Tensegrity greenhouse: an innovative covering structural system with low shading

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Abstract

Based on the structural principle of "Tensegrity" (tensional integrity), an innovative typology of greenhouse was developed. The principle behind the study uses structural elements of small sections (bars and cables) and employs compressed elements included in a network of tensioned elements. The innovative greenhouse structure allows covering larger spans than the most common greenhouse typologies on the market, improving the surface area usable for crops and reducing the structural sections. The present research focuses on the evaluation of the shading caused by the structural elements inside the tensegrity greenhouse, compared with the most common commercial typologies. At this aim, simulations of illuminance factor (IF) at different distance from the ground level were assessed by means of Revit, a software for building information modelling (BIM), developed by Autodesk Inc., which allows analyzing the impact of natural light and shadows on the interiors of buildings. The IF of the tensegrity greenhouse model (TGM) was compared with the one calculated for different greenhouse typologies (planar pitched roof and vaulted roof) having the same area (118.75 m^2) and height of the gutter (3.5 m) placed in Rome (Italy). For all kind of greenhouses, the daily variation of the IF was evaluated in two representative days of the year: June 21 and December 21. As result, the TGM showed a value per square meter of the IF Higher than about 20% compared to traditional structures.

Keywords: steel structures, greenhouse structures, illuminance factor

INTRODUCTION

Greenhouse technology improvement contribute to solve global issues such as the shortage of food, energy and resources compared to the increase in world population. Many of the research in the field of greenhouse facilities technologies focus on improving the use of resources. Sustainable agriculture goals are energy efficiency, climate control (Asdrubali et al., 2012; Chou et al., 2004; Hassanien et al., 2016; Blanco et al., 2013; Fabrizio 2012; Sethi and Sharma, 2007; Panwar et al., 2011) and water saving (Zaragoza et al.,2007; Chapagain and Orr, 2009; Salokhe et al., 2005). At the same time, there are researches on technologies for crops in protected environment that focus on the study of structural elements and structural behavior analysis (Cepeda et al., 2013; Giacomelli et al., 2008; Waaijenberg, 2006; Iribarne et al., 2007; Castellano et al., 2004; Scarascia Mugnozza, 2003). Buildings for protected crops are complex and multidisciplinary systems, where the correct utilization of natural lighting is fundamental for plants growth (Castellano and Tsirogiannis, 2015; Caldwell, 1971).

Designing a structure in a coherent and complete way must take into account the optimization of the functions that the system has to guarantee. In this context building information modelling (BIM) allows in-depth study of buildings by incorporating geolocation

information, climatic information and the characteristics of materials, components and construction systems. The purpose of this study is to analyze the improvement of the daylight performance in an innovative greenhouse (Tensegrity greenhouse Model), based on the structural principle of tensegrity.

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MATERIALS AND METHODS

Simulations of illuminance values (lux) induced by the solar radiation on the internal greenhouse canopy average surface, 75 cm height from the ground level, were assessed by means of Revit, an Autodesk (https://www.autodesk.com/) software for BIM.

All the greenhouse models had the same area A=118,75 m^2 (Figures 1-3) and were designed according to the standard EN13013-1 (European Commission, EN 13031-Greenhouses – Design and construction - Part 1: Commercial production greenhouse, 2004) hypothesizing Rome- coordinates 41.8°N, 12.6°E – as building site location and all greenhouses have the north-south orientation of the ridge line.

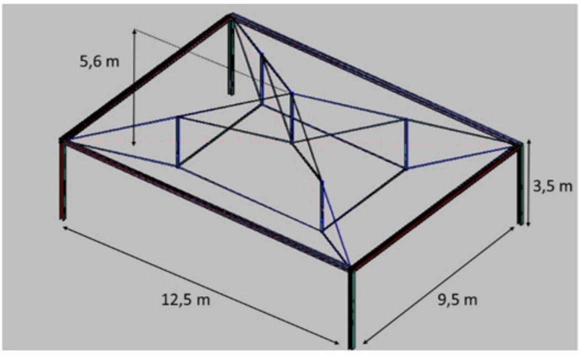

Figure 1. Tensegrity greenhouse model (TGM).

