Civil Engineering Research Journal
ISSN: 2575-8950

Juniper Publishers
key to the Researchers

Review Article
Volume 10 Issue 1 - March 2020
DOI: 10.19080/CERJ.2020.10.555777

Civil Eng Res J

Creation of Net Zero Carbon Emissions Residential Buildings due to Energy use in the Mediterranean Region: Are they Feasible?

John Vourdoubas*

Mediterranean Agronomic Institute of Chania, Greece

Submission: February 17, 2020; **Published:** March 03, 2020

***Corresponding author:** John Vourdoubas, Mediterranean Agronomic Institute of Chania, Greece

Abstract

Creation of buildings with zero carbon footprint due to energy use is of primary importance for mitigation of climate change. The technical and economic feasibility of constructing carbon neutral residential buildings in the Mediterranean region has been investigated and the required sustainable energy technologies which can be used have been identified. A study of a carbon neutral residential building with a covered area of 120 m2 has been implemented and the required renewable energy systems have been sized. They include a solar thermal system, a solar photovoltaic system and a ground source heat pump. It is indicated that the use of endogenous renewable energy resources in this region can zero the net carbon emissions of residential buildings while the required technologies are mature, reliable and cost-effective. The installation cost of the required solar photovoltaic system for achieving carbon neutrality in the residential building due to life cycle energy consumption has been estimated at 5-10% of the initial construction cost which corresponds to between 59.84 €/m^2 and 123.84 €/m^2. The annual CO_2 savings in the residential building have been estimated from 74 kgCO_2/m^2 to 134 kgCO_2/m^2. It is concluded that the creation of net zero carbon emissions buildings due to life cycle energy use in the Mediterranean region is technically and economically feasible and it should be promoted in the future with appropriate policies and incentives as well as with the removal of the existing barriers..

Keywords: Carbon emissions; Embodied energy; Mediterranean; Operational energy; Residential buildings; Solar energy; Sustainable energies

Introduction

Buildings consume large amounts of energy and contribute to greenhouse gas (GHG) emissions into the atmosphere. The necessity to mitigate climate change requires the sharp decrease of their electricity and fossil fuel consumption. New EU regulations promoting nearly-zero energy buildings (NzEBs) have made the decrease of energy consumption obligatory in new buildings and the increase of energy efficiency in old buildings which should be refurbished. Additionally, to the operational energy usage, buildings consume energy during their construction, refurbishment and demolition, defined as embodied energy. When buildings' operational energy consumption is reduced, the share of embodied energy in their total life cycle energy use is increased. Apart from the building sector, the challenge to reduce fossil fuel consumption in the transport sector necessitates the replacement of conventional vehicles, having internal combustion engines, with electric vehicles (EVs). The electric batteries of these vehicles can be recharged with solar electricity generated with solar photovoltaic (solar-PV) systems installed in residential buildings. Solar energy is abundant in the Mediterranean region and it can be used for heat and electricity generation with solar thermal and solar-PV systems. The required solar energy technologies are mature, reliable, cost-effective, and they are already used commercially in buildings and other applications. Promotion of net zero carbon emissions (NZCE) residential buildings in the Mediterranean basin, using locally available benign energy sources, for covering their embodied and operational energy needs as well as the energy required in residents' electric cars could assist in the achievement of the global targets regarding carbon emissions reductions. Various existing barriers should be overcome for future promotion of NZCE buildings. The required sustainable energy technologies are cost-effective while the necessary legislative framework is favorable in many countries.

Literature Survey

Energy consumption in buildings

A calculation of the energy consumption and the carbon emissions in housing construction in Japan has been presented [1]. The authors stated that the embodied energy of residential buildings depends on the type of construction and the materials used. They estimated that their embodied energy varied between 833-8,777 KWh/m^2 while their carbon emissions due to embodied energy was at 250-850 kgCO_2/m2. Energy consumption in EU and Hellenic buildings has been reported [2]. The authors mentioned that total annual energy consumption in EU buildings varied between 150-230 KWh/m^2. They also stated that annual residential energy uses per capita varied from 1,500-5,000 KWh/capita in Southern Europe up to 8,000 KWh/capita in Northern Europe. A study on the energy performance of existing dwellings has been published [3]. The authors mentioned that, in the EU, the final energy consumption of the building sector corresponds to 40.3% of the total EU-25 final energy use while the consumed energy in dwellings corresponds to 25.4% of the total final energy use. A study on energy consumption in buildings has been published [4]. The authors stated that energy consumption varies significantly according to end uses among EU countries while the largest share of energy consumption corresponds to use for air-conditioning.

