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# Realization of a Small Residential Building with Zero $CO_2$ Emissions Due to Energy Use in Crete, Greece

John Vourdoubas

Correspondence: Department of Natural Resources and Environmental Engineering, Technological Educational Institute of Crete, Chania, Crete, Greece, 3 RomanouStr, GR 73133, Greece. Tel: +30-28210-23070.

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**Abstract**

European buildings account for large amounts of energy consumption and $CO_2$ emissions and current EU policies target in decreasing their energy consumption and subsequent $CO_2$ emissions. Realization of a small, grid-connected, residential building with zero $CO_2$ emissions due to energy use in Crete, Greece shows that this can be easily achieved. Required heat and electricity in the building were generated with the use of locally available renewable energies including solar energy and solid biomass. Annual energy consumption and on-site energy generation were balanced over a year as well as the annual electricity exchange between the building and the grid. Technologies used for heat and power generation included solar-thermal, solar-PV and solid-biomass burning which are reliable, mature and cost-effective. Annual energy consumption in the 65 $m^2$ building was 180 $KWh/m^2$ and its annual $CO_2$ emissions were 84.67 $kgCO_2/m^2$. The total capital cost of the required renewable energy systems was estimated at approximately 10.77% of its total construction cost, and the required capital investments in renewable energy systems, in order to achieve the goal of a residential building with zero $CO_2$ emissions due to energy use, were 1.65 € per $kgCO_2$**,** saved annually. The results of this study prove that the creation of zero $CO_2$ emissions buildings is technically feasible, economically attractive and environmentally friendly. Therefore they could be used to create future policies promoting the creation of this type of building additionally to the existing policies promoting near-zero energy buildings.

**Keywords**: $CO_2$ emissions, Crete-Greece, electricity, energy, heat, near-zero energy buildings, renewable energies, residential buildings

## 1. Introduction

### *1.1 Energy Use in Residential Buildings*

A review on buildings' energy consumption has been presented by *Perez-Lombard et al, 2008***.** The authors stated that HVAC systems' energy use contributes 50 % of total building energy consumption. They also reported that in the US the average energy consumption in dwellings is 147 $KWh/m^2$ yr. *Balaras et al, 2007* have reported on the energy consumption of the Hellenic building stock. The authors stated that annual total energy consumption in European residential buildings varies between 150-230 $KWh/m^2$. However in Eastern and Central European countries energy consumption in residential buildings is significantly higher, at 250-400 $KWh/m^2$ yr, than in Western EU countries. In Scandinavia, well insulated buildings have an annual energy consumption of 120-150 $KWh/m^2$ and the so-called low energy buildings of 60-80 $KWh/m^2$. According to the authors thermal and electrical energy consumption in residential buildings in Greece depends on the climatic zone and the year of construction. Electrical energy consumption varies between 22.53 to 39.20 $KWh/m^2$ yr and thermal energy consumption between 52.1 to 189.9 $KWh/m^2$ yr. Energy performance assessment of existing dwellings has been reported by *Poel et al, 2007*. The authors have presented a methodology and software to perform energy audits in buildings. They stated that in EU countries over 40 % of the final energy consumption is attributable to buildings and energy consumption in residential buildings corresponds to 63 % of the total energy used in the building sector. *Balaras et al, 2005* have reported on the heating energy consumption of the European apartment buildings stating that the European average heat consumption in them is 174.3 $KWh/m^2$ yr. The possibility of energy saving in Danish residential building stock has been reported by *Tommerup et al, 2006***.** The authors indicated that energy saving measures are cost-effective and they could decrease the energy consumption and $CO_2$ emissions from residential buildings in this country. They concluded that there are no technical or economic barriers to hamper the energy improvement of the buildings. The only barrier they mentioned is the lack of knowledge and interest of the people to renovate their homes.

