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Review on solar cooker systems: Economic and environmental study for different Lebanese scenarios

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ABSTRACT

In this work, a review on solar cookers is presented. This review includes principle and classification, parameters influencing the performance of a solar cooker, and energy and exergy analysis related to solar cooker systems. Moreover, an economic study is performed for different scenarios in Lebanon (home, hotel, restaurant and snack) and for several categories of solar cookers (solar box cooker, solar panel cooker, parabolic solar cooker and evacuated tube solar cooker with thermal storage). The main idea of the economic study is to estimate the payback period in function of percentage of time Pr where solar cooker is utilized, for each solar cooker and in each scenario. It was obtained that the higher dependence on solar cooker decreases payback period. Besides, environmental analysis is implemented to compute the amount of reduction in carbon dioxide emissions in the different scenarios as percentage of time where solar cooker is used varies. It was shown that the reduction in amount of carbon dioxide raised from 6.05 to 60.55 kg/month, 605.52 to 6055.2 kg/month, 399.64 to 3996.43 kg/month and from 90.82 to 908.28 kg/month in home, restaurant, hotel and snack respectively when Pr increased from 0.1 to 1. Hence, utilizing a solar cooker diminishes carbon dioxide emissions in all scenarios where P_r has direct relationship with minimization of carbon dioxide emissions.

1. Introduction

During the last centuries, world energy demand relied to a great extent on fossil fuels. Annually, energy consumption progresses by an average of 1% in developed countries and 5% in developing countries [1,2]. Due to the continuous rise in energy demand, several expectations reveal that fossil fuel will not meet this growing demand and its cost will definitely increase sharply. Thus, the mounting cost of fossil fuel in addition to some environmental issues such as pollution, greenhouse effect, global warming, etc., gave renewable energy [3–8] a remarkable interest at the international level during the last years. Renewable sources of energy are environmentally friendly and they are supplying about 14% of the world energy demand which will ascend in the future [9]. Indeed, solar energy occupies the throne of renewable energies. It is estimated that solar energy falls on the surface of the earth at an average of 120 pet watt. This reveals that solar energy received to the earth in one day is equivalent to energy demand required in 20 years. International Energy Agency showed that in year 2050 solar energy can supply approximately 45% of the world energy request [10].

Solar energy is used in a large diverse of applications that can be divided into two types of systems [11]: systems that rely on converting solar energy into thermal energy to be used for different purposes [12], and systems that transform solar energy directly into electricity by photovoltaic technology [13]. Solar energy can be categorized also according to the type of solar collector [14,15]. The main role of solar collector is to gather solar radiation, transform it into heat and transport it to a working fluid. Fig. 1 illustrates the major categories of solar energy and their types.

Solar cooker [1,16–19] is harnessed for cooking food, pasteurizing and sterilizing. Solar dryers [20–25] are used in agricultural and industrial products for mitigating bacterial growth and preserving them by removing moisture. Solar water heating systems [26–31] heat water for domestic and industrial purposes. The heated water in the storage tank flow through a coil to heat air directed to the coil by a fan and enters to the space and heat it [32–36]. Solar space cooling and refrigeration [37–42] are utilized for refrigerating medicines or food, or cooling space. Concentrated solar power [43–48] uses mirrors and lenses to concentrate solar energy and thus generating heat and power indirectly. Photovoltaic systems [49–54] convert sunlight directly into electricity by the absorption of photons.

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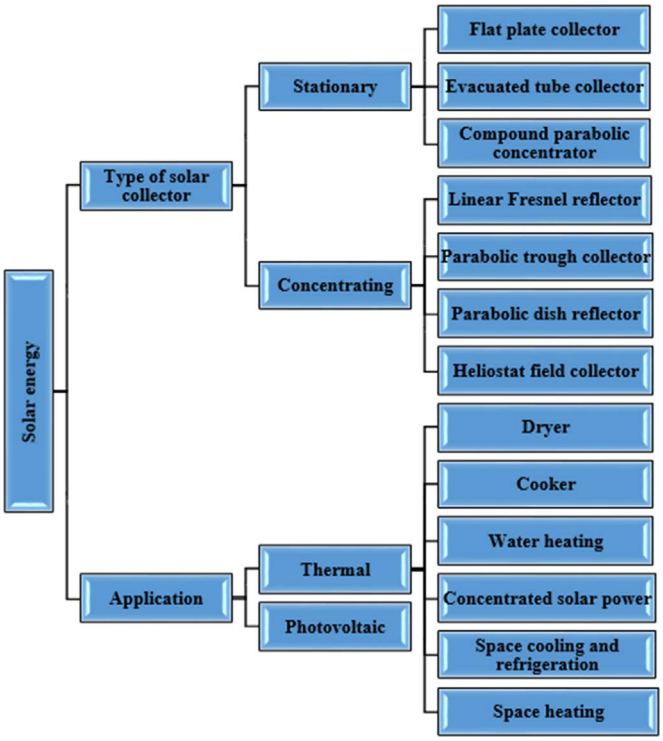

Fig. 1. Classification of solar energy.

Solar cooker is one of the most significant solar energy applications. Energy required for cooking represents about 36% of the global primary energy consumed [55]. Hence, solar cooker has a great potential in the domestic sector.

