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Creation of Zero CO_2 Emissions Residential Buildings due to Operating and Embodied Energy Use on the Island of Crete, Greece

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Abstract

The possibility of creating zero CO_2 emissions residential buildings due to life cycle energy use in the island of Crete, Greece has been examined. In a typical residential building located in Crete, Greece, its annual operating energy has been appraised at 170 KWh/m^2 and its embodied energy at 30 KWh/m^2. Various locally available renewable energies including solar energy, solid biomass and low enthalpy geothermal energy with heat pumps have been considered for generating the required heat and offsetting the grid electricity used. Their technologies are mature, reliable and cost-effective. Offset of the annual grid electricity use in the building with solar-PV electricity is allowed according to the net metering regulation. For zero carbon emissions due to embodied energy of the building, generation of additional solar electricity injected into the grid is required. A mathematical model has been developed for sizing the required solar-PV system installed in the building in order to offset the grid electricity use. For a residential building in Crete, Greece with a covered area of 100 m^2, the power of the additional solar-PV system has been estimated at 1.6 KWp and its cost at 2400 €. In the current work, it is indicated that the creation of a zero CO_2 emissions residential building due to life cycle energy use in Crete, Greece does not have major difficulties and it could be achieved relatively easily.

Keywords

Buildings, CO_2 Emissions, Crete, Greece, Embodied Energy, Operating Energy, Renewable Energies

1. Introduction

Energy consumption in buildings corresponds at 40% of the total energy consumption in the EU and in subsequent greenhouse gas emissions. Improvement of their energy efficiency is of paramount importance for promoting sustainability and current European regulations are targeting at nearly zero energy buildings focusing on their operating energy. However, the concept of zero CO_2 emissions buildings due to operating and embodied energy use has not been developed so far, neither are there regulations targeting at this type of building.

1.1. Low Energy Buildings

European legislation is forcing towards the creation of new buildings with nearly zero energy consumption and the refurbishment of old buildings in order to reduce their energy use (Directive 2002/91/EC, Directive 2010/31/EU). Torcellini *et al.*, 2006 [1] have reported on various definitions of zero energy buildings. The authors reported four definitions as follows: net zero site energy, net zero source energy, net zero energy costs and net zero energy emissions. A net zero energy emissions building, according to them, produces at least as much emissions-free renewable energy as it uses from emissions-producing energy sources. Marszal *et al.*, 2011 [2] have presented a review of definitions and calculation methodologies for zero energy buildings. The authors stated that the zero energy building concept requires a clear and consistent definition and a common agreed energy calculation methodology. They discussed various issues and approaches which should be clarified in order to facilitate a consistent and common agreed definition of zero energy building. Current published literature, according to the author's knowledge, has not included so far the embodied energy in the calculation of zero energy buildings. Vourdoubas, 2016 [3] has reported on the creation of zero CO_2 emissions residential buildings due to operating energy use in Crete, Greece. The author estimated, for a typical residential building in Crete, Greece, its annual CO_2 emissions due to operating energy use at 84.55 $kgCO_2$ per m^2. Realization of a small residential building with zero CO_2 emissions due to energy use in Crete, Greece has been reported from Vourdoubas, 2017 [4]. The author reported that renewable energy sources including solar thermal energy, solar-PV energy and solid biomass were used covering all the heating needs in the building and offsetting its annual grid electricity consumption. The cost of the required renewable energy systems corresponded at 10.77% of its construction cost and it was equal to 1.65 € per kg CO_2 saved annually in the building. Tselepis, 2015 [5] has implemented various case studies, including households, concerning electricity generation with solar-PVs in Greece according to the net-metering regulations, indicating that it was profitable.

