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Use of Renewable Energies for the Creation of Net Zero Carbon Emission Residential Buildings in Northern Greece

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Abstract

The necessity to cope with the global threats of climate change has increased our concern on the energy sources used increasing the share of renewable energies and shifting from fossil fuels to benign energy sources. European Union through various directives aims at increasing sustainability in buildings reducing their energy consumption, fossil fuels use and carbon emissions. In this context, the use of renewable energies covering all the energy needs and zeroing the carbon footprint in a residential building located in northern Greece has been investigated. Use of locally available sustainable energies including solar energy, solid biomass and waste heat rejected from power plants has been proposed for covering all the energy needs in a house. Their technologies for heat and power generation are mature, reliable and cost effective. Results have indicated that the combined use of the abovementioned sustainable energies can cover all the energy needs in the building, zeroing its carbon emissions due to operating energy use. The investment cost for a house at 150 m^2 varies between 6200 € to 10,700 € or 41.33 to 71.33 € per m^2 of the building covered surface, which is relatively low compared with its construction cost. Therefore, the creation of zero CO_2 emissions residential buildings due to energy use in northern Greece is technically and economically feasible.

Keywords

Carbon Emissions, Electricity, Greece, Renewable Energy, Residential Buildings

1. Introduction

1.1. Biomass Use in the Residential Sector

Carlini *et al.* [1] have reported on the economic assessment of biomass boiler plants for heating Italian residential buildings. The authors have stated that solid biomass, including wood and pellet boilers, can provide heat for space heating and domestic hot water in a house. They concluded that the installation of a biomass boiler resulted in economic benefits which would be higher if a governmental subsidy was offered. A review of biomass heating for UK homes has been presented by Dwyer [2]. The author has stated that the use of biomass for heating should be considered in the early stages of the building's design. A study of biomass boilers heat generation in residential buildings in Spain has been reported by Las-Heras-Casas *et al.* [3]. The authors have stated that biomass use in residential sector could assist in the achievement of EU's 2020 goals for climate and energy. They also claimed that biomass use could reduce primary no-renewable energy consumption in buildings by 93% and CO_2 emissions by 94%.

1.2. Use of Solid Biomass in District Heating Systems

Ericsson *et al.* [4] have reported on the introduction and expansion of biomass use in Swedish district heating systems. The authors stated that district heating satisfies about 60% of the heat demand in Swedish buildings and biomass alone accounts for about half of the heat supply. Design of biomass district heating systems has been reported by Vallios *et al.* [5]. The authors have presented a methodology for designing biomass fuelled district heating systems using a parametric logic which assists an inexperienced engineer to be able to design such systems. Biomass district heating in pilot installations for public buildings has been presented by Chatzistougianni *et al.* [6]. The authors have proposed a methodology for heating public buildings with district heating systems fuelled by biomass. They concluded that the benefits for rural municipalities are important in terms of operating costs and environmental protection. Margaritis *et al.* [7] have reported on the introduction of renewable energies in the district heating system in Greece. The authors have stated that various district heating systems in northern Greece are utilizing waste heat rejected from the lignite fuelled thermal power stations. However, these power stations are going to close down in the coming years. They have estimated that solid biomass, locally available, could be used instead of waste heat in the existing district heating systems and that the fuel replacement is cost effective.

1.3. Use of Waste Heat in District Heating Systems

Dorasic *et al.* [8] have reported on excess heat utilization in district heating systems. The authors have stated that district heating systems offer many economic and environmental benefits compared with individual heating systems. They also reported that excess heat can be easily utilized in an operating district heating system depending on the available excess heat supply and its distance from the heat demand. Karlopoulos *et al.* [9] have reported on the experience of the district heating systems operating in northern Greece using waste heat rejected from the lignite fired thermal power plants. The authors have stated that many economic and environmental benefits have resulted, during the last ten years, due to the operation of these systems in northern Greece. Fang *et al.* [10] have investigated the industrial waste heat utilization for low temperature district heating. The authors have proposed a holistic approach to the integrated and efficient utilization of low grade industrial waste heat. They mentioned four important advantages including: 1) The improvement of thermal energy efficiency in the factories, 2) more cost-efficient heating than the traditional, 3) reduction of greenhouse gas emissions, and 4) reduction of heat pollution due to industrial waste heat discharge.

