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Editorial

Integrated Solar Thermal Systems

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1. Introduction

The renewable energy technologies attracted 70% global energy investment in 2021, but the global CO_2 emission is increased by 1.5 billion tons in the same year [1]. However, these positive trends are not sufficient to limit the increase of carbon dioxide emissions due to the rapid economic slowdown due to the COVID 19 pandemic. According to the 2030 climate and energy framework of the European Union (EU), emissions should be cut with a binding target at least by 40% before 2030 in comparison to its 1990's level [2]. One aspect is to increase the share of renewable energy production at least by 32%, and the other one is to improve energy efficiency at least by 32.5% [3]. Such goals can be achieved using a plurality of renewable energy technologies, mainly including the solar ones. In particular, solar technologies (such as solar thermal collectors [4], photovoltaic (PV) panels [5] or photovoltaic/thermal (PVT) collectors [6]) can be easily integrated in many sectors. Such technologies seem very attractive to avoid or reduce the use of natural gas boilers and power from the grid [7]. For example, it is possible to install a PV field to produce electricity or a solar thermal collector field to supply thermal energy for the building space heating and domestic hot water demands [8]. Many applications are deeply investigated in the available literature and commercialized in several energy sectors. For example, a photovoltaic field may be integrated with heat pumps for meeting building space heating/cooling and domestic hot water [9]. In fact, the energy savings related to this approach have been proved in several investigations that focus on the attainment on 'net zero energy building' target through the use of PV systems coupled to heat pumps [10,11]. In the private single buildings and building districts, solar thermal collectors can also be integrated to match the thermal energy demand of the users as well as the cooling energy demand by absorption and adsorption chillers. In the power sector, solar thermal collectors producing high temperature heat can be included in solar power plants for electric energy production. In the agricultural sector, solar thermal energy can be used to dry agricultural materials reducing the energy consumption and improving the product quality [12]. Moreover, photovoltaic technology may be integrated with electric vehicles, providing renewable electricity for charging purpose [13]. In the framework of the transport sector, PV may be also exploited for producing renewable biofuels (for example, driving biomethane upgrading plants) [14].

The present editorial aims at presenting the novelties introduced by the papers included in the special issue "Integrated Solar Thermal Systems" of the Energies journal in the above-mentioned research fields. In order to better show the findings of these papers and the related advancements in knowledge, the main findings of each paper are summarized here. In particular, Section 2 shows a detailed analysis of the papers presented in the "Integrated Solar Thermal Systems" Special Issue, regarding the topics related to the energy saving, emission reduction, solar heating and cooling systems, and solar thermal power generation plants. The reported analysis clearly shows that the present special issue presents important points of advancement with respect to the findings available in literature. The presented papers include different alternatives for the production of solar thermal energy and related conversion in useful outputs for different applications. The contributions summarized in this editorial are useful for researchers and engineers working in the field of solar thermal energy systems by means recent and advanced low-carbon and sustainable technologies.

2. Research Papers Represented in This Special Issue

A total of five papers were selected for this special issue. The main ideas of these papers are briefly reviewed in the following sections in order to summarize the main outcomes of the presented works.

2.1. Assessing the Energy-Saving Potential of a Dish-Stirling Con-Centrator Integrated into Energy Plants in the Tertiary Sector

Guarino et al. [15] evaluated the environmental and energy benefits combining a dish-Stirling concentrator with energy systems utilized for meeting the air conditioning energy demand of a suitable case study of the tertiary sector. In particular, an office building located in Palermo (Southern Italy) is assumed as a case study. Two conventional reference energy systems were considered: (i) a reversible heat pump for both heating and cooling energy purposed; and (ii) a natural gas boiler for heating energy purposes and air-cooled chillers in the cooling months. The heat pump and the air-cooled chillers use R410A as a refrigerant. For both energy systems, a dish-Stirling concentrator is taken into account to work first in an electric-mode and then in a cogenerative-mode (wherein the heat recovered from the Stirling engine is used to meet the heating demand).