1.2. Environmental Impacts of Buildings due to Energy Use

A review of current trends of operating versus embodied emissions in buildings has been published by Ibn-Mohammed *et al.*, 2013 [6]. 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 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. Estimation of energy consumption and CO_2 emissions due to housing construction in Japan has been presented by Suzuki *et al.*, 1995 [7]. Energy consumption at 3 - 10 GJ/m^2 (833 - 2777 KWh/m^2) has been found depending on the type and construction of the building and its CO_2 emissions during the construction stage varied between 250 - 850 kg/m^2. Guellar-Franca *et al.*, 2012 [8] have investigated the environmental impacts of the UK residential sector. The authors reported that over a period of 50 years, 90% of the global warming potential of the residential buildings is due to their operation and only 10% is due to their embodied carbon. Syngros *et al.*, 2016 [9] have reported on embodied CO_2 emissions in building construction materials in Hellenic dwellings. The authors analyzed CO_2 emissions corresponding to construction materials for four typical dwellings in Greece, estimating the average CO_2 emissions at 777 kg CO_2 per m^2. Over a life span of 50 years, the annual embodied CO_2 emissions corresponding to the construction materials were 15.54 kg CO_2 per m^2. The authors also stated that the emissions were mainly due to construction materials and the share of electro-mechanical installations was below 2%.

1.3. Energy Consumption in Buildings

Karimpour *et al.*, 2014 [10] have reported on minimizing the life cycle energy of buildings. The authors stated that in mild climates embodied energy in buildings can represent up to 25% of the total life cycle energy. In the future when operating energy in buildings will be reduced due to the construction of nearly zero energy buildings, the ratio of embodied energy to total life cycle energy will be increased. The need for an embodied energy measurement protocol for buildings has been reported by Dixit *et al.*, 2012 [11]. The authors stated that studies have revealed the growing significance of embodied energy in buildings. However current estimations of embodied energy are unclear and vary greatly. The authors recommended an approach to derive guidelines that could be developed into a globally accepted protocol. Cellura *et al.*, 2014 [12] have reported on the operating and embodied energy of an Italian building. The authors emphasized the key issue of the embodied energy of the building 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. Dixit *et al.*, 2010 [13] have presented a literature review regarding the identification of parameters for embodied energy measurements in buildings. The authors stated that current methods of estimation are inaccurate and unclear. They concluded in a set of parameters that differ and which cause variation and inconsistency in embodied energy estimation. Berggren *et al.,* 2013 [14] have reported on life cycle energy analysis in buildings. With reference to net zero energy buildings, where on-site renewable energy generation covers the annual energy load, the authors analyzed the increase of embodied energy compared with the decrease of operating energy. They concluded that: a) in the last decades the embodied energy in new buildings has slightly decreased, b) the relationship between embodied energy and life cycle energy use is almost linear, and c) the relative share of embodied energy to life cycle energy use has increased. A methodology for life cycle building energy rating has been developed by Hernandez *et al.*, 2011 [15]. Apart from the operating energy consumed during its operation, usually the embodied energy consumed during the construction of the building is not taken into account. For buildings with "zero net energy use" during its operation, the only life-cycle energy use is the embodied energy. In a case study of a detached house in Ireland, the authors have estimated the embodied energy at 1000 KWh/m^2. A review on the energy use in the life cycle of conventional and low energy buildings has been reported by Sartori *et al.*, 2007 [16]. The authors analyzed 60 cases found in the literature which showed that operating energy is represented by the largest part of total energy demand. They stated that there is a linear relation between operating and total energy use, concluding that low energy buildings are more energy-efficient even though their embodied energy is slightly higher. Ramesh *et al.*, 2010 [17] have presented an overview on life cycle analysis of buildings. The authors analyzed the results of 73 cases from 13 countries including residential and office buildings. They found that operating energy corresponds at 80% - 90% of the life cycle energy use and the rest corresponds to embodied energy. They estimated the life cycle primary energy requirements at 150 - 400 KWh/m^2 y for residential buildings and 250 - 550 KWh/m^2 y for offices. The authors also observed that low energy buildings perform better than zero operating energy buildings in the life cycle context. Adalberth *et al.*, 2001 [18] have reported on life cycle assessment, regarding environmental impacts, of four multi-family buildings located in Sweden built in 1996. The authors stated that environmental impacts during the operation of the buildings contributed at 70% - 90% of their total life cycle impacts. Since environmental impacts are directly related with their energy consumption, they suggested that design and construction of energy-efficient buildings using low emissions energy results in minimizing their environmental impacts. A report on life cycle energy and environmental performance of a new university building has been made by Scheuer *et al.*, 2003 [19]. The authors conducted a life cycle assessment of a 7300 m^2 six- story building located in the University of Michigan campus. The primary energy intensity over a life cycle of 75 years was estimated at 1171 KWh/m^2 y and the operating energy accounted at 94.4% of its life cycle energy use. Ramesh *et al.*, 2013 [20] have reported on a case study of life cycle energy analysis of a multifamily residential house in India. The authors estimated that operating energy in the house corresponded at 89% of its life cycle energy use and the remaining 11% corresponded to embodied energy. The primary energy consumption was estimated at 288 KWh/m^2 y and the authors concluded that building-integrated photovoltaics were promising for the reduction of life cycle energy use. Fay *et al.*, 2000 [21] have reported on a case study of life cycle analysis of buildings in Australia. The authors stated that as operating energy in buildings becomes lower due to efficiency improvements, embodied energy becomes more significant. They also reported that while a net zero operating energy building is now achievable, a zero life cycle energy building is likely to be more difficult.