1.4. Use of Solar Thermal Energy for Domestic Hot Water Production

Greening *et al.* [11] have reported on domestic solar water heating in United Kingdom. Taking into account the low solar irradiance in U.K. the authors have concluded that the potential of solar thermal systems to contribute to a more sustainable domestic energy supply in U.K. is limited. A review of solar water heating systems has been presented by Vinubhai *et al.* [12]. The authors have stated that solar water heating is one of the most effective technologies to convert solar energy into thermal energy and it is currently a developed and commercialized technology. However, they concluded, there exists opportunities to further improve the system performance and increase its reliability and efficiency. Aelenei *et al.* [13] have reported on systematic characterization of solar thermal systems installed in buildings. The authors have stated that apart from their energy performance characterization, additional criteria for assessing these systems should include structural, functional and aesthetical aspects. Tian *et al.* [14] have reviewed solar collectors and thermal energy storage in solar thermal applications. The authors have reviewed various types of concentrated and non-concentrated solar collectors with or without sun tracking systems. They have also reviewed solar thermal energy storage as sensible heat, latent heat and in chemical heat storage materials. The authors concluded that among the non-concentrated collectors the photovoltaic-thermal collectors show the best overall performance. Kalogirou [15] has reported on thermal performance, economic and environmental life cycle analysis of thermosiphonic solar water heaters. The author has studied a simple thermosiphonic system producing hot water for a family of four persons. His results indicated that it can cover up to 79% of the annual needs in domestic hot water of the family. The payback period of the investment varies between 2.7 - 4.5 years, depending on the back-up system used, while greenhouse gas savings obtained are at 70%.

1.5. Use of Solar-PV Systems

Salem *et al.* [16] have reported on building integrated photovoltaics in Mediterranean countries. The authors have stated that Mediterranean basin is characterized by high solar irradiance, at 7.5 - 8 KWh/m^2 annually, and high temperatures which decrease the efficiency of the solar cells. They concluded that solar-PVs placed on commercial buildings, which mainly operate during the day, can cover the most of their electricity needs. Hayter *et al.* [17] have reported on applications of solar-PVs in buildings. The authors have investigated the performance of three solar-PV systems, at 7 KWp to 60 KWp, installed in three commercial buildings. They concluded that these systems have reduced the electricity loads in the buildings suggesting that they should be integrated into the building in its initial design phase. Biyik *et al.* [18] have reported on building integrated photovoltaic systems (BIPV). The authors have stated that BIPVs have attracted the last decade an increasing interest and they are considered as a feasible technology to cover part of the electricity load in buildings. They have also investigated the possibility of ventilating the solar-PV system in order to decrease the temperature of the panels and to increase their efficiency. Tselepis [19] has reported on the PV market developments in Greece with reference to net-metering case studies. The author has stated that net metering regulations were introduced in Greece in the end of 2014. The two case studies presented for a household and a commercial enterprise indicated their attractiveness and the viability of the net-metering program in Greece.

