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Creation of Zero CO_2 Emissions School Buildings Due to Energy Use in Crete-Greece

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Abstract

Decrease of energy consumption in buildings and increase of the share of renewable energies in them are currently technologically and economically feasible and it is promoted by E.U. policies. After 2019, all the new public buildings in EU countries must be near zero energy buildings reducing their energy consumption and CO_2 emissions. Use of various renewable energies for heat and power generation in school buildings in Crete-Greece can result in zeroing their fossil fuels consumption and CO_2 emissions. Purpose of the current work is to investigate the possibilities of creating zero CO_2 emissions school buildings in Crete-Greece due to operational energy use in them. A methodology which allows the replacement of fossil fuels with renewable energies in school buildings is proposed. Solar energy, solid biomass and low enthalpy geothermal energy, which are abundant in Crete, can be used for that. School buildings in Greece consume significantly less energy, 68 KWh/m^2 year, and emit less CO_2, 28 kgCO_2/m^2 year, than the corresponding buildings in other countries. The installation cost of renewable energies systems in order to replace all fossil fuels used in school buildings in Crete-Greece and to zero their CO_2 consumption due to energy use in them has been estimated at 47.42 - 87.71 €/m^2, which corresponds to 1.69 - 3.13 €/kg CO_2 saved.

Keywords

Crete, Energy, Renewable Energies, School Buildings, Zero CO_2 Emissions

1. Introduction

School buildings consume electricity for lighting and operation of various electric devices, including space cooling and heat for space heating and hot water preparation when needed. Their total energy consumption is low compared to other buildings like hospitals, residential buildings and offices. Greek school buildings have a

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total annual energy consumption of 68 KWh/m^2. Energy requirements for space heating are 55 KWh/m^2 year and for electricity 13 KWh/m^2 year [1]. Compared to other European school buildings, they consume significantly less energy, probably due to the mild climate in the country. The significant gap between design energy estimates and actual energy performance of the school buildings has been investigated [2]. Results from a study in 15 school buildings across the U.K. have shown that operational issues like occupants behavior have a major influence on energy performance of them. Life cycle energy assessment of Australian secondary schools has been reported [3]. Embodied energy is estimated at 15.81 - 16.33 GJ/m^2 (4395 KWh/m^2 - 4540 KWh/m^2) and operating energy at 21.53 - 40.52 GJ/m^2 (5985 - 11,265 KWh/m^2) over a period of 60 years.