The aim of the current study is to investigate the possibility of creating zero CO_2 emissions grid-connected residential buildings due to operating and embodied energy use with reference to the island of Crete, Greece. Appraisal of operating and embodied energy needs in the building is conducted first, followed by sizing the electricity generating solar-PV systems in order to zero the overall CO_2 emissions due to both operating and embodied energy use. The current study indicates the way that renewable energy technologies can be used in residential buildings in order to zero their overall carbon emissions due to operating and embodied energy use with reference to the island of Crete, Greece.

2. Operating and embodied energy in buildings

Energy is consumed in various phases during the life cycle of a building and it can be categorized as:

a) Energy consumed during its construction,

b) Energy consumed during its operation,

c) Energy consumed during its refurbishment, and

d) Energy consumed during its demolition.

The sum of energies consumed during its construction, refurbishments and demolition is considered as the embodied energy in the building. Although there is a lack of a generally accepted methodology for the estimation of the embodied energy in various types of buildings, the results of many studies implemented worldwide have shown that for conventional buildings the embodied energy corresponds approximately at 15% of the total life cycle energy use. Therefore operating energy has the largest share in total life cycle energy use. The necessity to cope with climate change and the efforts to reduce greenhouse gas emissions have altered the way that new buildings are constructed and the old buildings are energy-renovated. Use of various cost-effective renewable energy technologies in buildings is also promoted, resulting in reduced carbon emissions due to energy use. Apart from Europe in many other countries the creation of energy-efficient buildings is in high priority. Creation of buildings with high energy efficiency requires the use of new materials with more embodied energy. Therefore the new buildings which will have nearly zero energy consumption will also have a lower share of operating energy in their total life cycle energy use. Embodied energy will have an increased share in their total energy use which could exceed 25% compared with the current 15%. Therefore the significance of embodied energy in total life cycle energy use in new and in energy-renovated buildings will be increased in the future.

3. Zero CO_2 Emissions Residential Building Due to Operating Energy Use

Residential buildings consume energy for space heating, hot water production, lighting and operation of various electric appliances. Total and per sector energy consumption in a building depends on many parameters including the type of building construction, local climate, occupants' behavior etc. A high quality constructed building having proper thermal insulation requires less operating energy and it emits less carbon due to energy use. Therefore its transformation to zero CO_2 emission building is easier compared to a lower quality constructed building. Vourdoubas, 2016 [3] has reported that a grid-connected residential building could zero its CO_2 emissions due to energy use if the following two conditions are fulfilled:

a) Fossil fuels used for space heating and hot water production would be replaced by renewable energy sources, and

b) Grid electricity used annually in the operation of the building would be offset by solar-PV electricity generated on site with photovoltaic panels and injected into the grid.

