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SUITABILITY OF GREENHOUSE BUILDING TYPES AND ROOF COVER MATERIALS FOR GROWTH OF EXPORT TOMATOES IN THE BESOR REGION OF ISRAEL. I. EFFECT ON CLIMATIC CONDITIONS*

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DAYAN E., ENOCH H. Z., FUCHS M. and ZIPORI I. *Suitability of greenhouse building types and roof cover materials for growth of export tomatoes in the Besor region of Israel. I. Effect on climatic conditions.* BIOTRONICS **15**, 61–70, 1986. Growth conditions in a narrow bay, low roof Dutch greenhouse (Venlo type) and in a wide bay, high roof Israeli greenhouse (Sharsheret type), were studied. Roof-cover materials that were tested in the Israeli greenhouses included glass, polyethylene, corrugated fiberglass and tabular polycarbonate. The differences in climatic conditions between the greenhouses were usually small and without a specific trend. Day temperatures in all building types were 1–6°C higher than the values measured outdoors simultaneously. During most of the season, excessively high temperatures could be avoided by opening ventilation windows. In the Dutch greenhouse, day temperature control was rather limited. Night temperatures in all greenhouses were usually higher by 1°C or less than the outside temperature. In the polycarbonate-covered greenhouse, night temperatures were higher. Radiation inside the greenhouses was about 55%–60% of the outside level. In the polycarbonate-covered greenhouse, radiation levels were about 10% lower than the others. The photosynthetically active fraction of global radiation was higher inside the greenhouses than outside.

Key words: greenhouse; covering material; microclimate; global radiation; PAR; air temperature; air exchange.

INTRODUCTION

The first commonly introduced greenhouse for growing export tomatoes in the Besor region of Israel was a Venlo type, developed in Holland. The high cost of such construction and the excessive daytime temperature created inside, brought about the need to study plant performance under other construction conditions and

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different types of roof-covers (*5*). In this work, building types and roof covers were studied.

MATERIAL AND METHODS

The experiment was carried out at the Besor Experiment Station (western Negev, Israel) during the season of 1979 to 1980.

Two types of buildings were tested:

1) Venlo—a Dutch type, walls and roof made of glass.

2a) Sharsheret—an Israeli type, made of polyethylene walls and with a glass roof.

Three additional materials were tested as roof covers in the Sharsheret-type constructions:

2b) double-layer, ultra violet-resistant polyethylene (P.E.). The space between the P.E. sheets was blown with air for better thermal isolation and stability.

2c) Corrugated fiberglass (F.G.).

2d) 6 mm, tabular polycarbonate (P.C.) sheets.

The Venlo greenhouse was 19 m by 33 m. The roof was divided into six bays, 3.2 m wide and 4 m high at the gable. Each wing of the roof had ten vents, 72 cm wide × 167 cm long, spaced 300 cm apart. Side vents, 110 cm wide, were installed all along the eastern and western walls.

The Israeli type greenhouses were 27 m by 22 m, divided into three bays each 9 m wide. Gutters were at 3.2 m and the gable was at 5.5 m. All four side walls were covered with double-layer polyethylene sheets, while the space between them was blown with air at night. Three side walls (east, south and west) could be opened by rolling them up. The top triangle of each bay had a sliding window, 1.8 m by 1.7 m.

Tomato seeds (cv. Angela, Hazera Seed Company, Israel) were sown in a nursery on Sept. 15, '79. Transplanting of seedlings into the greenhouses took place on Oct. 21, '79. All agrotechnical treatments were according to common practice in the region, and to recommendations of the Extension Service.

Microclimatic data were logged every 30 min with a data logger (Campbell Scientific Inc., Logan, Utah, U.S.A., Model 5C). Global radiation was measured by integrating the output of pyranometers (Kipp & Zonen, Delft, The Netherlands), two of which were installed outside the greenhouses, 5.5 m above the ground, and six were installed, in turn, inside each of the greenhouses, above the plants.