Development of a methodology for energy performance benchmarks with reference to Irish primary schools has been presented [4]. Good practice guide for UK schools regarding heating energy gives typical and best practice values for heating energy 157 KWh/m^2 year and 110 KWh/m^2 year. Estimations from 88 Irish schools have shown annual median heating energy consumption of 96 KWh/m^2 and standard deviation 50 KWh/m^2. An estimation model and benchmark for heating energy consumption in school buildings in Germany has been reported [5]. A mean value of 93 KWh/m^2 year with standard deviation of 28 KWh/m^2 year is estimated and the guidelines specify the average heating energy consumption for schools at 90 KWh/m^2 year. A benchmark on energy efficiency and greenhouse gases emissions of school buildings in central Argentina has been published [6]. Data analysis for 15 public school buildings has shown an average energy consumption of 122.7 KWh/m^{2}year with standard deviation of 41.1 KWh/m^2 year. Average CO_2 emissions in these educational buildings due to the use of natural gas and electricity are estimated at 31.4 $KgCO_2/m^2$ year with standard deviation 10.5 $KgCO_2/m^2$ year. An analysis of energy consumption in high schools of a province in central Italy has been presented [7]. The authors have concluded that thermal energy savings can reach 38% and electrical energy savings 46%. A review on buildings energy consumption has been presented [8]. The authors report that in USA energy consumption in schools is 262 KWh/m^2 year, substantially higher than in most E.U. countries. An assessment of heating energy consumption in 120 Italian school buildings in Torino area has been presented and the average energy consumption in these buildings is estimated at 115 KWh/m^2 year [9]. A report on energy performance in Hellenic schools has been presented [10]. Case studies in different schools which have been implemented during 1970-2007 have shown specific heat energy consumption between 23.1 - 83.8 KWh/m^2 year and electric energy consumption between 7.7 - 28.55 KWh/m^2 year. A review of definitions and calculation methodologies of near zero energy buildings has been presented [11]. The authors have pointed that 60% of the recorded indoor temperatures, one third of relative humidity and about 17% - 35% of CO_2 concentration in the sample schools are inconsistent with indoor conditions prescribed by international standards. They have concluded also that the existing NZEB definitions and the proposals for calculations methodologies indicate complexity of the concept and lack of common agreement in order to proceed in the deployment of NZB. However, NZBs have the potential to significantly reduce the energy use and to increase the overall share of renewable energies. Energy consumption and potential energy saving in 24 old school buildings in Slovenia has been reported [12]. The authors have found that average energy consumption was 192 KWh/m^2 year, the room air temperatures were too high and the indoor air quality was inadequate, with CO_2 concentrations exceeding 4000 p.p.m. The use of display energy certificates to quantify schools energy consumption has been reported [13]. Taking into account a benchmark 150 KWh/m^2 year for thermal energy and 40 KWh/m^2 year for electrical energy, it was found that 45% of primary schools are below of the electrical benchmark and over 60% below the thermal benchmark. Results from a big number of primary, secondary and academic schools have shown an average annual energy consumption of primary schools 184 KWh/m^2 and annual CO_2 emissions of 52 $kgCO_2/m^2$, for secondary schools 188 KWh/m^2 and 55 $kgCO_2/m^2$ and for academies 205 KWh/m^2 and 68 kg CO_2/m^2. Possibilities of creating zero CO_2 emission buildings in Crete-Greece has been presented [14] [15]. According to the author, renewable energies like solar thermal, solar-PV, solid biomass and low enthalpy geothermal energy with heat pumps can be used in order to cover all the energy requirements of various buildings, replacing fossil fuels and zeroing their CO_2 emissions due to energy use. The abovementioned renewable energies are reliable, mature and cost effective and their use can reduce substantially CO_2 emissions from the buildings. Energy consumption of Greek schools is significantly lower than similar schools in other countries according to the existing literature. Apart from the mild climate in Greece, occupant's behavior, including proper controlling of indoor temperature influences their energy utilization resulting in lower energy consumption and in lower CO_2 emissions as well. Investigation on benchmarking comparability regarding energy consumption in British schools has been presented [16]. Data analysis of 465 primary and secondary schools has shown that average electricity consumption in secondary schools was 51 KWh/m^2 year, higher than in primary schools which consumed 44 KWh/m^2 year. Fossil thermal energy was almost the same with average values 122 and 121 KWh/m^2 year respectively. A field study on the energy consumption of the school buildings in Luxemburg has been published [17]. Analyzing data from a large number of various schools, the authors have found that the average thermal energy consumption was 93 KWh/m^2 year and the standard deviation was 46 KWh/m^2 year. The fuels used in these buildings included gas, heating oil, district heat, wood pellets and co-generated heat with a gas boiler. They have also measured the electricity consumption of 64 buildings separately where the mean value was 32 KWh/m^2year and the standard deviation 15 KWh/m^2 year. A study on the energy consumption of elementary schools in South Korea has been presented [18]. The authors have found that electricity consumption in 2010 was 1040 MJ/m^2 year (289 KWh/m^2 year), oil consumption 92 MJ/m^2 year (25.6 KWh/m^2 year) and gas consumption 325 MJ/m^2 year (90 KWh/m^2 year). Results from various studies have shown that school buildings require more heat than electricity and their total energy consumption in Europe does not exceed 200 KWh/m^2 year, although it is influenced by many factors including the type of buildings construction, local climate and occupants behavior. However, in USA and in South Korea energy consumption in school buildings is higher than in Europe and two studies for Greek school buildings have indicated that their energy consumption is significantly lower than in other EU countries. The purpose of the current research is to develop a methodology for the creation of zero CO_2 emissions school buildings due to operational energy consumption in them in Crete-Greece, using various combinations of reliable and cost effective renewable energies instead of fossil fuels in them.