Embodied and operational energy consumption

A report regarding the embodied carbon in buildings has been released [5]. It mentions that the impacts of embodied energy in buildings become greater with the decrease of their operational energy usage while increasing their thermal insulation has minimal impacts on their embodied emissions. It also mentioned that the concrete structure has the highest amount of embodied carbon followed by steel and timber. An analysis on the life cycle energy consumption of buildings has been published [6]. The authors mentioned that the life cycle primary energy requirement of conventional residential buildings falls in the range of 150-400 KWh/m^2y which includes both operating and embodied energy. The operating energy corresponds to 80-90% of the total energy used and the embodied energy to 10-20%. They also reported that demolition energy has a negligible effect on the total energy balance of the building. A report on the operating and embodied energy of an Italian building has been published [7]. The authors emphasized the key issue of its embodied energy which is particularly important in the case of low energy buildings. They also pinpointed the difficulty in defining the reference area in the building, including service and unheated zones and the absence of an internationally accepted protocol for that. A life cycle energy analysis in buildings has been implemented [8]. With reference to net zero energy buildings, where on-site renewable energy generation covers the annual energy load, the authors mentioned the increase of the share of embodied energy compared with the operating energy. They stated that: a) in the last decades the embodied energy in new buildings has slightly decreased and b) the relative share of embodied energy to life cycle energy use has significantly increased due to the sharp decrease in operating energy consumption because of more strict energy regulations. An investigation on the possibility of creating NZCE buildings in Crete, Greece due to life cycle energy use has been made [9]. The author stated that the creation of net zero CO_2 emissions residential buildings due to life cycle energy use in Crete, Greece does not have major difficulties and it could be achieved relatively easily with the use of mature and reliable renewable energy technologies. A review of current operating trends versus embodied emissions in buildings has been published [10]. The authors stated that in order to mitigate climate change, buildings must be designed and constructed with minimum environmental impact. Total life cycle emissions from buildings are both due to operating and embodied energy use. Considerable efforts have been made to reduce operating emissions from buildings, but little attention has been paid to embodied emissions. Therefore, a critical review on the relation between operating and embodied emissions is necessary in order to highlight the importance of embodied emissions. A report on life cycle energy consumption in net zero energy buildings has been released [11]. The authors stated that apart from the operating energy consumed during the operation of the house, its embodied energy used during its construction, refurbishment and demolition should be considered.

Net zero energy buildings

A comparison of a conventional house with a net zero energy house has been performed [12]. The authors have proposed the use of energy saving systems, a solar water heater and solar-PV panels in net zero energy houses. They indicated that many of these sustainable energy systems are cost-effective. A presentation of the myths and facts regarding zero energy and zero carbon buildings has been made [13]. The author stated that in recent years these types of buildings have attracted much attention in many countries although there is a lot of debate as to whether their construction is feasible. He concluded that energy self-efficiency in buildings can be achieved and zero energy and zero carbon emissions buildings will soon become economically and socially accepted. A report on net-positive energy buildings has been released [14]. The author stated that net-positive buildings introduce several new design considerations and possibilities. He mentioned that net-positive energy buildings involve energy and economic exchanges and negotiations with power utilities. A review of the research already published on low or zero carbon emissions buildings has been published [15]. The authors have considered the use of renewable energy technologies, the use of low carbon building materials, and the design and assessment methods used. Among renewable energy technologies, they mentioned wind turbines, solar-PVs, solar thermal collectors, wood heating and high efficiency heat pumps. A holistic study on the concept of zero energy buildings has been realized [16]. The author mentioned that firstly energy saving measures should be considered, and secondly renewable energies should be utilized in order to supply the required energy in the buildings. It was stated that it is always easier to save energy than to produce it. It was also suggested that indoor climate conditions should be defined

How to cite this article: John Vourdoubas. Creation of Net Zero Carbon Emissions Residential Buildings due to Energy use in the Mediterranean Region: Are they Feasible?. Civil Eng Res J. 2020; 10(1): 555777.DOI: 10.19080/CERJ.2020.10.555777.

in order to compare zero energy buildings (ZEBs) in different locations. A critical look at zero energy buildings has been made [17]. The authors have defined four types of ZEBs as follows: (a) Net zero site energy; (b) Net zero source energy; (c) Net zero energy cost; and (d) Net zero energy emissions. They have also commented on the advantages and disadvantages of each one of them. A review on net zero energy buildings has been presented [18]. The authors stated that net zero energy buildings are the future target in the design of buildings, and this requires a clear and consistent definition of them, as well as a commonly agreed methodology for their calculations.