Fig. 2 shows the number of studies conducted on solar cookers from 1990 to 2016. It is shown that the number of researches on solar cookers is striking of all over the years and especially for the last four years. This explicates the magnitude of solar cookers as a solar energy device and its capability of being vital application in the coming years. In this context, the present work concerns a review on solar cooker technology. It presents particularly the principle, classification, and parameters affecting the performance of a solar cooker. Also, Energy and exergy analyses are exhibited. Moreover, environmental and economic concerns are presented to highlight the requisite role of solar cooker on both fields and for several scenarios in Lebanon country.

Section 2 of the paper presents the principle and classification of solar cooker. Section 3 delineates the effective parameters that impact the solar cooker performance. Section 4 is devoted to energy and exergy analysis. In Section 5, economic and environmental concerns are exposed. Section 6 draws the main conclusions of the work.

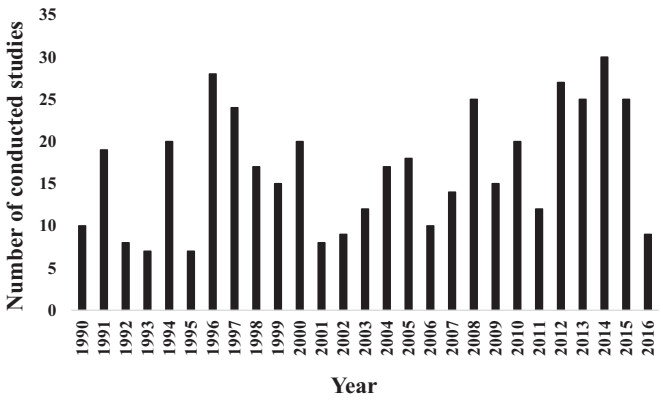

Fig. 2. Number of solar cooker studies over the years.

1.1. Historical note

Cooking food was unknown before the age of civilization, people used to eat food in its condition as they found it [56]. In 1767, Horace de Saussure, a French-Swiss physicist built box to cook fruit using solar energy where it reached temperature to 88 °C. In 1830, an English astronomer named Sir John Herschel tried to cook food in an insulated box cooker during campaign to South Africa. W. Adams progressed oven of octagonal shape made up of 8 mirrors in 1876. He stated that the oven cooked in two hours lots for seven soldiers. In 1945, Sri M. K. Ghosh, an Indian pioneer fabricated the first trade box type solar cooker. Dr. Metcalf and his student Marshall Longvin carried out water pasteurization using solar box cooker in 1979 [16]. In these days, solar cooker became a favorable application in which it provokes utilization of environmentally friendly renewable sources of energy and reduces dependence on conventional power sources. Due to its importance, various numerical, analytical and experimental studies [57–65] have been performed to enhance power capacity of solar cookers, evaluate its performance and identify parameters which help in optimizing it.

2. Principle and classification of solar cookers

Solar cooker is a viable and with great facility application of solar energy. Otte [66] briefly defined solar cooker as it is a way to exploit energy of sun in order to cook. Several studies [19,67–69] described the principle of solar cooker. Hence, solar cooker is an appliance that absorbs solar radiation, transfers it into heat, retains the heat and transmits it to food through cooking pot walls. It can be used for heating or cooking food or drink. Also, it can be utilized to achieve vital processes mainly pasteurization and sterilization.

Many sorts of solar cookers may be found in the literature. Moreover, new solar cookers designed with new improvements are continuously proposed, which requires continuous update of solar cooker classifications. However, it can be confirmed that solar cookers can be categorized into direct and indirect type according to the heat transfer mechanism to the cooking pot [18]. Sedighi and Zakariapour [17] presented a review on direct and indirect solar cookers with experimental, numerical and theoretical analysis to evaluate performance and compare efficiency of solar cookers. Box, panel and concentrated solar cookers are under the direct type. Indirect type is categorized according to the solar collector used, or energy storage. Cooking process in the direct type occurs by using sunlight directly, whereas in the indirect type, heat is transferred to the cooking unit using a heat transfer fluid. Fig. 3 represents a diagram showing the main types of solar cooker. Regattieri et al. [70] implemented an easy-use portable solar cooker by reutilizing cardboard packaging waste. Such device is demonstrated to complete kitchen-set for humanitarian people to solve problem of fuel and wood leakage. The cooker can be utilized for heating, cooking meals, boiling water and purifying raw water from rivers and lakes. Several cooker prototypes were designed, developed and tested by the authors to determine the optimum shape and predict the efficiency of the solar cooker. The results showed that parabolic configuration yields that best results where its efficiency ranges between 14% and 18%.

2.1. Direct solar cooker

2.1.1. Solar box cooker

Box type solar cooker [71–75] consists of an insulated box with single or double transparent window made up of glass or plastic. Solar radiation passes through the transparent window and is absorbed by the cooking utensils, the walls and the bottom of the cooker [76]. The inner part of the box and the cooking pots must be painted in black color to maximize the heating effect [77]. The window provides a greenhouse effect in which it permits the passage of solar radiation but prevents it to get out from the cooking vessel [78]. Thus, heat