Integration aspects of solar energy systems to renovated buildings

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Abstract: Most of existing buildings could be improved in energy consumption by applying smart building energy technologies to reduce the energy load and by installing solar energy systems and other renewable energy sources. The application of solar energy technologies, alone or combined with other renewable energy technologies, should adapt effectively the minimum possible cost, energy supply and aesthetic integration, according to building requirements. In this paper, aspects for the integration of solar energy technologies to building eco-retrofitting are analyzed. A study for energy and building eco-improvement of a typical one family Greek house and a second one, for a hotel, are presented and discussed. The effect of slope and azimuth angles and solar radiation incidence angle to PV panels were studied experimentally, to record their energy output. Considering building energy retrofitting and mainly the nearly zero energy building concept, the availability of the external surface area is important and hybrid PV/T systems can be recommended, as they can provide simultaneously electricity and heat, while covering smaller surface area in comparison with separately installed thermal collectors and PV panels. Towards low cost PV/T systems, an experimental model with water heat extraction by using plastic pipe was developed, with promising results.

1. Introduction

Building sector is the most important one for the energy consumption and every step to energy saving and conventional energy source replacement by renewable energy sources, contributes to overcome environmental and economical problems. Considering the zero energy building concept, although it is not addressed to old buildings, most of existing buildings could be improved by reducing the energy consumption and by the installation of solar thermal collectors, photovoltaics and hybrid photovoltaic/thermal (PV/T) systems.

In order this solar energy prospect to be successful, improved methodologies in energy saving and operation should be used, applying smart technologies, which will reduce the energy load of building. Renewable Energy Sources (RES) and among them photovoltaics, have started to play an important role to energy demand in the built sector, by replacing conventional energy sources. The application of solar energy systems, alone or combined with wind energy units, should consider building geometry and adapt effectively the requirements for cost, energy supply and aesthetic integration of them to buildings (Tripanagnostopoulos, 2014).

The application of improved energy technologies, accompanied by the use of solar energy and other RES, is interested to be studied. In this paper, integration aspects for solar energy technologies adapted to building eco-retrofitting and considerations for energy and building eco-improvement of a typical one family Greek house and of a hotel, are included. Towards the wide installation of solar energy systems to buildings, the effect of slope and azimuth angles to power output and additionally a low cost hybrid PV/T collector, are presented.

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2. **Energy saving and RES in the built sector**

Building sector is responsible for about 40% of energy consumption, affecting environment, global warming and climate change. Energy targets of EC for 2020 are critical requirements to energy saving and CO_2 reduction and new technologies are coming to adapt essential energy needs. In Greece, as Mediterranean country with low demand on building space heating, these needs account about 70% of total energy consumption. The energy consumption for electric devices, cooking, lighting and air conditioning, amounts 18% of the total energy balance [OECD/IEA, 2011]. Domestic hot water is the rest 12% of the total energy. The major consumption of non-renewable energy sources and the corresponding greenhouse gas emissions are identified in the period of building usage. The energy consumed in that period and considering lifetime of 50 years, it is 80% to 90% of its total energy [Thomark, 2006]. Indicators of energy consumption by OECD in 2010, show that the built construction sector used 25% to 40% of total energy, while in some countries this figure reaches 50% [Asif et al, 2007].

Solar energy systems appear as a new material in the architect's hands, ready to be shaped to create alternative buildings and they can be an important part of the building design. Towards zero energy buildings, a wider installation of photovoltaics to buildings will be performed, effectively combined with other smart building energy technologies. Critical parameters for the effective integration of solar energy systems are the building orientation and the external surface availability. Energy needs of the building could be covered by RES, although energy-efficient renovation cannot adapt all favorable conditions for RES. One main issue is that all external surfaces of the building are not available for efficient installation of photovoltaics and collectors and the orientation of the building is not always suitable. A second issue is that energy requirement of building is high and the available external surfaces are usually small. In addition, the investment cost of using RES is higher than that of conventional systems and the building is possibly located at a historical place with traditional architecture requirements.