Net zero carbon emissions buildings

A report on the feasibility of zero carbon homes in England by 2016 from the perspective of house builders has been published [19]. The authors stated that achieving the targets for carbon emissions in the UK by 2050, all industries, including the housing sector, must reduce their carbon emissions. They found that although zero carbon homes are technically feasible in the long term, clear and concise actions are required from both the government and the house building industry. A study on the existing barriers for constructing zero carbon homes in the UK has been realized [20]. The authors mentioned that, from the point of view of the construction industry, five barriers have been identified which are categorized as economic, skills and knowledge, industry, legislative and cultural. They stated that although the barriers are more than the drivers in the zero-carbon homebuilding industry, new policy mechanisms could overcome them. A study on sustainable design for zero carbon architecture has been made [21]. The authors mentioned that zero carbon homes (ZCBs) are expected to decrease their energy requirements via effective "passive and active design solutions", and secondly by means of renewable energy systems to supply the remaining energy demand. They also stated that the focus would be on the "building's envelope". A study on the cost of carbon reduction in new buildings has been reported [22]. The study indicated that an additional capital cost at 5-11% of the initial building's construction cost is required in order to achieve the zero carbon emissions targets. A report concerning net zero carbon emissions buildings has been published [23]. The report mentioned that, in new buildings, embodied energy has a share of approximately 50% of their life cycle energy consumption. It also stated that five steps should be followed in achieving a net zero carbon emissions building which includes planning, reduction of construction impacts, reduction of operational impacts, increase in renewable energy supply and offset of any remaining carbon. The creation of net zero CO_2 emissions residential buildings due to operational energy use in Crete, Greece has been reported [24]. The author stated that the use of reliable and cost-effective renewable energy technologies including solar thermal, solar-PV, solid biomass combustion and ground-source heat pumps could cover all its operational energy requirements. A study on zero carbon building refurbishment has been realized [25]. The authors categorized a range of technologies in a hierarchical manner. The proposed hierarchical pathway of sustainable energy technologies included building insulations, high efficiency equipment and micro-generation using renewable energy technologies.

Use of solar electricity to charge electric car batteries

An investigation on the possibilities of charging electric car batteries with solar-PV systems installed in residential buildings in Sweden has been implemented [26]. The authors mentioned that home charging of electric batteries increases self-consumption of solar electricity. They stated though that due to climate conditions, this option is not attractive in Sweden while it would be an interesting solution in countries with high solar irradiance throughout the year. Research on the possibility of charging electric vehicle batteries with solar energy in workplaces in the Netherlands has taken place [27]. The authors mentioned that due to low solar irradiance in the country, the PV panels can be oversized with respect to the converter's power. They also stated that the solar-PV charger can integrate a storage system in order to be independent from the grid. A report on smart EV charging systems in Norway has been published [28]. The report investigates the interaction of charging stations with the energy needs in buildings and the local generation. Solar-PV systems installed in homes can be used for charging since they increase the electricity self-consumption. Power use during charging varies between 2.3 KW to 3.6 KW while fast charging requires higher power.

The aims of the current study are:

a) The investigation of the possibility of creating NZCE residential buildings in the Mediterranean region with reference to their requirements in operational and embodied energy as well as the energy consumed for recharging the batteries of residents' electric cars.

b) The presentation of the appropriate sustainable energy technologies which could be used in these buildings, and

c) The cost estimation of the required sustainable energy systems for achieving this goal.

The methodology followed includes: 1. Estimation of the energy consumption in a residential building including its operational energy, embodied energy and energy used in recharging electric batteries of vehicles, 2. Presentation of the characteristics of the reliable, mature and cost-effective renewable energy technologies which could be used, 3. Presentation of a case study for a NZCE residential building and sizing of the required sustainable energy systems, and 4. Cost and environmental considerations.

Energy Requirements in Residential Buildings

Energy consumed in a residential building over its life span includes the energy used during its construction, its operation,

How to cite this article: John Vourdoubas. Creation of Net Zero Carbon Emissions Residential Buildings due to Energy use in the Mediterranean Region: Are they Feasible?. Civil Eng Res J. 2020; 10(1): 555777.DOI: 10.19080/CERJ.2020.10.555777.

its refurbishment and its demolition. The energy consumed during the phases of construction, refurbishment and demolition is defined as the embodied energy of the building. Operational energy in a residential building is the energy consumed during its operation. Embodied energy has a low share in its life cycle energy consumption while operational energy has the highest share in the total energy used in the building.

Operational energy use

Energy is consumed in various sectors of residential buildings including:

1. Space heating,
2. Space cooling,
3. Domestic hot water (DHW) production,
4. Lighting, and
5. Operation of various electric appliances and apparatus

The main energy sources used are grid electricity for lighting, operation of electric devices and air-conditioning, while fossil fuels, mainly diesel oil and natural gas, are often used for space heating and DHW production. The typical operational energy consumption in a residential building, with a covered area of 120 m^2, located in the island of Crete, Greece is presented in Table 1.

Table 1: Typical operational energy consumption in a residential building1 located in the island of Crete, Greece.

Sector	Specific Energy Requirements (KWh/m^{2}y)	Energy Requirements (KWh/y)	% (Energy Requirements)	Specific CO_2 Emissions (kgCO_2/m^{2}y)	CO_2 Emissions (kgCO_2/y)	% (CO_2 Emissions)
Space heating [2]	107.1	12,852	63	33.2	3,984	44.85
Space cooling[3]	11.9	1,428 4	7	2.55	306	3.45
Lighting	20.4	2,448	12	15.3	1,836	20.68
Operation of various electric devices	15.3	1,836	9	11.475	1,377	15.51
DHW production [5]	15.3	1,836	9	11.475	1,377	15.51
Total	170	20,400	100	74	8,880	100

1 Covered area=120 m^2, 2 Use of diesel oil= 0.31 kgCO_2/KWh, 3 Use of heat pump with C.O.P.=3.5, 4 Energy consumption by the heat pump = 408 KWh/y, 5 Use of electricity= 0.75 kgCO_2/KWh

Assuming that the life span of the residential building is 50 years, then its overall operational energy consumption over this period is estimated at 1,020,000 KWh or 8,500 KWh/m^2 while its CO_2 emissions are 444,000 kgCO_2 or 3,700 kgCO_2/m^2.