*1.2 Life Cycle Energy Analysis in Buildings*

Energy is consumed in various stages over the lifespan of the building in its initial construction, during its operation, during its refurbishment and finally during its demolition. *Ramesh et al, 2010* have presented an overview of the life cycle energy analysis of various buildings. The authors analyzed data from 73 buildings across 13 countries concluding that operating energy corresponds to 80-90 % of the life-cycle energy demand. Life-cycle primary energy requirements in conventional residential buildings fall in the range of 150-400 $KWh/m^2$ yr. *Suzuki et al, 1995* estimated the energy consumption and the $CO_2$ emissions due to construction of different types of residential buildings in Japan. The authors found that depending on the type and construction of the buildings their energy consumption varied between 833-2777 $KWh/m^2$ and their $CO_2$ emissions between 250-850 $KgCO_2/m^2$. *Hernandez et al, 2011* have presented a methodology for life-cycle building energy rating. The authors stated that current methods for assessing the energy performance of buildings account only for the operational energy use. However the embodied energy should also be taken into account in order to have a more accurate energy classification of various buildings. *Hernandez et al, 2010* have reported on defining life-cycle zero-energy buildings. According to them, a life-cycle zero-energy building is a building whose primary energy use in operation plus the energy embedded in materials and systems over the life of the building is equal to or less than the energy produced by renewable energy systems within the building.

*1.3 Use of Renewable Energies in Residential Buildings*

Various renewable energy technologies are currently used in situ in residential buildings for heat and electricity generation including:

a) Solar thermal energy

b) Solar photovoltaic energy

c) Low enthalpy geothermal energy with heat pumps

d) Solid biomass

Applications of small wind turbines in residential buildings are currently rather limited. The necessary technologies for energy generation from renewable energy sources are reliable, mature and cost-effective. The high drop in the prices of photovoltaic cells in the last few years has increased their penetration in the building sector. The recently introduced legal framework of net metering allows the increased use of solar-PVs in buildings from environmentally conscious consumers. The technology of semi-transparent photovoltaic cells facilitates their integration in the building envelope. Although the majority of the currently used renewable energy technologies in buildings could produce on-site heat and cooling energy, the most practical renewable energy technology which could generate electricity in small buildings is solar photovoltaic. Co-generation for heat and power using biomass as fuel is another option for power generation. District heating using biomass or waste heat could also be considered for providing heat in buildings. Depending on their availability, renewable energy technologies could replace fossil fuels in heat generation in buildings. Zero-carbon energy technologies which could be used in residential buildings are presented in Table 1.

Table 1. Sustainable energy technologies which could be used in residential buildings[1]

| R.E. technology | Space heating | Space cooling | Electricity generation | Domestic hot water production |
|---|---|---|---|---|
| Solar thermal with flat plate collectors | | | | + |
| Solar-PV | | | + | |
| Solid biomass burning | + | | | + |
| High efficiency Heat pumps | + | + | | + |
| Wind energy | | | + | |
| Co-generation of heat and power | + | | + | + |
| District heating with biomass | + | | | + |
| District heating with waste heat | + | | | + |

[1]Source: Own estimations

### *1.4 Zero Energy Buildings*

*Li et al, 2013* have presented a review concerning zero-energy buildings (ZEBs). The authors reported that ZEBs involve two design strategies. The first concerns minimizing the need for energy use in buildings through energy-saving measures and the second the adoption of renewable energy technologies to meet the remaining energy needs. They concluded that ZEBs will play an important role in the future in sustainable development. *Torcellini et al, 2006* have presented a critical look at zero-energy buildings. The authors stated that a net zero-energy building is a residential or commercial building with greatly reduced energy needs through energy efficiency gains such that the balance of energy needs can be supplied with renewable technologies. The authors stated that there are four (4) commonly used definitions for zero-energy buildings:

a) Net-zero site energy

b) Net-zero source energy

c) Net-zero costs, and

d) Net-zero energy emissions.

A net-zero energy emissions building produces at least as much emissions-free renewable energy as it uses from emissions-producing energy sources. *Marszal et al, 2011* have reviewed definitions and calculating methodologies of zero-energy buildings. The authors stated that the concept of a zero-energy building requires clear and consistent definition and a commonly agreed energy calculation methodology. *Wang et al, 2009* have presented a case study in the UK of a grid-connected zero-energy house. The house was using solar-PVs and wind turbines for electricity generation, a solar thermal system for hot water production, and an under-floor heating system with a heat pump for space heating. *Iqbal, 2004* has presented a feasibility study of a grid-connected zero-energy home in Newfoundland. The author stated that in St. Johns Newfoundland the average annual wind speed is 6.7 m/s and he indicated that a wind turbine could provide all the required energy to the home. He also estimated that the total cost of the energy system in order to convert the home to a zero-energy home is about 30 % of the cost of a typical house in Newfoundland. *Parker, 2009* has reported on perspectives of very low-energy homes in USA. He stated that very low-energy buildings can be easily achieved in North America. He suggested that energy efficiency measures should be a prerequisite to installation of solar water heating and solar electricity to near-zero energy homes. *Musall et al, 2010* have presented an overview of net-zero energy solar buildings. They stated that the biggest challenge for all zero-energy building projects is the best fit of energy saving and renewable energy technologies used. For a small residential building they proposed the following combination of sustainable energy technologies:

