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Solar cooling system using concentrating collectors for office buildings: A case study for Greece

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ABSTRACT

On a European level there is intense research activity to broaden the applications of solar thermal systems beyond their established domains (hot water, space heating support) and to foster their participation in the energy maps of the EU-Member States. Concentrated Solar Thermal (CST) systems are expected to play a key role in this effort, especially for achieving the medium and high temperatures needed, for electricity generation, for industrial applications but also for hybridized solar heating/cooling and desalination applications.

This paper presents a proposal for implementation of a CST system in the building sector, based on a research carried out in the Laboratory of Environmental and Energy Efficient Design of Buildings and Settlements at the University of Thrace. Specifically, an integrated solar cooling system using parabolic trough solar collectors and double-effect chiller is discussed, used to cover the cooling needs of typical office building in Greece.

As it was shown, the use of concentrating solar collectors leads to significantly higher output temperatures that can enable the use of two stage absorption chillers with a higher COP. Alternatively, when low or medium temperature heat is required, the use of CST systems takes less space to cope with it than traditional flat plate collectors. The combination of these parameters can contribute to removing key barriers associated with the broader diffusion of solar cooling technology, enhancing the potential to become more competitive to the conventional air conditioning technologies.

1. Introduction

The use of Renewable Energy Sources (RES) is an important tool for EU member countries in order to meet their targets in terms of energy security, reduce greenhouse gas emissions and energy costs as well as sustainable development in general.

As it is well known, Greece has a favourable climate and topography for using RES. A series of studies attempted to explore the overall energy market perspectives and the present status-quo of RES in Greece [1–5]. The majority of them identified that wind power generation play the key role for the RES electricity production in Greece, following by photovoltaics – that have exceeded already the national objectives set for 2020 [6].

Compared with other European countries, Greece has a high solar radiation with high sunshine duration and therefore has a strong advantage for efficient solar applications. Especially in the field of solar thermal energy, Greece is recognized as one of the leading countries worldwide in the use of solar systems for hot water (low temperatures, <100° C), presenting one of the highest solar collector area installed per capita rates [7,8]. The main solar thermal product was and still is the thermosiphon water heater, comprising of flat plate collector (s) and storage tank.

Furthermore, the building sector is the most energy intensive sector of the Greek economy by consuming more than 66% of the produced final electricity [9–11]. It is therefore logical that every effort to reinforce the use of solar thermal systems in buildings is of particular interest.

CST systems are not new: Their first introduction is recorded in the 19th century, when the first solar cookers and water distillers

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Nomenclature

η	Collector thermal efficiency, with reference to T^*_i (−)
η_0	Eta zero (η at $T^*_i = 0$), reference to T^*_i(−)
T_{in}	Collector inlet temperature (°C)
T_{out}	Collector outlet temperature (°C)
T_{amb}	ambient or surrounding air temperature (°C)
TMY	typical meteorological year (−)
COP	coefficient of performance (−)
CST	concentrated solar thermal
CSP	concentrating solar power
EER	energy efficiency ratio
HVAC	heating ventilation air conditioning

were presented, followed by a plant in Egypt in 1913 for irrigation purposes and two other plants in Italy in 1964 and in 1965. The Solar Electric Generating Systems (SEGS) in California was the first CSP plant to enter industry in 1980 and operates until now. Spain is the pioneer in CST introduction in Mediterranean region, with other countries such as Egypt, Morocco, Algeria, Israel, Portugal, Italy, Greece, Malta and Cyprus showing great interest in the specific technology too [12].

Having as main targets the attainment of sustainable, cheap and compatible with environment electricity supply based on available secure resources, a series of studies analyzed the scenario of interconnecting the EUMENA (Europe, Middle East and North Africa) region, the MED-CSP and the TRANS-CSP being the most prominent ones [13,14]. As the studies concluded, those targets can be met, based both on covering the local demand and on exporting solar electricity from MENA to Europe, given the development of the necessary transmission infrastructure. The DESERTEC project's loss of momentum, does not alter the fundamental perspectives of solar technologies for the MENA and Mediterranean region, especially since there are further benefits that make CST system attractive for this region: Water consumption both in MENA and in South Europe is rising, a fact which combined with the given water scarcity can render such regions highly dependent on desalination for meeting domestic and industrial purposes. The combination of desalination plants with desalination plants can be highly beneficial. A recent techno-economic analysis made for Almeria, Spain, and Abu Dhabi, United Arab Emirates, indicated that a low-temperature Multi-Effect Distillation system can be ideally coupled to a CST plant [15].