Regarding orientation, the slope and azimuth angle of building inclined roof and azimuth angle of the façade, are not always the ideal by the energy point of view. A significant energy output reduction in heat and electricity is observed in most cases, due to not perfect orientation. We studied experimentally the effect of slope and azimuth angles and solar radiation incidence angle to photovoltaic surface, to record the energy output. Considering external surface availability, the use of hybrid PV/T systems (Tripanagnostopoulos et al, 2002) can be recommended, as they can provide electricity and heat, covering smaller surface area in comparison with separately installed thermal collectors and PV panels. These systems can provide preheated fluid, which can be heated to the final temperature by an efficient solar thermal collector. The heat from PV/T system can be also used to improve the COP of a Heat Pump, used for space heating of the building. For limited availability of building external surface for solar energy systems, the use of PV/T systems can be considered as an effective solution, but low cost heat extraction mode is necessary to adapt benefit requirements.

In this paper, parameters to optimize the contribution of photovoltaics to building energy demand and suitable technologies for building eco retrofitting are presented. We study energy improvements to a Greek house and to a hotel, suggesting energy renovation of buildings according to the new energy saving rules. Considering that in many buildings the installation of solar energy systems is not the optimum regarding orientation and slope, we studied the effect of azimuth and slope angles to PV panel performance. In addition, we investigated low cost improvements to PV/T collectors, to make their application wider.

In building energy renovation, there are required changes that are based on new technologies, which can improve the carbon footprint of it. These changes are displayed regarding visual and thermal comfort of users, the best and most efficient way of life, the effective use of building space and the economy. On a larger scale, the selected works should minimize the use of renovating materials and other resources (building materials, energy, water) and benefit the environment by reducing or eliminating the impact to it (e.g. pollutants) and therefore reduce global problems as climate change, greenhouse effect, etc. Studying the building in holistic mode, the combination of passive systems of improved conventional technologies together with RES is ideal to achieve the targets of energy, functionality, aesthetics and environmental, as well as economical, issues. Minimizing heating and cooling building loads, RES can overcome the energy needs. Furthermore, the RES can become competitive, when they are combined with conventional systems and the investment cost is reduced. Using technologies and materials that are already available in the market, the careful management of heating and cooling systems can result to the decrease of the energy consumption of a building to 40%-60%. In this way, the required amount of installed photovoltaics will be reduced, corresponding therefore to lower system cost. Towards this aim, the use of advanced systems, as of hybrid PV/T collectors, will provide the building with more energy.

3. Case study of a one family house

To make clear the effect of building retrofitting with respect to energy, a typical one family house in Greece was selected. This house was built before 30 years and is located at a place with mild weather conditions and close to the sea. This house has a total area of 140 m^2 and uses conventional incandescent lamps, has not sufficient thermal insulation, has common double glazing, conventional space heating system with oil boiler and thermally unprotected high ceiling. In Table A the energy consumption in the energy sectors of the house is briefly presented (left column). The share of electricity is 6700 kWh or 28.27% of the total energy consumption. Regarding heat, it is 17000 kWh or 71.73% of the total energy consumption. We notice that the majority of Greek houses have similar energy performance. Last years, there is in operation the national rule for energy saving of buildings (KENAK), but it is not applied enough and it is used rather for filling official documents, than for the improvement of buildings with regard to lower level of energy consumption. The installation of PV panels on buildings, being usually connected to grid and operating under net metering status, it is a contribution to rise up the energy level towards A+, but it is not enough. If there are not other energy reduction systems complementary applied (e.g. stronger thermal insulation, use of efficient heating systems, etc) the produced electricity from the installed photovoltaics is overcome by the operation of higher consumption electrical devices and building heat losses.

A main purpose of building renovation, in addition to improving or replacing construction elements, it is important to improve its energy footprint by applying low cost energy saving modifications and using photovoltaics and solar thermal collectors to cover, in a yearly energy balance mode, all building energy needs in electricity and heat. In that case, house renovation with the energy saving modifications and the replacement of conventional energy (oil and natural gas) by heat through heat pump driven by PV electricity, has a positive result in energy, environment and the owner for the pay-back time of the investment cost. Towards this aim the following changes in the energy figure of the building are considered. As a first step, the energy consumption in lighting can be reduced by replacing the incandescent lamps with low energy consumption lamps or even LED lamps.