a) A full passive house with solar thermal collectors,

b) Use of a heat pump,

c) Use of efficient electric appliances, and

d) A solar-PV system for electricity generation.

*Sartori et al, 2012* have reported on net zero energy buildings. The authors stated that although the concept of zero-energy buildings is generally understood, an internationally agreed definition is still lacking. They proposed the combined assessment of two criteria for zero-energy buildings. The first concerns the energy flaws exchanged between the building and the grid and the second the balance between the energy generation on-site and the energy consumption in the building. *Zhu et al, 2009* have presented an energy and economic analysis on a zero-energy house versus a conventional house in the US. The authors found that various energy measures were cost-effective, among them high performing windows, energy saving lights, air conditioners with a water-cooled condenser and a highly insulated roof. A solar-PV system and a solar thermal system installed in the zero-energy house had higher payback times than the previous energy-saving technologies.

### *1.5 Zero $CO_2$ Emissions Buildings Due to Energy Use*

*Levine et al, 1996* have reported on mitigation options for $CO_2$ emissions from buildings. The authors stated that between 1971 and 1992 annual growth in $CO_2$ emissions from buildings varied widely ranging from 0.9 % in industrialized countries, 0.7 % in Eastern Europe and the former Soviet Union and 5.9 % in developing countries. Much of the $CO_2$ emissions increase is the result of population growth and growth in energy services particularly in developing countries. Policy instruments to reduce energy use and $CO_2$ emissions in buildings are increases in energy prices, promotion of energy efficiency policies, technology transfer, and increased research in innovative energy technologies used in buildings. *Urge-Vorsatz et al, 2007* have presented an appraisal of policy instruments for reducing building $CO_2$ emissions. The authors stated that currently the building sector contributes approximately one third of energy-related $CO_2$ emissions worldwide and that it is economically possible to achieve a 30 % reduction. However, they claimed that numerous barriers prevent the realization of high economic potential. Assessing many policy evaluation reports from various countries, the authors concluded that the most cost-effective instruments achieving energy and $CO_2$ savings at negative costs for the society were appliances standards, demand-side management programmes and mandatory labeling. *Urge-Vorsatz et al, 2008* have estimated the potential and costs of $CO_2$ mitigation in the world's buildings. Their findings showed that the highest potential for $CO_2$ mitigation in buildings in developing countries is associated with electricity savings in lights and appliances. The highest potential in developed countries and economies in transition results from fuel savings. *Vourdoubas, 2015* and *Vourdoubas, 2016* presented the possibility of creating zero-$CO_2$ emissions hotels and residential buildings due to energy use in Crete, Greece. The author indicated that two combinations of renewable energy technologies could cover all the energy needs of the buildings zeroing their $CO_2$ emissions in Crete. The first combination includes the use of solar thermal energy, solar-PV energy and solid biomass, and the second the use of solar thermal energy, solar-PV energy and high efficiency heat pumps.

The purpose of the current work is to present the realization of a small grid-connected residential building with a zero-carbon footprint due to energy use located in Crete, Greece. This was easily achieved only with the use of locally available renewable energies including solar energy and solid biomass. Their technologies for heat and power generation on-site are mature, reliable and cost-effective. The use of energy saving technologies in the building although desirable was not necessary. Economic and environmental analysis reveals that the transformation of the grid-connected residential building in Crete, Greece to a zero-carbon emissions building with the use of the above-mentioned energy technologies is economically and environmentally attractive.

