Journal of Engineering and Architecture
June 2018, Vol. 6, No. 1, pp. 19-27
ISSN: 2334-2986 (Print), 2334-2994 (Online)

Publishedby American ResearchInstituteforPolicyDevelopment
DOI: 10.15640/jea.v6n1a2
URL: https://doi.org/10.15640/jea.v6n1a2

Energy Consumption and Carbon Emissions in Venizelio Hospital in Crete, Greece: can it be Carbon Neutral?

John Vourdoubas[1]

Abstract

Hospitals consume large amounts of energy and emit a lot of greenhouse gases. They mainly use fossil fuels to cover their energy needs and the use of renewable energies in them is rather limited. Current work investigates the possibility of using renewable energies for covering all the energy needs in Venizelio hospital, with 440 beds, in Crete, Greece, zeroing its carbon emissions due to operational energy use. The use of solar thermal energy, solar photovoltaic energy, solid biomass and ground source heat pumps has been examined for heat, cooling and electricity generation in the hospital. It has been indicated that the combined use of the abovementioned renewable energy sources could cover all the energy needs in the hospital in a cost-effective way. Total energy consumption in Venizelio hospital has been estimated at 280.4 KWh m^{-2} $year^{-1}$, CO_2 emissions due to operational energy use at 168 kg CO_2 m^{-2} $year^{-1}$, while the share of electricity is almost double that of the share of heating oil. The investment cost in renewable energy technologies covering all its energy requirements varies between 5,898,300 € to 8,930,100 € resulting in annual fuel cost savings between 867,600 € to 943,000 €. The results of the current study indicate that the use of various, reliable and cost-effective renewable energies replacing fossil fuels inVenizelio hospital would be profitable and environmentally advantageous.

Keywords: Carbon emissions, Crete, Energy consumption, Greece, Renewable energies, Venizelio hospital

1. Introduction

European policies currently promote the transition to a low-carbon economy in order to mitigate climate change. For achieving this target, energy efficiency must be improved and the share of renewable energies in the energy mixture must be increased in all sectors of the economy. Hospital buildings consume large amounts of energy compared with residential and commercial buildings due to their continuous and complex operation. However their potential in reducing energy consumption and carbon emissions is high. Energy consumption in hospitals varies depending on the type and year of construction, the mode of operation, their location and the local climate.

1.1 Energy consumption in hospitals

Hu et al, 2004 have reported on energy consumption and cost in a large acute hospital in Taiwan. The authors stated that air conditioning has a share of 52% in total energy consumption, lighting at 12% and other utilities at 36%. They also reported that annual energy use in the hospital was 259.45 KWh m^{-2} while 88% of its heat requirements were covered with electricity and the remaining 12% with gas. Moghimi et al, 2011 have reported on energy consumption in a large scale educational hospital in Malaysia. The authors stated that its annual energy consumption was 245 KWh m^{-2}, while electricity had a share at 75% on that. A best-practices programme for energy consumption in hospitals has been published by the Department of Environment, Transport and the region's energy efficiency, U.K., 1999. The report states that currently annual heat energy consumption in a typical hospital (in the UK) is 445 KWh m^{-2} while the annual electricity consumption is 160 KWh m^{-2}. A good practice target for the same hospital would be 339 KWh m^{-2} for heat energy consumption and 103 KWh m^{-2} for annual electricity consumption. Energy consumption in Brazilian hospitals has been reported by Szklo et al, 2004.

[1]Mediterranean Agronomic Institute of Chania, Agrokipio, 73100, Chania, Crete, Greece, E-mail: vourdoubas@maich.gr

