as well as the costs of the renewable energies used are presented.

Table 6: Annual costs of fuels used for covering all the energy needs of a hospital in Crete-Greece

	Use of conventional fuels (€ per year)	Use of solar energy and solid biomass(€ per year)	Use of solar energy and geothermal energy (€ per year)
Grid electricity cost	576, 500	-	-
Heating oil cost	304, 689	-	-
Solid biomass cost	-	65, 500	-
Total	881, 189	65, 500	0
Total per bed	2, 937	217	0

- Cost of grid electricity = 0, 25 €/KWh
- Cost of heating oil= 1 €/kg
- Cost of solid biomass (Olive kernel wood) = 0.10 €/kg

5. Environmental benefits due to renewable energies use in a hospital

Use of various renewable energies in order to cover all the energy requirements of a hospital in Crete-Greece results in environmental benefits due to savings of CO_2 emissions in the atmosphere. In order to estimate these CO_2 emissions savings it will be assumed that the hospital uses conventional energy sources like electricity (generated from fossil fuels) and heating oil in order to cover all its heating needs. CO_2 emissions in the hospital resulted from the use of fossil fuels are presented in table 7.

Table 7: CO_2 emissions due to fossil fuels use in the hospital

Fuel	Use	Annual consumption (MWh)	Annual CO_2 emissions (tons CO_2)
Electricity	Operation of various electric devices and machinery	2, 306	2, 281
Heating oil	Space heating, hot water production, other heat uses	3, 184	975
Total		5, 490	3, 256
Total per bed		18.3	10.9

- Emissions coefficient for electricity 0.989 kg CO_2/KWh
- CO_2 emissions from heating oil 3.2 kg CO_2/kg
- Net heating value of heating oil 9, 000 kcal/kg (10.45 KWh/kg)

Therefore, the use of renewable energies in order to cover all the energy needs of the abovementioned hospital in Crete-Greece will result in annual savings 3, 256 tons of CO_2 due to energy use in it.

6. Conclusions

Hospitals are high energy consuming buildings using mainly conventional energy sources like electricity, heating oil and natural gas.However recent advances in renewable energy technologies allow their use in order to cover all the energy requirements of the hospitals zeroing at the same time CO_2 emissions due to energy use in them. Although many hospitals are trying to use energy saving techniques and technologies in order to reduce their energy consumption there are not currently many applications of renewable energy technologies replacing fossil fuels in them. Solar energy, solid biomass and low enthalpy geothermal energy are available in Mediterranean region and can be used for power, heat and cooling generation in hospitals. A case study for a 300 beds hospital in Crete-Greece has shown that solar thermal, solar PV and solid biomass can cover all the energy needs of it zeroing its CO_2 emissions due to energy use.The necessary investments of the abovementioned renewable energy technologies have been estimated at 7, 434 €/bed and CO_2 emissions savings at 10.9 tons CO_2/bed.year. An alternative case study in the same hospital has shown that solar thermal energy, solar PV and low enthalpy geothermal energy with heat pumps can also cover all the energy requirements of the same hospital zeroing also its CO_2 emissions due to energy use.

The necessary investments in that case are slightly higher than previously at 8, 679 €/bed. Further work is needed in order to estimate the net present value of these investments and to assess the profitability of using renewable energies instead of fossil fuels in the hospitals.

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