The analysis proposes the integration of the detailed modelling of the dish-Stirling concentrator with the ones of the heat pump and chiller. Such an approach allows one to better understand plant behavior, along with providing a more reliable assessment of avoided CO_2 emissions and energy-saving potential. The proposed systems and all of the included components are modelled in detail in the TRNSYS environment. The model of the dish-Stirling systems was also validated by experimental data obtained during the monitoring of the facility test site in Palermo. The numerical model of the dish-Stirling concentrator is developed according to the scheme of the energy balance reported in Figure 1. Simulations of full-load and part-load operation of chillers and heat pumps were carried out using plant simulator IMST-ART v.3.80, a tool performing a detailed thermohydraulic modelling of heat exchangers, refrigerant lines, and accessories.

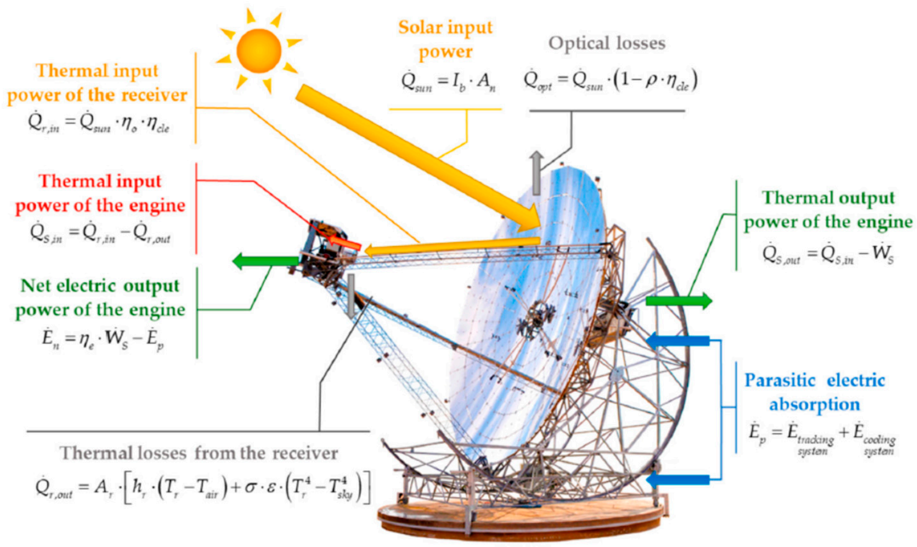

Figure 1. Scheme of the energy balance of the dish-Stirling concentrator [15].

In Figure 2, the following profiles are shown: (i) the yearly cooling demand (a); (ii) the thermal demand which accounts for space-heating and domestic hot water (DHW) (b); and (iii) the electricity demand related to the lighting system and office appliances (c). Such profiles were available from energy audits performed in the framework of previous research [16].

