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Creation of zero CO_2 emission office buildings due to energy use: A case study in Crete, Greece

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Abstract

Creation of buildings with very low energy consumption is the main target of the European Union in the coming years. The possibility of creating buildings with zero CO_2 emissions due to energy use is currently a challenge which could contribute in the mitigation of climate change. An investigation using various reliable and cost-effective renewable energy sources for providing all the heat and electricity required in an office building located in Crete, Greece has been implemented. It has been indicated that locally produced solid biomass and solar electricity could cover all the energy requirements of an office building. The same result could be obtained with the use of low enthalpy geothermal energy with a heat pump and solar electricity. Preliminary cost analysis indicates that the required investments in the abovementioned renewable energies in Crete, Greece are not high and they could result in a zero CO_2 emissions office building.

Keywords: co_2 emissions, crete, energy consumption, office buildings, renewable energy

1. Introduction

Buildings consume approximately 40 % of total the energy used in the EU and current EU policies aim in reducing their energy consumption and their CO_2 emissions, and in increasing the use of renewable energies in them. According to the *EU directive 2010/31/EU*, after 2018 and 2020 all new public and private buildings must be nearly zero energy buildings (nZEBs). Energy consumption in an office building depends on the type of construction, the local climate and the required indoor conditions.

1.1 Literature survey

A report on cost optimal and nearly zero energy office buildings in Estonia has been presented by *Pikas et al, 2014*. The authors developed a methodology following three steps including: a) Selection of optimal insulation thickness, b) Development of cost and energy efficient solutions, and c) Use of local energy production in order to achieve nearly zero energy buildings (nZEB). The authors concluded that due to the cold Estonian climate, existing nZEB solutions are not cost-optimal. Cost-optimal design for nearly zero energy office buildings located in warmer climates has been reported by *Congedo et al, 2015* [3]. The authors studied various energy-efficient measures for office buildings in Italy indicating that they could reduce energy consumption by 39% and CO_2 emissions by 41% with low cost. They concluded that their methodology could be applied in new office buildings in warm climates in compliance with current EU policies. Data analysis of lighting energy use in large office buildings in China has been reported by *Zhou et al, 2015* [4]. The authors stated that lighting consumes about 20-40% of the total electricity use in large office buildings in China. They studied 15 large office buildings in Beijing and Hong-Kong and they found that the annual average lighting energy consumption varied from 15 to 70 KWh/m^2 and the ratio of lighting energy consumption in different office buildings varied approximately by 30-70%. The influence of intelligent glazed facades on the energy and comfort performance of office buildings in Denmark has been reported by *Liu et al,* 2015 [5]. Their results indicated that energy consumption in an office building in Denmark could be reduced by approximately 60% in the case that a static façade could be replaced by an intelligent one. A comparative evaluation of optimal energy efficiency designs for French and U.S. office buildings has been published by *Krarti et al, 2015* [6]. The authors presented a general approach for design optimization of energy efficient office buildings. They found that optimizing life cycle costs resulted on average in 30% primary energy savings for office buildings located in U.S. and 40% savings in France. However in order to achieve an ZEB, PV panels must be placed on the roof of the building and additionally off-site if the necessary roof surface is not enough. Energy consumption comparisons of high energy efficiency buildings in China and U.S. have been presented by *Liu et al, 2014* [7]. The authors analyzed the total annual energy consumption of various high energy efficiency office buildings and they found that the mean annual energy consumption in China was 74.83 KWh/ m^2 compared to 88.81 KWh/m^2 in the U.S. The higher energy consumption in office buildings in the U.S. was justified from the fact that the designers pursue extraordinary indoor thermal comfort. An assessment of natural resources conservation in office buildings using TOBUS, a European methodology for office building refurbishment, has been presented by *Balaras et al, 2002* [8]. The authors examined various scenarios for energy conservation in office buildings. They found that energy conservation in Hellenic and Danish office buildings range for space heating from 5 to 71 and 0.5 to 6 %, for space cooling from 1 to 38 and 4 to 20 %, for lighting from 40 to 53 and 26 to 62 %, for office equipment from 13 to 62 % and 13 to 87 % and for elevators at 35 and 23 % respectively. Life-cycle energy use in office buildings has been reported by *Cole et al, 1996* [9]. The authors studied the embodied and operating energy in an office building with a covered area of 4,620 m^2 in

