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Possibilities of Using Hybrid Solar PV/T Systems and Other Solar Energy Technologies in Hotels in the Mediterranean Region

John Vourdoubas*

Mediterranean Agronomic Institute of Chania, Agrokipio, 73133, Chania, Crete, Greece
Email: vourdoubas@chania.teicrete.gr

Abstract

Replacement of fossil fuels with renewable energies is a necessary step in the mitigation of climate change. Hotels utilize large amounts of energy in their operation. The Mediterranean region is a popular tourism destination particularly in the summer. During this period, when the majority of the hotels operate, solar irradiance is abundant. Therefore the use of benign energy sources like solar energy for covering part or all of the energy requirements in summer-operating hotels in the Mediterranean region is of paramount importance. Various solar energy technologies can be used to generate electricity, heat and cooling. Some of them are mature, reliable, cost-effective and already being used. Others are not mature but they are promising and their commercialization requires further improvements and financial support. The possibility of using solar energy technologies for covering the energy requirements in hotels in the Mediterranean region has been examined. Solar photovoltaic technology for electricity generation, solar thermal technology for domestic hot water production and solar thermal cooling technology for air-conditioning have been investigated. Additionally hybrid solar PV/T systems for co-generation of heat and power have also been examined.

Keywords: Crete; solar energy; hotel; hybrid solar systems; Mediterranean; photovoltaic.

1. Introduction

Hotels consume large amounts of energy in various sectors. The main energy source currently used is electricity while renewable energies have limited applications in the hotel industry so far. In order to cope with climate change and to mitigate the greenhouse effect, the efforts to promote sustainable energy technologies have been multiplied. Solar energy is abundant in the Mediterranean region. The area is the destination of millions of tourists every year.

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* Corresponding author.

Therefore the efforts to promote solar energy technologies for covering the energy demand in summer-operating hotels in this region have been increased. Solar thermal technology for domestic hot water production is a mature, reliable and cost-effective technology used for many decades in various applications including in hotels. Solar photovoltaic technology for electricity generation is broadly used during the recent years due to the sharp decrease in its cost. Solar thermal cooling is used occasionally for air conditioning but it is not broadly used since the technology needs further improvement. Finally hybrid solar PV/T technology for simultaneous heat and electricity generation is a promising technology having various advantages compared to separate solar electricity and heat generation.

1.1 Hybrid solar PV/T systems

A briefing paper on solar thermal and hybrid solar photovoltaic/thermal (PV/T) systems for energy generation has been published by Grantham Institute, Imperial College London [1]. The report states that hybrid solar PV/T systems are ideal when heat and electricity are required simultaneously. It also points out that hybrid solar systems can cover a large amount of heat and cooling requirements in residential buildings in Southern Europe. The authors in [2] have reviewed the integration of solar thermal and solar-PV systems. The authors stated that the demand of solar thermal and solar PV systems is increasing rapidly. Systems co-generating heat and electricity from the same device could be the next step in solar energy promotion. They concluded though that the development of commercial products and real system applications is still limited. Noro and his colleagues [3] have reported on advancements in hybrid solar PV/T systems. The authors presented a state-of-the-art analysis of hybrid solar PV/T systems which allow to extract heat from PV moduli, reducing the operating temperature and improving their electrical efficiency. Their description included building integrated solar PV/T, concentrating solar PV/T and solar PV/T heat pump systems. The authors in [4] have reviewed the use of hybrid solar PV/T systems in buildings. The authors stated that the solar PV/T market is very small, the existing products are more expensive than the alternative installations and their use depends on available subsidies. They also mentioned that the size of modern new hybrid solar PV/T systems is larger while they utilize liquids instead of air including hybrid PV/T systems with heat pumps. The authors in [5] have reported on hybrid PV/T systems for domestic hot water and electricity generation. The authors investigated with simulation techniques the performance of hybrid solar systems in Nicosia, Cyprus (35^o) and in Athens, Greece (38^o). They concluded that the hybrid solar systems increased the overall energy generation, and in locations with high solar irradiance, their economics were more favorable. They also stated that amorphous silicon panels gave better economic results than the poly-crystalline-Si panels, although they are less energy-efficient due to their lower cost. Good and his colleagues [6] compared the performance of solar thermal, solar-PV and hybrid solar PV/T systems for achieving net zero energy buildings in Norway. The authors concluded that hybrid solar PV/T systems can reach a higher energy output than the separate solar systems. However, they concluded that a building with only PV modulus and without solar collectors is closer to nZEB requirements in Norway.
The authors in [7] reported on hybrid solar PV/T systems for combined heating, cooling and power generation in the urban environment. The authors proposed that the most efficient hybrid solar system for applications in households is the combination of hybrid PV/T with a water-water heat pump. They also mentioned that the overall efficiencies in hybrid solar systems can be up to 70% with electrical efficiencies up to 15-20% and thermal efficiencies in excess of 50%. Herrando and his colleagues [8] have investigated the use of hybrid solar