Embodied energy use

The average embodied energy in a typical residential building varies depending on many factors. It has been estimated in various published studies at approximately 5-20% of its life cycle energy requirements. Assuming that in the previously mentioned residential building, its embodied energy corresponds to 15% of its specific life cycle energy used, it is calculated at 30 KWh/m^{2}y. For the abovementioned residential building and for a life span of 50 years,its overall embodied energy consumption is estimated at 180,000 KWh or 1,500 KWh/m^2. Therefore, its specific life cycle energy consumption, including its embodied and operational energy, is 200 KWh/m^{2}y while its total energy consumption is 1,200,000 KWh.

Energy required for recharging the batteries of electric vehicles

Replacement of conventional internal combustion vehicles with EVs is increasing in many countries for environmental and other reasons. EVs require frequent recharging of their batteries which can be done at home. In this case, additional electricity is needed in the residential building for battery charging. It is assumed that the residents own two vehicles and each vehicle travels 15,000 Km annually while their electricity consumption is 0.2 KWh/Km. In that case the annual electricity requirements for fueling electric vehicles are estimated at 6,000 KWh/y. This corresponds to additional specific energy consumption in the residential building at 50 KWh/m^{2}y.

Nearly-zero energy residential buildings

A NzEB is a building which has significantly reduced its operational energy consumption using various energy saving techniques and technologies resulting in lower heat, cooling and electricity needs. The necessity to mitigate climate change has increased the efforts to improve the energy behavior of buildings, lowering their energy consumption, their fossil fuels use and their carbon emissions. New regulations, building codes and legislation in many countries have made the construction of new buildings obligatory, with nearly-zero energy consumption, while the old buildings should be renovated in order to decrease their energy use. With reference to the previously mentioned residential building, its energy renovation could decrease its specific operational energy consumption from 170 KWh/m2y to 50 KWh/m^{2}y. In this case, its specific life cycle energy consumption will be at 80 KWh/m2y which is significantly lower than the initial estimated consumption at 200 KWh/m2y. The energy requirements of the abovementioned residential building regarding its embodied energy, operational energy and energy

How to cite this article: John Vourdoubas. Creation of Net Zero Carbon Emissions Residential Buildings due to Energy use in the Mediterranean Region: Are they Feasible?. Civil Eng Res J. 2020; 10(1): 555777.DOI: 10.19080/CERJ.2020.10.555777.

required for recharging the batteries of two EVs are presented in Table 2.

Table 2: Energy requirements of the residential building regarding its embodied energy, operational energy and energy required for recharging the batteries of two electric vehicles.

Specific Energy Requirements	Conventional Residential Building	Nearly-Zero Energy Residential Building
Embodied energy (KWh/m^{2}y)	30	30
Operational energy (KWh/m^{2}y)	170	50
Embodied and operational energy (KWh/m^{2}y)	200	80
Energy required for recharging electric batteries (KWh/m^{2}y)	50	50
Total energy including embodied, operational and energy for recharging electric batteries (KWh/m^{2}y)	250	130
Share of embodied to total energy (%)	12	23.08
Share of operational to total energy (%)	68	38.46
Share of embodied and operational to total energy (%)	80	61.54
Share of energy for recharging electric batteries to total energy (%)	20	38.46

Use of renewable Energy Technologies in Residential Buildings

Various locally available renewable energy sources have been used for providing heat, cooling and electricity in residential buildings. Their technologies are mature, reliable and cost-effective, while their use in buildings results in net zero carbon emissions in the atmosphere due to operational energy use. The most common renewable energies used in the Mediterranean region are solar energy, solid biomass and low enthalpy geothermal energy, while the technologies used include the following:

Solar thermal energy

It is used for DHW production with flat plate solar collectors, providing hot water at 50-70oC, depending on the local solar irradiance. These systems are simple in operational and maintenance requirements, while they have been used commercially in residential and commercial buildings in the last five decades.

Solar photovoltaic energy

Solar-PVs are used commercially during the last 10-12 years for electricity generation in on-grid and off-grid residential buildings as well as in other applications. Their use has taken off due to the sharp decrease in their prices during the last two decades. Their annual productivity depends on solar irradiance while their requirements in operation and maintenance are very low. National legislation in many countries encourages and facilitates the use of solar-PVs in buildings and other applications.

Solid biomass

Locally produced solid biomass can be burnt in appropriate wood stoves or fireplaces generating heat used in space heating and for DHW production. It has been used for heat generation for many years and the burning systems currently used are reliable and cost-effective. Solid biomass is usually a cheap and renewable fuel which can replace fossil fuels for heat generation in residential buildings located in rural areas. However, its use does not result in net zero carbon emissions, like solar energy, due to the energy consumed during its processing and transportation.