Canada. They found that operating energy represents the largest component of life-cycle energy use. For a typical building life of fifty (50) years the embodied energy represents only 10-20 % of the life-cycle energy use. However the authors stated that if operating energy could be reduced significantly in the future then embodied energy would represent the largest part of the life-cycle energy use in office buildings. A life-cycle energy assessment of a typical office building in Canada has been reported by *Kofoworola et al, 2009* [10]. The authors studied a building with a covered surface of 60,000 m^2 concluding that the operating energy accounted for 81 % of the life-cycle energy consumption. The rest is embodied energy corresponding in manufacture and construction at 17.4 %, in maintenance at 0.8 %, and in demolition at 0.4 %. They also stated that the annual energy consumption in office buildings in Thailand, Malaysia, Singapore, Indonesia and Taiwan varies between 80 to 300 KWh/m^2. A report regarding life-cycle zero energy buildings has been presented by *Hernandez et al, 2010* [11]. The authors defined, in accordance with the energy performance buildings directive, a net energy building as "a building where, as a result of a very high level of energy efficiency of the building, the overall primary energy consumption is equal to or less than the energy production from renewable energy sources on site." They also stated that "net zero site energy" means that a site produces at least the same energy as it uses in a year, independent of the type of energy produced or used. The improvement of the renewable energy mix in a building towards the nearly zero energy status has been presented by *Visa et al, 2014* [12]. The authors developed a three-step methodology in order to achieve the nearly zero energy status. Initially they evaluated the energy status of the building, then they developed measures to reduce its energy consumption and finally they proposed on-site renewable energy mixes in order to cover all the energy requirements of the building. Use of solar energy for net zero energy buildings has been reported by *Good et al, 2015* [13]. The authors investigated and assessed the use of three solar energy technologies in order to achieve net zero energy buildings in Norway. The three compared technologies in their study were solar thermal, solar-PV and hybrid PV-thermal. Their results showed that the high efficiency PV modulus is the most appropriate in order to achieve a zero energy balance in a Norwegian residential building. The use of photovoltaics in order to achieve zero energy buildings has been reported by *Scognamiglio et al, 2012* [14]. The authors stated that in a zero energy building, PVs are suitable for generating energy either on-site or off-site. They concluded that there are challenging issues regarding the use of PVs in zero energy buildings including their integration in the building envelope. Use of solid biomass for greenhouse heating in Italy has been reported by *Bibbiani et al, 2016* [15]. The authors stated that biomass boilers are cost-effective and their use for heating is highly recommended. They also reported that biomass is considered carbon neutral excluding the greenhouse gas emissions during its harvesting, processing and transport. Creation of zero CO_2 emissions residential buildings in Crete has been reported by *Vourdoubas, 2015* [16]. The author examined two different combinations of renewable energy sources available in Crete to achieve a zero CO_2 emission building. The first included the use of solar thermal energy, solar-PV and solid biomass and the second the use of solar thermal energy, solar-PV and low enthalpy geothermal energy. He concluded that the cost of the required renewable energy systems in order to achieve a zero CO_2 residential building corresponds to 10-12% of the total construction cost. The same author (*Vourdoubas, 2015*) [17] has investigated the possibility of creating zero CO_2 emissions hospitals due to energy use in them implementing a case study in Crete, Greece. He examined two different cases estimating the investment cost of the required renewable energy systems and the CO_2 emission savings, firstly using solar energy and solid biomass and secondly using solar energy and ground source heat pumps. He concluded that the investment cost in the first case was lower than in the second case. An analysis on several heat pump applications in large public buildings has been reported by *Liu et al, 2015* [18]. The authors compared traditional heating systems and heat pumps used in large buildings regarding the initial investment costs. They concluded, with reference to China, that heat pumps are better in the economy and technology in heating and cooling large buildings than the traditional heating systems. Creation of buildings with low energy consumption and CO_2 emissions are in the core of E.U. policies and currently a project promoting new policies for zero CO_2 emission buildings is financed by the E.U. INTERREG EUROPE program *(http://www.interregeurope.eu/zeroco2/).*