Second step can be the replacement of the old electrical devices (of high energy consumption) with devices of higher efficiency (a-class) and therefore of low electrical energy consumption, in the kitchen, for cleaning, cooling, etc. Regarding space heating, the improvement in thermal insulation is necessary to walls, beams and ceiling. In addition, the typical fireplace can be improved to energy efficient one, contributing to the space heating energy load. In this way the heat demand for house space heating will be reduced and can be covered by heat pumps, using the electricity from photovoltaics. In addition, a solar thermal collector system for hot water could be installed. This system can apply hot water to bathroom and kitchen, for the dishwasher and washing machine, etc. The system can contribute also to space heating during winter, when there is a surplus of heat due to sunny days. It is estimated that thermal collectors of $5m^2$ can provide thermal energy of 1.700 kWh per year at temperature of about 60^o , covering domestic hot water demand and contributing to building space heating load.

The high energy consumption, due to the relatively low thermal insulation in walls, roof and beams of the house, it can be reduced by the above referred changes. In that case, the needed PV module surface area, calculated for their mounting on building roof and aiming to cover the building yearly electrical demand, is 78 m^2, consisting of 49 PV panels, of power 250 W and 225 € in cost, each one. The number of installed photovoltaic panels has been calculated as following: The pc-Si modules are installed on the south-facing roof with slope of 25^o, the mean yearly efficiency of them is considered 14% and the produced electricity 1.300 kWh per kWp (160 kWh/m^2). This PV installation is of total power 12.25 kW and costs 11025 €.

By applying the above described building energy saving modes, there will be a reduction in energy consumption, which is calculated to 51.18% for the annual basis. The existing, as well as the new suggested (after the renovation modifications) energy consumption profiles, are presented in Table A, the previous in the left columns and the new in the right ones. It is calculated that after the interventions, the saving of energy consumption is annually reduced by 68.75% for lighting, 33.33% for cooking, 33.33% for electrical equipment, 85.71% for washing, 51.18% for space heating and 28.57% for space cooling by the air conditioning system. In that case, the electricity demand is reduced and thus the required PV installation of smaller surface area. The new PV installation is calculated to be 38 m^2 surface area and the installed power 4.59 kW. This installation can cover all house needs in electricity and heat (perhaps, an installation of 5 kW could be preferable). The existing oil boiler can be kept for a back-up space heating system, for any case that the PV system cannot respond according to the demand. For the calculations, it was considered that the space heating loads of Table A (in thermal kWh) have been transformed to electrical kWh by a conversion factor 3, considering that the suggested Heat Pump consumes electricity (from PV panels) and has a COP=3 in converting electricity to heat.

Table A: Energy consumption before and after (bold) the interventions

TABLE A	Before energy renovation		**After energy renovation**	
	kWh	%	**kWh**	**%**
Lighting	1600	6,75%	**500**	**4,35%**
Cooking	2100	8,86%	**1400**	**12,17%**
Washing	1400	5,91%	**200**	**1,74%**
Electrical equipment	900	3,80%	**600**	**5,22%**
Heating	17000	71,73%	**8300**	**72,17%**
Air conditioning	700	2,95%	**500**	**4,35%**
Total energy consumption kWh	23700	100,00%	**11500**	**100,00%**

In Table B, the calculated photovoltaic installation data (energy, cost and PV panels) before building energy renovation (case A) and after energy renovation (case B), is presented. These results show that the application of energy saving modifications to the building, not only reduce the total energy demand (in electricity and heat) but makes easier and of lower cost the installation of PV panels on building roof, requiring smaller available surface area by 51%. We can study also other building renovation cases and through more complex techniques, based on environmental, economic, functional and aesthetic parameters, but the obtained results from the present study can give a first image of the suggested energy improvements.