Energy used for space heating and solar water production in a residential building can be produced with solid biomass, solar thermal energy and heat pumps. Solar energy, solid biomass and low enthalpy geothermal energy are available in many territories in Southern Europe and the required technologies are reliable, mature and cost-effective. In many countries annual grid electricity used in a building can be offset with solar-PV generated electricity and injected into the grid according to a net-metering initiative. In southern European countries solar photovoltaics are not only used in buildings but also for electricity generation injected directly into the grid. The current drop in the prices of solar-PV panels have increased their cost effectiveness and their attractiveness regarding their installation on the roofs of grid-connected residential buildings, generating annually part or all of their electricity needs, obtaining at the same time financial compensation. However if the installed solar-PV system will annually generate and inject into the grid more electricity than the actual annual consumption in the building, the excess electricity is not financially compensated. In fact the current legal framework for net metering in many countries does not exclude the installation of solar-PVs in residential buildings, generating annually more electricity than the actual consumption in the building. In this case, though, there is no financial compensation for the excess electricity provided. The renewable energy sources and the required technologies for the creation of a zero CO_2 emissions residential building are presented in **Table 1**.

Table 1. Renewable energy sources and their technologies which could be used in Crete in order to zero CO_2 emissions due to energy use in a building.

	Renewable energy source	Technology used	Generated energy
1.	Solar energy	Solar thermal	Hot water
2.	Solar energy	Solar photovoltaic	Electricity
3.	Solid biomass	Biomass burning	Heat for space heating and hot water production
4.	Low enthalpy geothermal energy	Heat pumps	Heat and cooling

4. Zero CO_2 Emissions Residential Building due to Operating and Embodied Energy Use

In order to zero CO_2 emissions due to life cycle energy use in a residential building, an additional requirement to those in section 3 must be fulfilled as follows:

c) An additional solar-PV system installed on site must generate annually and inject into the grid an amount of electricity equal to its total embodied energy, divided by the life span of the building.

With reference to a residential building located in Crete, Greece the nominal power of the required solar-PV system is estimated in two cases. In the first case, solid biomass is used for space heating, and in the second, a high efficiency heat pump. The sizing of the solar-PV system is made for offsetting its operating electricity and its embodied energy as well. In the following analysis three dimensionless parameters have been used including: a) the percentage of embodied energy to life cycle energy use in the building, b) the coefficient of performance (C.O.P.) of a heat pump, and c) the share of grid electricity generated by non-CO_2 emitting fuels. The first parameter varies depending on the construction of the building, the behavior of the occupants and the local climate and its indicative value has been taken from existing literature data. The value of the second parameter is usual in commercial heat pumps and the third parameter depends on the electric grid and the energy mix used. Its value taken in the following estimations is currently representative for Crete, Greece.

4.1. Mathematical Formulation

The following equations were used:

X1 = energy consumed for space heating in the building (KWh/m^2 y)

X2 = energy consumed for hot water production (KWh/m^2 y)

X3 = energy consumed for lighting (KWh/m^2 y)

X4 = energy consumed for the operation of various electric appliances (KWh/m^2 y)

Xoper = energy consumed during the operation of the building (KWh/m^2 y)

Xemb = embodied energy in the building (KWh/m^2 y)

Xli.cy. = life cycle energy use (KWh/m^2 y)

a = percentage of embodied energy to life cycle energy use (dimensionless number)

z = generated energy from a solar-PV system (KWh/year per KWp)

C.O.P. = coefficient of performance of a heat pump (dimensionless number)

P = Nominal power of a solar-PV system (KWp)

$$\text{Xoper} = \text{X1} + \text{X2} + \text{X3} + \text{X4} \tag{1}$$

$$\text{Xli.cy.} = \text{X1} + \text{X2} + \text{X3} + \text{X4} + \text{Xemb} \tag{2}$$

$$\text{Xli.cy.} = \text{Xoper} + \text{Xemb} \tag{3}$$

$$\text{Xemb} = \text{a} * \text{Xli.cy.} = \text{a} * [\text{Xoper} + \text{Xemb}] = \text{a} * \text{Xoper} + \text{a} * \text{Xemb} \tag{4}$$

$$\text{Xemb} = \text{Xoper} * \text{a}/(1 - \text{a}) \tag{5}$$

In the case that electricity is not consumed for space heating and for hot water production in the building, then

$$\text{P} = (\text{X3} + \text{X4} + \text{Xemb})/\text{z}\ (\text{KWp}/\text{m}^2) \tag{6}$$