## 2. Differences between Near-zero Energy Buildings and Zero-$CO_2$ Emission Buildings

*EU directive 2010/31/EU* promotes the creation of near-zero energy buildings (NZEBs) which are buildings with low energy consumption and low $CO_2$ emissions. Existing or new buildings could be transformed to NZEBs with the use of energy saving techniques and technologies which however are in some cases costly. Their low energy load could be covered either with the use of conventional fuels or with the use of renewable energies. Depending on the energy source used they could emit zero, low or higher amounts of $CO_2$ in the atmosphere. On the contrary a zero-$CO_2$ emissions building (Z$CO_2$EB) does not necessarily reduce its energy consumption. However it uses only renewable energies in order to cover its energy loads and consequently it does not emit $CO_2$. A Z$CO_2$EB could utilize grid electricity derived from fossil fuels which though must be offset with green electricity over a year, and the overall balance must be zero. Therefore the transformation of an existing building to Z$CO_2$EB does not necessarily require investments in energy-efficient (EE) technologies, which are in various cases costly, in order to reduce its overall energy consumption. However it requires investments in renewable energy technologies (RET), preferably on-site, which are available, reliable, mature and cost effective. Currently the EU finances the *promotion of zero-$CO_2$ emissions buildings due to energy use* through the INTERREG EUROPE programme in order to improve current policies and to propagate good practices concerning the promotion of buildings with low or zero-energy consumption and $CO_2$ emissions. Although Greek legislation has complied with the European legislation regarding NZEBs there is currently no legal framework promoting Z$CO_2$EBs. The main differences between a NZEB and a Z$CO_2$EB are presented in Table 2.

Table 2. Differences between a NZEB and a Z$CO_2$EB

| | NZEB | Z$CO_2$EB |
|---|---|---|
| Energy consumption | Low | Not necessarily low |
| . Energy sources used | Conventional fuels and/or renewable energies. | Only renewable energies. If fossil fuels are used they must be offset with renewable energies. |
| $CO_2$ emissions due to energy used | Low or zero. | Zero |
| Energy investments | In E.E. technologies and possibly in Renewable energies. | In renewable energies but not necessarily in E.E. technologies. |
| Cost effectiveness of the energy technologies used | Some E.E. technologies are not cost effective.<br>Various R.E.T. are cost effective. | Various R.E.T. are cost effective. |

## 3. Realization of a Small Residential Building with Zero-$CO_2$ Emissions Due to Energy Use Located in Crete, Greece

### *3.1 Building Characteristics*

The small residential building is located in the village of Gerani in the municipality of Platanias, in Western Crete, Greece (latitude 35.502 452 North and longitude 23.876735 East). Its covered surface is 65 $m^2$, it is connected with the electric grid and a family of four people is currently living there. The building was constructed with reinforced concrete during 2001 and it was not properly thermally insulated. Greece is divided into four (4) climatic zones and the residential building is located in zone A, having the mildest climate. Average monthly air temperatures in this area vary from 10.8 °C in January to 26.6 °C in July. The annual solar irradiance is estimated at 1738 KWh/m$^2$. The building envelope is not properly insulated but its door and windows are energy-efficient, constructed with double glazing.

*3.2 Requirements for Zeroing the Carbon Footprint in the Residential Building*

In order to zero the $CO_2$ emissions due to operational energy use in this building, the following requirements must be fulfilled:

1. Fossil fuels must not be used in the building. They must be replaced with renewable energy sources, and
2. Grid electricity used must be offset annually with green electricity, like solar-PV electricity. The electric grid of Crete is not interconnected with the continental grid and it is assumed that all the grid electricity is generated with fossil fuels. However currently in Crete, Greece renewable energies generate approximately 18 % of the annual generated electricity in the island.

*3.3 Energy Loads*

Energy is used in the building in various sectors including space heating, space cooling, hot water production, lighting and operation of various electric appliances. Overall energy consumption in the residential building is estimated at 180 KWh/m$^2$ year (11 700 KWh/m$^2$). The estimated energy consumption per sector is presented in Table 3.

Table 3. Energy consumption in the residential building in various sectors[1]

| Sector | % of total energy used | Energy consumption (KWh/m$^2$ yr) | Energy consumption (KWh/yr) |
|---|---|---|---|
| Space heating | 63 | 113.4 | 7371 |
| Hot water production | 9 | 16.2 | 1053 |
| Heating energy | 72 | 129.6 | 8424 |
| Lighting | 12 | 21.6 | 1404 |
| Operation of various appliances including space cooling | 16 | 28.8 | 1872 |
| Electricity | 28 | 50.4 | 3276 |
| Total operational energy | 100 | 180 | 11 700 |
| Embodied energy [2] | 17.65 | 31.76 | 2064.7 |
| Total energy consumption including the embodied energy [2] | 117.65 | 211.76 | 13 764.7 |

[1]Covered area 65 m$^2$

[2]Assuming that operational energy corresponds at 85 % and embodied energy at 15 % of the total life cycle energy consumption

According to Table 3 the total amount of energy used for heating in the residential building is significantly higher than that used for electricity.