1.6. Net Zero Energy and Zero Carbon Emission Buildings

Ferrante *et al.* [20] have investigated the creation of zero energy balance and zero on-site CO_2 emission houses in Mediterranean climate. With reference a town in southern Italy the authors have stated that houses with zero energy balance and zero CO_2 emissions are feasible in Mediterranean basin. They can be achieved using energy efficient technologies, local materials and traditional construction processes. Vourdoubas [21] has reported on the creation of zero CO_2 emission residential buildings in the island of Crete, Greece. The author has stated that zero carbon emission buildings can be created with the combination of various renewable energy technologies. He reported that solar thermal energy, solar-PV, solid biomass and ground source heat pumps combined, can generate all the heat and electricity required in the building zeroing its carbon footprint due to energy use. Creation of zero CO_2 emissions residential buildings due to operating and embodied energy use has been reported by Vourdoubas [22]. The author has stated that the combination of various renewable energies could zero its CO_2 emissions due to operating energy use. He also stated that in order to zero the embodied energy use in the building, generation of additional solar electricity injected into the grid is required. Nielsen *et al.* [23] have reported on excess heat production of future net zero energy buildings (NZEBs) within district heating areas in Denmark. The authors have stated that most of the buildings in Denmark are connected to electricity grids and around half of them with district heating systems. This fact allows the exchange of heat and electricity among the buildings and the grids. They found that excess heat produced from solar thermal systems installed in NZEBs can be sent into the district heating system reducing the fuel used for heat generation.

Although many studies have focused on the use of various renewable energies in buildings the possibility of creating net zero energy buildings replacing fossil fuels with reliable and cost effective renewable energy technologies has not paid attention so far. However in the current age of sustainable development and climate change minimizing carbon emissions in various sectors is of paramount importance. Current study indicates the way that the use of well proven renewable energy technologies could result in net zero carbon emission residential building in Greece.

Aims of the current work are:

1) The presentation of various sustainable energy technologies which can be used in residential buildings in northern Greece for zeroing their carbon emissions,

2) A preliminary sizing of the sustainable energy technologies used in a typical residential building for zeroing its carbon footprint, and

3) Assessment of the feasibility of creating net zero carbon emission residential buildings in northern Greece.

2. Energy Use in Residential Buildings

Residential buildings consume energy in various sectors including:

1) Space heating,

2) Space cooling,

3) Domestic hot water production,

4) Lighting, and

5) Operation of various electric appliances.

Energy consumption in various sectors in residential buildings depend on various parameters including:

1) The local climate,

2) The quality of the building construction which characterizes its energy performance, and

3) The behavior of the residents.

Typical operating energy use in various sectors in a residential building located in Crete, Greece is presented in **Table 1**.

Table 1. Energy consumption in a residential building located in Crete, Greece[1].

Sector	% Energy used	Energy consumption (KWh/m^2 year)
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

[1]Source: Vourdoubas, 2016.

3. Requirements for a Net Zero Carbon Emission Building Due to Energy Use

A grid connected residential building would zero its carbon emissions due to operating energy use if the following conditions are fulfilled.

1) All its heating requirements for space heating and hot water production are covered with renewable energies or other non-carbon emitted energy resources, instead of fossil fuels, and

2) Its grid electricity consumption is offset annually with green electricity, like solar-PV electricity generated by solar-PV panels placed on the roof of the building.

If those two conditions are fulfilled the net carbon emissions due to operating energy use of the residential building would be zero. It has been assumed though that all the grid electricity is generated by fossil fuels emitting CO_2 in the atmosphere. However part of grid electricity in Greece is generated by renewable energies including hydroelectric, wind and solar-PV plants. Apart from the energy consumed during the operation of the building, additional energy is also consumed during its construction, its refurbishment and its demolition. Vourdoubas, 2017, reviewing results from various studies, has indicated that operational energy use in a building corresponds approximately at 85% of its total life cycle energy consumption and the rest 15% is its embodied energy. In order to zero carbon emissions due to life cycle energy consumption in the building a larger size solar-PV system is required and it can be installed. However the existing net-metering regulations in Greece compensate only the PV's electricity generated which is equal to the annual consumption in the building. Excess electricity generated is sent into the grid while the producer-consumer does not receive any financial compensation for that.