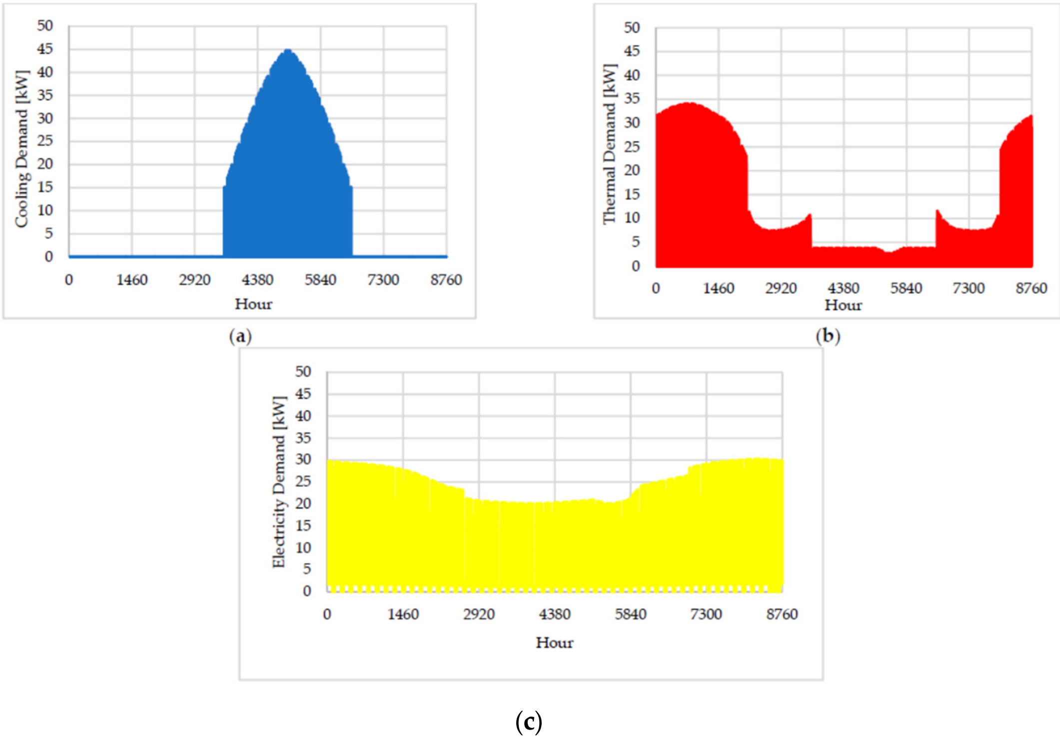

Figure 2. Hourly profiles of the case study: (**a**) cooling, (**b**) thermal, and (**c**) electricity demands [15].

To assess the economic feasibility of the analyzed scenarios, the Net Present Value (NPV) and the Discounted Payback Time (DPBT) of the investment were assumed as economic and risk indicators. The results show that in the first plant, the decrease in natural gas consumption is about 85%. In the second plant, 66.7% is the increase in avoided electricity purchase. When the concentrator is operating in electric mode, the electricity purchased from the grid decreases by about 72% for the first plant, and 65% for the second plant. Similar results are obtained for CO_2 emissions. Even better performance may be achieved in the case of the cogenerative-mode, wherein the heat recovered from the Stirling engine is used to meet the heating demand. The integration of the dish-Stirling system determines promising energy-saving results and a significant reduction in CO_2 emissions. The economic analysis of the proposed systems showed that the installation of a dish-Stirling system integrated into a building is economically viable only when financial supports are taken into account. Therefore, there is a clear need to develop appropriate incentive systems to promote the deployment of such systems. Then, technological improvements and economies of scale will promote the reduction in total installed cost until it is competitive with that of other currently fully commercialized concentrating solar power technologies.

2.2. Operation and Performance Assessment of a Hybrid Solar Heating and Cooling System for Different Configurations and Climatic Conditions

Figaj and Żołądek [17] performed dynamic simulations of a solar heating and cooling system, coupling an absorption or adsorption chiller, a reversible heat pump and a solar dish concentrator (see Figure 3) with thermal collectors. The system is used to match the energy needs of a suitable case study, adopted to investigate the system energy and economic performance of a building consisted of a one floor single family household with an attic and a sloped roof.

Figure 3. Parabolic dish concentrator [17].

The information about building envelope components and the assumptions for the calculation of the building energy demand are reported in the paper. In particular, the thermal energy produced by thermal collectors is used for heating purposes in winter months and for cooling purposes in summer months and for the production of domestic hot water all year long.

The model, developed in the TRNSYS environment, includes a detailed assessment of the energy and economic performance of the plant, taking into account different localities and plant layouts (absorption or adsorption chiller, auxiliary thermal energy to drive the sorption chillers, etc.). The aim of this study is to increase the knowledge about micro-scale solar heating and cooling systems based on sorption chillers and on heat pumps.

The work presents a dynamic simulation model of the above mentioned system, which is used to predict system performance for other weather conditions. The whole model is based on user-defined models previously validated against experimental and/or technical data and built-in software components. In particular, the model of the concentrating solar collector was based on a validated model of the parabolic dish solar concentrator previously developed by the authors. Note that the present layout is based on a solar cooling system integrating such concentrator investigated in a previous paper by the authors [18].

The results show that for Naples (Southern Italy) the space cooling energy demand is provided by solar thermal energy in a range between 46.1 to 99.1%, depending on the adopted sorption chiller and or the use of auxiliary heat for a natural gas boiler. For the weather conditions of Cracow (Southern Poland) the space cooling demand is matched by solar energy from 49.0 to 97.6%. However, the simple pay back period of about 20 years in case of Cracow suggests that the proposed system is not profitable. A viable location for the solar cooling and heating systems is the city of Naples, considering that the simple pay back period obtained by the dynamic simulations ranges from 8 to 12 years. The weekly variation of solar collectors efficiency is significant, ranging between 0.159 and 0.705. Conversely, apart from few weeks in the mid-season period, the efficiency of the concentrator is stable, varying from 0.738 to 0.817. The variation of the Coefficient of Performance of the adsorption chiller is pretty small (0.514–0.619). The variation of the Primary Energy Saving ratio for all of the system configurations in Cracow is from 0.261 and 0.297, showing that the effect of the type of chiller and the adoption of an auxiliary device is scarce. On the other hand, for Naples, the same ratio varies between 0.480 and 0.664, and the effect of the operation on the energy-saving is higher.