*3.4 Renewable Energy Technologies Used*

Three different renewable energy technologies were used in the residential building. They included a solar thermal system for hot water production, a solar photovoltaic system for electricity generation and a solid biomass burning system for space heating. The solar thermal system was installed on the roof terrace and the area of its solar collectors was 2 m$^2$ corresponding to a solar power of 1.4 KWth. It is expected to cover approximately 85 % of the annual needs in hot water of the residential building. The solar photovoltaic system had a nominal power of 3 KWp and its annual electricity generation has been estimated at 4500 KWh. It was installed on the roof terrace of the building according to the net-metering initiative. Since the annual electricity consumption in the building was expected to be lower than 4500 KWh the excess generated electricity from the solar-PV would be fed into the grid. A wood stove of 6 KWth was installed in the building utilizing olive tree wood for space heating, also providing hot water when needed. The annual wood consumption was estimated at 3 tons and its thermal efficiency was not exceeding 60 %. Solid biomass is expected to cover all the space heating needs of the building during the winter. The three renewable energy systems used generating the required energy were located on the site of the building.

*3.5 Energy Balance in the Building*

The heat and electricity generation from the renewable energy systems installed in the building has been estimated as follows

a) Heating value of the solid biomass used: 3600 Kcal/kg, with thermal efficiency of the wood stove 60 %, and an annual operation of 600 hours,

b) Annual heat generation from the solar thermal system: 860 KWh/KWth,

c) Electricity generation from the solar-PV: 1500 KWh/KWp.

Energy generation from the renewable energy systems in the residential building as well as the energybalance is presented in Table 4.

Table 4. Energy generation and energy balance in the residential building

| Energy system | Power of the energy system | Annual energy generation (KWh/yr) | Annual energy consumption (KWh/yr) | Energy surplus (KWh/yr) |
|---|---|---|---|---|
| Solar thermal | 1.4 KWth | 1204 | 1053 | 151 |
| Biomass burning | 6 KWth | 9031 | 7371 | 1660 |
| Heating energy | | 10 235 | 8424 | 1811 |
| Solar-PV ( Electricity) | 3 KWel | 4500 | 3276 | 1224 |
| Total | 7.4 KWth + 3 KWel | 14 735 | 11 700 | 3035 |

Energy generation from the above-mentioned renewable energy systems, according to Table 4, is higher than the average energy consumption in the building in order to cope with unexpected variations or failures. The over-design of the energy systems results in slightly higher investment costs and it should be noted that according to current regulations for net-metering in Greece the surplus electricity generated is fed into the grid without any financial compensation. The annual energy surplus in the building, 3035 KWh/yr**,** exceeds its embodied energy, calculated in Table 2, which is 2064.7 KWh/yr.

**4. Cost Analysis**

The capital cost of the three renewable energy systems installed in the residential building has been estimated as well as the annual solid biomass cost. The cost of the solar thermal system of 1.4 KWth is 1000 €, the unit cost of the biomass burning system is 500 €/KWth and the unit cost of the solar-PV system is 1700 €/KWp. Current cost of solid biomass in Crete is 0.13 €/kg. Cost estimations are presented in Table 5.

Table 5. Cost estimations of the renewable energy systems installed in the small residential building in Crete.

| Energy system | Power | Capital cost ( €) | Operating cost [1] (€/yr) |
|---|---|---|---|
| Solar thermal | 1.4 KWth | 1000 | 0 |
| Solar-PV | 3 KWel | 5100 | 0 |
| Solid biomass burning | 6 KWth | 3000 | 390 |
| Total | | 9100 | 390 |

[1]Maintenance and depreciation costs have not been calculated

Assuming that the current construction cost of the small residential building in Crete is 84 500 € (1300 €/$m^2$), the total installation cost of the above-mentioned renewable energy systems corresponds to10.77 % of its construction cost. Since heating oil has been replaced by woody biomass, and the electricity as well as the hot water used in the building are generated on-site by solar energy, significant annual savings concerning the energy bill have been obtained.