4. Availability of Solar Energy, Solid Biomass and Waste Heat in Northern Greece

Solar energy is abundant in northern Greece and it is already used for heat and power generation with solar thermal and solar-PV systems. Both of them are currently used in buildings for covering their energy needs. The systems used are mature, reliable and cost-effective. The use of solar-PV systems for electricity generation in grid connected buildings is allowed according to the Greek legislation with the net metering regulations. Solar thermal systems are broadly used in Greece for domestic hot water production. However their use for space heating and cooling is rather limited. Availability of solid biomass in northern Greece is high, including agricultural and forest by-products, residues and wastes. It is broadly used for heat generation, including space heating and domestic hot water production, in residential buildings. Various types of solid biomass are used for energy generation including fire-woods, pellets and wood briquettes, feeding wood stoves, fire places and central heating systems. Although the use of solid biomass in residential buildings in northern Greece is well developed, its use in fuelling district heating systems is lacking. Taking into account the current severe economic crisis in Greece heating residential buildings with solid biomass, instead of conventional fuels, is considered as a cheap and affordable method of heating for many people. The availability of waste heat in northern Greece is high particularly in areas with lignite-fired thermal power stations. These power plants discharge large quantities of hot water which could be recycled and reused in district heating systems providing heat in buildings and in other activities. Although waste heat from these power stations cannot be considered as renewable energy source, its reuse is desirable, promoting circular economy, increasing the overall efficiency of the power stations, avoiding thermal pollution of water reservoirs and eliminating carbon emissions due to fossil fuels use. Currently district heating systems utilizing waste heat discharged from power stations provide heating in few cities in northern Greece including Kozani and Ptolemaida which are located nearby the stations. Solar energy, solid biomass and waste heat, if combined, can cover all the energy needs in residential buildings resulting in zero net carbon emissions due to operational energy use. The use of solar energy, solid biomass and waste heat for covering the energy needs in residential buildings is presented in Table 2.

5. Use of Solid Biomass and Solar Energy for Covering All the Energy Needs in Residential Buildings

Renewable energies can cover all the heating needs in residential buildings while solar-PVs placed on the roof can generate electricity equal to the amount consumed annually in the building. Solid biomass can be used in individual systems for space heating and hot water production while solar thermal systems with flat plate collectors can be also used for hot water production. Both technologies are reliable, mature and cost-effective and they are currently used in residential buildings in northern Greece. Solar-PV systems are recently used in grid connected buildings for electricity generation offsetting annually the grid electricity consumed in the building according to net metering regulations. Their use has been promoted the last few years due to the fact that their prices have been sharply reduced and their use is cost effective. Alternatively district heating systems fuelled with solid biomass can provide all the required heat in the buildings.

Table 2. Use of solar energy, solid biomass and waste heat for covering the energy needs in residential buildings.

Energy source	Space heating	Domestic hot water production	Electricity generation
Solar thermal energy		+	
Solar-PV energy			+
Solid biomass in individual or district heating systems	+	+	
Waste heat in district heating systems	+	+	

Unfortunately district heating systems utilizing solid biomass are not currently used in Greece. Therefore the combined use of solid biomass, solar thermal energy and solar-PV systems can cover all the energy needs in grid connected residential buildings resulting in net zero carbon emissions due to operational energy use in them. The characteristics of the abovementioned renewable energy technologies are presented in Table 3.

The sizing of the required renewable energy systems for providing all the required energy in a residential building in northern Greece resulting in net zero carbon emissions has been calculated according to the following assumptions.

1) The covered area of the house is 150 m^2,

2) Energy consumption in various sectors in the house is similar with that presented in Table 1. Therefore, the energy requirements for space heating are 14,175 KWh_{th}/year, for hot water production 2025 KWh_{th}/year and for electricity 6300 KWh_{el}/year, totally 22,500 KWh/year,

3) Solid biomass is used in individual systems covering all its needs in space heating and 50% of its needs in domestic hot water. Solid biomass should provide 15,187.5 KWh_{th}/year assuming that it will operate 1000 hours in the winter time.