The authors stated that annual energy consumption for a medium-size hospital varied between 230-460 KWh m^{-2} while more electricity than heating fuel was used. Santamouris et al, 1994 have reported on energy performance and energy conservation in health care buildings in Greece. The authors studied 30 healthcare buildings and they found that their energy consumption varied between 275-407 KWh m^{-2}. They also stated that space heating required 65.3-73.4% of the total energy consumption while the use of energy saving techniques could reduce the overall energy consumption by 10%. Kolokotsa et al, 2012 have reported on energy conservation techniques in hospital buildings. The authors reported that the use of state-of-the-art energy-saving technologies could reduce energy consumption by 10%. They also indicated that energy breakdown in a good practice 500-bed hospital is 34% for space heating, 14% for base load, 14% for lighting and 38% for other electricity uses. Santamouris et al, 1994 have reported on the use of renewable energies and energy conservation technologies in various buildings in Europe. The authors stated that the annual energy consumption per sector in a typical Greek hospital is 3 KWh m^{-2} for cooling, 299 KWh m^{-2} for heating, 52 KWh m^{-2} for lighting, and 53 KWh $m^{-2}$for the operation of various equipment: in total 407 KWh m^{-2}. Sofronis et al, 2000 have reported on the energy consumption in Greek hospitals. The authors stated that annual energy consumption varies according to the climate zone from 270 KWh m^{-2} in the south, to 438 KWh m^{-2} in the north. The average annual energy consumption was 370 KWh m^{-2}, distributed at 290 KWh $m^{-2}$for heating and 80 KWh $m^{-2}$for electricity.

A report on energy saving in hospitals has been published by CADDET, 1997. According to this report the annual energy consumption in hospitals varies between 250-1,000 KWh $m^{-2}$and the use of appropriate energy-saving techniques could result in energy reduction by 20-44 %. The report mentions that the annual energy consumption in Greek hospitals is estimated at 300 KWh $m^{-2}$for heating and 110 KWh $m^{-2}$for electricity. Van Schijndel, 2002 has reported on energy co-generation in hospitals for covering their heating, cooling and electricity needs which could be profitable. Bujak, 2010 has reported on heat consumption for preparing hot water in hospitals. The author reported that in Poland, during 2003-2008, the annual energy consumption in large hospitals with over 600 beds varied between 250-333 KWh m^{-2}. Short et al, 2009 have studied the use of low energy ventilation and cooling strategies in the design of new hospitals, indicating that it will decrease energy consumption and it will be profitable. Saidur et al, 2010 studied the energy use in Malaysian hospitals indicating that the use of high efficiency electric motors could decrease energy consumption significantly and they can be highly profitable. Herrera et al, 2003 have studied the use of pinch technology in hospitals reporting that power savings at 38% could be achieved. Argiriou et al, 1994 have investigated the energy consumption and the indoor air quality for office and hospital buildings in Athens, Greece. They reported that the concentration of NO_x and SO_2 did not exceed the upper limits of the World Health Organization.

1.2 Use of renewable energies in hospitals

There are not many reports published so far regarding the use of renewable energy technologies in hospitals. During the implementation of an Intelligent Energy Europe project, RES-hospitals, the use of renewable energies in European hospitals was presented. Paksoy et al, 2000 have designed a solar heating system combined with heat storage in an underground aquifer for providing heating and cooling in Balcali hospital in Adana, Turkey. The authors stated that their simulation results indicated that an underground aquifer with dimensions 350X400 m would be enough for storage of roughly 14,000 MWh $year^{-1}$ in the form of heat and cold at $+10^{o}C$. Buonomano et al, 2014 have reported on a novel renewable poly-generation system for a hospital building located in Naples, Italy. The system was integrating concentrated photovoltaic thermal collectors and solar heating and cooling technologies. The authors stated that the energy performance of the system was excellent since the generated energy was consumed *in situ* while its payback period was approximately 12 years. Vourdoubas, 2015 has reported on the creation of zero CO_2 emission hospitals due to operating energy use with reference to the island of Crete, Greece.

The author assumed that the share of electricity in total energy consumption was 42% while for heating it was 58%. He also estimated that the investment cost of using only renewable energy technologies for covering all the energy needs in hospitals in Crete, Greece varies between 7,434 € bed^{-1} – 8,679 € bed^{-1}. Vourdoubas, 2016 has reported on using solid biomass for covering all the heating needs of the hospitals in Crete, Greece. He has proposed the use of olive kernel wood, a by-product of the olive processing industry, for covering all the heating needs of the hospitals which have been assumed at 300 KWh m^{-2} $year^{-1}$. The author estimated that the investment cost of the required biomass heating systems varies between 1,963 € bed^{-1} – 2,328 € bed^{-1}.

