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Experimental study on development of thermal conditions in ground beneath a greenhouse

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ABSTRACT

The authors assume that determining temperature distribution and heat flux directions in the ground beneath a greenhouse can help to establish the role of ground in its thermal management and explain how soil temperature of cultivated plants is shaped.

Measurements of temperature distribution in the ground and in the air were conducted in a greenhouse situated in the south of Poland. Both the foundation as well as the floor has not been thermally insulated. The greenhouse has been adjusted to biennial flower cultivation.

Results of air and ground temperature measurements along the vertical and horizontal measurement planes are presented in a graphic form.

The observed temperatures and directions of heat transfer in the ground helps to explain the mechanism of heat flows to and from greenhouse during the whole year. In particular heat losses in winter and stabilizing of inner air temperature through heat buffering in summer periods and during intermittent heating in cold periods. Estimated heat exchange with the ground is very small in comparison with heat flows through transparent thermal envelope and does not essentially influence thermal balance of the greenhouse.

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1. Introduction

Temperature range tolerated by plants is much broader that the range defined according to thermal comfort in residential buildings. Critical, minimal temperature in most cases is 5–10 °C above zero and problems with too high temperature start by 30 °C. In most European countries greenhouses require periodical heating in order to ensure the minimal temperature needed for particular plant cultivations. For economic reasons no active cooling is applied to avoid overheating. In hot periods increased day and night ventilation and shadowing is applied. Poor inner climate control, reduced to heating, is the reason for high temperature fluctuations both in summer and in winter. This causes intensive heat exchange with the ground, the only component with high thermal capacity in a greenhouse.

Heating enclosed spaces with transparent partitions entails significant heat loss to the atmosphere. The aim of the study is the estimation of transient heat losses and gains caused by thermal coupling between greenhouse and the ground and thus the impact on energy balance and microclimate. Only reliable, experimental results were used, which means particular case study with some observations of general regularities.

Research on heat exchange with the ground related hitherto mostly to residential buildings in regard to energy balance. Lot of papers are devoted to calculation methods and tools. Some works presents also results of experimental measurements [1–4]. Only a few publications related to thermal performance of ground in a greenhouse could be found.

In unbuilt-up areas, annual temperature amplitude in the ground mainly depends on air temperature, type of vegetation, incline and exposure. Temperature fluctuations are most significant in the top layer of the ground; whilst at the depth of around 10 m, ground temperature approximates the annual average temperature of air in the given area [5]. Temperature distribution in the ground around heated buildings is more complex as it is shaped by an additional factor which is heat transfer from the building.

Previous research on ground temperature in greenhouses concentrated on improvements of local microclimate [6,7] or thermal and humidity conditions in the arable ground layer [8,9]. The experimental research [8] was conducted in Iraq in winter, inside a cucumber cultivation greenhouse of the following dimensions: 55 m × 10 m. The studies revealed that along the longitudinal axis of the greenhouse, momentary temperature at the depth of −0.05 m varied between 17 °C and 23.5 °C. The lowest temperatures were observed at greenhouse gables. In the northern near-wall zone, the

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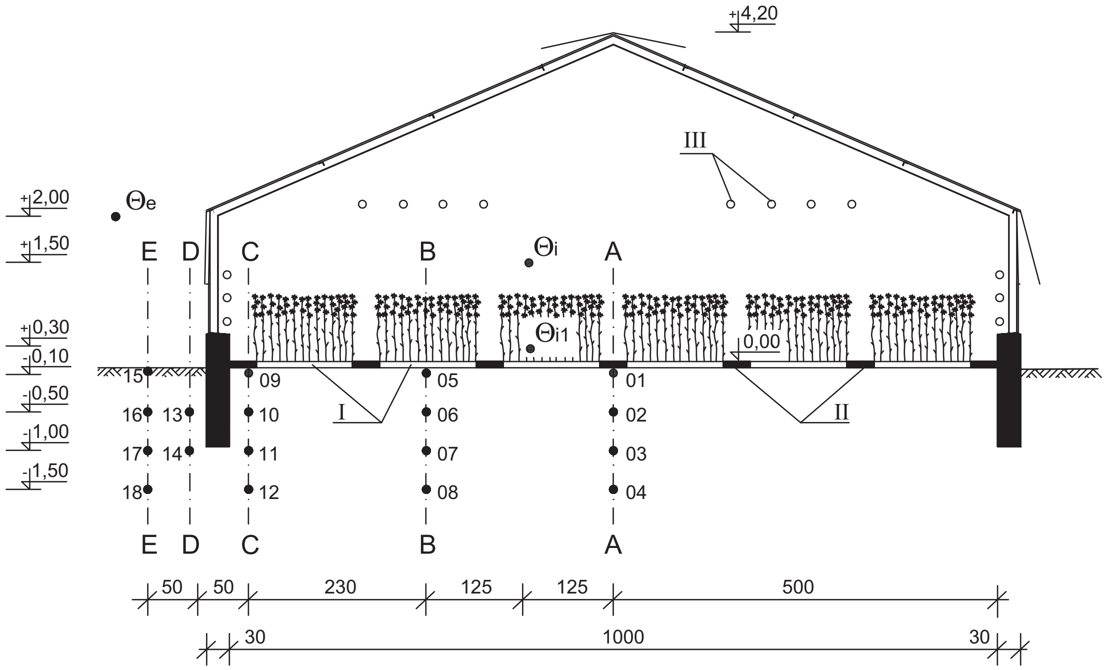

