Asian Journal of Energy Transformation and Conservation
2016 Vol. 3, No. 1, pp. 1-9
ISSN(e): 2409-4293
ISSN(p): 2412-3390
DOI: 10.18488/journal.81.2016.31.1.9

POSSIBILITIES OF CREATING SWIMMING POOLS WITH ZERO CO_2 EMISSIONS DUE TO ENERGY USE IN THEM

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Article History
Received: 12 January 2017
Revised: 24 February 2017
Accepted: 21 March 2017
Published: 4 April 2017

Keywords
CO_2 emissions
Crete-Greece
Energy consumption
Renewable energies
Swimming pool.
Carbon footprint

ABSTRACT

Swimming pools consume large amounts of energy compared with various buildings. Most of them utilize conventional fuels for covering their heating and electricity needs. Increase of their sustainability could be achieved with the replacement of conventional fuels with renewable energies. The possibility of using only renewable energies for covering all their energy requirements has been examined. Solar thermal energy, solid biomass and low enthalpy geothermal energy with heat pumps could cover their heating needs. Solar-PV energy could generate the necessary electricity in the pool. Investigation of the possibility of using different combinations of the abovementioned renewable energies in swimming pools indicate that they could cover all their energy needs zeroing their CO_2 emissions and their carbon footprint due to energy use. These renewable energy technologies are also reliable, mature and cost effective. A case study in Crete, Greece has been implemented indicating that an investment in renewable energy systems of 1,072 to 1,474 € per m^2 of pool would achieve reduction of 1,538 kg CO_2 per m^2 of pool zeroing their CO_2 emissions. A significant decrease of the operating cost of the swimming pool due to lower fuel cost would be also achieved offering an attractive payback period of the investment.

Contribution/ Originality: The study contributes in the existing literature regarding the creation of swimming pools with low environmental impact due to energy use. It indicates the replacement of fossil fuels used in them with reliable and cost effective renewable energy technologies minimizing the CO_2 emissions.

1. INTRODUCTION

Creation of a low carbon society consists of one of the main targets of European Union. According to the EU directive 2009/28/EC in 2020 greenhouse gas emissions must be reduced by 20 %, 20 % of the final energy consumption must be met by renewable energy resources and the energy efficiency must be increased by 20 %. It is expected that the transition to a low carbon society will allow to limit anthropogenic temperature rise to no more than 2°C [1]. Buildings consume a large part up to 40 % of total energy used in E.U. and the use of renewable energy in buildings is easier than in other sectors of economy like industry , agriculture and transport [2]. Greenhouse gas (GHG) emissions from buildings could be cut with three ways:

a) Reducing energy consumption in them,
b) Replacing fossil fuels used with renewable fuels ,and
c) Reducing the emissions from non-CO_2 GHG

Swimming pools consume energy for space heating and ventilation, for water heating, for lighting and for the operation of various electric devices [3]. Energy cost consists of 25-30 % of their total operating cost. Average pool water temperatures in indoor swimming pools vary between 26-30 °C. Energy saving measures in swimming pools includes:

a) Use of co-generation of heat and power systems,
b) Use of condensing boilers,
c) Heat recovery from the ventilation system , and
d) Heat recovery from the pool water

According to the same study the proportion of energy used in an indoor swimming pool is 53 % for space heating, 25 % for water heating, 6.5 % for lighting and 15.5 % for operation of various electric equipments. Therefore indoor swimming pools use more energy in heating than in operation of various electric apparatus and lighting.

Indoor swimming pools consume significantly more energy per m^2 than various buildings like residential buildings, offices, hospitals, schools, etc.