PV/T systems in a typical house in London, U.K. The authors estimated that the hybrid solar system can cover 51% of the annual electricity demand and 36% of the annual hot water demand in the home. They also found that the hybrid solar system reduces the carbon emissions while it could have an attractive payback period with a small financial subsidy. The authors in [9] have reported on using hybrid solar PV/T systems in Italian homes. The hybrid solar systems were coupled with a heat pump contributing to space heating. Using computer simulations, the authors estimated the primary energy savings at 35-65% while the discounted payback period of the investment in mild Italian climate was around 10 years. They also found that electricity generated could cover up to 77% of the annual requirements in the household and heat energy up to 50%. Tselepis and his colleagues [10] have analyzed hybrid solar PV/T systems regarding their energy generation and economic performance. The authors calculated the energy generation in Athens, Greece (38^o) with hybrid solar PV/T systems with amorphous and poly-crystalline-si cells. Solar irradiance in Athens is 1,686.87 KWh/m^2 at 40^o inclination of the panels. For the PV/T system with amorphous-Si the annual electric efficiency was 5.27% and the heat efficiency 40.41%. For the PV/T system with poly-crystalline-Si the annual electric efficiency was 12.61% and the thermal efficiency 35.83%. They also estimated the payback period for the hybrid PV/T systems, concluding that systems with amorphous-Si were more attractive with payback periods around 5 years while systems with poly-crystalline-Si had higher payback periods at 8-10 years. The authors in [11] have reported on experimental and simulation investigation of solar systems based on PV panels and hybrid PV/T collectors in Italy. The authors used two different systems at 1 KW_{el}. Each one consisted of solar-PV panels with poly-crystalline silicon and PV/T collectors. They mentioned that simulation analysis showed an overall efficiency at 26% while the experimental results showed an average thermal efficiency of around 13% and electrical efficiencies in both technologies at 15%. Karim and his colleagues [12] have reported on the experimental performance of hybrid solar PV/T systems using poly-crystalline silicon modulus in Abu Dhabi. The authors used simple systems with natural heat convection suitable for building integration. They estimated the thermal efficiency of the systems at around 50% while the electric efficiency was around 13%. The authors in [13] have reported on a movable hybrid solar PV/T system. The system consisted of poly-crystalline silicon, equipped with rolling wheels, and it could be moved in remote areas and islands when needed. The authors estimated its electric efficiency at 11.83% and its overall efficiency at 42.82%. Cuce and his colleagues [14] have reported on theory and applications of hybrid solar PV/T systems. The authors stated that these systems can achieve electric efficiencies in the range of 8-14% while concentrated systems can reach up to 30%. Thermal efficiency is a function of ambient parameters and it can vary significantly. However thermal efficiencies in the range of 30-40% are realistic although different values have been observed in pilot tests and in real applications. They also mentioned that payback periods of hybrid PV/T systems can vary between 4-14 years. The authors in [15] have investigated the energy generation in a British house with a hybrid solar PV/T system placed on its terrace. Environmental conditions in Britain are characterized with low solar irradiance and low ambient temperatures. The authors, using an appropriate model, estimated that the hybrid solar PV/T system could cover 51% of the total annual electricity load and 36% of the total domestic hot water requirements. Rawat and his colleagues [16] have presented a comparative experimental analysis of hybrid solar PV/T water and air systems in Bhopal, India. The authors reported very high overall efficiencies exceeding 62.57% for the air system and 70% for the water hybrid system. Electric and thermal efficiencies for the air system were exceeding 6.56% and 56.47% correspondingly and for the water system 7.54% and 70%. The authors in [17] have reported on the performance of a hybrid solar PV/T system in Sharjah, UAE. The authors estimated experimentally the electric and thermal efficiencies of the hybrid system. They reported that the electric efficiency of the hybrid system, due to temperature decrease, was 15-20% higher compared to a PV panel. They also reported that its thermal efficiency was around 60-70%, resulting in a very high overall energy efficiency. Calise and his colleagues [18] have reported on a tri-generation system based on hybrid solar PV/T system producing electricity, space heating and cooling, and domestic hot water. The authors, using simulation techniques, have implemented a case study for a University building located in Naples, Italy. They mentioned that the system operates very well during the summer, providing space cooling with an absorption chiller. They concluded that the system could be profitable if financial subsidies were offered.