**5. Environmental Analysis**

Since renewable energies have replaced the use of conventional fuels in the residential building its $CO_2$ emissions due to energy use have been zeroed. In order to estimate the $CO_2$ emissions saved, it is assumed that initially the building was covering all its energy needs with electricity and heating oil. Electricity was used for cooling, hot water production and operation of various electric appliances, and heating oil was used for space heating. $CO_2$ emissions savings are presented in Table 6.

Table 6. $CO_2$ emission due to conventional fuels used in the small residential building in Crete[1]

| Fuel | Use | Quantity (KWh/yr) | $CO_2$ emissions ( Kg $CO_2$/year) | $CO_2$ emissions ($KgCO_2$/year $m^2$) |
|---|---|---|---|---|
| Electricity consumption | Cooling , hot water production and operation of electric devices | 4329 | 3247 | 49.95 |
| Heating oil consumption | Space heating | 7371 | 2257 | 34.72 |
| Total energy | | 11 700 | 5504 | 84.67 |

[1] Electricity emission coefficient= 0.75 kg $CO_2$/KWh , Heating oil emission coefficient= 3.2 kg $CO_2$/kg of oil , Net heating value of diesel oil= 9000 kcal/kg

According to Table 6, $CO_2$ emissions in the building due to electricity use are higher than emissions due to heating oil use. Therefore the annual total $CO_2$ emissions savings due to the use of renewable energies in the building are 5504 $KgCO_2$. The required capital investments in the above-mentioned renewable energy systems in order to achieve the goal of a residential building with zero-$CO_2$ emissions due to energy use are 1.65 € per $kgCO_2$ saved annually.

## 6. Discussion

Reducing or zeroing $CO_2$ emissions due to energy use in residential buildings is of paramount importance for mitigating climate change. Zero-$CO_2$ emissions buildings could be achieved by increasing their energy efficiency and by replacing conventional fuels used with renewable energies. The methodology used for the realization of the small residential building with zero $CO_2$ emissions due to energy use is based in the followings. a) Definition of the criteria for achieving a zero $CO_2$ emission building, b) Estimating the energy demand in the building, and c) Estimating the locally available and cost effective renewable energies which could cover the energy demand in the building. The abovementioned methodology assumes that a) All grid electricity is generated with fossil fuels, and b) The solar-PV system will operate smoothly without failures providing continuously electricity into the grid. It is obvious that other combinations of renewable energy technologies apart from those mentioned previously could achieve the same result in the residential building. *Mussal et al, 2010* have presented another combination of renewable energy technologies which also result to a net-zero energy solar building. The proposed technologies include a full solar passive house with solar thermal collectors, a heat pump, efficient electric appliances and a solar-PV system. Another combination of different renewable energy technologies for achieving the same result has been proposed by *Wang et al, 2009*. The authors proposed, for a grid-connected zero-energy house in UK, solar-PVs and a wind turbine for electricity generation, a solar thermal system for hot water production and a heat pump for space heating. The estimated cost of the required RET in order to transform the residential building in Crete into a $ZCO_2EB$ corresponds at 10.77 % of its construction cost which is significantly lower than the required cost reported by *Iqbal, 2004* for a grid connected zero energy home in Newfoundland which has been estimated at 30 % of its construction cost. In each territory the availability of various renewable energies combined with their cost effectiveness and the size of the buildings would indicate the optimum combinations of them in order to zero their carbon footprint. It should be pointed out that for a small building in Mediterranean area including the island of Crete, the best renewable energy technology for electricity generation on site is the solar-PV technology. Wind turbines are suitable and cost effective only in the case that the annual wind speeds on site are high. On the contrary there are more available RET for heat generation. In the current building a different combination of RET for zeroing its carbon emissions could be a) A solar thermal system for hot water production, b) A high efficiency heat pump for space heating and cooling, and c) A solar-PV system for electricity generation. The possibility of zeroing the carbon footprint of the building due its embodied energy over its life cycle should be examined. In order to achieve that, the building should be energy positive supplying annually more electricity into the grid than its annual consumption. The excess solar electricity injected into the grid over its life time should be equal to its embodied energy. However the existing legal framework for the net-metering in Greece does not foresee financial compensation in the case that more electricity is injected annually into the grid than the energy consumption in the building. This fact discourages the building owners to install solar-PV systems with higher nominal capacities in order to create positive energy buildings and to compensate the embodied energy over their life time.