Low enthalpy geothermal energy

High efficiency heat pumps including ground source heat pumps are very efficient energy devices used extensively in residential buildings for heat and cooling generation. They utilize the heat stored under the ground while they consume electricity generating heat and cooling. They are reliable devices having a high initial installation cost but, in the long run, they are cost-effective.

Other sustainable energy technologies

Various other renewable or low carbon energy technologies, when appropriate, can be used in residential buildings. These include wind turbines generating electricity, heat and power co-generation systems generating heat and electricity, district heating systems providing heat and systems using rejected industrial heat. Other technologies like solar thermal cooling need further development in order to be commercialized. The most often used renewable energy sources in residential buildings in the Mediterranean region are presented in Table 3.

Table 3: Most commonly used renewable energy technologies in buildings providing heat, cooling and electricity.

Energy source	Energy technology used in the building	Energy generation
Solar energy	Solar thermosiphonic system with flat plate collectors	Heat-Hot water
Solar energy	Solar-PV panels	Electricity
Solid biomass	Burning in wood stoves and wood fireplaces	Heat providing space heating and hot water
Low enthalpy geothermal energy	High efficiency heat pumps	Heat and cooling, air-conditioning and hot water

Net Zero Carbon Emissions Buildings

Buildings consume fossil fuels and grid electricity for covering their energy requirements and they emit CO_2 into the atmosphere.

How to cite this article: John Vourdoubas. Creation of Net Zero Carbon Emissions Residential Buildings due to Energy use in the Mediterranean Region: Are they Feasible?. Civil Eng Res J. 2020; 10(1): 555777.DOI: 10.19080/CERJ.2020.10.555777.

A net zero carbon emissions (NZCE) building is considered the building which either does not emit CO_2 due to its operational energy use or it compensates all its operational energy consumption related to carbon emissions with carbon emissions-free energy generated by renewable energy sources in-situ or off-situ. It can be assumed that a typical residential building uses grid electricity which is generated by fossil fuels. It also uses fossil fuels including diesel oil or natural gas for heat generation. In that case, a NZCE residential building should:

a) Replace all fossil fuels used with renewable energies, and

b) Offset all the grid electricity used annually with electricity generated by renewable energies like solar-PV electricity, generated in-situ or off-situ. If solar electricity, when generated, is not consumed in the building, it will be fed into the grid. Its embodied energy, additionally to its operational energy, can be offset with green solar electricity.

Compensation of Grid Electricity Consumption in Residential Buildings with Green Electricity Generated in them

Grid electricity consumption can be offset with green electricity generated with renewable energies and fed into the grid. This is allowed in many countries according to the net-metering regulations. These regulations allow the compensation of net annual grid electricity consumption in the building with solar-PV electricity. Solar-PV panels can be installed on-site or off-site in the building generating electricity, which is partly consumed in the building, if needed, while the rest is fed into the grid. Electricity balance is made on an annual or bi-annual basis. If the amount of green electricity generation is higher than the grid electricity consumption, the owner does not usually get any financial compensation for the surplus energy sent into the grid. If the solar-PV system has been seized to generate as much electricity as the building consumes annually, then its net electricity consumption is zero. In this case, if grid electricity is generated with fossil fuels, the net carbon emissions in the building due to electricity use are zero.

A Case Study for a Residential Building with Net Zero Carbon Emissions due to Energy use Located in Greece

A case study for a residential building with NZCEs due to energy use is presented. The building is in Greece which has high solar energy resources. The energy requirements of the residential building are covered with a) A solar thermal system for DHW production, b) A solar-PV system for electricity generation, and c) A high efficiency ground source heat pump for air-conditioning. The building relates to the electric grid and it compensates all its annual electricity consumption with solar electricity according to the net-metering regulations. In order to calculate the required energy systems in the building, the following assumptions have been made:

a. Its covered area is 120 m^2 and its specific operational energy consumption is 170 KWh/m^2 y,

b. Its embodied energy is equal to 15% of its life cycle energy requirements,

c. The residents have two EVs and they charge their batteries at home. Each car travels 15,000 Km/year and its consumption is 0.2 KWh/Km,

d. A solar thermal system with flat plate collectors is producing two thirds (2/3) of the annually required DHW. The rest is produced with an electric heater. The area of the collectors is 2 m^2. Its installation cost is 450€ per m^2 of collector area. The cost of an electric heater producing DHW is 150€,

e. A solar-PV system is generating the required electricity. The solar-PV system generates 1,500 KWh/KWp annually while its installation cost is 1,200€/KWp,

f. A ground source heat pump is covering all its air-conditioning requirements. It operates 1,600 hours/year while its C.O.P. is 3.5. Its installation cost is 2,000 €/KWel.

