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Passive solar energy utilization: A review of cross-section building parameter selection for Chinese solar greenhouses

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ABSTRACT

Chinese solar greenhouses (CSG) are fully passive solar greenhouses for growing vegetables without auxiliary heating during the winter. The building parameters then have an important effect on the solar energy utilization and the temperatures in the greenhouse. This paper reviews greenhouse building design research and development that is leading to improved solar energy usage with consideration of various design parameters involving the building span, height, south roof shape and angle, wall thickness and composition, and north roof length and angle. Most studies have focused on the influence of the building span and height on the inner thermal environment through experimental and numerical models, the optimum south roof shape that allows the maximum amount of beam radiation into the building and the north wall thickness and configuration that all markedly influenced the solar energy absorption, storage and release. The building parameter selection and the numerical methods used to model Chinese greenhouses introduced in this review will lead to improved designs of future CSG that maximize the solar energy utilization.

Contents

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1. Introduction

1.1. Background

Chinese solar greenhouses (CSG) are used to grow vegetables in the winter without any auxiliary heating, even when the monthly daily average temperatures in the coldest three months of the year fall below −10 °C. Thus, these are fully passive solar greenhouses [1]. The first CSG, which was a simple structure with only leafy vegetables produced during the winter, was developed in the southern part of Liaoning Province, China, in 1930s [2,3]. As the materials and the building design parameters gradually improved, vegetables and even fruit could be produced in the CSG without additional heating during the winter, with temperature differences of 21 °C–25 °C between the inside and outside in areas from 32°N to 41°N in China [3,4]. The inside and outside of a typical CSG are shown in the pictures in Fig. 1. The south and north directions in the picture are for the northern hemisphere.

CSG are mostly used in Northern China [5] with CSG built on over 80% of the land area in China [6]. According to the statistical data of the Chinese Ministry of Agriculture, the total CSG area reached 78.34×10^4 hm^2 in 2010 with yearly total areas as shown in Fig. 2 [7]. The CSG area rapidly increased in the early 1990s during the Eighth-five Year Plan (1990–1995) of China which promoted the CSG as a key scientific and technological project of the Ministry of Agriculture that greatly accelerated development of the CSG. This development was followed by a major science and technology project in the Ninth-five Year Plan (1996–2000) by the Ministry of Science and Technology and a key project of the National Natural Science Foundation of China [8,9]. However, this fast increase of the CSG area resulted in problems, such as poorly designed structures, poor quality materials and inadequate supervision [10,11]. Therefore, there is a great need for quality CSG building standards. Local CSG building standards were established in Liaoning, Shandong, Gansu, Xinjiang and in other regions between 2006 and 2010; however, there is still a need for quality systematic building standards for CSG [12]. The need for better CSG has led to many theoretical studies. The first paper was published in 1960 but only two papers were published in 1960s and four in 1970s [6]. The number of papers published each year since 1980s that are related to CSG designs are shown in Fig. 3 based on a web search of http://www.cnki.net. The increase in the number of published papers follows the same trend as the growth in the CSG area.

The Twelfth-five Year Plan (2011–2015) for Chinese Protected Agriculture Development projects that the CSG area will continue to steadily increase with more emphasis put on design theory and methods to improve CSG structures and operational measures.

1.2. CSG building parameters

Generally, CSG are 50 m–100 m long with the structures getting longer as the farm machinery improves. Thus, the end walls have little effect on the inner microclimate, while the designs of the

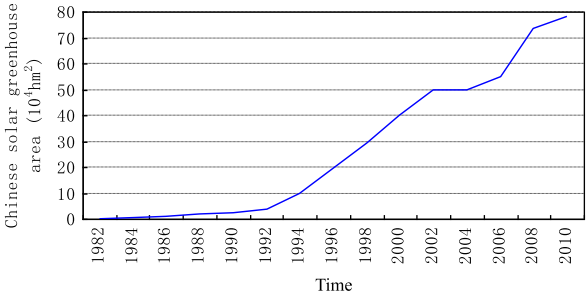

Fig. 2. Yearly total CSG areas.

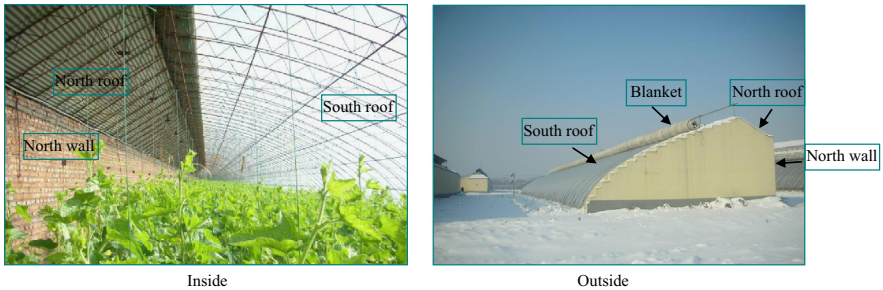

Fig. 1. Pictures of the inside and outside of a CSG.