4) A solar thermal system is covering the rest 50% of its needs in domestic hot water providing 1012.5 KWh_{th}/year. It will provide hot water during the warm days when space heating is not needed. A system with flat plate collectors at 2 m^2 can provide it. It is assumed that the solar thermal system will produce in the summer 600 KWh per m^2 of the flat plate collectors.

5) A solar-PV system installed on the roof and connected with the grid generates annually the amount of grid electricity consumed in the building, according

Table 3. Characteristics of various renewable energy technologies and waste heat used for energy generation in residential buildings in northern Greece.

Energy source/Technology	Energy generated	Energy use in the building	Reliability of the technology	Cost effectiveness of the technology	Current use in buildings in northern Greece
Solid biomass in individual systems	Heat	Space heating, hot water production	High	Satisfactory	Yes
Solid biomass in district heating systems	Heat	Space heating, hot water production	High	Satisfactory	No, it has not been studied
Solar thermal energy-Flat plate collectors	Heat	Hot water production	High	Satisfactory	Yes
Solar-PV systems	Electricity	Lighting, Operation of electric appliances	High	Satisfactory	Yes
Waste heat rejected from various plants	Heat	Space heating, hot water production	High	Satisfactory	Yes

to the net metering initiative, providing 6300 KWh_{el}/year. It is assumed that a solar-PV system located in northern Greece generates annually 1400 KWh per KW_p.

The size of the required renewable energy systems in the residential building is:

1) A solid biomass burning system with thermal power 15 KW_{th},

2) A solar thermal system with flat plate collectors of 2 m^2, and

3) A solar-PV system with nominal power 4.5 KW_p.

The capital cost of the abovementioned energy systems is estimated assuming that their unit costs are: for the biomass burning system, 300 € per KW_{th}, for the solar thermal system, 400 € per m^2 of the solar collector and for the solar-PV system, 1200 € per KW_p. Therefore the cost of the biomass burning system is 4500 €, of the solar thermal system 800 € and for the solar-PV 5400 €, totally 10,700 € or 71.33 € per m^2 of the building covered surface.

6. Use of Waste Heat and Solar Energy for Covering All the Energy Needs in Residential Buildings

Waste heat rejected from thermal power plants in northern Greece is currently used in district heating systems for providing heat in residential buildings. Although rejected waste heat cannot be considered as a renewable energy source its impacts are similar with renewable energies since its use is not related with emissions of greenhouse gases while thermal pollution to reservoirs is avoided. Additionally the pricing of the waste heat rejected is very low and the cost of heat for the residential buildings is lower compared with a district heating system fuelled with solid biomass. District heating systems using waste heat can also utilize solid biomass or heat produced from incineration of various wastes. They could also utilize heat generated by solar thermal systems. With reference to a house at 150 m^2 mentioned in the previous section, waste heat can be used for heat production combined with a solar heating system. A solar-PV system can provide all the grid electricity consumed over the year in the house. In this case the required renewable energy systems in the residential building include only the solar thermal system and the solar-PV system while heat will be also provided by the district heating system.

1) The district heating system will provide annually 15,187.5 KWh_{th}/year,

2) A solar thermal system with flat plate collectors at 2 m^2 providing 1012.5 KWh_{th}/year, and

3) A solar-PV system with nominal power 4.5 KW_p providing 6300 KWh_{el}/year.

The capital cost of the energy systems has been estimated multiplying their size by their unit costs mentioned in the previous section. In the case of providing heat by a district heating system an individual space heating system is not needed and the cost of the solar thermal and solar-PV energy systems is 6200 € or 41.33 € per m^2 of the building covered surface. The capital cost of the sustainable energy systems providing all the required energy in the residential building are presented in **Table 4**.

Table 4. Capital cost of sustainable energy systems covering all the energy needs of a house, with covered area 150 m^2, in northern Greece[1].