Solar electricity generation for covering all its operational energy needs

1. The annual energy requirements for DHW in the building are 1,836 KWh/y. The solar thermal system produces 1,224 KWh/y while the remaining 612 KWh/y are produced with an electric heater. The solar thermal system has flat plate collectors with an area of 2m2 and its installation cost is 900€. The power of the electric heater is 3 KWel and its installation cost at 150€.

2. The annual energy requirements for air-conditioning (space heating and cooling) are 14,280 KWh/y. Air-conditioning will be provided by a high efficiency heat pump with C.O.P. at 3.5. The electricity consumption by the heat pump is 4,080 KWh/y. Its power will be 2.55 KWel while its installation cost is 5,100€.

3. The total electricity requirements in the residential building include needs for lighting, operation of various electric devices, requirements for the electric heater and the heat pump. The total amount is 2,448+1,836+612+4,080=8,976 KWh/y. The nominal power of a solar-PV system providing the required electricity annually is 5,984 KWp and its installation cost is 7,180.8€.

The size and installation cost of the required energy systems for covering all the operational energy needs in the residential building are presented in Table 4.

How to cite this article: John Vourdoubas. Creation of Net Zero Carbon Emissions Residential Buildings due to Energy use in the Mediterranean Region: Are they Feasible?. Civil Eng Res J. 2020; 10(1): 555777.DOI: 10.19080/CERJ.2020.10.555777.

Table 4: Size and installation cost of the required energy systems for covering all the operational energy needs 1.

Energy system	Energy generation	Energy use in the building	Size of the energy system	Installation cost (€)
Solar thermal-flat plate collectors	Heat-hot water production	DHW	Collector area 2 m2	900
Electric heater	Heat-hot water production	DHW	3 KWel	150
Solar-PV	Electricity	a) Lighting b) Operation of electric devices c) Operation of a heat pump d) Operation of an electric heater	Nominal power 5,984 KWp	7,180.80
Ground-source heat pump	Heating and cooling	Air-conditioning	Electric power 2.55 KWel	5,100
Total				13,330.80

[1]Covered area=120 m^2

Solar electricity generation for covering the embodied energy of the residential building

Additional solar electricity could be generated and fed into the grid for covering the embodied energy of the residential building. In that case, the building is considered as a "negative carbon emissions building" since it generates annually more solar electricity than it consumes from the grid and therefore it contributes to atmospheric carbon removal. The construction and operation of this type of building probably requires negotiations and agreements with the power utility regarding its financial compensation. Therefore, the size of the solar-PV system should be increased. The embodied energy of the residential building is 30 KWh/m^2 y (Table 2) or 3,600 KWh/y. The additional size of the solar-PV system for generating the embodied energy annually is 2.4 KWp and its installation cost is 2,880€.

Solar electricity generation for recharging the electric batteries of two vehicles

Additional solar electricity should be generated in order to be used for recharging the electric batteries of residents' cars. The required energy for recharging the batteries of the two EVs is 50 KWh/m^2 y (Table 2) or 6,000 KWh/y. The additional size of the solar-PV system for generating annually the electricity required for recharging the batteries is 4 KWp and its installation cost is 4,200€.

Economic and Environmental considerations

Cost estimations

A conventional grid-connected residential building usually includes a DHW producing system and an air-conditioning system. However, a solar-PV system generating all the required electricity in the building should be additionally installed according to the net-metering regulations. The size of the solar-PV system should be, depending on the energy requirements that it will cover, between 5,984 KWp and 12,384 KWp, while its cost varies between 7,180.8€ (59.84€/m^2) and 14,860.8€ (123.84€/m^2) correspondingly.

Environmental estimations

The use of renewable energy technologies in the residential building will result in the reduction of carbon emissions due to energy use. For calculating the environmental benefits, the following assumptions are made:

1. The building initially used a solar thermal system for DHW production, electric energy for producing part of the DHW required, lighting and operation of the electric devices including space cooling, while it used diesel oil for space heating. The C.O.P. of the heat pump used in space cooling was 3.5.
2. CO_2 emissions due to energy use are 0.75 kgCO_2/KWh,
3. CO_2 emissions due to diesel oil use are 0.31 kgCO_2/KWh

Table 5: Cost and environmental impacts of the solar-PV system installed in a residential building zeroing its net carbon emissions due to energy use1.

Solar-PV system	Size of the Solar-PV System (KWp)	Cost (€)	Cost (€/m^2)	Annual CO_2 Emissions Savings (kg CO_2)	Annual CO_2 Emissions Savings (kg CO_2/m^2)
Covering only the operational energy demand	5,984	7,180.80	59.84	8,880	74
Covering the operational and the embodied energy demand	8,384	10,060.80	83.84	11,580	96.5
Covering the operational, embodied and energy demand for recharging the electric batteries	12,384	14,860.80	123.84	16,080	134

1 Covered area = 120 m^2

How to cite this article: John Vourdoubas. Creation of Net Zero Carbon Emissions Residential Buildings due to Energy use in the Mediterranean Region: Are they Feasible?. Civil Eng Res J. 2020; 10(1): 555777.DOI: 10.19080/CERJ.2020.10.555777.