Trianti-Stourna, et al. [4] have presented the energy conservation strategies in swimming polls. The authors stated that for Mediterranean type climate the average annual total energy consumption per water pool surface area is 4,300 KWh/m^2. For the continental European climate the corresponding energy consumption is higher at 5,200 KWh/m^2. Space and water heating and ventilation are the primary energy consumption sources. According to the authors typical energy consumption in swimming pool facilities is made up of 45 % for ventilation of the pool hall, 33 % for pool water heating , 10 % for heat and ventilation for the remainder of the building , 9 % electricity for power equipment and lighting and 3 % for hot water services. A report on energy efficiency in swimming facilities has been presented by Kampel [5]. The author has collected data from 43 Norwegian swimming facilities and has analyzed them. He found a significant variation in final annual energy consumption and he estimated the potential reduction of their energy use to be approximately at 28 %. Analyzing a large number of data concerning the annual energy consumption in swimming pools he estimated an average value of 4,004 KWh/ m^2 with a standard deviation of 1,821 KWh/ m^2. According to him various reports in Scandinavian countries have estimated the annual energy consumption in swimming pools. In Sweden it varies between 1,500-8,400 KWh/m^2 with an average value 4,481 KWh/m^2 and in Denmark between 2,291-2,608 KWh/m^2. Reports from Finland estimate the annual energy consumption at 4,475 KWh/m^2. Data on the distribution of energy use in swimming pools vary considerably. However the highest amount of energy is consumed for space and water heating. Kampel [5] has also reported that according to British swimming pools association 52 % of the energy is used in ventilation, 26 % for water heating, 5 % for lighting and the rest 17 % for the operation of various electric devices. Vourdoubas [6]; Vourdoubas [7] has presented a methodology for zeroing CO_2 emissions in various buildings due to operational energy consumption in them with the use of various renewable energy sources. He stated that the current legal framework including the net-metering initiative, the technological improvements and the decrease in the cost of various renewable energy technologies allow their broad applications in buildings for heat and power generation. According to him in order to zero CO_2 emissions in a building two criteria must be fulfilled. The first is to replace all the fossil fuels used with renewable energies and the second to offset annually the grid electricity used with solar-photovoltaic electricity. Various renewable energy technologies could be used in a building in order to zero its CO_2 emissions. The author presented various case studies for buildings located in Crete, Greece. They used solar thermal energy, solid biomass and low enthalpy geothermal energy with heat pumps for providing heat and cooling and solar-PV for generating green electricity. Current technological advances in the abovementioned renewable energy technologies have decreased their cost and have increased their reliability allowing their use in buildings for covering all their energy needs.

The purpose of this study is to examine the possibility of using a known methodology for zeroing CO_2 emissions in swimming pools due to operational use of energy in them. This could be achieved with the use of reliable, mature and cost-effective renewable energy technologies instead of conventional fossil fuels energy technologies. A case study analysis in a swimming pool located in Crete, Greece demonstrates the proposed methodology and the possibility of using various renewable energy technologies for providing heat and electricity in it.

2. USE OF RENEWABLE ENERGIES IN SWIMMING POOLS

Solar thermal energy is the most common used renewable energy in swimming pools. A report on the solar energy use in outdoor swimming pools [8] states that the level of implementation of solar heating systems in outdoor swimming pools varies greatly among the EU countries. According to this report there approximately 6,700 public swimming pools in Germany and half of them are outdoors pools. In the end of 2007 there were 799 public pools in Germany equipped with solar thermal systems. The absorber surface area of implemented thermal systems is mainly medium and large-size, greater than 100 m^2. In other EU countries the number of installed solar thermal systems in swimming pools is smaller. In Greece where the solar irradiance is high and the number of swimming pools is also high only a small percentage of them is equipped with heating systems. During July and August when temperatures are high the outdoors pools do not require heating. A method for solar heating of outdoor swimming pools by placing a plastic cover on the water surface in Australia has been described by Czarnecki [9]. A mathematical modeling and simulation of the thermal performance of a solar heated indoor swimming pool has been reported [10]. The authors stated that up to 87 % of the water heating demand could be met by solar heating systems. Use of geothermal energy in swimming pools in Island and Ecuador has been reported by Haraldsson and Cordero [11]. The authors stated various applications of direct use of geothermal fluids with temperatures between 45-75°C for heating swimming pools in Ecuador. At the same time ground source heat pumps were used for space heating of the touristic complexes. In Iceland, they reported, there many indoor and outdoor swimming pools utilizing the hot geothermal fluids in this country for heating. The feasibility of heating residential swimming pools with geothermal heat pumps in USA has been reported by Chiasson [12]. The author stated that in northern areas of USA it is not economic feasible to heat pools with ground source heat pumps (GSHP). On the contrary in southern areas it is economically justified to heat pools with GSHP. An analysis of heat pumps applications in large public buildings in China has been presented by Liu, et al. [13]. The authors presented the advantages and drawbacks of the current heat pumps used in this country. An analysis of the ground source heat pumps used in Cyprus has been presented by Michopoulos, et al. [14]. The authors concluded that significant economic and environmental benefits could be achieved with the substitution of the conventional heating systems with ground source heat pumps in Cyprus.