1.2 Energy consumption in office buildings

The energy characteristics and the savings potential in office buildings in Greece have been presented by *Santamouris et al, 1994* [20]. The authors monitored 186 office buildings in Greece estimating their energy consumption for heating, cooling, lighting and operation of office equipment. They found that half of their energy consumption was used for heating, 10.7 % for lighting, 12.6 % for cooling and 25.9 % in office equipment. The mean annual energy consumption of the 186 office buildings was estimated at 187 KWh/m^2. The authors proposed that proper energy saving measures could reduce the mean annual energy consumption at 150-154 KWh/m^2. The energy consumption in office buildings in the U.K. has been presented (*Energy consumption guide 19, 2003*) in a report which categorized office buildings in four groups according to their air conditioning system and the type of construction, giving typical energy consumption as well as good practice values for each group. For an air conditioned standard office building the typical annual energy consumption is 226 KWh/m^2 and the gas or oil consumption 178 KWh/m^2. For the same type of building the good practice annual energy consumption is 128 KWh/m^2 and 97 KWh/m^2 respectively. In standard office buildings 44.1 % of the total energy was used for heating, 7.7 % for cooling, 13.4 % for lighting and the rest (34.8 %) for the operation of various equipment. Typical energy consumption in office buildings located in Greece and the U.K. are presented in Table 1.

Table 1: Annual energy consumption in office buildings in Greece and the U.K. (KWh/m^2)

Country	Total	Heating	Cooling	Lighting	Operation of electric equipment
Greece[1]	186	94.4	23.4	20	48.2
U.K. --Standard building[2]	404	178	31	54	141
U.K. Best practice building[2]	225	97	14	27	87

[1] ***Source:*** Santamouris *et al*, 1994 [20]

[2] ***Source:*** Energy consumption guide 19, 2003

The aim of the current work is to investigate the possibility of creating zero CO_2 emissions office buildings due to the energy use in them, with reference to the island of Crete, Greece where the climate is mild. This could be achieved with the use of renewable energy sources (RES) available in the island which could cover all the heat and power requirements in office buildings. A methodology for the creation of zero CO_2 emissions office buildings with the use of various RES has also been developed. Finally a case study of an office building with zero CO_2 emissions in Crete has been presented and the characteristics of the renewable energy systems used have been described.

2. Availability of renewable energy sources in the island of Crete, Greece

Renewable energy sources are abundant in the island of Crete, particularly solar energy, wind energy and solid biomass. They are currently used in power and heat generation. Solar photovoltaics and wind farms are used for electricity generation. Solar thermal energy with simple thermoshiphonic systems is used for hot water production, and solid biomass, particularly olive tree by-products and residues, is used for space heating as well as for process heat generation in various industries. The potential of hydroelectric energy and geothermal energy is very small. However the use of ground source heat pumps for heat and cooling production in buildings is increasing.

Average annual solar irradiance in Crete has been estimated at 1,700-1,880 KWh/m^2 (*Kagarakis, 1987*) [22]. Solar thermal systems are extensively used for hot water production in buildings for the last 30 years and the technology is reliable, mature and cost-effective. Solar-PV use is growing partly due to the fact that there has been a sharp decrease in their prices in the last few years. They are placed on the building roofs either obtaining attractive feed-in tariffs or with the net-metering initiative and they are cost-effective. Solid biomass is broadly used in Crete for many years for heat generation in buildings, in agriculture and in industry. Due to olive tree cultivation in Crete, many olive tree byproducts and residues are produced annually on the island. It has been estimated that the annual olive kernel wood production in Crete is approximately 110,000 tons (*Vourdoubas, 2015)* [23]. Since solid biomass is rather cheap compared with other heating fuels and electricity, its use has rapidly increased partly due to the current economic crisis in Greece. Low enthalpy geothermal energy with heat pumps is increasingly used for heat and cooling production, mainly in large buildings. However their high installation cost is offset by the high efficiency of these systems. Finally wind energy is extensively used for power generation with large wind farms but the use of small wind systems in buildings is very limited. The use of renewable energy systems for energy generation in buildings in Crete is presented in Table 2.