The use of geothermal energy in a hospital in New Zealand has been reported by Steins et al, 2012. The heating requirements of the hospital were covered by high enthalpy steam which could be used in the future for electricity generation. A case study concerning the use of a solar absorption cooling system in a Greek hospital has been reported by Tsoutsos et al, 2010. The authors indicated that its use is cost-effective. An aquifer thermal storage system in a Belgian hospital has been reported by Vanhoudt et al, 2011. The thermal energy storage system was combined with a heat pump for space heating and cooling in the hospital. The authors stated that the primary energy consumption of the heat pump was 71% lower than the conventional system using gas-fired boilers. They also mentioned that the pay-back period of the energy investment was 8.4 years without any subsidies. Bizzari et al, 2006 have reported on the use of new technologies for an effective retrofit in hospitals. The authors studied the use of a phosphoric acid fuel cell, a solar thermal system and a solar photovoltaic (solar-PV) system, concluding that their use in a hospital's refurbishment could be profitable. Bizzari et al, 2004 have also studied the use of a fuel cell hybrid plant in a hospital in northern Italy, concluding that its use could result in significant heat and power savings. Renedo et al, 2006 have studied four different co-generation alternatives for providing heat, air-conditioning and hot water in a large hospital in Spain, concluding that all of them could be profitable, and indicating that tri-generation technology should be promoted in southern Europe. Ziher et al, 2006 have studied the economics of a tri-generation system with natural gas turbines for power, heat and cooling generation in a hospital in Slovenia. The authors concluded that the system could be profitable, having a low pay-back period and a high net present value.

The aims of the current study are:

a) The estimation of the energy consumption and the carbon emissions in Venizelio hospital, in Crete, Greece;
b) The investigation of the possibility of using various locally available renewable energies for covering the energy needs of the hospital, reducing or zeroing its carbon emissions due to energy use; and
c) The cost estimation of the renewable energy investments as well as the savings in fuel costs in the hospital if renewable energies were used.

2. Description of the hospital

Venizelio hospital in Heraklion, Crete, Greece, was established in 1967 and since then it has gradually expanded. Its covered area is 26,172 m^2, its capacity is 440 beds and its staff includes 1,000 employees. Most of its energy systems are old, having low energy efficiencies. Their replacement with new and more efficient systems is going to reduce its energy consumption and it would probably be cost-effective. The hospital covers all its energy needs with electricity and heating oil. Unfortunately renewable energy sources are not currently used in it. The energy characteristics of the hospital and its energy consumption are presented in Table 1.

Table 1. Capacity of energy systems[1], energy consumption[2] and carbon emissions[3] in Venizelio hospital in Heraklio, Crete, Greece (2015)

Total heatingpower[1]	6,105 MW
Total coolingpower[1]	2,455 MW
Total electricpower[1]	1,400 kVA
Number of beds	440
Annualelectricityconsumption[2]	4,895 MWh_{el}
Annualheatingoilconsumption[2]	2,444 KWh_{th}
Annual total energyconsumption[2]	7,339 MWh
Annual total energyconsumption per bed[2]	16.7 MWh bed^{-1}
Annualcost of electricity	680,000 € $year^{-1}$
Annualcost of heatingoil	263,000 € $year^{-1}$
Total energycost	943,000 € $year^{-1}$
Total energycost per bed	2,143 € $year^{-1}$ bed^{-1}
Specificenergyconsumption	280.4 KWh m^{-2} $year^{-1}$
CO_2emissionsduetoelectricity use [3]	3,671 tonsCO_2 $year^{-1}$
CO_2emissionsduetoheatingoil use [3]	733 tonsCO_2 $year^{-1}$
Total CO_2emissionsduetoenergy use [3]	4,404 tonsCO_2 $year^{-1}$
Annual total CO_2emissionsduetoenergy use per bed[3]	10 tonsCO_2 bed^{-1}
Specific CO_2emissions[3]	168 kgCO_2 m^{-2} $year^{-1}$

[1,2]Personal communication, [3] Carbon emission coefficients, electricity 0.75 kg CO_2 KWh^{-1}, heating oil 0.30 kg CO_2 KWh^{-1}

Energy is used in the hospital for space heating and cooling, hot water production, lighting and the operation of various electric appliances and devices. Both electricity and heating energy are used in order to cover all its energy requirements. Energy distribution and consumption in various sectors in the hospital has been assumed to follow the pattern presented in Table 2, according to data published in various studies.