Development is no less interesting in the United States, where the Department of Energy launched the Sun Shot initiative in 2011, in order to make solar energy fully cost competitive by 2020. This initiative places great emphasis on CST technologies and by the end of 2015, there were more than 1.8 GW of CST plants expected to be operational in 7 states, with another 4.5 GW being licensed within the frame of Power Purchase Agreement contracts [16].

On the other hand, there have been less successful examples: in India 200 MW of CST plants were foreseen to be constructed by 2015 and another 470 by 2020. However, no progress was made and CST has certainly not taken off yet, despite the favourable climate and demand conditions. A combination of regulatory and technical barriers has been recognized as responsible for the slow progress [17].

CST systems use different mirror/reflector configurations to gather the direct beam of solar radiation reaching middle (100–400° C) and high (>400° C) levels of temperatures, to produce heat, electricity or fuel. CST technology use only direct sunlight (DNI, Direct Normal Irradiance), i.e. the fraction of solar radiation that is not reflected by clouds, fumes and dust in the atmosphere and reaches the Earth's surface as a parallel beam. Four configurations for CST technologies are currently used on a commercial level, with less or broader market penetration: The parabolic trough, the linear Fresnel, the disk/engine and the central receiversas depicted in Fig. 1 [18]. Currently the predominant technology with the higher market share in worldwide level is the parabolic trough.

Parabolic trough systems are linear concentration systems, focusing direct sunlight onto a receiver pipe along their axis. A parabolic trough system consists of long parallel rows of curved reflectors that focus sunlight onto a receiver pipe. A fluid with high heat storage and transfer properties is circulated through the pipes and collects the solar heat. The collector is provided with a single-axis solar tracking system (single − tracking) to ensure that the solar beam runs parallel to its axis. The technology of parabolic trough systems can be used either for electricity generation (solar concentrator power stations) or for industrial applications including solar air-conditioning [19–22]. The type of the parabolic solar collector is selected depending on the application, and hence the temperatures required.

For power plants installations, typical aperture width of the parabolic collector is about 6 m, typical length is about 100–150 m, with a geometric concentration ratio between 20 and 30 and temperature range between 300 and 400 °C.Thegenerated heat is used to produce steam and the steam drives a conventional steam-Rankine turbine generator. Indirect molten-salt storage can be added to increase dispatchability and operation hours.

Industrial applications of the parabolic collectors require temperatures between 100 and 250 °C.These cases mainly concern either industrial thermal processes, either low temperature heat demand with high consumption rates (hot water, domestic hot water, space heating and pool heating) as well as solar air conditioning and refrigeration. Typical aperture width is between 1 and 3 m, the total length is between 2 and 10 m, with geometric concentration ratio between 15 and 20 [23,24].

Regarding CST systems installations in Greece, currently there is no facility in operation. Two projects, "Minos" and "Maximus", coordinated by Greek partners, were selected for funding in the first round of the NER300 funding program of the European Union [25].

Solar cooling is a growing technology, with great potential especially for the Mediterranean countries, similarly with other types of applications of solar thermal energy such as hot water preparation, heating swimming pools and assisted space heating [26]. The use of solar thermal energy in Greece for driving air conditioning systems is very promising, since the cooling load is generally coincident with the availability of solar energy and thus the cooling requirements of a building coincide with high solar radiation [27–30].

Solar cooling systems have the advantage of using absolutely harmless working fluids in cooling machines such as water or salt solutions for their operation. They are energy efficient and environmentally friendly. They can be used either as stand-alone systems or in combination with conventional cooling systems, to meet the cooling requirements of all types of buildings, contributing to a reduction of conventional energy consumption and CO_2 emissions.

In this respect, solar cooling contributes to prevent overheating during the summer and also helps to reduce electrical peak loads, usually recorded during the summer midday. Solar cooling technology is based on the use of thermal energy generated by solar radiation, in order to feed/drive a cooling device, namely solar thermal chiller. Solar cooling systems used so far can be classified into "*closed systems*" which have solar chillers providing cold water