Table B: Saving energy and cost data

TABLE B	Case A	Case B	Savings
kWh/year	**12367**	**5967**	**6400**
Electricity cost (€)	1731	835	896
PV surface (m^2)	**78**	**38**	**40**
PV panels	**49**	**24**	**25**
PVpanel cost (€)	225	225	
PV total cost (€)	**11025**	**5400**	**5625**

4. Case study of a hotel

The second case study of this paper is referred to the energy saving improvement of a hotel, located at a near sea area of western Greece, close to Patra. The hotel is consisting of nine (9) independent small buildings with two apartments each (see Fig. 1). The total surface that is used for the hotel customers is 869 m^2 and the consumed energy is 714,5 kWh/m². This energy is the 1.53*RB of the reference building, according to the energy saving rules, classifying therefore the hotel at the energy level D. To improve building energy performance and rise the energy saving level, it is necessary to avoid building high energy losses by increasing the thermal insulation, applying several low energy elements and using solar and other RES systems. In order to reduce the thermal bridges and the heat exchange of the building to ambient, it is essential to add an insulation layer at the external walls. It is also import, to avoid thermo-conductive frames at the windows of the building and replace the single glazing with energy efficient low-e glazing. The outcome from the above energy renovation actions is the reduction of building energy consumption and the improvement of building energy classification. The new calculated demand was calculated as 617.3 kWh/m² and it is the 1.32*RB of the reference building, classifying it as C.

Replacing the energetic systems of the building and including simple BMS systems to achieve lower energy consumption, the COP of the heating system can be increased from 2.2 to 4.24, increasing also the EER of the cooling system from 2.00 to 3.64. For the production of hot domestic water the flat solar thermal collectors can be increased from 9m^2 to 34 m^2. In addition, we can consider improvements to lighting and to the basic automation system. In this way, these energy improvements can classify the building to level B, because the energy consumption is now reduced to 346 kWh/m², which is the 0.74*RB of the reference building energy level. Finally, installing solar energy systems, the energy consumption level of the hotel can be further improved. An existing building is not usually designed with passive house techniques and is necessary to consume high amounts of energy. By installing solar thermal collectors and photovoltaics (Fig. 1), the incoming electrical energy from the grid is considerably reduced. Solar thermal systems contribute not only to provide domestic hot water but they could be also used for space heating if are combined with a heat pump.

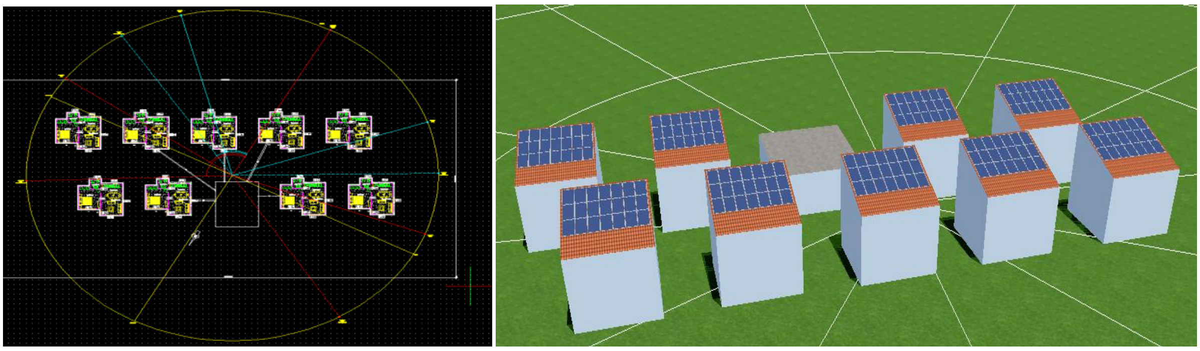

Fig. 1 The topographical view of the hotel unit and the PV panel roof installation

Photovoltaics can reduce the electricity needs of the building through net-metering operation mode. The installation of 40,59 kW by pc-Si PV panels on hotel roofs (Fig. 1) can produce 64262 kWh/year. This electricity production results to building energy consumption of 131.89 kWh/m^2 and improves its energy classification from B to A, as corresponding to 0.2*RB% of the reference building. Following this energy improvement, a higher installed power of photovoltaics can be considered, as of 54 kW, with yearly energy production of 88363 kWh. This energy results to a hotel consumption of 51.49 kWh/m^2 and improves further the hotel energy classification to A+, as corresponding to 0.11*RB of the reference building. The energy consumption of the hotel after energy renovation is included in Table C, where the values for the reference building are also included for a direct comparison.