Table 2. Distribution of energy consumption in Venizelio hospital[1]

Sector	Energy consumed (%)	Annual energy consumption (MWh)
Space heating	34	2,495
Hot wáter production	13	954
Space cooling	18	1,321
Lighting	14	1,028
Other electrical uses	21	1,541
Total	100	7,339

[1]According to Santamouris et al, 1994; Sofronis et al, 2000; Kolokotsa et al, 2012; and Hu et al, 2004

3. Energy Use and Carbon Emissions in Hospitals

Fossil fuels and electricity derived by them dominate in the energy mixture in the majority of hospitals. The use of renewable energies in them is rather limited so far. However current advances in renewable energy technologies combined with appropriate governmental policies promoting them are expected to change the landscape, increasing their use in hospitals. Current advances in energy-saving technologies can also reduce their energy consumption and carbon emissions. Depending on the location, there are various renewable energies which are mature, reliable and cost-effective, and they can be used for generation of electricity, heat and cooling in hospitals. In the case of Crete, Greece, they include solar energy, solid biomass and low enthalpy geothermal energy. Carbon emissions in hospitals depend on the share of fossil fuels in their energy mixture. In order to zero CO_2 emissions due to energy use in them, the following criteria must be fulfilled:

a) Fossil fuels must be replaced by renewable energies in heat generation and if possible in power generation;
b) The use of high-efficiency energy technologies like co-generation systems and heat pumps must be encouraged; and
c) The same amount of grid electricity used annually must be offset by electricity derived by renewable energies, such as solar-PV electricity. Current regulations in various countries, such as net-metering, allow that.

4. Useof Various Renewable Energy Technologies for Covering the Energy Requirements in VenizelioHospital

Various renewable energy sources, which are locally available, can be used for covering the energy needs of the hospital. They include solar thermal energy, solar-PV, solid biomass and low enthalpy geothermal energy with high efficiency heat pumps. The high solar irradiance in Crete allows the use of solar energy for heat and electricity generation. The availability of large quantities of olive kernel wood in the island allows its use for heat production. Their technologies are mature, well-proven, reliable and cost-effective.

4.1 Use of solar thermal energy

Solar thermal energy can be used for hot water production in the hospital. Flat-plate solar collectors can be used placed on the roof terrace of the buildings while the hot water would be stored in well-insulated water storage tanks. The annual heat energy of the required hot water has been estimated at 954 MWh. Assuming that the annual heat generation from flat-plate solar thermal collectors in Crete is 700 KWh m^{-2}, their required area in order to generate all the hot water needed in Venizelio hospital is 1,363 m^2.

4.2 Use of solid biomass

Solid biomass could be used for providing the energy required for space heating in the hospital. Various types of locally produced biomass in Crete can be used including olive tree wood and olive kernel wood.

Olive kernel wood has very good burning characteristics, its price is low compared with its heating value and it is currently being used broadly for space heating in Crete. Its average annual production in the island is 110,000 tons and it is currently consumed for heating in residential and commercial buildings, greenhouses as well as in industry.

Assuming that the annual requirements for space heating in the Venizelio hospital are 2,495 MWh, the heating value of olive kernel wood is 3,800 kcal kg^{-1} and the efficiency of the heating system is 75%, it is estimated that the required quantity of the olive kernel wood in order to produce all the heat used for space heating in the hospital is 754 tons annually. Olive kernel wood could be additionally used for hot water production in the hospital if solar heaters were not used. Assuming that the heating system was operating for 5,843 hours annually and the peak heating load in the hospital was double than the annual average heating load, it is estimated that the thermal power of the biomass burning system would be 854 KW_{th}.