In the case that a heat pump is used for space heating and electricity is not consumed for hot water production in the building, then

$$\text{P} = (\text{X1}/\text{C.O.P.} + \text{X3} + \text{X4} + \text{Xemb})/\text{z}\ (\text{KWp}/\text{m}^2) \tag{7}$$

4.2. Adjustment due to Grid Electricity Generation from Renewable Energies and Nuclear Power

A part of the grid electricity is generated by non-CO_2 emitting fuels like renewable energy sources and nuclear power. In this case the solar-PV system in the building should offset only the grid electricity generated by fossil fuels.

If Y% is the share of grid electricity generated by non-CO_2 emitting fuels, then Equations ((6) and (7)) can be written as follows:

$$\text{P1} = ((100 - \text{Y})/100) * (\text{X3} + \text{X4} + \text{Xemb})/\text{z} \tag{6a}$$

and

$$\text{P2} = ((100 - \text{Y})/100) * ((\text{X1}/\text{C.O.P.}) + \text{X3} + \text{X4} + \text{Xemb})/\text{z} \tag{6b}$$

where P1 and P2 are the nominal powers of the required solar-PV systems adjusted for the share of non-CO_2 emitting fuels used in grid electricity generation.

4.3. Estimation of the Required Solar-PV System in Order to Zero CO_2 Emissions due to Life Cycle Energy Use in a Residential Building When Solid Biomass Is Used for Space Heating

Energy consumption per sector for a residential building located in Crete, Greece is presented in Table 2.

It should be mentioned that the high share of energy use for space heating in the residential building, although the climate is mild, is due to the fact that most buildings constructed before 2010 in Greece are very poorly thermally insulated. For the following estimations, it has been assumed that the embodied energy in the residential building with a life span of 50 years is equal to 15% of its life cycle

Table 2. Typical operating energy use in a residential building in Crete, Greece.

Sector	% of energy used	Energy consumption KWh per m^2 per y
Space heating	63	107.1
Hot water production	9	15.3
Lighting	12	20.4
Operation of various appliances including space cooling	16	27.2
Total	100	170

(Vourdoubas, 2016).

energy use (Ramesh *et al.*, 2010 [17]). This is an average value reported also in other studies concerning life cycle consumption in buildings.

Setting in Equation (5), Xoper = 170 KWh/m^2y, and a = 0.15, then Xemb = 30 KWh/m^2y

Setting in Equation (6), X3 = 20.4 KWh/m^2y, X4 = 27.2 KWh/m^2y, Xemb = 30 KWh/m^2y

and for Crete, Greece, z = 1500 KWh/y per KWp, Y = 0.18

Annual electricity generation from steady (non rotated) solar photovoltaics installed in Crete, Greece is approximately 1,500 KWh per KWp.

It is estimated that currently in Crete, Greece, 18% of the annual grid electricity is generated from renewable energy sources mainly wind and solar-PV energy.

$$\text{then} \quad P = 0.052 \text{ KWp}/\text{m}^2 \quad \text{and} \quad P1 = 0.042 \text{ KWp}/\text{m}^2$$

Therefore the nominal power of the required solar-PV system which will generate annually and inject into the grid the amount of electricity used for lighting, for the operation of electric appliances and for annual compensation of the embodied energy of the building over a period of 50 years, is 0.042 KWp/m^2. For a residential building with a covered surface of 100 m^2, it is 4.2 KWp.

Assuming that the solar-PV system will generate annually only the electricity used for the operation of the building (Xemb. = 0), then Equation 6(a) gives P1 = 0.026 KWp/m^2. For a residential building with a covered area of 100 m^2, the nominal power of the required solar-PV system is 2.6 KWp. The estimated additional nominal power of the solar-PV system, which is 1.6 KWp, will generate and inject into the grid, over a period of 50 years, electricity equal to the embodied energy in the building.