Three different scenarios have been considered regarding the use of solar-PVs for a) covering only its operational energy demand, b) covering its operational and embodied energy demand, and c) covering its embodied, operational and energy demand for recharging the batteries of two electric cars. The annual CO_2 savings have been calculated at 8,880 to 16,080 $kgCO_2$ or 74 to 134 $kgCO_2$ per m^2. The solar-PV cost per annual carbon savings varies between 0.81€/$kgCO_2$ to 0.92€/$kgCO_2$. The cost and the environmental benefits due to the use of sustainable energy technologies are presented in Table 5.

Assuming that the construction cost of the abovementioned residential building is at 1,400€/m^2 the cost of the required renewable energy systems for transformation to a NZCE building is estimated at 4.27% to 8.85% of its initial construction cost.

Discussion

Decreasing energy consumption and carbon emissions in buildings is necessary for the achievement of climate change mitigation targets. The creation of NZCE buildings requires firstly the reduction of their energy consumption and secondly the replacement of fossil fuel use with renewable energies. Apart from the operational energy use in buildings, energy is consumed during their construction, refurbishment and demolition, defined as embodied energy. Although in conventional buildings the share of embodied energy is approximately 15% of their life cycle energy consumption, it could reach 50% in NzEBs. In our case study the annual energy consumption in the residential building is in the same range of values reported in published literature. Current European policies promote the creation of NzEBs with low energy consumption and low carbon emissions. Various reliable, mature and cost-effective renewable energy technologies which are required for the creation of NZCE buildings are already broadly used in various applications. Therefore, their technical feasibility as well as their cost-effectiveness has already been established. Among them, solar energy technologies used for heat and electricity generation are very important. Solar energy is abundant in the Mediterranean region and it is currently used for energy generation in many applications. The additional cost of the required solar-PV system for achieving a NZCE building has been estimated in previous studies as well as in the current study at 5-10% of the initial construction cost of a conventional residential building. Renewable energy technologies necessary for achieving a NZCE residential building can be used for recharging the batteries of the residents' EVs. In this case, solar electricity self-consumption in the buildings will be increased. Creation of NZCE residential buildings will promote energy democracy, increasing the independence of their residents from energy providing utilities. It has been indicated that energy saving is easier and more desirable than energy generation. However, reduction of the energy consumption in the residential building studied has not been considered. If, however the energy consumption is decreased, then the size of the required sustainable energy systems would be lower. Different existing barriers hinder the promotion of NZCE buildings including economic, knowledge and legislative issues. The definition of NZCE buildings should be clarified while a commonly agreed calculation methodology should be established. Coordination of all stakeholders, involved in the creation of NZCE buildings including governmental organizations, building designers, construction companies and the general public, is necessary for their promotion and construction on a large scale.

Conclusion

The creation of NZCE residential buildings in the Mediterranean region is technically feasible and the required sustainable energy technologies are cost-effective and already commercialized. The renewable energy sources which can be used include solar energy, solid biomass and low enthalpy geothermal energy combined with heat pumps. Solar energy can be used for DHW production and electricity generation, solid biomass for heating and ground source heat pumps for air-conditioning. The availability of solar energy in the Mediterranean region is high and its use for energy generation is attractive. The abovementioned renewable energies can cover all the operational and embodied energy requirements of a residential building as well as the energy required for recharging the batteries of residents' EVs in a cost-effective way, zeroing its net carbon emissions. The total installation cost of the required solar-PV system for achieving carbon neutrality due to life cycle energy consumption in the residential building, studied in the present work, varies between 5-10% of its initial construction cost which corresponds to 59.84€/m^2 to 123.84€/m^2. The annual CO_2 savings in the residential building have been estimated at 74 $kgCO_2/m^2$ to 134 $kgCO_2/m^2$. Therefore, creation of NZCE buildings in the Mediterranean region are technically and economically feasible using the local benign energy sources which are mature, reliable and cost-effective. Their promotion will require the development of appropriate policies and the removal of various barriers which currently hinder their promotion. Further research should be oriented towards estimating the technical and economic feasibility of NZCE buildings with nearly zero energy consumption according to the current EU regulations.

References

1. Suzuki, M, Oka T, Okada K (1995) The Estimation of Energy Consumption and CO_2 Emission due to Housing Construction in Japan. Energy and Buildings 22: 165-169.
2. Balaras CA, Gaglia AG, Georgopoulou E, Mirasgedis S, Sarafidis Y et al. (2007) European residential buildings and empirical assessment of the Hellenic building stock, energy consumption, emissions and potential energy savings. Building and Environment 42: 1298-1314.
3. Poel B, Cruchten GV, Balaras CA (2007) Energy performance assessment of existing dwellings. Energy and Buildings 39: 393-403.
4. Perez Lombard L, Ortiz J, Pout C (2008) A review on buildings energy consumption information. Energy and Buildings 40: 394-398.
5. https://sbcanada.org/wp-content/uploads/2018/04/Embodied-Carbon-White-Paper.pdf.