Biomass can be used for space and water heating in swimming pools. In general biomass use is important when 100 % renewable energy systems are going to be achieved. Studies for 100 % renewable systems in countries like Denmark [15] Ireland [16] and Macedonia [17] have been reported. Various renewable energy mixtures were studied in order to ensure that the countries were going to be independent from fossil fuels. In all cases, among renewable energies, biomass was an important energy source for heat generation, electricity generation and for producing transport fuels. The limitation of biomass use for heating in 100 % renewable energy systems has been presented by Mathiesen, et al. [18]. Since biomass is an important energy source for heating in those systems, the authors presented alternative renewable energy sources which could cover the heating loads allowing the use of biomass in other sectors like power generation. The possibility of using biomass for energy generation replacing fossil fuels has been presented by Balat and Ayar [19]. The authors stated that biomass can be considered as a carbon neutral fuel assuming that the biomass stock is not gradually diminished. Wood biomass as sustainable energy for greenhouse heating in Italy has been reported by Bibbiani, et al. [20]. The authors stated that solid biomass is highly recommended regarding its economic feasibility. They also reported that it can be considered carbon neutral excluding the greenhouse gases generated during its harvesting , processing and transport to the consumption site. The possibility of using solar-PVs in zero energy buildings has been reported by Scognamiglio and Rostvik [21]. The authors stated that after 2020 solar-PVs will play an important role in the implementation of near zero energy buildings in Europe. Investigation of using various solar energy technologies in order to achieve a near zero energy building has been reported by Good, et al. [22]. The authors studied various solar energy systems including solar thermal, solar-PV and combined solar thermal/PV concluding that the best performance was achieved with the solar-PV systems. The improvement of the renewable energy mix in order to achieve zero energy status in a building has been presented by Visa, et al. [23]. The authors presented a case study of a solar house which used a combination of geothermal energy, solar thermal and solar-PV energy for achieving its zero energy status.

The abovementioned reports indicate that various renewable energy sources could be used for covering all the energy needs in swimming pools zeroing the CO_2 emissions due to energy use in them. 100 % renewable swimming pools is currently technologically and economic feasible since the required technologies are mature, reliable and cost-effective. Solar thermal energy and solid biomass could be used for heat generation. Ground source heat pumps could be used for heat and cooling production. Cooling is needed for air conditioning in the pool hall. Finally solar-PV energy could be used for electricity generation. The necessary PV system could be sized in order to generate the same amount of electricity that the pool consumes all over the year according to the net-metering principle. The possibility of using these technologies in swimming pools is presented in table 1.

Table-1. Possibilities of using various renewable energy technologies in swimming pools

Energy source	Energy generation	Possibility of covering all the energy needs
Solar thermal	Heat	No
Solid biomass	Heat	Yes
Low enthalpy geother mal energy with heat pumps	Heat and cooling	Yes
Solar-PV	Electricity	Yes

Source: Own estimations

3. CREATION OF ZERO CO_2 EMISSIONS SWIMMING POOLS DUE TO ENERGY USE IN THEM

In order to zero CO_2 emissions during the operation in swimming pools the following two criteria must be fulfilled:

a) The swimming pool must use only renewable energy sources for covering all its heating needs , and

b) It must generate all the grid electricity consumed annually with a solar-PV system using the net-metering principle. In this case it offsets the fossil fuel generated grid electricity with green solar electricity.

It has been assumed that the renewable energies used, including solid biomass , do not produce GHG and the grid electricity is generated from fossil fuels.

Since the previous two criteria are fulfilled it is concluded that the carbon footprint due to energy use in the swimming pool is zero. Among renewable energy sources which could be used for space and water heating in swimming pools, solid biomass, geothermal energy with heat pumps and solar thermal energy have been used in many applications in buildings and elsewhere. Their technologies are reliable, mature and cost effective compared with technologies utilizing fossil fuels. In the case of solid biomass it is assumed that its net CO_2 emissions are zero, neglecting the emissions during its harvesting, processing and transport.

4. CREATION OF A ZERO CO_2 EMISSIONS SWIMMING POOL. A CASE STUDY IN CRETE, GREECE

In order to size and assess the energy systems used in a zero CO_2 emissions swimming pool located in Crete, Greece the following assumptions are made.

a) The water surface area is 750 m^2 ,
b) The annual energy consumption in the pool is 4,000 KWh/m^2 ,
c) The annual heat consumption in the pool is 3,400 KWh/m^2 ,
d) The annual electricity consumption in the pool is 600 KWh/m^2 , and
e) The annual electricity generation from a solar-PV system in Crete , Greece is 1,500 KWh/KWp

Two different cases will be examined as follows:

In the first solar thermal energy and solid biomass will be used equally for covering all its heating needs and in the second solar thermal energy and ground source heat pumps will be used equally for that. In both cases solar-PV systems would generate the necessary electricity.