2.3. Heat Generated Using Luminescent Solar Concentrators for Building Energy Applications

Daigle and O'Brien [19] measured the thermal energy output from luminescent solar concentrators under practical conditions for building applications. These conditions include normal temperatures and pressures and an absorber at the luminescent solar concentrators edges that is comparable to the size of a typical window frame. This experiment aims at showing how luminescent solar concentrators can be considered a promising technology for integration and renewable energy generation in buildings. These devices are suitable for the building integration considering their several features. Luminescent solar concentrators are lightweight, inexpensive, aesthetically versatile, and can concentrate both diffuse and direct radiation. The authors point out that luminescent solar concentrators were extensively investigated for purposes of power generation based on photovoltaic effect but a lack of knowledge in literature regards the investigation about the use of thermal energy generated at the edges of luminescent solar concentrators. For this aim, in this paper, Newton's law of cooling is implemented in order to measure the thermal flow rate obtained at the edge of luminescent solar concentrators modules using solar-simulated radiation.

To measure the thermal energy generated, the luminescent solar concentrators modules were placed under two 1000-W Sunmaster FullNova MH light bulbs (41983 SM. 1000 W.FullNova). The frames of the modules were supported at their corners above a table to prevent conductive heat losses from their underside. The temperature of the frame was measured using K-type thermocouples. A 1 mm thin aluminum reflective shield was placed 5 cm above the absorbing frame to prevent it from receiving light directly from the lamps. The modules were left under the lamps for approximately 2 h, allowing them to reach steady state. Subsequently, the lamps were turned off and the modules were left to cool to room temperature. The temperatures were measured and recorded every 5 s over the duration of the experiments. Results show that the dye in single-panel luminescent solar concentrators modules can generate 17.9 W/m^2 under solar-simulated radiation with an intensity of 23.95 mW/cm^2 over the spectral region from 360 to 1000 nm. Assuming a mean daily insolation of 5 kWh/m^2, the dye in the single-panel modules can generate 100 kWh/m^2 annually. If the surface area of a building is comparable to its floor space, thermal energy generated from on the buildings surface could be used to substantially reduce the buildings energy consumption.

2.4. The Role of Innovation in Industry Product Deployment: Developing Thermal Energy Storage for Concentrated Solar Power

Prieto et al. [20] presented a study which highlights the contribution of innovation in industry product deployment in the sector of the concentrated solar power plants. Due to the development and growth during the last years of this sector, the cost of electricity produced through concentrated solar power plants significantly decreased (from 0.35 USD/kWh in 2010 to 0.07 USD/kWh in 2020). This decrease was mainly achievable for the innovation projects developed through a complex network of research and development (R&D) collaborations and intense investments (both public and private). In order to highlight the importance of the innovation in this sector, the paper also presents a case study which shows that innovation in a company is the key point to achieve successful commercialization of new technologies. The presented case study regards the development of a thermal energy storage (TES) for a conversion solar plant at Abengoa. The first stage is based on the creation of the R&D network in 2007, where the biggest challenges were the confidentiality needed between the company (Spanish CENIT project ConSOLida 2008–1005), and the R&D institutions. The second stage was the testing at pilot plant at the University of Lleida, where a 0.3 MW pilot plant was built to test the proprieties of the molten salts and container materials. The third stage was tested at demo plant scale at Abengoa, where an 8.4 MW was built to test real components of the future commercial plants and to study the scaling up of the technology. Parabolic trough collectors that use thermal oil as heat transfer fluid are considered in order to transfer the heat to molten salts by a heat exchanger.