4.3 Use of low enthalpy geothermal energy with heat pumps

Ground source heat pumps can be used for covering the heating and cooling needs in the hospital. They are energy-efficient devices using electricity with COP in the range of 3-4. Assuming that the annual needs for space heating in Venizelio hospital are 2,495 MWh and for space cooling 1,321 MWh, the required annual electricity consumption of the heat pumps can be estimated. Assuming that the COP of the ground source heat pumps used is 3.5, the annual required electricity for their operation would be 1,090 MWh. The required power of the heat pump for covering the peak heating and cooling loads in Venizelio hospital has been estimated at 1 MW_{el}. Ground source heat pumps are using electricity which could be generated by solar-PV systems. Therefore the heating and cooling needs of the hospital can be covered by benign energy sources.

4.4 Use of solar-PV energy

Solar-PV systems, placed on the fields or on building roofs, are currently used in Crete for power generation due to high solar irradiance in the island. Solar-PV energy could be used for electricity generation in the hospital. Generated electricity could be fed into the grid, achieving attractive feed-in tariffs or with net-metering regulations. It is estimated that flat solar-PV panels without tracking systems in Crete annually generate 1,500 KWh per KW_p. Therefore the required nominal power of solar-PV panels in order to generate the required electricity in Venizelio hospital (3,890 MWh), if solid biomass is used for space heating, is 2,593 KW_p. In the case that low enthalpy geothermal heat pumps are used for space heating instead of solid biomass, the electricity requirements would be higher. In this case, total annual electricity requirements would be higher than in the previous case, at 4,980 MWh, and the size of the solar-PV system would be 3,320 KW_p.

The size of the systems of various renewable energy technologies which could cover all the energy requirements in Venizelio hospital are presented in Table 3.

Table 3.Size of various renewable energy systems which could be used in Venizelio hospital for covering its energy requirements.

Renewable energys ystem	Energy generated	Annual energy production (MWh $year^{-1}$)	Size
Solar termal system	Hot water	954	Area of flat plate collectors, 1,363 m^2
Solar-PV system	Electricity (in the case that biomass isused for space heating)	3,890	2,593 KW_p
Solar-PV system	Electricity (in the case that ground source heat pumps are used for space heating)	4,980	3,320 KW_p
Solid biomass burning system	Heat for space heating	2,495	854 KW_{th}
Ground source heat pumps	Heat energy for space heating and cooling	3,816	1,000 KW

5. Cost estimation

The investment cost of the required renewable energy systems generating all the energy used in Venizelio hospital has been estimated, knowing the size of the energy systems and their unit cost. It has been assumed that the unit costs of the renewable energy systems are: a) For the solar thermal system, 700 € m^{-2} of the flat-plate collectors; b) For the solar-PV system 1,200 € KW_p^{-1}; c) For the solid biomass burning system 300 € KW_{th}^{-1}; and d) For the ground source heat pump, 2,000 € KW^{-1}. The investment costs in renewable energy systems generating all the energy used in the hospital are presented in Table 4 for two scenarios. In the first scenario, it is assumed that solar thermal energy is used for hot water production, solid biomass for space heating and a solar-PV system for electricity generation equal to the grid electricity used annually. In the second scenario, a solar thermal system is used for hot water production, a ground source heat pump for space heating and cooling, and a solar-PV system for electricity generation equal to the grid electricity used annually.