How to cite this article: John Vourdoubas. Creation of Net Zero Carbon Emissions Residential Buildings due to Energy use in the Mediterranean Region: Are they Feasible?. Civil Eng Res J. 2020; 10(1): 555777.DOI: 10.19080/CERJ.2020.10.555777.

6. Ramesh T, Prakash R, Shukla KK (2010) Life cycle energy analysis of buildings: An overview. Energy and Buildings 42:1592-1600.

7. Cellura M, Guarino F, Longo S, Mistretta M (2014) Energy Life-Cycle Approach in Net Zero Energy Buildings Balance: Operation and Embodied Energy of an Italian Case Study. Energy and Buildings 72: 371-381.

8. Berggren B, Hall M, Wall M (2013) LCE Analysis of Buildings-Taking the Step towards Net Zero Energy Buildings. Energy and Buildings 62: 381-391.

9. Vourdoubas J (2017) Creation of zero CO_2 emissions residential buildings due to operational energy and embodied use on the island of Crete, Greece, Open Journal of Energy Efficiency 6: 141-154.

10. Ibn-Mohammed T, Greenough R, Taylor S, Ozawa-Meida L, Acquaye A (2013) Operational vs. Embodied Emissions in Buildings-A Review of Current Trends. Energy and Buildings 66: 232-245.

11. Hernandez P, Kenny P (2008) From net energy to zero energy buildings: Defining life cycle zero energy buildings. Energy and Buildings 42: 815-821.

12. Zhu L, Hurt R, Correa D, Boehm R (2009) Comprehensive energy and economic analyses on a zero-energy house versus a conventional house. Energy 34: 1043-1053.

13. Hui SCM (2010) Zero energy and zero carbon buildings: myths and facts, In Proceedings of the International Conference on Intelligent Systems, Structures and Facilities (ISSF2010): Intelligent Infrastructure and Buildings, 12 January 2010, Kowloon Shangri-la Hotel, Hong Kong, China p. 15-25.

14. Cole RJ (2015) Net-zero and net-positive design: a question of value. Building Research & Information 43(1): 1-6.

15. Farhan SA, Shafiq N, Mold Azizli KA, Jamaludin N, Safdar Gardezi SS (2014) Low carbon buildings: Renewable energy systems, materials and assessment methods. Australian Journal of Basic and applied Sciences 8(15): 260-263.

16. Iyer-Raniga U (2019) Zero energy in the built environment: A holistic understanding, Applied Science. 9: 3375.

17. Torcellini P, Pless S, Deru M, Crawley D (2006) Zero energy buildings: A critical look at the definition, Conference paper NREL /CP-550-39833, ACEEE summer study, Pacific Grove, California.

18. Marszal AJ, Heiselberg, P, Bourrelle JS. Mussal E, Voss, K, Sartori I et al., (2011) Zero energy buildings–A review of definitions and calculation methodologies, Energy and Buildings 43, 971-979.

19. Osmani, M, O'Reilly, A (2009). Feasibility of zero carbon homes in England by 2016: a house builder's perspective. Building and Environment 44 (9): 1917-1924.

20. Heffernan E, Pan W, Liang X, De Wilde P (2015). Zero carbon homes: Perceptions from the EU construction industry, Energy Policy 79: 23-36.

21. Al-Temmamy MZ, Abd-Rabo LM (2019) Sustainable design for zero carbon Architecture, IOP conference series: Materials Science and Engineering 609.

22. https://www.bathnes.gov.uk/sites/default/files/sitedocuments/Planning-and-Building-Control/Planning-Policy/LP20162036/cost_of_carbon_reduction_in_new_buildings_report_publication_version.pdf.

23. https://www.ukgbc.org/wp-content/uploads/2019/04/Net-Zero-Carbon-Buildings-A-framework-definition.pdf.

24. Vourdoubas, J (2016) Creation of zero CO_2 emissions residential building due to energy use: A case study in Crete, Greece. Journal of Civil Engineering and Architecture Research 3(2): 1251-1259.

25. Xing Y, Hewitt N, Griffiths P (2011) Zero carbon buildings refurbishment-A hierarchical pathway, Renewable and Sustainable Energy Reviews 15: 3229-3236.

26. Luthander R, Lingfors D, Munkhammar J, Widen J (2015) Self-consumption enhancement of residential photovoltaics with battery storage and electric vehicles in communities, Proceedings of ECEEE summer study, Energy Use in Buildings, Projects, Technologies pp 991-1002.

27. Chandra Mouli GR, Bauer P, Zeman M (2016) System design for a solar powered electric vehicle charging station for workplaces, Applied Energy 168: 434-443.

28. https://ntnuopen.ntnu.no/ntnu-xmlui/handle/11250/2504976.

DOI: **10.19080/CERJ.2020.10.555777**

How to cite this article: John Vourdoubas. Creation of Net Zero Carbon Emissions Residential Buildings due to Energy use in the Mediterranean Region: Are they Feasible?. Civil Eng Res J. 2020; 10(1): 555777.DOI: 10.19080/CERJ.2020.10.555777.