The next step was the development of a thermal energy storage system concept for direct steam generation based on solid particle and phase change materials (PCM) solutions. The demo plant led to the commercialization of the technology with the commissioning of the plant in the USA. This strategy was fully supported by public funds, although the developments would not have been possible without a significant funding by the company. This cost is not always feasible for private companies, limiting the technological advances necessary for society. The authors concluded that strong public financing policies are necessary to promote the development of new strategic technological products.

2.5. Evaluation of Energy Efficiency and the Reduction of Atmospheric Emissions by Generating Electricity from a Solar Thermal Power Generation Plant

Ampuño et al. [21] presented the modeling of a solar thermal energy generation plant consisted a field of solar collectors, a storage tank, and an energy conversion system. In particular, the solar collector field is based on the parabolic trough collectors technology, storage tank, steam generation, steam turbine, and electrical generator. The thermal energy accumulated in the storage tank is used by a steam generator which produces a steam pressure driving a turbine. The layout of the investigated system is displayed in Figure 4. The total mirror area of the solar field is 2635 m^2, whereas the power capacity of the turbine is equal to 0.5 MW.

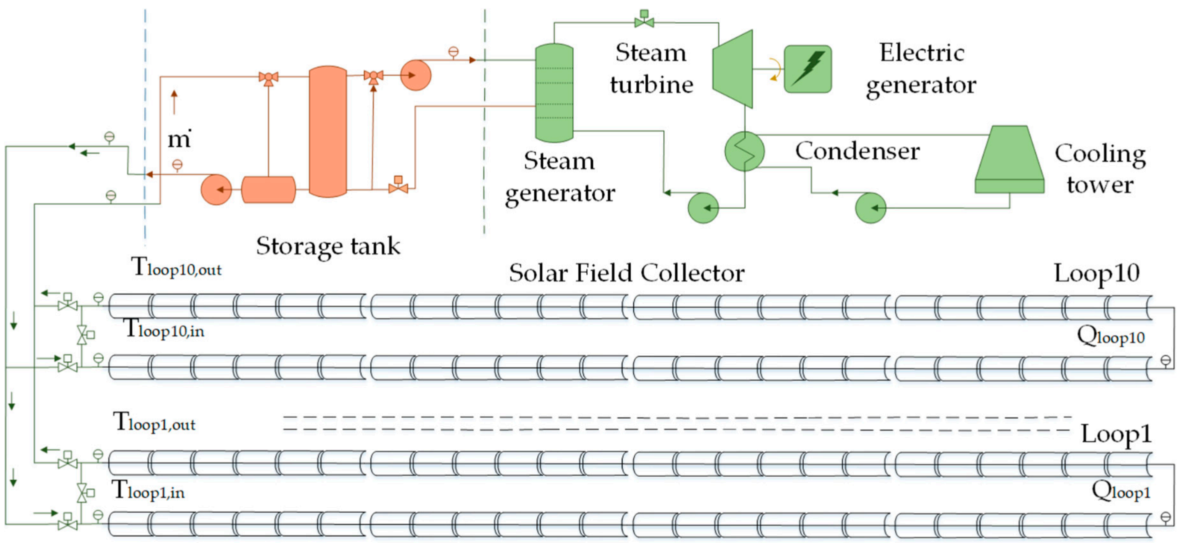

Figure 4. Proposed plant [21].

Different weather conditions of two coastal cities and one island of Ecuador are considered, namely San Cristóbal, Manta, and Guayaquil. Authors state that the main contribution of this study with respect to the previous works is a model considering both outlet temperature and oil flow at the same time to simulate and evaluate the produced power by the conversion power system. The simulation was carried out by the TRNSYS software and MATLAB software was adopted in order to validate the model of the solar field and power conversion system. In the TRNSYS environment, different options of solar collectors, energy demands for space heating, and domestic hot water for family dwellings are considered. The time history of the efficiency of the plant, defined as the electric power rate obtained by the electric generator divided the incident beam radiation for the three selected cities ranges from 31.1% to 41.1%. The highest total avoided emissions, equal to 544 t/year, are obtained in Cristóbal, and the lowest ones are equal to 81 t/year in Guayaquil. In addition, considering that the highest solar thermal energy production and electric energy are obtained in Cristóbal, equal to 3664 MWh/year and 1090.7 MWh/year, respectively. The implementation of thermos-solar allows for the reduction in the consumption of fossil fuels and CO_2 emissions.

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