Table 4. Investment costs of the renewable energy systems generating all the energy used in Venizelio hospital

Renewable energy system	Unit cost of the energy system	Costs: First scenario	Costs: Second scenario
Solar termal system	700 € m^{-2}	954.100 €	954.100 €
Solar-PV system	1,200 € KW_p^{-1}	4,688,000 €	5,976,000 €
Solid biomass burning system	300 € KW_{th}^{-1}	256,200 €	
Low enthalpygeo thermal heat pumps	2,000 € KW^{-1}		2,000,000 €
Total investment cost		5,898,300 €	8,930,100 €
Total cost per bed		12,405 € bed^{-1}	20,296 € bed^{-1}
Total investment cost per KWh consumed annually in the hospital		0.80 € KWh^{-1}	1.22 € KWh^{-1}
Total investment cost per CO_2 emitted annually in the hospital due to energy use		1.34 € kg CO_2^{-1}	2.03 € kg CO_2^{-1}
Annual savings in fuel cost		867,600 €	943,000 €
Annual savings in fuel cost per bed		1,972 € bed^{-1}	2,143 € bed^{-1}

From Table 4, it is concluded that the investment costs in the case of using a ground source heat pump are significantly higher than in the case of using a solid biomass heating system due to the high installation cost of heat pumps. The use of renewable energy systems for energy generation in Venizelio hospital result in significantly lower fuel costs. In the first scenario, the fuel costs are limited to the cost of solid biomass and in the second scenario, the fuels costs are zero. Assuming that the cost of olive kernel wood in Crete is 0.1 € kg^{-1}, the annual consumption of 754 tons of olive kernel wood in the hospital will cost 75,400 €. Taking into account that currently the annual total energy cost in Venizelio hospital is 943,000 €, it is concluded that the use of renewable energy technologies, providing all the energy needed, would result in significant energy cost savings.

6. Discussion

Hospital buildings consume large amounts of energy, due to their complex activities, compared with other residential, commercial and industrial buildings. Heating and cooling of hospitals have a high share in total energy consumption while electricity is currently the main energy source used in them. Use of well-known and cost-effective energy-saving techniques could reduce the total energy consumption by at least 10%. The current use of renewable energies in Greek hospitals is rather limited. However, due to current European policies for reduction of energy consumption, carbon emissions and mitigation of climate change, their use in the near future will be increased. Additionally, recent technological innovations have resulted in the improvement of their reliability and cost effectiveness, promoting their uses in hospital buildings.

Among the renewable energies with high availability in the Mediterranean region are included solar thermal energy, solid biomass, solar-PV energy and low enthalpy geothermal energy with heat pumps. All of them have been used so far to some extent in various hospitals with satisfactory results. They are also broadly used in residential and commercial buildings.

Additionally, the need for both electricity and heat energy in hospitals, throughout the year, favors the use of high-efficiency co-generation or tri-generation systems in them. Unfortunately natural gas is not available in Crete but LPG could alternatively be used for fuelling these systems. However co-generation systems are not currently used in hospitals in Crete. Due to the deep economic crisis in Greece, there is a lack of own financial resources funding the necessary energy investments in hospitals. A solution to that could be cooperatingwith energy-saving companies through energy-performance contracting for funding their investments. Hospitals consume energy, besides their operation, in construction, refurbishment and demolition. In order to zero their life cycle carbon emissions, energy consumption in all stages of their life cycle should be taken into account.

7. Conclusions

Energy consumption in Venizelio hospital in Crete, Greece, is presently 280.4 KWh m^{-2} $year^{-1}$, which is lower than the values reported for other Greek and European hospitals, while its carbon emissions, due to operational energy use, are 168 kg CO_2 m^{-2} $year^{-1}$. The electricity share in the energy mixture is approximately double compared with that of heating oil. However the use of renewable energies for heat and power generation in the hospital are not yet developed. Various renewable energies which are abundant in Crete could be used for heat and power generation. They include solar thermal energy, solar-PV energy, solid biomass and low enthalpy geothermal energy with heat pumps. These benign energy sources are already used in Crete in various applications and their technologies are mature, reliable and cost-effective. Their use could reduce or zero carbon emissions due to energy use in the hospital, reducing or even zeroing the annual costs of the fuel currently used. It has been estimated that the combined use of solar thermal energy, solid biomass and solar-PV energy for covering all the energy needs would require an investment cost of 5,898,300 €, saving 867,600 € annually in fuel costs. Alternatively the combined use of solar thermal energy, solar-PV energy and ground source heat pumps would require an investment cost of 8,930,100 €, saving 943,000 € annually in fuel costs. A cost analysis indicated that the replacement of fossil fuels with renewable energies in Venizelio hospital would be profitable, resulting in economic benefits, as well as environmental and social benefits. Further work should investigate the possibility of using LPG for co-generation of heat, power and cooling in Venizelio hospital combined with offsetting CO_2 emissions, due to LPG use, with the generation of green solar-PV electricity injected into the grid.