4.1. Use of Solar Thermal Energy and Solid Biomass for Heat Generation

Flat plate solar collectors will be used for heat generation as well as solid biomass. The annual heat consumption in the pool will be 2,550 MWh_{th} equally provided from solar energy and biomass. It is assumed that the annual heat generation of the solar collectors in Crete, Greece is 1.2 MWh/m^2 [24] the heat content of the solid biomass is 4,200 Kcal/kg and the efficiency of the biomass burning system is 75 %. The price of solid biomass is 150 €/ton. The biomass boiler will operate 2,550 hours per year and its power will be 500 KW_{th}. The annual electricity consumption in the swimming pool is 450 MWh_{el}. CO_2 emission coefficients for heating oil is 0.32 kg CO_2/KWh and for grid electricity 0.75 kg CO_2/KWh. The sizing of the required renewable energy systems in order to generate all the energy needed in the swimming pool is presented in table 2. The capital cost of these systems as well as the annual fuel cost has been also estimated.

Table-2. Sizing of the renewable energy systems (solar thermal , solid biomass burning and solar-PV) generating all the required energy in the swimming pool in Crete, Greece.

Annual heat consumption in the pool	**2,550 MWh_{th}**
Heat provided from solar collectors	1,275 MWh_{th}
Size of flat plate solar collectors	1,062.5 m^2
Cost of flat plate collectors (300 €/ m^2)	318,750 €
Heat generated from the solid biomass	1,275 MWh_{th}
Power of biomass burning system	500 KW_{th}
Cost of the biomass burning system (250 €/KW_{th})	125,000 €
Annually required biomass	348.5 tons
Cost of the required biomass	52,275 €
Annual electricity consumption in the pool	450 MWh_{el}
Nominal power of the PV system	300 KWp
Cost of the PV system (1,200 €/KWp)	360,000 €
Annual cost of the renewable fuels providing all the energy in the pool	52,275 €
Total capital cost of the required renewable energy systems	803,750 €

Source: Own estimations

In order to estimate the annual CO_2 emission savings due to the use of renewable energies it is assumed that in the case that the swimming pool was using heating oil for heat generation and grid electricity for powering various electric apparatus its CO_2 emissions would be

a) Due to heating oil use , 2,550 MWh X 320 kg CO_2/MWh = 816,000 kg CO_2
b) Due to grid electricity use , 450 MWh X 750 kg CO_2/MWh = 337,500 kg CO_2

Totally 1,153,500 kg CO_2 per year

In order to estimate the quantities and the costs of the conventional fuels used , heating oil and grid electricity , for covering all the energy needs of the swimming pool it is assumed that the net heating value of heating oil is 11 KWh/kg , its cost is 1 €/kg and the cost of grid electricity is 0.25 €/KWh.

The required annual quantity of heating oil is 232 tons, its cost is 232,000 € and the cost of electricity 112,500 €. Therefore the annual cost of the conventional fuels used for providing all the required energy in the pool is 344,500 €.

4.2. Use of Solar Thermal Energy and a Ground Source Heat Pump for Heat Generation

Flat plate solar collectors will be used for heat generation as well as a ground source heat pump. The annual heat consumption in the pool will be 2,550 MWh_{th} equally provided from solar energy and geothermal energy. The GSHP will operate 2,550 hours per year and its C.O.P. will be 4.5. Its power will be 111 KW_{el}. The sizing of the required renewable energy systems, solar thermal, solar-PV and GSHP in order to generate all the energy needed in the swimming pool is presented in table 3. The capital cost of these systems has been also estimated.

