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Renewable and sustainable energy saving strategies for greenhouse systems: A comprehensive review

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ABSTRACT

In this study, a comprehensive review focusing on key strategies of energy saving and climate control technologies for greenhouses is presented. Following the brief and concise assessment of existing greenhouse systems in terms of their role in total energy consumption; cost-effective, energy-efficient and environmentally friendly technologies are analyzed in detail for potential utilization in greenhouses for notable reductions in energy consumption and emission levels. The technologies considered within the scope of this research are mainly renewable and sustainable based solutions such as photovoltaic (PV) modules, solar thermal (T) collectors, hybrid PV/T collectors and systems, phase change material (PCM) and underground based heat storage techniques, energy-efficient heat pumps, alternative facade materials for better thermal insulation and power generation (heat insulation solar glass, PV glazing, aerogel and vacuum insulation panel, polycarbonate sandwich panels), innovative ventilation technologies using pre-heating and cooling (high performance windcatchers) and efficient lighting systems. The findings from the research clearly reveal that up to 80% energy saving can be achieved through appropriate retrofit of conventional greenhouses with a payback period of 4–8 years depending on climatic conditions and crop type.

Contents

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1. Introduction

It is unequivocal that life is directly affected by energy and its consumption. Energy saving has become more than significant nowadays [1] due to shortage of energy reserves [2], considerably soaring energy prices [3] and growing significance of environmental problems such as global warming, ozone layer depletion and climate change [4]. Renewable energy technologies are widely considered [5] to reduce total world energy consumption which is still dominated by fossil fuels, and to mitigate greenhouse gas emissions in the atmosphere through clean energy generation. However, recent reports clearly reveal that renewables can supply only about 14% of total energy demand [6]. In this respect, additional decisive measures are required for effective minimization of global energy consumption and urgent stabilization of carbon emissions [7–14].

Energy saving strategies are of vital importance for all types of sector from transportation to buildings [15]. However, it can be easily asserted that the scenario is much more crucial for greenhouse sector as they currently play a significant role in total energy use. The growing need for energy in the greenhouse sector becomes an important issue for securing sustainable harvesting [16,17]. Conventional facade materials utilized in greenhouse constructions currently have poor thermal insulation features, hence 20–40% of the energy loss in a typical greenhouse occurs from the greenhouse envelope [18]. The most common facade materials considered in greenhouses are glass [19,20], polyethylene [21,22], semi-rigid plastic [23], and the plastic film [24,25]. Besides their insufficient thermal resistance values causing notable heating demand in winter, conventional facade materials have very high shading coefficients resulting to remarkable solar heat gains in summer, which also plays an important role cooling demand of greenhouses [26,27]. Growing significance of environmental issues is another challenge of greenhouses as they are responsible for a great percentage of carbon emissions since they are mostly based on fossil fuels. Several developed countries have invoked new standards for mitigating carbon emissions from building sector covering greenhouses. For instance, in 2008 the UK government issued a policy to reduce greenhouse gas emissions (GHGs) by 80% from 1990 until 2050 [28]. Meanwhile, the buildings including greenhouses still contribute to GHGs in the world by 30% and energy consumption by up to 40% of [29]. In this respect, it encourages researchers and scientists to search for alternative sources of energy, environmentally friendly technologies and energy saving solutions.

Besides physical structure of the greenhouses, the type of cultivation and entire aim is also of significance in terms of energy consumption. The purpose of cultivation in greenhouses can be attributed to provide land which is conducive to the vegetables and fruits to grow and develop [30], to protect them from the severe weather conditions [31], pests and disease [32], and to improve the quality of the crop [33]. Moreover, the need for temperature, lighting and humidity vary in each region. Therefore the technology applied in greenhouses in various regions is also different [34]. The countries of the four seasons are usually more in need of a technology that can provide heating for most of the year. For example, the countries of the Mediterranean [35], China [32], Netherlands [36] and some parts of the Middle East [20] are mostly cold and thus it requires more energy for heating. Therefore in such climates, underground based thermal energy storage systems are preferred. The energy is stored usually in water or soil and this heat is then used at night in accordance with the requirement of the greenhouse [37]. Passive solar heating technologies utilized in conventional greenhouse systems differ from each other by storage medium such as water [38], rock [39,40], phase change material [41], thermal curtains [42], soil water collector [22] and mulching [43]. In such systems, the storage method is usually able to maintain the air temperature in 2–4 °C higher than the outside temperature. Overall thermal performances of these systems are promising. Benli et al. [41] investigate the thermal performance of such a latent heat storage system with phase change material for new solar collectors design in greenhouse heating. The system provides about 18–23% of total daily thermal energy demand of the greenhouse for 3–4 h, in comparison with the conventional heating device. In another work, Benli [19] studies the performance characteristics of a ground-source heat pump greenhouse heating system with a horizontal closed-loop ground heat exchanger and the use of PCM for energy saving and management in greenhouses. The overall coefficient of performance (COP) of the said system is obtained to be 2–3.5, which is noticeable. It is also noted that an additional heat source might be necessary in sudden heat drops and frozen. Through this, Esen et al. [23] experimentally investigate the thermal behavior of a greenhouse heating by biogas, solar and ground energy. During the winter period, 2231.83 l of gas production by biogas system is provided to maintain the greenhouse temperature of 23 °C. Bouadila [35] et al. report that the utilization of solar air collectors in greenhouse heating is very common in Mediterranean countries. Such systems become much more cost-effective when integrated with PCM. For a typical case, the payback period is determined to be around 5 years with an annual heat gain potential of 1800 kW h. A similar evaluation is done for Iraq [20], and the results indicate that solar air heaters can cover more than 60% of heating demand of greenhouses. The Government of Canada make an approximate calculation of energy needs and cost required by a 496 m^2 greenhouse with a conversion efficiency of 70% [44]. Assuming typical energy required by a double poly greenhouse