Energy system	Use of solid biomass burning system, solar thermal system and solar-PV (Costs in €)	Use of district heating system fuelled with rejected waste heat, solar thermal system and solar-PV (Costs in €)
Solid biomass burning system	4500	-
Solar thermal system	800	800
Solar-PV system	5400	5400
Waste heat reuse with district heating system	-	0
Total	10,700	6200
Total costs per m^2 of covered area	71.33	41.33

[1]Unit costs: Solid biomass burning system: 300 € per KW_{th}, Solar Thermal system: 400 € per m^2 of flat plate collectors, Solar-PV: 1200 € per KW_p.

7. Discussion

Residential buildings in few towns in northern Greece can be connected in two grids including the electric grid, with the net-metering regulations, and the municipal district heating grid fuelled by industrial waste heat. The connection of the building with the two grids allows it to generate electricity with photovoltaic panels and to inject it into the grid. It can also generate heat with solar thermal systems installed on its roof and injected into the district heating network when it is not needed in the house. Therefore the building could behave like a pro-sumer producing and consuming electric and thermal energy. Use of solar thermal energy for domestic hot water production and local biomass resources for space heating in residential buildings is very common in Northern Greece due to the availability of renewable energies and to their low cost compared with fossil fuels. Biomass use is more cost effective in rural areas compared to urban areas due to lower transportation costs. Additionally farmers could utilize biomass residues from their own farms at a very low cost. Apart from using solid biomass and waste heat in the residential building another alternative for its space heating is the use of high efficiency heat pumps, a reliable and cost effective technology. However heat pumps use electricity and their initial cost is high. If they will be used though the solar-PV system required would be of higher capacity in order to generate additional electricity consumed by them. The use of energy saving techniques and technologies, for reducing its overall energy consumption, has not been considered so far and emphasis has been given only in zeroing fossil fuels use and CO_2 emissions. Reducing though the energy consumption in the residential building will result in smaller sizing of the required energy systems and in lower capital costs for zeroing its carbon emissions due to energy use. However according to the EU directives and the current Greek legislation, complying with these directives, the reduction of electric and thermal energy consumption is of high priority. In the case that space heating in the building is provided by the district heating system the capital cost of the renewable energy systems is lower compared with the cost in the case of using solid biomass for heat production. Existing district heating systems in Greece currently utilize industrial waste heat due to low cost. However on the long term lignite fired power plants should be closed down due to European legislation. Then the existing district heating systems should utilize locally available biomass resources for heat generation. However in both cases the capital cost of the energy systems is low compared with the construction cost of the building which exceeds 1000 € per m^2 of the building covered surface. The abovementioned renewable energies including solar energy and solid biomass could be also used in residential buildings outside Greece particularly in areas with high solar irradiance and high availability of biomass resources like in various Mediterranean countries and in Central European countries.

8. Conclusion

The combined use of various renewable and non-carbon emitted energy resources could result in zeroing carbon emissions in residential buildings in northern Greece. Due to high availability of various sustainable energies in northern Greece, the creation of zero carbon emission residential buildings is feasible. Solar energy, solid biomass, and waste heat rejected from thermal power plants, operating in the region, can be used for that. Their technologies for heat and power generation are mature, reliable and cost-effective. The legal framework allows their use in residential buildings for heat and electricity generation. Two different options have been analyzed. In the first solar thermal energy, solar-PV energy and solid biomass are used for covering all the energy needs in the building. In the second, solar thermal energy, solar-PV energy and industrial waste heat are used for that. The capital cost of the above mentioned renewable energy systems for zeroing carbon footprint of the house due to energy use varies between 6200 € to 10,700 € or 41.33 to 71.33 € per m^2 of the building covered surface. Current work indicates that the creation of zero CO_2 emission buildings due to operational energy use in northern Greece using locally available sustainable energies is technically feasible and economically attractive. Further work should be focused in the realization of a zero net carbon emissions residential building in northern Greece using the above mentioned sustainable energy systems and recording its energy balance over time verifying its carbon neutrality.

Conflicts of Interest

The author declares no conflicts of interest regarding the publication of this paper.

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