Table 2: Use of various renewable energies in buildings in Crete

Energy source	Energy produced	Main use	Availability
Solar thermal	heat	Hot water production	High
Solar-PV	electricity	Electricity generation	High
Solid biomass	heat	Space heating and hot water production	High
Low enthalpy geothermal energy with heat pumps	heat and cooling	Heat and cooling	High

3. Creation of zero CO_2 emissions office buildings

Creation of zero CO_2 emissions office buildings due to operating energy use in them could be achieved if the following conditions could be fulfilled:

a) Only renewable energy sources should be used for covering all its heating needs, and
b) Annual grid electricity used in the office building should be offset with solar-PV electricity generated in the building. Photovoltaic panels could be used in the building roof; if there is not enough space, they could be located off-site.

Energy consumption in the building could be reduced with various energy-saving measures and most of them are cost-effective. In this case the capacity of the required renewable energy systems providing all the heat and electricity needed would be lower, reducing their installation cost as well. Although the reduction of energy use in buildings is desired, the target of zero CO_2 emissions could be obtained without lowering their initial energy consumption.

Since there is no fossil fuel consumption in the office building and the grid electricity used, which is mainly derived from fossil fuels, has been replaced annually by solar green electricity, its carbon footprint would be zero. The embodied energy in the building which in a life span of fifty (50) years corresponds to 10-20 % of its total operating energy has not been taken into account. Neither has the embodied energy in the renewable energy systems used in the office building. It has also been assumed that renewable energy sources like solid biomass, used for heat generation in the building, has zero CO_2 emissions. Therefore CO_2 emissions due to its harvesting, processing and transport have not been taken into account.

4. Design of an office building in Crete with zero CO_2 emissions

Renewable energy sources available in Crete could be used for covering all the energy requirements in a building in Crete, Greece. Solid biomass or ground source heat pumps could be used for heat and cooling production, combined with solar-PV for electricity generation in the building. In order to estimate the required renewable energy systems, an office building in Crete with a cover surface of 1,000 m^2 will be considered. It is assumed that its energy consumption will be similar with the energy consumption in buildings in Greece reported by *Santamouris et al, 1994* [20]. Therefore its total annual energy consumption is 186,000 KWh/m^2, distributed in 94,400 KWh/m^2 for heating, 23,400 KWh/m^2 for cooling, 20,000 KWh/m^2 for lighting and 48,200 KWh/m^2 for the operation of various equipment. It is also assumed that the office building is connected with the electric grid and all its annual electricity consumption will be offset by solar-PV electricity according to the net-metering initiative. However, since part of the grid electricity has been generated with renewable energies, the calculated PV system is overdesigned.

4.1 Use of solar energy and solid biomass for covering all its energy requirements

Solar-PV energy and solid biomass could be used for covering the electricity and heating needs of the building. Total annual electricity and heating needs in the 1,000 m^2 office building are 91,600 KWh and 94,400 KWh respectively. It is assumed that woody biomass will be used with heat content at 4,200 Kcal/kg and the efficiency of the biomass burning system is 75 %. The price of solid biomass in Crete is 150 €/ton. The biomass boiler will operate 1,200 hours per year and its power will be 78.7 KW_{th}. Annual consumption of solid biomass would be 26.3 tons and its cost would be 3,945 €. It has also been assumed that the electricity generation from PV panels in Crete is 1,500 KWh/KWp and their cost is 1,200 € per KWp. Therefore the nominal power of the required PV system to provide all the electricity consumed in the office building would be 61.1 KWp and its cost 73,320 €. In order to estimate the CO_2 emissions savings due to the use of renewable energies in the office building, it has been assumed that the CO_2 emissions coefficient for heating oil is 0.32 kg CO_2/KWh and for grid electricity 0.75 kg CO_2/KWh. If heating oil and grid electricity were used in the office building, then the CO_2 emissions would be 68.7 tons/year due to electricity and 30.2 tons/year due to heating oil, in total 98.9 tons/year. The design characteristics and the cost of the renewable energy systems as well as the CO_2 emission savings are presented in Table 3.