4.4. Estimation of the Required Solar-PV System in Order to Zero CO_2 Emissions due to Life Cycle Energy Use in a Residential Building When a High Efficiency Heat Pump Is Used for Space Heating

When a heat pump is used for space heating in the residential building, its electricity consumption is higher compared with the previous case. The nominal power of the required solar-PV system in order to zero its CO_2 emissions due to life cycle energy use is estimated from equation 7. Assuming that the C.O.P. of the heat pump is 3 and according to Table 2, X1 = 107.1 KWh/m^2y, X3 = 20.4 KWh/m^2y, X4 = 27.2 KWh/m^2y, Y = 0.18 and Xemb = 30 KWh/m^2y, then:

$$P = 0.076\ KWp/m^2 \quad \text{and} \quad P1 = 0.062\ KWp/m^2$$

Therefore the nominal power of the required solar-PV system which will generate annually and inject into the grid the amount of electricity used for space heating with a heat pump, for lighting, for the operation of electric appliances and for annual compensation of the embodied energy of the building over a period of 50 years, is 0.062 KWp/m^2. For a residential building with a covered surface of 100 m^2 it is 6.2 KWp, which is higher than in the previous case. Assuming that the solar-PV system will generate annually only the electricity used for the operation of the building (Xemb = 0), then Equation 7(a) gives P1 = 0.046 KWp/m^2. For a residential building with a covered area of 100 m^2, the nominal power of the required solar-PV system is 4.6 KWp.

The results of the above-mentioned estimations are presented in Table 3.

Equations (6(a), 6(b)) and 5 indicate that the nominal power of the required solar-PV system in both cases depends on the share of the embodied energy to life cycle energy in the building, (a), and from the share of grid electricity generated from non-CO_2 emitting fuels, (Y). In Table 4 the power of the solar-PV system for different values of a is presented and in Table 5 the power for different values of Y.

Table 3. Estimation of the required nominal power of a solar-PV system which could zero CO_2 emissions due to operating and life cycle energy use in a residential building in Crete, Greece with a covered area of 100 m^2 adjusted for grid electricity generation from non-CO_2 emitting fuels.

Use of heating energy in the building	Space heating with solid biomass and hot water production with solar energy	Space heating with a heat pump with C.O.P. = 3 and hot water production with solar energy
Nominal power of a solar-PV system generating annually the electricity used during its operation (KWp)	2.6	4.6
Nominal power of a solar-PV system generating annually the electricity used during its operation plus its embodied energy (KWp)	4.3	6.2
Additional power of the solar-PV system for covering its embodied energy (KWp)	1.6	1.6
Cost of the additional solar-PV system in the building for covering its embodied energy[1]	2400 €	2400 €

[1]Cost of the solar-PV system = 1500 €/KWp.

Table 4. Nominal power of a solar-PV system which could zero its CO_2 emissions due to life cycle energy use in a residential building in Crete, Greece, (Y = 0.18).

Share of the embodied energy to life cycle energy in the building	P1 (KWp/m^2)[1]	P2 (KWp/m^2)[2]
0.05	0.031	0.050
0.10	0.036	0.056
0.15	0.042	0.062
0.20	0.049	0.069
0.25	0.057	0.077
0.30	0.066	0.085

[1]P1, Power of solar-PV when electricity is not consumed for space heating and for hot water production in the building. [2]P2, Power of solar-PV when a heat pump is used for space heating and electricity is not consumed for hot water production in the building.

Table 5. Nominal power of a solar-PV system which could zero its CO_2 emissions due to life cycle energy use in a residential building in Crete, Greece, (a = 0.15).

share of grid electricity generated by non-CO_2 emitting fuels	P1 (KWp/m^2)[1]	P2 (KWp/m^2)[2]
0.10	0.047	0.068
0.18	0.042	0.062
0.20	0.041	0.060
0.30	0.036	0.053
0.40	0.031	0.045
0.50	0.026	0.038

[1]P1, Power of solar-PV when electricity is not consumed for space heating and for hot water production in the building. [2]P2, Power of solar-PV when a heat pump is used for space heating and electricity is not consumed for hot water production in the building.