2. Energy Consumption in School Buildings in Greece

Energy consumption in Greek schools is low compared to school buildings in other countries and it is estimated at 55 KWh/m^2 year for heating and 13 KWh/m^2 year for electricity, totally 68 KWh/m^2 year. Yet, neither indoor temperatures nor the behavior of the occupants, students and teachers were recorded for these estimations. The most common fuels used for heating were heating oil followed by gas. Solid biomass is not a popular fuel for heating school buildings in Greece. Electricity is used for lighting, operation of electric devices and for cooling when needed. The energy consumption in a typical Greek school building and its CO_2 emissions due to energy use are presented in **Table 1**.

Since total energy consumption in school buildings in Greece is low compared to other countries, total CO_2 emissions due to energy use are also lower than the reported values in other countries which are in the range of 52 - 55 kgCO_2/m^2 year.

3. Use of Renewable Energies for Energy Generation in School Buildings in Crete-Greece

Various renewable energy sources can be used in order to cover the energy requirements of schools. Among them are:

1) Solar energy including solar thermal and solar electricity.
2) Solid biomass.
3) Low enthalpy geothermal energy with ground source heat pumps.

Their technologies are mature, reliable and cost effective and they can meet school buildings requirements for electricity, heat and cooling. Although hot water requirements in schools are low, solar thermal systems can be used with simple thermosiphonic systems particularly in areas with high solar irradiance. Solar irradiance in Crete-Greece is high, approx 1700 - 1880 KWh/m^2 year. Solar-PV energy can be used for electricity generation covering all the power needs of schools. When these systems are properly sized they can generate annually the same amount of electricity that the school buildings consume. Taking into account the net metering initiative, PV panels placed on the roofs of grid connected schools buildings, can generate green electricity feeding it into the grid, offsetting the fossil fuels grid electricity which the building consume. Current decrease in the prices of PV panels allows their increasing applications including their use in various buildings. Solid biomass is a cheap energy source compared to heating oil and gas in Greece and it is broadly used for space heating in various buildings. Many types of solid biomass like fire woods, wood pellets or wood briquettes can be used in Crete as a heating fuel in schools. Biomass heating systems are operationally simple, cost effective and can cover all the heating requirements of school buildings. Low enthalpy geothermal energy with ground source heat pumps can be also used for heat and cooling generation in various buildings. These systems consume electricity and having a high coefficient of performance in the range 3 - 4, produce three to four times more heat and cooling than the consumed electricity. They have a high installation cost, but low operation cost which results in their cost effectiveness over their life span. Geothermal heat pumps have currently increasing applications all over the world and they can be used for covering all the heat and cooling requirements of school buildings in Crete.

4. Design of School Buildings with Zero CO_2 Emissions in Crete-Greece

According to EU directive 31/2010 on the energy performance of buildings [19] all the new public buildings after 31/12/2018 must be near zero energy buildings. Also, public buildings which undergo deep renovation must improve their energy performance. Therefore, fossil fuels use in public buildings including schools must be decreased and the share of renewable energies must be increased. Buildings consume energy during their life cycle in the phases of construction, refurbishment, operation and demolition. Life cycle analysis of residential buildings [20] has shown that embodied energy, which includes construction, refurbishments and demolition energy, corresponds to 10% - 20% of the total energy consumption and the operational energy to 80% - 90% of it.

The approach followed in the present work assumes that the public school building has decreased its energy consumption using various energy saving techniques and technologies and it uses only renewable energies for meeting its energy requirements. The absence of fossil fuels consumption zeros its CO_2 emissions due to energy use. Renewable energies used in the school building are either on-site, like solar energy and geothermal energy, or off-site, like solid biomass.

In order to zero fossil fuels use and CO_2 emissions in school buildings due to operational energy use the following two criteria must be fulfilled:

1) Fossil fuels must not be used.