Questions and Answers

1. What hypotheses or questions does this work addresses?

Current work tries to answer the question if various renewable energies can be used for covering the energy requirements of hospitals with reference the Venizelio hospital in Crete, Greece.

2. How does this work advance our current understanding of civil engineering science ?

Current work is focused in the energy consumption in buildings (hospitals) and the possibility of using environmentally friendly renewable energies replacing the use of fossil fuels in them. The results indicate that, although renewable energies are not broadly used to day in hospitals, their use results in economic and environmental benefits. Therefore current fossil fuels use in buildings can be replaced with the use of mature, reliable and cost effective renewable energies.

3. Why is this work important and timely ?

The use of renewable energies in buildings is currently supported by European and global policies in order to mitigate climate change. At the same time the use of renewable energies in hospitals is rather limited. Current work indicates that their use in hospitals results in many (economic and environmental) benefits and it should be promoted in the near future.

References

S.C., Hu, J.D., Chen, Y.K., Chuah, Energy cost and consumption in a large acute hospital, International Journal of Architectural Science, 5(1) (2004) 11-19.

S., Moghimi, S., Mat, C.H., Lim, A.,Zaharim, K.,Sopian, Building energy index (BEI) in large scale hospitals: Case study of Malaysia, Recent Advances in Geography, Geology, Energy, Environment and Biomedicine, 167-170. 4th WSEAS International Conference on Engineering Mechanics, Structures, Engineering Geology, EMESEG'11, 2nd International Conference on Geography and Geology 2011, WORLD-GEO'11, 5th International Conference on EDEB'11 - Corfu Island, Duration: 14 Jul 2011 → 16 Jul 2011

Energy consumption in hospitals, (1999). Energy consumption guide 72, The Department of the Environment, Transport and the region's Energy Efficiency Best Practice programme, retrieved on 2/5/2018 from https://www.cibse.org/getmedia/a9ab0fc1-97ed-4048-b6b5-936116334bc4/ECG72-Energy-Consumption-in-Hospitals-1999.pdf.aspx

A.S., Szklo, J.B., Soares, M.T., Tolmasquim, Energy consumption indicators and CHP potential in the Brazilian hospital sector, Energy Conversion and Management, 45(13-14) (2004) 2075-2091. doi:10.1016/j.enconman.2003.10.019

M. Santamouris, E., Dascalaki, C. Balaras, A., Argiriou, A., Gaglia, Energy performance and energy conservation in health care buildings in Hellas, Energy Conversion and Management, 35 (1994) 293-305.

D., Kolokotsa, Th., Tsoutsos, S., Papantoniou, Energy conservation techniques for hospital buildings, Advances in Building Energy Research, 6(1) (2012) 159-172. https://doi.org/10.1080/17512549.2012.672007

M. Santamouris, A. Argiriou, Renewable energies and energy conservation technologies for buildings in Southern Europe, International Journal of Solar Energy, 15 (1994) 69-79.

H., Sofronis, G. Markogiannakis, Energy consumption in public hospitals,(2000), Bulletin of Association of Mechanical Engineers, Retrieved on 2/5/2018 from www.thelcon.gr/pdfs/publication%20hospitals.pdf. (In Greek).