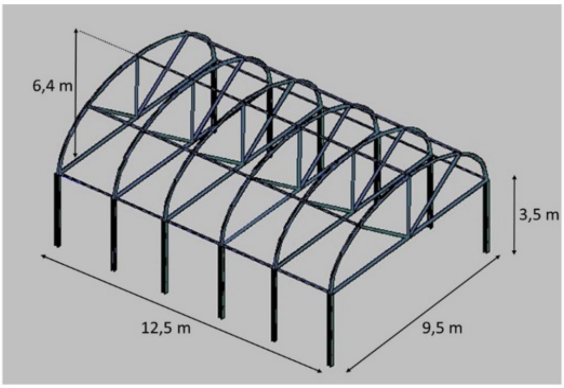

Figure 2. Vaulted greenhouse model.

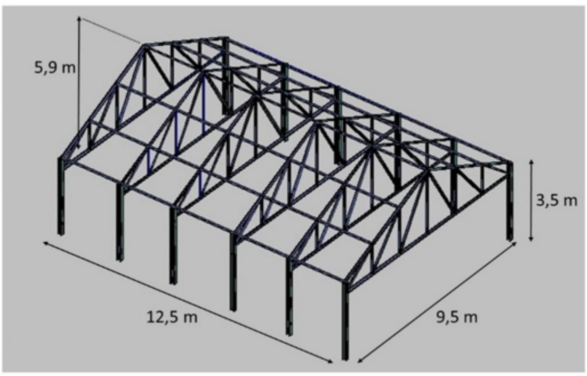

Figure 3. Duo-pitched greenhouse model.

The choice was made not to apply a roofing material to the greenhouses as the purpose of this work is to compare the shading of the different supporting structures.

Structural sizing it is assumed using the same roofing material, consisting of plastic film.

In particular, the elements of the roof of the vaulted greenhouse are 25 mm hollow tubes. The structural components of the cover of the duo-pitched are rectangular elements of 30×50 mm.

The illuminance was evaluated for each of the three considered model of greenhouse during two representative days of the year: the solstice days of June 21 (the day with the most hours of sunshine of the year) and December 21 (the day with less light hours in the year). For each hour of the two days the maximum, the minimum and the medium value of the illuminance were analyzed. The Illuminance Factor of the TGM was calculated as the value of average illuminance in one-hour step divided by the value of the reference open field lighting.

RESULTS AND DISCUSSION

Figures 4 and 5 show respectively the values of illuminance for each hour of daylight on June 21st and in each hour of light on December 21st for the analyzed greenhouse typologies.

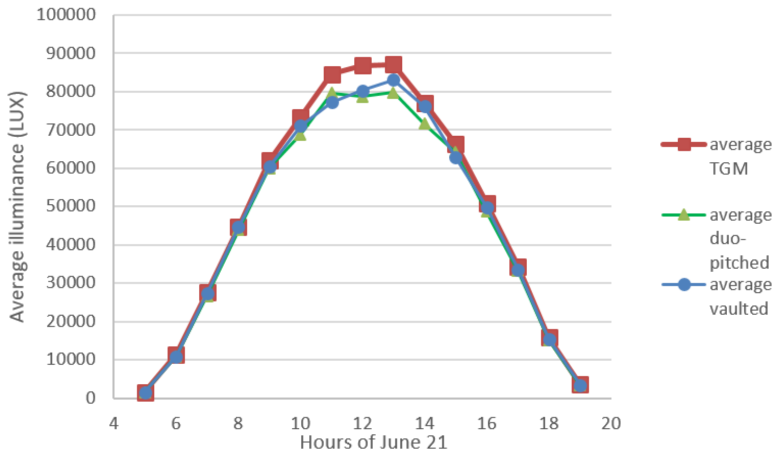

Figure 4. Average illuminance in each hour of light on June 21.

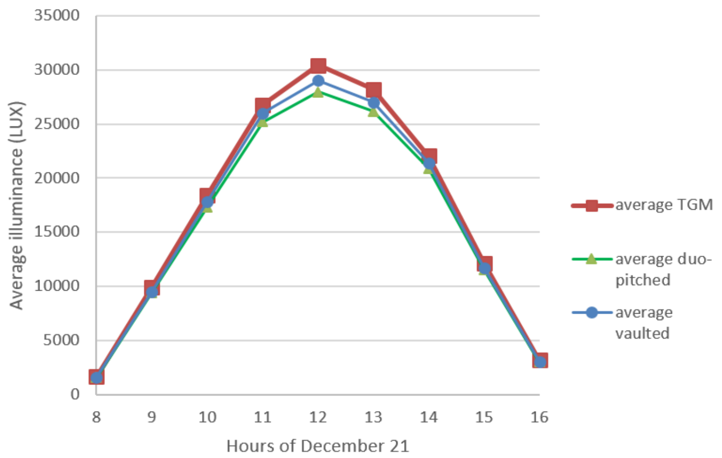

Figure 5. Average illuminance in each hour of light on December 21.