5. Discussion

For the creation of zero CO_2 emissions buildings due to energy use, emphasis has been given in the use of renewable energy technologies. However the improvement of their energy efficiency reducing their overall energy consumption per covered area would result in lower annual energy needs and lower sizing of the required renewable energy systems. Particularly important is the reduction of the heating and cooling energy which could be achieved with increased thermal insulation. In the abovementioned analysis, the grid electricity generated by renewable energies which do not contribute in CO_2 emissions in Crete has been taken into account, including solar-PV and wind energy. Currently approximately 18% of the total grid electricity is generated by renewable energies in the island. The technologies proposed for generation of heat, cooling and electricity in buildings are mature, reliable, well-proven and cost-effective. Solar-PVs are broadly used in southern European countries but their use in northern climate zones is rather limited. Therefore offset of grid electricity use is more difficult in northern countries. Although separate use of the abovementioned renewable energy technologies is common in various buildings, their combined use in order to zero their CO_2 emissions due to energy use has not been reported as a high priority so far. Since these technologies are cost-effective, financial incentives for their promotion are not necessary. Currently part of the European structural funds are utilized in Greece for the promotion of sustainable energy technologies in buildings, like solar thermal energy and solid biomass, in order to improve their energy rating. The legal framework in Greece allows the use of solar-PVs in buildings in order to counterbalance the annual grid electricity use (operating electricity). However in the case of installing a solar-PV system injecting into the grid more electricity than its annual consumption, additional financial compensation is not foreseen. Current European policies promote the creation of nearly zero energy buildings without mentioning or promoting the zero carbon emissions buildings. The main barriers for the creation of zero CO_2 emissions buildings due to both operating and embodied energy use are related with the following:

a) Lack of awareness among the public authorities and the citizens regarding the importance of this type of building,

b) Lack of a common accepted methodology for defining and estimating a zero CO_2 emissions building,

c) Lack of pilot demonstration buildings with zero CO_2 emissions used as good examples to the general public,

d) Lack of appropriate legal framework allowing the offset and the financial compensation of the embodied energy with solar-PV generated electricity, and

e) Lack of appropriate European or national regulations promoting zero CO_2 emissions buildings like the existing regulations promoting the nearly zero energy buildings.

6. Conclusions

Creation of zero CO_2 emissions residential buildings due to life cycle energy use in Crete, Greece can be achieved without major difficulties. Life cycle energy in a building is the sum of its operating and its embodied energy. In order to create such buildings, various reliable, mature and cost-effective renewable energy technologies can be used. With reference to the island of Crete and the local availability of renewable energies, they include solar thermal energy, solar-PV energy, solid biomass and low enthalpy geothermal energy. The share of embodied energy varies in different buildings and on average it corresponds to 15% of its life cycle energy use. It has been indicated that the embodied energy in a building can be offset with electricity generated with solar photovoltaics installed in it and injected into the grid. A simple mathematical model has been developed for the estimation of the required solar-PV system, compensating its operating electricity and its embodied energy as well. The embodied energy in the building and the share of CO_2-free fuels used in grid electricity generation have been taken into account. According to **Table 4**, higher share of embodied energy to life cycle energy in the building results in higher nominal power of the required solar-PV system. According to **Table 5**, higher share of grid electricity generated by non-CO_2 emitting fuels results in lower nominal power of the required solar-PV system. For a small residential building located in Crete, Greece with a covered area of 100 m^2, the required nominal power of the solar-PV system offsetting its embodied energy has been estimated at 1.6 KWp with a cost of 2400 €. However, the electricity injected into the grid offsetting its embodied energy is not financially compensated according to the current net-metering regulations in Greece. Creation of zero CO_2 emissions buildings due to life cycle energy use has not been reported so far and future realization of such buildings requires the removal of several barriers. Current work indicates that the creation of zero CO_2 emissions buildings due to life cycle energy use can be achieved in the future in a cost-effective way with the use of various existing and well-proven renewable energy technologies promoting overall sustainability.

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