Table C Energy consumption improvement for the studied hotel

Final use	Energy Consumption of Reference Building (kWh/m^2)	Energy Consumption of the studied Hotel (kWh/m^2)
Heating	71.6	191.9
Cooling	124.8	238.0
Lighting	212.0	214.0
How water	14.7	28.2
Renewable energy	0.0	0.0
Total	465.4	714.5

5. Azimuth angle effect to PV performance

In Solar Energy Laboratory (SEL) at the University of Patras, there is performed research on solar energy systems. Among them, PV performance improvement has been studied and especially the PV electrical output decrease from its temperature increase, by developing the hybrid PV/T solar systems with water and air heat extraction [Tripanagnostopoulos et al, 2002]. Among other system operating and performance parameters, the effect of non optimum orientation and the higher cost should be studied, especially as there are new requirements for the coming soon (2020) nearly Zero Energy Buildings (nZEB) concept.

In these applications, the high energy demand makes necessary to cover almost all building externally available surfaces with PV panels and to use also the rest roofs, in addition to south facing roofs. The study of PV performance for different slopes and azimuth angles can give a figure of the application potential, for pc-Si PV panels. The optimal placement of PV is inclined with slope of 10^o to 15^o below the latitude of the location and with azimuth angle 0° (southern orientation). In all other cases, the installation on the roof or facade of the building results to less energy output, which is depending on the orientation and site conditions.

The determination of the power output, regarding incidence angle of solar radiation and considering azimuth angle and slope of the absorbing surface, was performed using pc-Si PV panels under clear sky conditions. The effect of the azimuth angle and inclination of PV in their electrical performance, for different incidence angles of the sun, was studied experimentally. The PV testing system (pc-Si PV panel) was placed on a moving platform with flexibility in choosing slope and azimuth angle and the experiments were performed at solar noon, measuring the PV electrical output. The experimental results are included in the diagrams of Fig. 2 and show that low latitude building installed PVs and with low roof slope, present low reduction to electrical output for the east and west facing roofs. For the north facing roofs, there is a significant reduction during winter, but considering that in this period the sunny days are usually few, the yearly reduction is still at an accepted level.

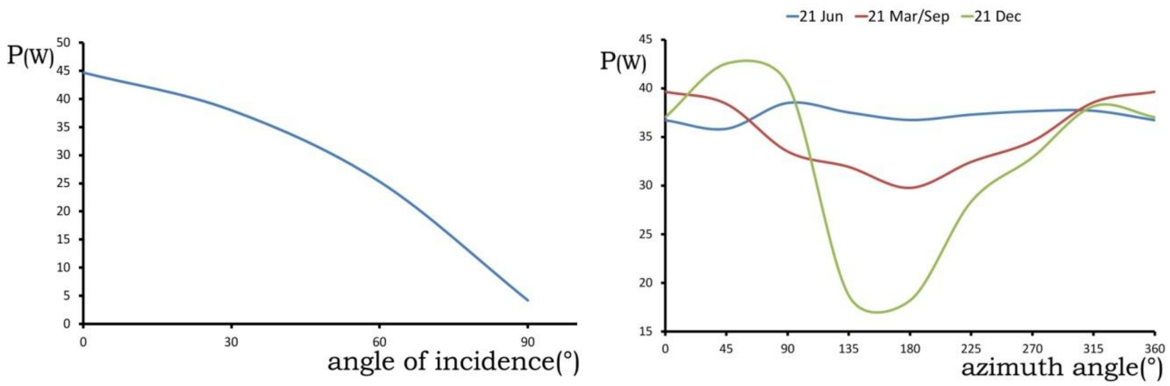

Fig.2 Effect of the angle of incidence of solar radiation on the photovoltaic effect (left)
Effect of azimuth angle for the main solar declination angles to PV power (right)

6. Low cost experimental PV/T system

A main problem of PV/T collectors is their cost, which is due to the interposition of the heat extraction unit, mainly in water type PV/T collectors, where a metallic absorber with pipes should be added behind PV panel to extract the heat. Towards minimizing the additional cost of the heat extraction unit in PV/T systems, we designed and tested an experimental model using a plastic pipe for the water heat extraction from PV panel. The constructed water cooled PV/T collector was consisted of a pc-Si PV module and a long plastic pipe curved properly and placed inside the case formed by the back side of the PV module and the thermal insulation. The system was placed on a moving platform with flexibility in selecting slope and azimuth angles. Fig. 3 shows the PV/T collector (a), its cross section (b) and the curved pipe inside the system case (c). The pc-Si PV module was of 0.4 m^2 aperture surface area, the plastic pipe had a length of 20 m and was mounted inside the collector case with the thermal insulation, to provide effectively warm water, avoiding system thermal losses.

