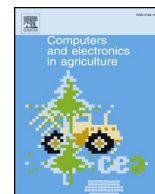




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New insights on span selection for Chinese solar greenhouses using CFD analyses

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ABSTRACT

Chinese solar greenhouses (CSG), with thin plastic films on the south roof for transmitting the sun's rays during the daytime and a heavy cover at night over the south roof with large thermal masses in the wall, north roof and soil to retain heat, can be used to produce vegetables and flowers year round without auxiliary heating during the winter. CSG spans can be increased to increase the production area; however, although the effect of increasing the span on the inside climate has been investigated experimentally, there is still no good guidance on selecting a suitable span configuration for growers. This investigation analyzed three groups of span configurations with spans of 10 m, 12 m and 14 m. The first set of designs had all the other dimensions varied in proportion to the span width. The second set had the same dimensions for the north roof and north wall with the other dimensions varied to fit the longer spans. The third set had the same south roof with a longer north roof to fit the longer span. The analyses were based on a 12 m span CSG simulation model validated in a former study with the thermal environments predicted using computational fluid dynamics (CFD) analyses. The results show that, for the CSG with all the dimensions varied in the same proportion, the inside air temperature is highest with the 14 m span and lowest with the 10 m span. For CSG with the same north roof and north wall dimensions, the air temperature is the highest with the 12 m span and lowest with the 14 m span. For the configurations using the same south roof size, the 10 m span with the taller north wall has similar air temperatures as the 12 m span, with temperatures inside both spans being higher than the other 10 m span with the shorter north wall height. Analyses of the solar heat gains, heat losses and temperature distributions for each group give good guidance for span selections for the growers.

1. Introduction

Greenhouse configurations influence the inside microclimate. Greenhouse design optimization in western countries mainly focuses on the vent configurations (Baeza et al., 2009; Vanthoor et al., 2012). However, Chinese solar greenhouses (CSG) are small and simple compared with the plastic/glass covered greenhouses used in western countries. A thin plastic film covers the south roof of the CSG for transmitting the solar rays during the daytime with a thermal blanket added on top during the night to retain heat. Furthermore, large thermal masses in the north wall, north roof and soil store solar heat during the day and release heat to the inside air at night. Thus, CSG can produce vegetables and flowers with little or no auxiliary heating during the winter. An outside picture and the names of the CSG components are shown in Fig. 1. The span of the CSG specifically refers to the width of the soil surface. Different spans can be found in existing

CSG since there is no established building code for guiding CSG construction (Zhou, 2012). CSG spans were usually from 5.5 m to 7.5 m before 2000 (Kang, 1990; Chen, 1994; Bai et al., 2002), then enlarged to 8–12 m (Tong et al., 2004; Chen, 2008) after high strength materials were introduced and construction methods were improved. To increase the crop production area inside a CSG, the spans were extended to 14 m in Jiangsu Province (Wang et al., 2012), 15 m in Shanxi Province, 18 m in Hebei Province (Wei et al., 2016) and 24 m in Shandong Province.

Increasing the span increases the soil and south roof areas which gives more area to plant crops, but these changes also change the thermal environment inside the greenhouse. Thus, there have been various studies on how the span affecting the interior temperatures with higher temperatures for longer periods of time during the winter giving better crop production. Kang et al. (1993) experimentally investigated the CSG inside temperatures of 6 m and 7 m spans in Anshan, Liaoning Province, with the 6 m span having higher temperatures and then

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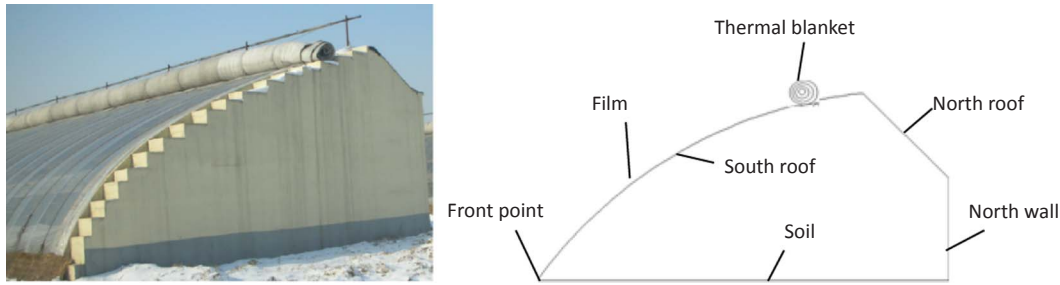


Fig. 1. CSG picture and names of the components.