1.2 Solar thermal cooling and energy consumption in hotels

A solar cooling position paper issued by the International Energy Agency [19] provides arguments on why and how solar cooling systems should be supported and promoted. The report states that more than 1,200 solar thermal cooling systems have been installed in recent years. It also mentions that market opportunities exist in places with high solar irradiance and high coincidence of loads and solar gains while it is indicated that hotel buildings are good candidates for such applications. Vourdoubas [20] has reported on the creation of hotels with zero CO_2 emissions due to energy use in Crete, Greece. The author states that the annual average energy consumption in Greek hotels is 273 KWh/m^2 while the combined use of solar thermal, solar-PV and low enthalpy geothermal energy with heat pumps could result in net zero carbon emissions hotels in Crete. Vourdoubas [21] has reported on energy consumption and the use of renewable energies in hotels in Crete, Greece. The author mentions that the energy analysis of five summer-operating hotels in Crete, Greece indicated that on average their annual energy consumption was 149 KWh/m^2 while electricity was the main energy source used with a share at 65-85% in their total energy use. Buonomono and his colleagues [22] have assessed the performance of a hybrid geothermal-solar tri-generation system in a hotel in Ischia, Italy. The authors modeled a system using geothermal fluid at 95^{o}C, solar energy collectors with an area of 25 m^2 and an Organic Rankine cycle micro-turbine at 6 KW$_{el}$. Using simulation techniques, they estimated its payback time at 7.6 years which could be decreased if subsidies were offered in the hotel. The authors in [23] have reviewed various studies on the application of solar thermal cooling. The author stated that researchers in Shanghai, China estimated the average efficiency of an experimental solar cooling system at 46%. They also mentioned that other researchers in China have calculated annual average efficiency of solar cooling systems at 37.6%. Moia-Pol and his colleagues [24] have reported on energy consumption in hotels in Mediterranean islands. The authors stated that energy audits in hotels in the Balearic islands, Spain indicated that the share of electricity was 54%, of LPG 10% and of diesel oil 36%. They also mentioned that integration of renewable energies in hotels, particularly solar energy, is an excellent challenge for the hotel sector. The authors in [25] have reported on renewable energy applications in Mediterranean hotels. The authors stated that summer-operating hotels in Balearic islands consume on average 150 KWh/m^2 while more than 50% of their total energy demand comes from thermal applications including HVAC and domestic hot water. They concluded that the use of renewable energies or tri-generation plants could reduce fossil fuels use by 20-40%. Information notes on solar cooling have been reported by the International Institute of Refrigeration [26]. According to this report, single-effect solar thermal cooling systems obtain COPs between 0.4 when the temperature of the hot fluid is around 70^{o}C and 0.8 when the temperature is around 85-90^{o}C.

The aim of the current work is the investigation of using solar energy technologies in Mediterranean hotels for covering part or all of their energy needs

2. Energy consumption in hotels in the Mediterranean region

Hotels consume energy in various sectors including space heating and cooling, domestic hot water production, lighting and operation of various equipment and devices. The distribution of energy consumption per sector varies depending on various parameters including local climate, type of construction, size of the hotel, period of operation and behavior of tourists. Published data indicate that hotel buildings are among the highest energy-consuming buildings. It is also indicated that the main energy source used is electricity while the share of renewable energies in their energy mix is rather low. Published data have reported that hotels in Greece consume on average annually 273 KWh/m^2 while summer-operating hotels in the Mediterranean islands have an annual energy consumption around 150 KWh/m^2. In summer-operating hotels in the Mediterranean basin, a large share of energy is consumed in HVAC and in domestic hot water production which have a share higher than 50% of the total energy use. Existing mature and reliable solar energy technologies could be used in a cost-effective way for electricity generation and domestic hot water production in hotels in the Mediterranean basin. Unfortunately only solar thermal energy is currently used in some hotels for domestic hot water production and, occasionally in recent years, solar-PV systems for electricity generation.