Table-3. Sizing of the renewable energy systems (solar thermal, solar-PV and GSHP) generating all the required energy in the swimming pool in Crete, Greece

Annual heat consumption in the pool	2,550 MWh_{th}
Heat provided from solar collectors	1,275 MWh_{th}
Size of flat plate solar collectors	1,062.5 m^2
Cost of flat plate collectors (300 €/ m^2)	318,750 €
Heat generated from the GSHP	1,275 MWh_{th}
C.O.P. of the GSHP	4.5
Power of the GSHP	111 KW_{el} , 500 KW_{th}
Cost of the GSHP (1,800 €/KW_{el})	200,000 €
Electricity consumption of the GSHP	283.05 MWh_{el}
Annual electricity consumption in the pool excluding the consumption of the GSHP	450 MWh_{el}
Total electricity consumption in the pool	733.05 MWh_{el}
Nominal power of the PV system	488.7 KWp
Cost of the PV system (1,200 €/KWp)	586,440 €
Annual cost of the renewable fuels providing all the energy in the pool	0 €
Total capital cost of the required renewable energy systems	1,105,190 €

Source: Own estimations

4.3. Comparison of the Two Different Combinations of Renewable Energy Systems for Providing All the Required Energy in the Pool

The results of the analysis for two different combinations of renewable energy systems generating the required energy in the pool are presented in table 4. Ignoring the depreciation and maintenance cost of the renewable energy systems the payback periods of the investments in different renewable energy technologies in the pool have been also estimated assuming that they will replace all the conventional fuels used in it. Payback period of the investments has been estimated as the ratio of the capital investments to the annual savings due to lower fuel costs.

Comparison of the abovementioned results shows that in the second case (solar energy and GSHP) the capital cost of the required energy systems is higher than in the first case. However the fuels cost in the first case (solar energy and biomass) is higher than in the second case (solar energy and GSHP) which is zero. The payback period of the two renewable energy investments based only on the annual gain due to lower fuel costs is very attractive. However maintenance and depreciation costs should be taken into account to get more accurate results regarding the economic feasibility of the investment.

Table-4. Comparison of two different combinations of renewable energy systems which could provide all the required energy in a swimming pool in Crete, Greece

Total capital cost (solar energy and biomass)	803,750 €
Total capital cost per m^2 of the pool (water surface)	1,072 €
Total capital cost (solar energy and GSHP)	1,105,190 €
Total capital cost per m^2 of the pool (water surface)	1,474 €
Operating cost (solar energy and biomass)	52,275 €
Decrease of the operation cost in the pool due to the installation of renewable energy systems (solar energy and biomass)	292,225 €
Operating cost (solar energy and GSHP)	0 €
Decrease of the operation cost in the pool due to the installation of renewable energy systems (solar energy and GSHP)	344,500 €
Annual savings of CO_2 due to the use of the renewable energy systems	1,153,500 kg CO_2
Annual savings of CO_2 due to the use of the renewable energy systems per m^2 of pool (water surface)	1,538 kg CO_2
Required investment per CO_2 emission annual savings (solar energy and biomass)	0.7 € per kg of CO_2 annual savings
Required investment per CO_2 emission annual savings (solar energy and GSHP)	0.96 € per kg of CO_2 annual savings
Payback period for the investment of solar energy and biomass	2.75 years
Payback period for the investment of solar energy and GSHP	3.21 years

Source: Own estimations

5. CONCLUSIONS

Reduction of energy use and CO_2 emissions and increase of the use of renewable energies in various buildings have been promoted by current EU policies. Creation of swimming pools with zero CO_2 emissions due to energy use could be obtained with the use of various renewable energy sources which could cover all their heating and power requirements. Many renewable energy technologies are reliable, mature and cost effective due to recent technological advances and breakthroughs. A case study in Crete, Greece has shown that the creation of a zero CO_2 emissions swimming pool is currently feasible with the use of locally available renewable energies. These renewable energies include solar thermal energy, solar photovoltaic, solid biomass and low enthalpy geothermal energy with heat pumps. This would result in the decrease of the carbon footprint due to energy use in the pool as well as in economic benefits during its operation. Two combinations of renewable energies could be used for covering all the heating and power needs of the swimming pool. In the first solar thermal energy and solid biomass could be used for heat generation and solar-PV for electricity generation. In the second, solar thermal energy and ground source heat pumps for heat generation and solar-PV for electricity generation. The capital cost of the installed renewable energy systems for zeroing its CO_2 emissions has been estimated between 1,072 and 1,474 € per m^2 of pool water surface. The same methodology could be used for the creation of zero CO_2 emissions swimming pools in other locations with different availability of renewable energies. Current work contributes in the promotion of low carbon buildings in Europe according to the EU Directive 2009/28/EC [25]. Further work is recommended focused in the implementation of a zero CO_2 emissions swimming pool in order to test and assess the use of various renewable energy systems in it.

Funding: This study received no specific financial support.
Competing Interests: The author declares that there are no conflicts of interests regarding the publication of this paper.

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