2) The grid electricity consumed in the schools must be offset annually by solar electricity which is generated on-site and must be fed into the grid.

In the following analysis, it has been assumed that all the grid electricity is generated by fossil fuels, which is not true since part of it, which is currently estimated at 13% - 14% in Crete-Greece, is generated by solar and wind energy. Therefore, the solar-PV system has been oversized.

For heat production, instead of heating oil either solid biomass or geothermal energy with ground source heat pumps can be used. For electricity generation, photovoltaic panels placed on the building roofs or terraces can generate all the power needed. Therefore, replacement of conventional fuels in school buildings can be achieved with combination of the abovementioned sustainable energies, which can generate all the required energy in the school buildings. The following two combinations are examined:

1) Solar photovoltaic for electricity generation and solid biomass for heat production.

2) Solar photovoltaic for electricity generation and geothermal heat pumps for heat and cooling production.

4.1. Design of a School Building in Crete-Greece Which Covers All Its Energy Requirements with Solar Electricity and Solid Biomass

Assuming that the specific energy consumption of the school building will be the same as in **Table 1**, and its covered surface is 1000 m^2 the characteristics and the sizes of the solar-PV system and the biomass boiler are presented in **Table 2**. The design of the school building is based in two principles:

1) The required heat will be generated by renewable energy-solid biomass and not by fossil fuels.

2) All the required electricity will be generated with solar photovoltaics, which will be fed to the grid offsetting the consumed grid electricity.

4.2. Design of a School Building in Crete-Greece Which Covers All Its Energy Requirements with Solar Electricity and a Geothermal Heat Pump

Alternatively, the energy requirements of the school building can be covered with a solar PV system providing the electricity needed and a geothermal heat pump for covering the heating and cooling needs of it. Heat pump is sized to cover the peak heating load, which can be 50% higher than the average load. Since the heat pump consumes electricity, the size of the solar PV system will be higher compared with the previous case, since it will generate electricity for lighting, operation of various electric devices and additionally the electricity needed by the heat pump. Assuming that the specific energy consumption of the school building will be the same as in **Ta-**

ble 1 and its covered surface will be 1000 m^2, the characteristics and the sizes of the solar PV system and the geothermal heat pump are presented in Table 3.

Comparing Table 3 and Table 4, it is concluded that the size of the photovoltaic system is higher in the second case and the capital costs of the required sustainable energies systems are also higher than in the first case. However, the annual cost of the renewable energies needed in the second case is zero compared with 1580 €/year in the first case, although these values will change if the maintenance and depreciation costs will be taken into account.

5. Economic Considerations

Use of various renewable energies in school buildings is currently cost effective and the installation of the R.E. systems can be easily justified. Capital cost estimations for the abovementioned renewable energies installed in

Table 1. Energy consumption and CO_2 emissions in typical Greek school buildings.

	Energy consumption KWh/m^2 year	CO_2 emissions Kg CO_2/m^2 year
Heat	55	17.6
Electricity	13	10.4
Total	68	28.0

*Electricity emission factor = 0.8 $kgCO_2$/KWh, Heating oil emission factor = 0.32 $kgCO_2$/KWh.

Table 2. Sizes and costs of renewable energy systems covering all the energy requirements of a school building in Crete-Greece.

Heat required	55,000 KWh/year
Electricity required	13,000 KWh/year
Total energy required	68,000 KWh/year
Nominal power of PV system	8.7 KWp
Cost of PV system	13,050 €
Power of solid biomass boiler	68.75 KW_{th}
Cost of solid biomass boiler	34,375 €
Quantity of solid biomass required	15.8 tons/year
Cost of required solid biomass	1580 €/year
Total capital cost of R.E. systems	47,425 €

*Operation of the heating system, 800 h/year, Net calorific value of solid biomass, 3000 kcal/kg, Cost of solid biomass in Crete, 0.1 €/kg, Unit costs: Biomass boiler 500 €/KWth, Solar-PV system: 1500 €/KWp.

Table 3. Sizes and costs of the renewable energy systems covering all the energy requirements of a school building in Crete-Greece.