3. Use of solar energy technologies in hotels

Summer-operating hotels in the Mediterranean region require energy when solar irradiance is high. Therefore it would be easier to use solar energy technologies in those hotels for covering all their energy needs. They require simultaneously electricity, cooling energy and domestic hot water. Nowadays most of them use grid electricity for lighting, air-conditioning and the operation of various devices. They also use diesel oil or solar thermal energy for domestic hot water production. Most of their energy requirements are covered with these energy sources and fuels. The high availability of solar energy in the region consists of a challenge for its use in the hotel sector. At the same time, current advances in solar energy technologies have increased their competitiveness as alternative technologies while their use is more than desirable for many reasons. Solar-PV technology is broadly used in recent years for electricity generation in many applications. Solar thermal cooling though still has limited applications. The possibility of the co-generation of heat and electricity and tri-generation of heat, cooling and electricity using solar energy technologies could reduce the dependence of hotels on fossil fuels and decrease their carbon emissions. In fact, solar energy could be used for covering the energy demand in all sectors in summer-operating hotels. A hybrid solar PV/T system could be used for providing electricity and heat. Heat can be partly used for covering the demand in domestic hot water and partly for fuelling a solar thermal cooling system providing air conditioning in the hotel. Alternatively high-efficiency heat pumps powered with solar electricity could be used for air-conditioning in hotels. The efficiencies of the solar energy systems which could provide all the energy required in a summer-operating hotel in the Mediterranean region are presented in Table 2. The efficiency of commercial solar-PV systems with flat plate crystalline-si modulus is around 15% while simple solar thermo-siphonic systems for hot water production with flat plate collectors have efficiencies of around 50%. Solar thermal cooling with single-stage systems and hot water temperature at 70^{o}C has low efficiency of around 40%. Finally hybrid solar PV/T systems have electric efficiencies of around 10% and thermal efficiencies of around 40% which may vary according to the climate conditions. It should be noted that these efficiencies are indicative and they can vary depending on the systems used and the local climate conditions. Parabolic or concentrated collectors and panels have higher efficiencies than flat plate collectors while the efficiency of solar thermal cooling can be increased significantly if a multi-stage system is used or if the temperature of the hot fluid is higher than 70^{o}C.

Table 1: Possibility of using solar energy technologies in summer-operating hotels in the Mediterranean region

Sector demanding energy in the hotel	Main energy sources/fuels currently used	Solar energy technologies which could be used
-Space cooling	Grid electricity	1.Solar thermal cooling 2.Solar-PV powered heat pumps
-Domestic hot water	Diesel oil and solar thermal energy	1.Solar thermal 2.Hybrid solar PV/T 3.Solar-PV powered heat pumps
-Lighting	Grid electricity	1.Solar-PV 2.Hybrid solar PV/T
-Operation of various electric devices	Grid electricity	1.Solar-PV 2.Hybrid solar PV/T

Table 2: Typical energy efficiencies in various solar energy systems and low carbon technology systems[1]

Technology	Energy efficiency -electric	Energy efficiency - heat/cooling	Energy efficiency - overall
1.Solar-PV	15%		
2.Solar thermal for domestic hot water production at 60-70^{o}C with flat plate collectors		50%	
3.Solar thermal cooling, single-stage systems with hot water at 70^o		40%	
4.Hybrid solar PV/T	10%	40%	50%
5.High efficiency heat pumps		350%	

[1] Source: average values in published literature

4. Combined use of various solar energy technologies for covering all the energy requirements in hotels in the Mediterranean region