Analyzing the simulation values (Table 1) we can note that compared to a traditional duo-pitched greenhouse the Illuminance Factor on June 21 of the tensegrity model undergoes an increase from 2 to 10%.

Table 1. Illuminance factor on June 21st.

Hour	IF (%)		
	TGM	Vaulted	Duo-pitched
5	0.96	0.93	0.91
6	0.97	0.93	0.92
7	0.95	0.93	0.92
8	0.95	0.95	0.93
9	0.97	0.94	0.94
10	0.95	0.92	0.89
11	0.98	0.89	0.92
12	0.96	0.89	0.87
13	0.99	0.94	0.90
14	0.95	0.93	0.88
15	0.96	0.91	0.93
16	0.95	0.93	0.91
17	0.95	0.94	0.92
18	0.95	0.93	0.91
19	0.96	0.93	0.91

While compared to a traditional vaulted greenhouse, the Illuminance Factor of the TGM shows a percentage increase from 1 to 9%.

The Illuminance factor of the TGM on December 21 (Table 2) appears to undergo an increase of between 2 and 6.7% compared to the traditional vaulted greenhouses. The lighting factor of the TGM increases with percentage values between 1 and 8.5% compared to the traditional duo-pitched greenhouses.

Table 2. Illuminance factor on December 21.

Hour	IF (%)		
	TGM	Vaulted	Duo-pitched
8	0.95	0.93	0.93
9	0.97	0.93	0.94
10	0.95	0.92	0.89
11	0.98	0.92	0.92
12	0.96	0.92	0.87
13	0.99	0.93	0.90
14	0.95	0.92	0.88
15	0.96	0.92	0.93
16	0.95	0.93	0.91

In order to obtain homogeneous comparisons, we have compared the same plan dimensions of the different types of greenhouses (Figure 6). The study of shading on the extension of the greenhouse TGM with high measurements for large greenhouse systems will be analyzed in future research.

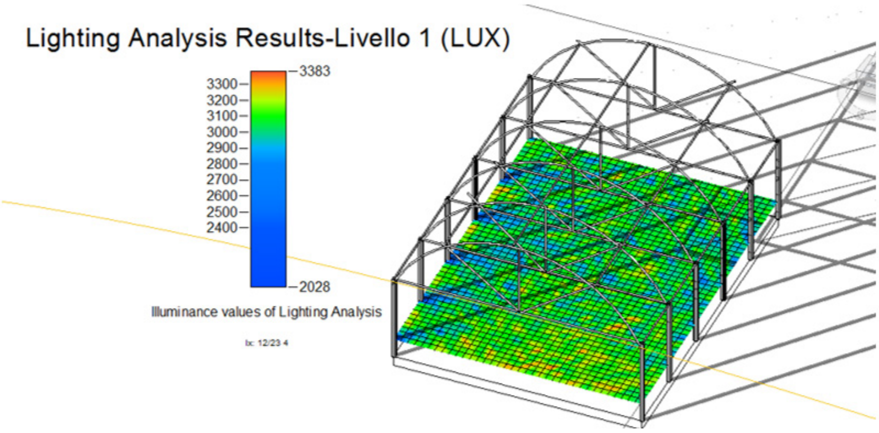

Figure 6. Example of graphical lighting analysis results performed with the Revit software.

CONCLUSIONS

The study shows a significant increase in solar lighting within the Tensegrity Greenhouse Model, analyzed in comparison to both the vaulted and the duo-pitched greenhouse. The simulation was carried out during the solstice days on December 21 and June 21. Compared to the traditional duo-pitched roof greenhouse the gain in terms of Illuminance Factor (%) is more significant, due to the greater dimensions of the structural components compared to the vaulted greenhouses. Future developments of this research will concern a wider spectrum analysis during different periods of the year in order to assess the consistency of the results and calibrate the model TGM.

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