Heat required	55,000 KWh/year
Electricity required	13,000 KWh/year
Total energy required	68,000 KWh/year
Additional electricity required for the operation of the heat pump	15,714 KWh
Total electricity required including the consumption of the heat pump	28,714 KWh
Nominal power of the PV system	19.14 KWp
Cost of the PV system	28,710 €
Operation of the heat pump	800 h/year
Coefficient of performance of the heat pump	3.5
Power of the heat pump	29.5 KW
Cost of the heat pump	59,000 €
Total capital cost of the R.E systems	87,710 €
Cost of primary energy used	0

*Heat pump is sized at 150% of the base load, Unit costs: Solar-PV system, 1500 €/KWp, Geothermal heat pump, 2000 €/KW.

Table 4. Capital cost estimation of the renewable energy systems used in order to cover all the energy needs of school buildings in Crete-Greece.

	Use of a solid biomass heating system and solar-PV panels	Use of a geothermal heat pump and solar-PV panels
Cost of solar-PV (€)	13,050	28,710
Cost of solid biomass burning system (€)	34,375	-
Cost of geothermal heat pump (€)	-	59,000
Total capital cost (€)	47,425	87,710
Total capital cost per m^2 of covered area of school building (€/m^2)	47.42	87.71

Table 5. CO_2 savings in school buildings which are covering all their energy requirements with renewable energies in Crete-Greece.

	Capital costs of the R.E. systems (€)	Annual CO_2 savings ($KgCO_2$)	Capital cost per annual CO_2 savings (€/$kgCO_2$)
Use of solar-PV and solid biomass	47,425	28.000	1.69
Use of solar-PV and geothermal heat pumps	87,710	28.000	3.13

school building with covered area of 1.000 m^2 are presented in **Table 4**.

From **Table 4**, it is concluded that, in the case of heating and cooling with the geothermal heat pump, which is an expensive equipment, the total capital cost of the R.E. systems is significantly higher than the case of heating the school buildings with solid biomass.

6. Environmental and Social Considerations

Transformation of school buildings to zero CO_2 emissions buildings will result in significant reduction to CO_2 emissions due to energy use in them. Estimations of CO_2 emissions savings due to renewable energy use in school buildings with a covered area of 1000 m^2 in Crete-Greece are presented in **Table 5**.

Use of renewable energies instead of fossil fuels in school buildings is important for Greece, which is highly depended on imported fuels. Additionally, it will result in benefits to the local economy due to the use of local energy resources and renewable energy systems which can be constructed and maintained locally. School pupils and teachers will learn about sustainable energy technologies and their environmental benefits, since the existing R.E. systems will act as a living laboratory placed on the school buildings where they spend many hours daily.

7. Conclusion

School buildings consume less energy than other types of buildings and Greek schools consume significantly less heat and electricity than the same buildings in other countries. Heat requirements of school buildings in Greece are estimated at 55 KWh/m^2 year and electricity at 13 KWh/m^2 year. Total CO_2 emissions are estimated at 28 $kgCO_2/m^2$ year. Changes in EU and national legislation require the decrease of energy consumption and the increase of the share of renewable energies in public buildings including school buildings in the near future. School buildings consume energy mainly for heating, cooling, lighting and operation of various electric devices. Current advances in various renewable energy technologies allow their use in a cost effective way in school buildings, replacing fossil fuels in them. Solar energy, solid biomass and ground source heat pumps can be used in school buildings in Crete-Greece for covering all their energy requirements zeroing the use of fossil fuels and CO_2 emissions in them. Use of the abovementioned renewable energies is cost effective and apart from the economic benefits their use results in environmental and social benefits as well. Total capital cost of the necessary R.E. systems in order to zero CO_2 emissions in Greek school buildings has been estimated at 47.42 - 87.71 €/m^2 or 1.69 - 3.13 €/$kgCO_2$ saved. In order to verify these cost estimations and to prove the technical, economical and operational viability of the proposed R.E. systems, their installation in few pilot school buildings in Crete-Greece is required.

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