A combination of various solar energy technologies together with high efficiency heat pumps could be used in hotels in order to provide part or all of their energy requirements in heating, cooling and electricity. When hotels in the Mediterranean region operate only during the summer, their requirements in space heating are minimal. It should be noted that space cooling can be provided either with a solar thermal cooling system or with a high efficiency heat pump powered by solar electricity. In the first scenario a solar-PV system is used for electricity generation. Electricity is used for lighting, for the operation of various equipment and devices, and for powering a heat pump used for heating and probably for air-conditioning. A solar thermal system with flat plate collectors is used producing the domestic hot water plus the hot water required for solar thermal cooling. Additionally a solar thermal cooling system is used for air conditioning in the hotel. In the second scenario a hybrid solar PV/T system is used for generation of electricity and heat. The hot water produced is used for domestic hot water applications and for fuelling the solar thermal cooling system providing space cooling. The hybrid solar PV/T system is covering all the heat loads and part of the electricity requirements. An additional solar-PV system is used for covering the remaining electricity needs in the hotel. Electricity is used for lighting, for the operation of various equipment and devices, and for powering a heat pump used for heating and probably for air-conditioning. In the third scenario a solar-PV system is used for generating all the electricity requirements for lighting, operation of electric devices and powering a high efficiency heat pump used in space heating and cooling. Domestic hot water is produced with a solar thermal system. Solar energy technologies combined with high efficiency heat pumps used in the above-mentioned three scenarios are presented in Table 3.

Table 3: Solar energy technologies combined with high efficiency heat pumps which could be used for providing energy in hotels in Mediterranean region

Scenario	Generation of electricity	Generation of heat	Generation of cooling
1.	Solar-PV	a)Solar thermal system for hot water production and for fuelling the solar thermal cooling system b)High efficiency heat pump for space heating	a)Solar thermal cooling b)High efficiency heat pump for space cooling
2.	a)Hybrid solar PV/T b)Solar-PV	a)Hybrid solar PV/T for hot water production and for fuelling the solar thermal cooling system b)High efficiency heat pump for space heating 40%	a)Solar thermal cooling b)High efficiency heat pump for space cooling
3.	Solar-PV	a)Solar thermal system for hot water production b)High efficiency heat pump for space heating	a)High efficiency heat pump for space cooling

5. Discussion

Combined use of various solar energy systems could cover all the energy requirements, including electricity, heat and cooling, in hotels in the Mediterranean region. The necessary solar energy technologies are either mature and reliable or they are promising but they require further development in order to be commercialized. Although solar thermal and solar-PV energy are broadly used in buildings their combined use in a compact unit will decrease the space required in separate solar energy systems. Additionally the compact unit will result in the decrease of the temperature in the photovoltaic module increasing its yield. Energy efficiency of hybrid solar PV/T systems varies on the local environmental conditions and the solar irradiance while big differences have been detected between experimental and real systems. It is increased when concentrated systems are used while it is higher if water instead of air is used for cooling the solar-PV modulus. Use of solar energy for covering all the energy needs in hotels results in the creation of net zero energy hotels due to operating energy use. At the same time carbon emissions due to energy use in them is decreased or zeroed contributing in the mitigation of climate change. The main solar thermal cooling systems used are closed-cycle absorption and adsorption systems and open-cycle systems using a desiccant. Energy efficiency of solar thermal cooling systems is affected by the temperature of the hot water while multi-stage systems have higher efficiencies than single-stage systems.

Table 4: Advantages and drawbacks of various solar energy systems which could cover all the energy needs in summer-operating hotels in the Mediterranean region.

Solar energy system	Advantages	Drawbacks
1.Solar-PV	1.a) Technology is mature and reliable 1.b) The recent years the sharp drop in their prices allowed the broad use of this technology in many applications including in hotels	1.a) Net-metering regulations are required to allow the use of solar-PVs in grid connected hotels 1.b) Free spaces for the installations of solar modulus are not always available in the hotels
2. Solar thermal heating	2.a) Mature and reliable technology which is used for many years for hot water production 2.b) It is broadly used in hotels more than any other solar energy technology	2.a) Free spaces for the installation of solar collector panels are not always available in the hotels 2.b) Sometimes it requires the use of an auxiliary heat source in order to ensure the availability of hot water in unfavorable climate conditions
3.Solar thermal cooling	3.a) Most applications are needed in pilot and demonstration stage 3.b) It is more attractive when used in large systems	3.a) If hot water produced by flat plate collectors at 70^{o}C is used the COP would be low 3.b) It needs financial support/subsidies in order to be profitable 3.c) It requires large spaces for the installation of solar collectors which might be not available in the hotel
4. Hybrid solar PV/T	4.a) It is a promising technology. Further pilot and demonstration installations are needed	4.a) The technology needs further development in order to prove its technical and economic viability

Three different scenarios regarding the combined use of solar energy technologies for covering the energy needs of hotels in the Mediterranean region have been presented. Solar energy technologies used in the third scenario are mature, reliable and already commercialized. Use of solar-PV technology in hotels is allowed with the net-metering regulations. In many countries virtual net-metering is allowed and the off-site installation of the solar-PV modulus has various advantages. Solar thermal cooling systems are already used; both positive and negative experience has been gained during their operation. In the case though of hybrid solar PV/T systems, experience from their operation in real systems is rather limited. Advantages and drawbacks of the above-mentioned solar energy systems are presented in Table 4.