Table 3: Characteristics of the solid biomass burning and solar-PV systems providing all the required energy in the office building in Crete

Annual heat consumption in the building	94,400 KWh
Annual electricity consumption in the building	91,600 KWh
Power of the biomass burning system	78.7KW_{th}
Cost of the biomass burning system (250 €/KW_{th})	19,675 €
Annual consumption of biomass	26.3 tons
Cost of the required biomass	3,945€/year
CO_2 emissions savings due to biomass use (instead of heating oil)[1]	30.2 tons CO_2/year
Nominal power of the solar-PV system	61.1 KWp
Cost of the solar-PV system	73,320 €
CO_2 emissions savings due to generation of solar-electricity	68.7 tons CO_2/year
Total capital cost of renewable energy systems	92,995 €
Total CO_2 emissions savings	98.9 tons CO_2/year
Total annual operating cost due to the use of renewable fuels	3,945€/year

[1] It is assumed that the CO_2 emissions due to biomass use are zero.

For a better estimation of the total annual operating costs of the renewable energy systems used, maintenance and depreciation costs must be added to the fuel costs.

4.2 Use of solar energy and low enthalpy geothermal energy for covering all energy requirements

The energy needs of the office building could be covered with a ground source heat pump (GSHP) providing heating and cooling and a solar-PV system generating annually all the grid electricity required. The heating and cooling needs are 117,800 KWh annually. Assuming that the C.O.P. of the GSHP is 4.5, it will consume 26,178 KWh per year for its operation. Since the annual needs for lighting are 20,000 KWh and for the operation of various equipment 48,200 KWh, the total electricity needs of the building are 94,378 KWh. Assuming that the heat pump will operate 2,200 hours per year, its power will be 12 KW_{el} (54 KW_{th}). Design characteristics of the renewable energy systems together with their capital cost and the CO_2 emissions savings achieved are presented in Table 4.

Table 4: Various characteristics of the renewable energy systems generating all the required energy in the office building in Crete

Annual heat and cooling needs in the building	117,800 KWh
C.O.P. of the heat pump	4.5
Operating hours of the heat pump	2,200 hours/year
Electricity consumption of the heat pump	26,178 KWh/year
Total electricity consumption in the building	94,378 KWh/year
Power of the heat pump	12 KW_{el}
Cost of the GSHP (1,800 €/KW_{el})	21,600 €
Nominal power of the solar-PV system	62.9 KWp
Cost of the solar-PV system	75,480 €
CO_2 emissions savings due to the use of renewable energies (instead of fossil fuels)	98.9 tons CO_2/year
Total capital cost of renewable energy systems	97,080 €

A comparison of the different renewable energy systems installed in the office building in Crete in order to zero its CO_2 emissions is presented in Table 5.

Table 5: Comparison of the different renewable energy systems installed in the office building in Crete for zeroing its CO_2 emissions

	Solid biomass and solar-PV	GSHP and solar-PV
Capital cost	92,995 €	97,080 €
Fuel cost	3,945 €/year	0
CO_2 emissions savings	98.9 tons CO_2/year	98.9 tons CO_2/year

5. Discussion and Conclusions

The work presented is original, investigating the possibility of creating zero CO_2 emissions office buildings due to the operating energy use. Current E.U. policies promote the creation of nearly zero energy buildings which results in nearly zero CO_2 emissions buildings as well. Depending on the availability of renewable energy sources in a location, the target of zero CO_2 emissions buildings could be achieved using a combination of sources. With reference to the island of Crete, Greece, it has been proved that with the use of solar-PV energy, solid biomass and low enthalpy geothermal energy, the target of zero CO_2 emissions buildings could be achieved. In order to obtain that, fossil fuels are not used and the grid electricity used in the office building is offset by solar electricity with the net-metering principle. The above-mentioned renewable energies are abundant in Crete, mature, reliable and cost-effective, used already in various other applications for heat and power generation. Two different combinations of renewable energy sources could be used in order to achieve a zero CO_2 emissions office building in Crete. The first includes the use of solid biomass and solar-PV energy and the second the use of ground source heat pumps and solar-PV energy. Cost analysis indicates that the necessary investments in renewable energy systems in office buildings in Crete in order to zero their CO_2 emissions are not high, estimated at slightly less that 100 € per m^2. In the previous analysis the embodied energy in the office building has not been taken into account, neither the embodied energy in the renewable energy systems used for energy generation. Therefore more accurate results could be achieved if a life cycle analysis could be implemented. The results of this study could be used for the creation of zero CO_2 emissions office buildings in various locations, probably with different combinations of renewable energies depending on their availability, in accordance with the current EU policies for the creation of a low carbon society and for the mitigation of climate change.

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