## 7. Conclusions

Realization of a small, grid-connected, residential building with zero-$CO_2$ emissions due to energy use in Crete, Greece has been implemented rather easily. The technical and economic feasibility has been proved as well as the environmental advantages. This indicates that there are not technical, economic or legal barriers for achieving zero-$CO_2$ emission buildings due to operational energy use. However incentives should be provided to the public and private sector in order to promote this type of buildings combined with awareness raising sensitizing the citizens. The creation of various demonstrative municipal buildings with zero $CO_2$ emissions using different RET could be a good example in order to familiarize the local society with them. Electricity generation on-site requires the use of a solar-PV system, and the net metering initiative which was legalized in Greece in the last two years allows that. The high solar irradiance on the island of Crete and the sharp drop in the prices of solar PVs make the use of those systems very attractive. Alternative renewable energy technologies for power generation in small residential buildings include the use of wind turbines and biomass co-generation systems which are not appropriate in the current case. The energy efficiency in the building has not been improved with proper thermal insulation but all its energy needs have been covered with the use of solar energy and solid biomass. The covered area of the building was 65 $m^2$, its annual specific energy consumption 180 $KWh/m^2$ and its total annual operating energy consumption 11 700 $KWh/m^2$. Renewable energies which are abundant in Crete were used. The applied technologies included a solar thermal system for hot water production, a solar-PV system for electricity generation and a solid biomass burning system for space heating. Heat and electricity generated on-site were slightly higher than the energy consumption in the building and electricity sent to the grid was also higher than the annually consumed electricity. The capital cost of the above-mentioned renewable energy systems was estimated at 9100 € which corresponds to 10.77 % of the total construction cost of the building. The achieved annual $CO_2$ emissions savings in the building have been estimated at 5504 $kgCO_2$ or 84.67 $kgCO_2/m^2$. According to various studies the embodied energy corresponds approximately at 15 % of its operational energy in its life cycle. The embodied energy of the building could be offset by slightly increasing the size of the solar-PV system and injecting surplus electricity into the grid. The proposed technologies for zeroing $CO_2$ emissions in the building are reliable, mature and cost-effective. Improvement of its energy efficiency with better thermal insulation of the walls and the roof could result in smaller sizing of the renewable energy systems used. Further work regarding the creation of $ZCO_2EBs$ in Crete is required, considering firstly the reduction of its energy consumption, and afterwards the use of renewable energy technologies. The future realization of a $ZCO_2EBs$ in Crete, Greece using only solar energy and geothermal heat pumps for covering all its energy needs is also desirable in order to compare its performance with the current building.

**References**


Balaras, C. A., Droutsa, K., Dascalaki, El., & Kontoyiannidis, S. (2005). Heating energy consumption and resulting environmental impact of European apartments buildings. *Energy and Buildings, 37,* 429-442. https://doi.org/10.1016/j.enbuild.2004.08.003

Balaras, C. A., Gaglia, A. G., Georgopoulou, El., Mirasgedis, S., Sarafidis, G., & Lalas, D. P. (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. https://doi.org/10.1016/j.buildenv.2005.11.001

EU directive 2010/31/EU, on the energy performance of buildings, 19/5/2010, retrieved on 21/6/2017 from http://eur-lex.europa.eu/LexUriServ/LexUriServ.do?uri=OJ:L:2010:153:0013:0035:en:PDF

Hernandez, P., & Kenny, P. (2010). From net zero to zero energy buildings. Defining life cycle zero energy buildings (LC-ZEB). *Energy and Buildings, 42,* 815-821. https://doi.org/10.1016/j.enbuild.2009.12.001

Hernandez, P., & Kenny, P. (2011). Development of a methodology for life cycle building energy ratings. *Energy Policy, 39,* 3779-3788. https://doi.org/10.1016/j.enpol.2011.04.006

Interreg Europe project "Promotion of zero $CO_2$ emission buildings due to energy use" retrieved on 21/6/2017 from https://www.interregeurope.eu/zeroco2/

Iqbal, M. T. (2004). A feasibility study of a zero energy home in Newfoundland. *Renewable Energy, 29*, 277-289. https://doi.org/10.1016/S0960-1481(03)00192-7