6. Conclusions

It has been indicated that combined use of various solar energy technologies could generate all the energy needed in hotels in the Mediterranean region. Among them solar-PV systems for electricity generation and solar thermal systems with flat plate collectors for domestic hot water production are mature and cost-effective technologies which are already used. Solar thermal cooling has limited applications so far; further improvements and probably financial subsidies are required for its wide promotion. Finally, hybrid solar PV/T systems can co-generate heat and power but the technology requires further development prior to its commercialization. The lack of experience in real hybrid solar PV/T systems necessitates the implementation of various demonstration installations in order to better assess their technical and economic performance. Further work should be oriented towards a detailed economic analysis of different combinations of solar energy technologies suitable for hotel applications in the Mediterranean region in order to assess their economic viability. Additionally, realization of a net zero energy hotel using the commercial solar energy technologies involved in scenario three (a solar-PV system for generating all the electricity requirements for lighting, operation of electric devices and powering a high efficiency heat pump in space heating and cooling, with domestic hot water produced via a solar thermal system) would help to verify the possibility of using combined solar energy technologies for covering all the energy needs in hotels in the Mediterranean region for zeroing their carbon footprint.

References

[1] Granthman Institute, Imperial College London, Briefing paper 22, Solar-thermal and hybrid Photovoltaic-thermal systems for renewable heating, (2017). Retrieved from https://www.imperial.ac.uk/media/imperial-college/grantham-institute/public/publications/briefing-papers/2679_Briefing-P-22-Solar-heat_web.pdf at 17/12/2018

[2] T.T. Chow, G.N. Tiwari, C. Menezo. “Hybrid solar: A review on Photovoltaic and Thermal Power Integration”, International Journal of Photoenergy, Article ID 307287 (2012) 17 pages. doi:10.1155/2012/307287

[3] M. Noro, R. Lazzarin, G. Bagarella. “Advancements in hybrid photovoltaic-thermal systems: performance evaluations and applications”, Energy Procedia, vol. 101, pp. 496-503, 2016. doi: 10.1016/j.egypro.2016.11.063

[4] C. Good, J. Chen, Y. Dai, A.G. Hestnes. "Hybrid photovoltaic systems in buildings - a review", Energy Procedia, vol. 70, pp. 683-690, 2015 . doi: 10.1016/j.egypro.2015.02.176

[5] S.A. Kalogirou, Y. Tripanagnostopoulos. "Hybrid PV/T solar systems for domestic hot water and electricity production", Energy Conversion and Management, vol. 47, pp. 3368-3382, 2006. doi:10.1016/j.enconman.2006.01.012

[6] C. Good, I. Andersen, A.G. Hestnes. "Solar energy for zero energy buildings – A comparison between solar, PV and photovoltaic-thermal (PV/T) systems", in proc. CISBAT, 9-11 September 2015, pp. 561-566.

[7] A. Ramos, M.A. Chatzopoulou, I. Guarracino, J. Freeman, Ch.N. Markidis. "Hybrid photovoltaic-thermal solar systems for combined heating, cooling and power provision in the Urban environment", Energy Conversion and Management, vol. 150 pp. 838-850, 2017. http://dx.doi.org/10.1016/j.enconman.2017.03.024

[8] M. Herrando, Ch.N. Markidis. "Hybrid PV and solar-thermal systems for domestic heat and power provision in the UK: Techno-economic considerations", Applied Energy, vol. 161, pp. 512-532, 2016. http://dx.doi.org/10.1016/j.apenergy.2015.09.025

[9] M. Noro, R.M. Lazzarin. "Hybrid Photovoltaic-thermal heat pumps systems: energy and economic performance evaluation in different climates", International Journal of Low Carbon Technologies, vol. 13(1), pp. 76-83, 2017. https://doi.org/10.1093/ijlct/ctx022