During system operation, the plastic pipe is heated from PV module rear side, by conduction from the attached pipe, by thermal radiation and by air convection. The pipe is connected directly to the tap and the flowing water inside the pipe (about 1.5 kg) cools PV module and keeps electrical output at a sufficient level. The experiments have given satisfactory results, achieving a maximum efficiency of 45% and stagnation temperature at 60 °C. Considering the very low cost of this heat extraction unit (the pipe costs 3 €) the suggested PV/T collector is actually a low cost solar energy system for water preheating and high electricity output.

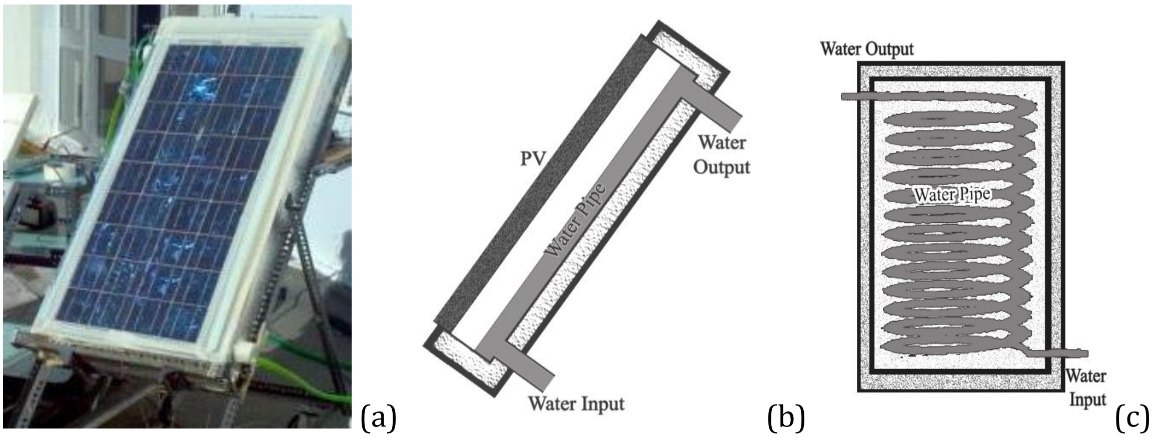

Fig. 3 Photo and cross section of the constructed PV/T module

7. Conclusions

The present work includes aspects for the optimized use of solar energy systems for cost effective building eco retrofitting. Two studies, one for a house and a second one for a hotel, show that the application of energy shaving improvements results to lower the needed PV installed power to cover the building energy demand. Towards nZEB concept, all available surface area of buildings could be used for mounting solar energy systems and experiments show the differences in PV power output regarding PV panel orientation. Finally, to decrease the cost of PV/T collectors a plastic pipe for the water heat extraction is suggested and a model was tested with satisfactory results regarding thermal and electrical efficiencies.

8. References

Asif M. Muneer T. Kelley R.: Life cycle assessment: a case study of a dwelling home in Scotland, Building and Environment, Volume 42, Issue 3, 2007, pages: 11-23

Organization for Economic Co-operation and Development: OECD/IEA, Energy Balances of OECD Countries (www.iea.org), (2011)

Thomark C.: The effect of material choice on the total energy need and recycling potential of a building, Building and Environment, Volume 41, Issue 8, August 2006, Pages 1019-1026

Tripanagnostopoulos Y., Nousia Th., Souliotis M., Yianoulis P.: Hybrid photovoltaic/thermal solar systems, Solar Energy 72, 2002, 217–234

Tripanagnostopoulos Y. New designs of building integrated solar energy systems. Energy Procedia, 2014; 57: 2186-2194.