Levine, M. D., Price, L., & Martin, N. (1996). Mitigation options for carbon dioxide emissions from buildings. *Energy Policy, 24*(10-11), 937-949. https://doi.org/10.1016/S0301-4215(96)80359-4

Li, D. H. W., Yang, L., & Lam, J. C. (2013). Zero energy buildings and sustainable development implications-A review. *Energy, 54,* 1-10. https://doi.org/10.1016/j.energy.2013.01.070

Marszal, A. J., Heiselberg, P., Bourrelle, J. S. , Mussal, E., Voss, K., Sartori, J., & Napolitano, A. (2011). Zero energy building-A review of definitions and calculation methodologies. *Energy and Buildings, 43,* 971-979. https://doi.org/10.1016/j.enbuild.2010.12.022

Mussal, E., Weiss, T., Voss, K., Lenoir, A., Donn, M., Cory, S., & Garde, F. (2010). Net zero solar buildings; An overview and analysis on worldwide building projects, *in conference proceedings in EuroSun 2010, International solar energy society*, Graz , Austria , 20/9-1/10. https://doi.org/10.18086/eurosun.2010.06.16

Parker, D. S. (2009). Very low energy homes in the United States: Perspectives on performance from measured data. *Energy and Buildings, 41*, 512-520. https://doi.org/10.1016/j.enbuild.2008.11.017

Perez-Lombard, L., Ortiz, J., & Pout, Chr. (2008). A review on buildings energy consumption information. *Energy and Buildings, 40,* 394-398. https://doi.org/10.1016/j.enbuild.2007.03.007

Poel, B., Cruchten, G. V., & Balaras, A. (2007). Energy performance assessment of existing dwellings. *Energy and Buildings, 39,* 393-403. https://doi.org/10.1016/j.enbuild.2006.08.008

Ramesh, T., Prakash, R., & Shukla, K. K. (2010). Life cycle energy analysis of buildings: An overview. *Energy and Buildings, 42,* 1592-1600. https://doi.org/10.1016/j.enbuild.2010.05.007

Sartori, I., Napolitano, A., & Voss, K. (2012). Net zero energy buildings: A consistent definition framework. *Energy and Buildings, 48*, 220-232.

Suzuki, M., Oka, T., & Okada, K. (1995). The estimation of energy consumption and CO2 emissions due to housing construction in Japan, *Energy and Buildings, 22,* 165-169. https://doi.org/10.1016/0378-7788(95)00914-J

Tommerup, H., & Svendsen, S. (2006). Energy savings in Danish residential buildings stock, *Energy and Buildings, 38*(6), 618-626. https://doi.org/10.1016/j.enbuild.2005.08.017

Torcellini, P., Pless, S., Deru, M., & Crawley, D. (2006). Zero energy buildings: A critical look at the definition. *Presented at ACEEE summer study*, Pacific Grove, California, USA, 14-18/8/2006.

Urge-Vorsatz, D., & Novikova, A. (2008). Potentials and costs of carbon dioxide mitigation in the worlds buildings, *Energy Policy, 36*, 642-661. https://doi.org/10.1016/j.enpol.2007.10.009

Urge-Vorsatz, D., Koeppel, S., & Mirasgedis, S. (2007). Appraisal of policy instruments for reducing building $CO_2$ emissions, *Building Research and Information, 35*(4), 458-477. https://doi.org/10.1080/09613210701327384

Vourdoubas, J. (2015). Creation of hotels with zero $CO_2$ emissions due to energy use: A case study in Crete-Greece, *Journal of Energy and Power Sources*, *2*(8), 301-307.

Vourdoubas, J. (2016). Creation of zero $CO_2$ emission buildings due to energy use. A case study in Crete-Greece, *Journal of Civil Engineering and Architecture Research, 3*(2), 1251-1259.

Wang, L., Gwilliam, J., & Jones, P. (2009). Case study of zero energy house in U.K., *Energy and Buildings, 41,* 1215-1222. https://doi.org/10.1016/j.enbuild.2009.07.001

Zhu, L., Hurt, R., Correa, D., & Boehm, R. (2009). Comprehensive energy and economic analysis on a zero energy house versus a conventional house, *Energy, 34*, 1043-1053. https://doi.org/10.1016/j.energy.2009.03.010