[10] S. Tselepis, Y. Tripanagnostopoulos. "Economic analysis of hybrid photovoltaic/thermal solar systems and comparison with standard PV modules", in Proc. of International Conference PV in Europe, 7-11 October 2002, Rome, Italy, pp. 856-859

[11] A.M. Buonomano, F. Calise, M. Vicidomini. " Design, Simulation and Experimental Investigation of a solar system based on PV panels and PVT collectors", Energies, vol. 9, pp. 497, 2016. doi:10.3390/en9070497

[12] M.R. Karim, A.A. Bhyiyan, R.I. Zaman, M.A.R. Akhanda. "Improvement of hybrid Photovoltaic thermal solar energy systems", presented at World Renewable Energy Congress, Abu Dhabi, UAE, 25-30/9/2010.

[13] L. Zhang, Z. Chen. "Design and Research of a Movable Hybrid Photovoltaic Thermal System", Energies, vol. 10, pp. 507, 2017. doi:10.3390/en10040507

[14] E. Cuce, E.K. Oztekin, P.M. Cuce. "Hybrid photovoltaic thermal systems: From theory to applications", Energy Research Journal, vol. 9(1) , pp. 1-71, 2018 . DOI: 10.3844/erjsp.2018.1-71

[15] M. Herrando, Ch.N. Markides, K. Hellgardt. "A UK-based assessment of hybrid PV and solar-thermal systems for domestic heating and power: system performance", Applied Energy, vol. 122, pp. 288-309, 2014. http://dx.doi.org/10.1016/j.apenergy.2014.01.061

[16] P. Rawat, T.S. Dhiran. "Comparative analysis of solar photovoltaic thermal (PVT) water and solar

photovoltaic thermal (PVT) air systems", International Journal of Civil, Mechanical and Energy Science, vol. 3(1), pp. 8-12, 2017.

[17] A.A. Alzaabi, N.K. Badawiyeh, H.O. Hantoush, A.K. Hamid. "Electric/thermal performance of hybrid PV/T system in Sharjah, UAE", International Journal of Smart Grid and Clean Energy, vol. 3(4), pp. 385-389, 2014. doi: 10.12720/sgce.3.4.385-389

[18] F. Calise, M. Dentice D' Accadia, L. Vanoli. "Design and dynamic simulation of a novel solar tri-generation system on hybrid PV/T collectors", Energy Conversion and Management, vol. 60, pp. 214-225, 2012.

[19] International Energy Agency, (2015). Quality assurance and support measures for solar cooling, task 48, Retrieved from http://www.iea-shc.org/data/sites/1/publications/IEA-SHC_Solar-Cooling-Position-Paper_Sep2015.pdf at 13/12/2018

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

[21] J. Vourdoubas. "Energy consumption and use of renewable energy sources in hotels: A case study in Crete, Greece", Journal of Tourism Hospitality and Management, vol. 4(2), pp. 75-87, 2016. DOI: 10.15640/jthm.v4n2a5

[22] A. Buonomano, F. Calise, A. Palombo, M. Vicidomini. "Energy and economic analysis of geothermal-solar tri-generation systems: A case study for a hotel building in Ischia", Applied Energy, vol. 138, pp. 224-241, 2015. https://doi.org/10.1016/j.apenergy.2014.10.076

[23] G. Singh, S.A. Mohod, M.B. Dhawade. "Review paper on application of solar thermal cooling", International Journal of Advance Research in Science and Engineering, vol. 4(9), pp. 125-132, 2015 .

[24] A. Moia-Pol, M. Karagiorgas, D. Coll-Mayor, V. Martinez-Moll, C. Riba-Romeva. "Evaluation of the energy consumption in Mediterranean islands hotels: Case study: The Balearic islands hotels", Renewable Energy and Power Quality Journal, vol. 1(3), pp. 105-109, 2005, https://doi.org/10.24084/repqj03.233

[25] A. Moia-Pol, M. Karagiorgas, V. Martinez-Moll, R. Pujol, C. Riba-Romeva. , (2014), Evaluation of the renewable energy application in Mediterranean hotels: Case Study: The Balearic islands hotels retrieved from https://www.researchgate.net/publication/239582784 at 5/10/2018

[26] International Institute of Refrigeration, 2017. Solar Cooling, 34th Informatory note on refrigeration technologies, , retrieved from http://www.iifiir.org/userfiles/file/publications/notes/NoteTech_34_EN.pdf , at 17/12/2018