Fig. 1. Orientation plan of the greenhouse and the distribution of measurement points: I, flowers on the ground; II, corridor; III, heating; A–E, measurement sections; Θ_i, Θ_{i1} and Θ_e, measurement points in the air; 01–18, measurement points in the ground.

ground temperature was about 17 °C; whilst in the southern part about 18.5 °C. Temperatures in the near-wall zones were lower than in the central zone, where they ranged between 20 and 23.5 K.

Tong et al. [10], which conducted a simulation calculation for selected 2 winter days, including one sunny and one cloudy day, presented momentary temperature distribution in the ground beneath a greenhouse with lettuce cultivation. Results of their studies also revealed that ground temperature was higher in the central zone of the greenhouse and lower in the near-wall zone. Thus, it can be concluded that the character of temperature distribution in the top layer of ground beneath a greenhouse in the winter season was similar irrespective of location and climatic zone (China and Poland – moderate climate, Iraq – subtropical climate). Little research has been made though on phenomena occurring in the deeper layer of ground beneath the greenhouse throughout the entire year. Such research has focussed so far mainly on winter seasons [10].

2. Materials and methods

Measurements of temperature distribution in the ground (Θ_G), indoor (Θ_i) and external air (Θ_e) have been conducted in a typical single-standing greenhouse (10 m × 43 m) owned by a horticultural farm situated in the south of Poland (50.1.1° N, 19.5.5° E). The greenhouse presented in Fig. 1 is located on a north-south axis in a flat area maintained as a lawn. The greenhouse is made of 4-mm thick glass panels. Both the foundation as well as the floor of the greenhouse has not been thermally insulated. The greenhouse is used for the cultivation of carnations (*Dianthus caryophyllus semperflorens flore pleno hybridum hortorum*), which almost completely shadowed the ground and narrow (0.3 m) communication corridors. The flowers were cultivated in 2-year cycles, whilst the total cultivation area amounted to 360 m^2. Flower density per 1 m^2 equaled 56 plants.

The greenhouse has been equipped with a central heating system, including tubular radiators installed along the side walls and 2.5 m above the floor level (see Fig. 1). The heating system is powered by a coal-fired boiler. The boiler's efficiency is controlled automatically via temperature sensors located at the height of 2.0 m. In the research period, the greenhouse was heated from 1 November 2005 to 13 April 2006 (164 days). As far as the ventilation system is concerned, the solution applied in the greenhouse included a gravitational system with mechanical airheads located in the upper halves of longitudinal walls and in the roof gable. In the summer period, the greenhouse was ventilated through the airheads practically 24 h a day; in winter and in colder seasons, the decision when and how much the airheads should be opened depended on temperature measured by thermometers. The greenhouse used automatic irrigation and fertilization systems: drip tape was applied with a dripper sparing range of 15 cm × 15 cm.

Macroscopic research of the ground revealed that a 0.1-m layer of humus was underlain by sandy clay, thick by 2.5 m. Groundwater level was situated at the depth of 6 m below ground level.

Measurement cross-section including the western part of the greenhouse was placed halfway through the length of the building. The distribution of measurement lines and points is presented in Fig. 1.

Ground temperature was measured by 18 PT-100 sensors with accuracy of ±0.1 °C. Indoor air temperature was measured by 2 PT-100 sensors, placed at the height of 2.2 m; whilst outdoor temperature was measured with 1 PT-100 sensor located in a meteorological box near the greenhouse. Air temperature was recorded every hour and results were registered by a multichannel HP data logger. The assumption of such a frequency has been justified by previous experiments devoted to heat exchange between various types of agricultural buildings and the ground, which revealed that hourly intervals are satisfactory, because changes in the ground are not sudden. The research was conducted from 21 July 2005 to 20 July 2007.

3. Results and analysis

A detailed presentation and analysis of ground temperature distribution around the greenhouse was conducted for the selected period from 21 July 2005 to 20 July 2006, with a hot summer and very cold winter. Temperature values in vertical measurement planes (Fig. 2) and horizontal planes (Fig. 3) have been presented

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