suggested that smaller spans should be used north of 40 °N. Zou et al. (1997) measured temperatures and heat fluxes for CSG with 6.9 m, 7.3 m, 8 m spans in Shaanxi Province and found that the 6.9 m span had higher average air temperatures and soil temperatures at 0.1 m deep than in the other two spans, so they recommended spans less than 7 m. The spans selected for the study were similar to CSG spans used in that region at that time. Recent studies have investigated the thermal climates in CSG built in Shaanxi Province with 8 m, 10 m and 12 m spans (Liu et al., 2012), 8 m, 9 m and 10 m spans (Liu et al., 2013) and 9 m, 10 m and 11.5 m spans (Jin et al., 2015), with the results showing that 10 m spans had higher temperatures. Others have studied the CSG thermal properties in Inner Mongolia with 8 m, 8.5 m, 9 m, 9.5 m and 10 m spans (Jiang et al., 2013) and in Gansu Province with 7 m, 8 m, 9 m, 10 m and 11 m spans (Tang et al., 2014) on site with both studies showing that the 10 m span should be selected for greenhouse construction because of its good thermal performance. All of these recent experiments were conducted on site but the CSG buildings had different walls (different heights and/or thicknesses) and/or different north roof (length and angle) sizes in each CSG set. Moreover, other differences may also have existed, such as different crop conditions, irrigation conditions, and sealing along the edges. Thus, additional studies are needed to get good guidelines for selecting the span based on comparisons of CSG with identical conditions.

Computational fluid dynamics (CFD) methods were used in this study since they provide detailed temperature information across the entire greenhouse at various times. Most importantly, all the input parameters in CFD models can be easily controlled to keep them the same during simulations unlike in field measurements where the uncertainties cannot be avoidable. CFD models have been used to successfully optimize greenhouse structures for tunnel greenhouses (Mistriotis and Briassoulis, 2002; Bartzanas et al., 2004), a sloped-roof glasshouse (Bournet et al., 2007), a sawtooth greenhouse (Kacira et al., 1998) and others to seek better vent configurations. The commercial

software Fluent was used here to analyze the effects of three spans, 10 m, 12 m and 14 m, on the CSG interior thermal climate. Predictions of similar CFD models were shown earlier (Tong et al., 2009) to agree well with field measurements. These span configurations were used in three groups with all the dimensions in the first group varied in proportional to the span width, with the same dimensions for the north roof and north wall in the second group and with the same south roof size in the third group. Analyses of the solar heat gains, heat losses and temperature distributions for each group are expected to give good guidance for span selection for the growers.

2. Materials and methods

2.1. Structures of the CSG used in investigation

The reference greenhouse was a 12 m span and 5.5 m ridge height CSG located in Shenyang, Liaoning Province, China. A 0.12 mm thick plastic film covered the south roof with a blanket placed over the film cover during the night. The north roof was 0.2 m thick and made of wood sheets, Styrofoam and other light materials. The north wall was a 0.6 m thick layered wall with a 0.36 m thick brick wall on the inside, a 0.12 m thick brick wall on the outside and a 0.12 m insulation layer in between. Lettuce was grown in the eastern part of the greenhouse with the soil under the crops and potted crops in the western section of the greenhouse covered with plastic. Detailed measurements for this 12 m span were conducted with measurements of the inside and outside temperatures, solar radiation, wind speeds, humidities and soil temperatures at various depths in the soil, and the inner surface temperatures of the north wall, north roof, soil and the south roof cover (Tong et al., 2009). This 12 m span CSG structure and the inside air temperature measurement points are shown in Fig. 2.

Tong et al. (2009) predicted the temperatures during three clear days (Feb. 18–20, 2004) followed by a cloudy day (Feb. 21, 2004) for

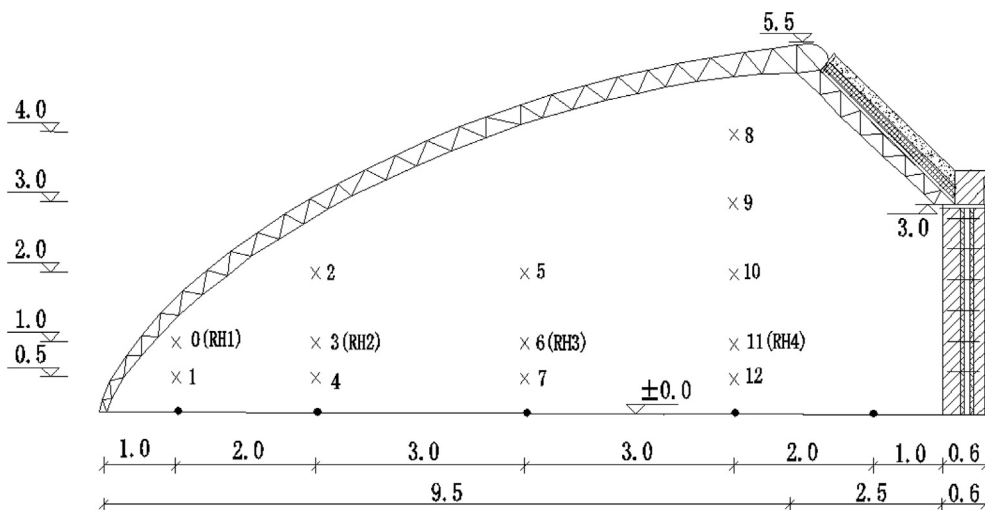


Fig. 2. Inside air temperature (X) and relative humidity (RH) measurement points with dimensions in meters.

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