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Module greenhouse with high efficiency of transformation of solar energy, utilizing active and passive glass optical rasters

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Abstract

Since the eighties of the 20th century, various types of linear glass rasters for architectural usage have been developed in the Czech Republic made by the continuous melting technology. The development was focused on two main groups of rasters – active rasters with linear Fresnel lenses in fixed installation and with movable photo-thermal and/or photo-thermal/photo-voltaic absorbers. The second group are passive rasters based on total reflection of rays on an optical prism. During the last years we have been working on their standardization, exact measuring of their optical and thermal-technical characteristics and on creation of a final product that could be applied in solar architecture.

With the project supported by the Ministry of Environment of the Czech Republic we were able to build an experimental greenhouse using these active and passive optical glass rasters. The project followed the growing number of technical objectives. The concept of the greenhouse consisted of interdependence construction – structural design of the greenhouse with its technological equipment securing the required temperature and humidity conditions in the interior of the greenhouse. This article aims to show the merits of the proposed scheme and presents the results of the mathematical model in the TRNSYS environment through which we could predict the future energy balance carried out similar works, thus optimizing the investment and operating costs.

In this article description of various technology applications for passive and active utilization of solar radiation is presented, as well as some results of short-term and long-term experiments, including evaluation of 1-year operation of the greenhouse from the energy and interior temperature viewpoints. A comparison of the calculated energy flows in the greenhouse to real measured values, for verification of the installed model is also involved.

Keywords: Rasters made of glass; Greenhouse; Solar architecture; Fresnel lens; Mathematical simulation

1. Introduction

The greenhouse designing required setting up the basic criteria that would enable its year-round use in temperate climatic conditions:

– Large glass openings.
– Sufficient ventilation and shading elements.
– Efficient heating system.
– Sufficient and appropriate thermal insulation against low outdoor temperatures.
– Sufficient stability against wind or snow loads, having regard to national standards.

Primarily there are two types of agricultural greenhouse that utilize sun for heating purposes: passive and active agricultural greenhouses. Passive solar systems can be integrated into agricultural greenhouses to reduce their energy consumption for heating. It was, therefore, necessary to find

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Nomenclature

ti	internal air temperature (°C)	VU	ventilation unit
te	external air temperature (°C)	SG	roof concentration collector
tm	mean temperature–air, heat transfer fluid (°C)	SF	facade concentration collector
G	solar irradiation (W m^{-2})	PT	photo-thermal
HP	heat pump	PV	photo-voltaic

out optimal design solutions of the building in terms of the highest use of passive solar gains which means the orientation and the shape of the building. We have found out (Sethi, 2008) that the best ridge orientation is east–west and the best shape of the roof is asymmetric (uneven-span). In terms of building structures it is necessary to ensure the greatest possible accumulation of matter. This can be achieved by several ways (Santamouris et al., 1994). From the options described by this authors, for the design of greenhouse northern storage wall was chosen, covered by 10 cm thermal isolation from outside. The floor of the greenhouse is sunk into the ground, which diminish heat loss and also serves as the accumulated mass. During the night, the stored heat is returned to the interior by natural convection and radiation. For maximum absorption of excess energy incident on surfaces of walls and floors, the choice of colours is important. When using a greenhouse for growing purposes, blue and red colour is appropriate. Blue colour reflects in the wavelength around 470 nm and the red wavelength of about 650 nm. These wavelengths are absorbed in chloroplast photosystem I (PSI), respectively in photosystem II (PSII) and used for photosynthesis (Kirk, 1994). A large glass system, opening on the south facade, of course, brings in the summer months excess of solar gains into the interior, which is necessary to take away by some cooling system (Sethi and Sharma, 2007). The reduction of the greenhouse interior temperature is achieved by two ways. Firstly, by natural ventilation with two rows of pop-up windows (in the lower and upper parts of the southern facade), secondly by reflecting a direct component of solar radiation back to the exterior by reflective grids or in the form of hot water using solar collectors with linear Fresnel lenses (Tripanagnostopoulos et al., 2007). A comprehensive review of worldwide applications of active solar agricultural greenhouses, along with a brief overview of each application, is available in Santamouris (1993).

With the planting challenges in the greenhouse it was necessary to maintain a steady temperature profile in the upper part of the greenhouse in both summer and winter months. For that reason, the warm air heating technology was chosen for heating a greenhouse which allows transporting warm air from the top of the greenhouse to the bottom, and under the windows.

Key elements of the experimental greenhouse are glass rasters (Jirka et al., 2002a). To their optimal functioning is necessary to keep south slope of the roof in a range of angles (30–45°). The first type are passive rasters, which operate on the principle of total reflection. The second type are the active rasters, in our case the rasters with linear Fresnel lens. This type of lenses is mentioned in many publications (Nelson et al., 1975; Kritchman et al., 1979; Nabelek et al., 1991; Leutz and Suzuki, 2001, etc.). Most of these lenses are only in a theoretical plane, or are made of acrylic, which is not suitable for integration into the building envelope for its low resistance to UV radiation (Tripanagnostopoulos et al., 2007).

Glass rasters developed and manufactured for experimental greenhouse eliminate this handicap. Problem is their optical quality, which is due to production technology (continuous melting technology). As a result of the cheapest manufacturing technology – the method of continuous melting of the glass panes, it is clear, that the shape of elements is not ideal. The energy balance is negatively affected specially by radius edges and other inaccuracies, contaminated landing flat surface, and similar effects which ultimately deteriorate the energy balance. These changes can be quantify with great difficulty, and therefore it is necessary to supplement the optical properties of raster with experimental measurements using the actual material and credible simulation of the angle between the direction of a ray coming from the sun and normal to the plane of the raster. The first measuring of optical characteristic of these glass rasters are describe in Jirka et al. (2002b). For more exact measuring, the structure "Simulator of solar radiation for optical rasters testing" was made, which made it possible to measure the actual energy transport in raster system. (see Fig. 6).

For predicting the energy performance of the experimental greenhouse and also generally of the systems using active and passive optical rasters integrated into the building envelope, the mathematical model of the greenhouse was made, where the optical characteristics of both types of grids were implemented. Unlike some works dedicated to this issue that create their own numerical models based on energy balances observed phenomena, such as simulations of heating by using thermal curtain and geothermal energy (Ghosal and Tiwari, 2004) or climate models created by Takakura et al. (1971), Kindelan (1980), Avissar and Mahrer (1982), or the model for the accumulation of heat into the wall material (Chen and Liu, 2004), a mathematical model of optical glass rasters was created by commercial software TRNSYS (TRNSYS Manual, 2004).

2. Modular greenhouse

The modular greenhouse is composed of six modules (no thermally separated) with interior ground plan dimensions