Saving energy with energy efficiency in hospitals, CADDET 1997, Report retrieved on 2/5/2018 from https://www.certh.gr/dat/834E8024/file.pdf

A.W.M. , Van Schijndel, Optimal operation of a hospital power plant, Energy and Buildings, 34(10) (2002) 1055-1065. https://doi.org/10.1016/S0378-7788(02)00027-0

J., Bujak, Heat consumption for preparing domestic hot water in hospitals, Energy and Buildings, 42(7) (2010) 1047-1055. DOI:10.1016/j.enbuild.2010.01.017

C.A., Short, S., Al-Maiyah, Design strategy for low energy ventilation and cooling of hospitals, Building Research and Information, 37(3) (2009) 264-292. DOI: 10.1080/09613210902885156

R., Saidur, M., Hasanuzzaman, S., Yogeswaran, H.A., Mohammed, M.S., Hossain, An end-use energy analysis in a Malaysian public hospital, Energy, 35(12) (2010) 4780-4785. DOI: 10.1016/j.energy.2010.09.012

A., Herrera, J., Islas, A., Arriola, Pinch technology application in a hospital, Applied Thermal Engineering, 23(2) (2003) 127-139. https://doi.org/10.1016/S1359-4311(02)00157-6

A., Argiriou, D., Asimakopoulos, C., Balaras, E., Daskalaki, A., Lagoudi, M., Loizidou, M., Santamouris, L., Tselepidaki, On the energy consumption and indoor air quality in office and hospital buildings in Athens, Hellas, Energy and Conversion Management, 35 (1994) 385-394.

Towards zero carbon hospitals with renewable energy systems, An Intelligent Energy Europe project, https://ec.europa.eu/energy/intelligent/projects/en/projects/res-hospitals

H.O., Paksoy, O., Andersson, S., Abaci, H., Evliya, B., Turgut, B., Heating and cooling of a hospital using solar energy coupled with seasonal thermal energy storage in a aquifer, Renewable Energy, 19 (2000) 117-122.

A., Buonomano, F., Calise, G., Ferruzi, L., Vanoli, A novel renewable poly-generation system for hospital buildings: Design, simulation and thermo-economic optimization, Applied Thermal Engineering, 67 (2014) 43-60. http://dx.doi.org/10.1016/j.applthermaleng.2014.03.008

J. Vourdoubas, Creation of zero CO_2 emission hospitals due to energy use. A case study in Crete, Greece, Journal of Engineering and Architecture, 3(2) (2015) 79-86. DOI: 10.15640/jea.v3n2a9

J. Vourdoubas, Possibilities of using solid biomass for covering the heating needs in hospitals in Crete, Greece, Studies in Engineering and Technology, 3(1) (2016) 124-131. doi:10.11114/set.v3i1.1777

Ch., Steins, S.J., Zarrouk, Assessment of a geothermal space heating system at Rotorua hospital, New Zealand, Energy Conversion and Management, 55 (2012) 60-70.

Th. Tsoutsos, E., Aloumpi, Z., Gkouskos, M., Karagiorgas, Design of a solar absorption cooling system in a Greek hospital, Energy and Buildings, 42(2) (2010) 265-272. doi:10.1016/j.enbuild.2009.09.002

D.,Vanhoudt, J., Desmedt, J., Van Bael, N., Robeyn, H., Hoes, An aquifer thermal storage system in a Belgian hospital: Long term experimental evaluation of energy and cost savings, Energy and Buildings, 43(12) (2011) 3657-3665. 10.1016/j.enbuild.2011.09.040

G., Bizzari, G.L., Morini, New technologies for an effective energy retrofit of hospitals, Applied Thermal Engineering, 26 (2006) 161-169. doi:10.1016/j.applthermaleng.2005.05.015

G., Bizzari, G.L., Morini, Greenhouse gas reduction and primary energy savings via adoption of a fuel cell hybrid plant in a hospital, Applied Thermal Engineering, 24 (2004) 383-400. doi:10.1016/j.applthermaleng.2003.09.009

C.J., Renedo, A., Ortiz, M., Manana, D., Silio, S., Perez, Study of different co-generation alternatives for a Spanish hospital center, Energy and Buildings, 38(5) (2006) 484-490. https://doi.org/10.1016/j.enbuild.2005.08.011

D,„Ziher, A. Poredos, Economics of a tri-generation system in a hospital, Applied Thermal Engineering, 26(7) (2006) 680-687. DOI :10.1016/j.applthermaleng.2005.09.007