Photosynthetically active radiation was measured by a quantum detector (S-190 Li-Cor, Lincoln, Nebraska, U.S.A.). Temperatures and relative humidity were measured with wet and dry thermocouples, installed inside ventilated psychrometers above the plants, and among the plants at half their height. Measurements outside the greenhouse were done at 2 m and 5 m above the ground.

The daily evaporation rate was measured from a pan installed in each greenhouse among the plants. Air exchange rate was measured by injecting N_2O (tracer gas) into the greenhouse and following the decrease in its concentration (*6*) with an infrared gas analyzer (Hartmann and Braun, West Germany).

RESULTS

Table 1 presents the average maximum day temperature measured in each greenhouse, to examine the relations between these values and the ones measured in the glass-covered, Sharsheret greenhouse, used as control.

Figure 1 shows the daily temperatures measured, on Jan. 3, '80, above the plants and within the canopy. The temperatures are shown in relation to the outside temperatures. On the day of measurement, plants were 2 m tall. All vent windows were fully open in the Venlo greenhouse. In the Sharsheret greenhouse, western and southern walls were rolled up and the gable windows were fully open.

Inside the greenhouses, daily temperatures were 1–6°C higher than the temperatures measured simultaneously outdoors. Usually, the day temperature inside the greenhouse was influenced more by the degree of ventilation apertures opening than by the type of roof-cover material. Above the plants, temperatures were higher than among them (Figs. 1b and 1c).

In the Venlo greenhouse, temperatures were about 1°C higher, during midday hours, than in the Sharsheret greenhouses. The maximum temperatures in the P.C.-covered greenhouse during the winter months (December through February) were lower than in the other ones.

Table 2 presents the average minimum night temperature measured in each greenhouse, to examine the relations between these values and those measured simultaneously in the reference greenhouse. All vents and side walls were closed at sunset for the night.

Figures 2a–2d show the night temperatures measured on Nov. 25–26, '79, both among and above the plants in relation to the outdoor temperature. Night temperatures inside the greenhouses were only 0.5–1°C higher than the values measured simultaneously outside. The values measured above the plants were closer to the outdoor temperature. In the P.E.-covered greenhouse, temperatures

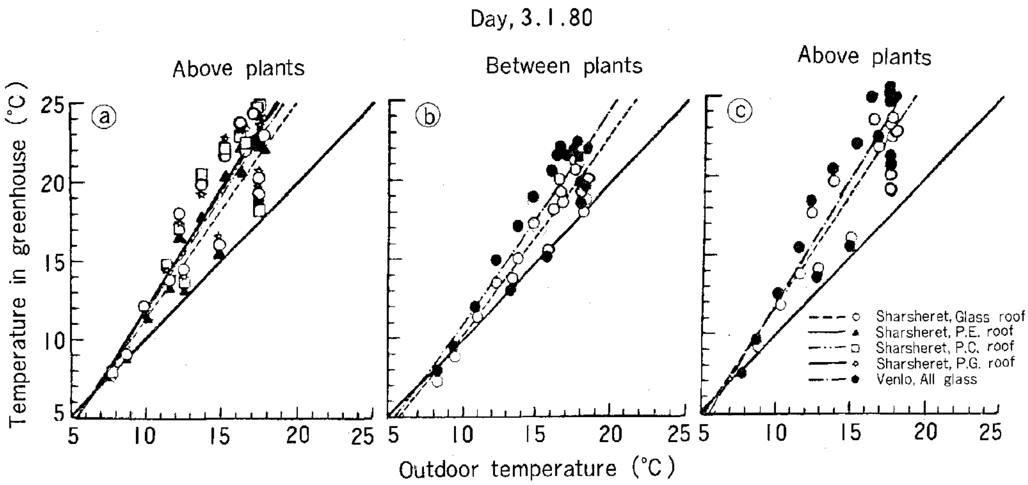

Fig. 1. Effect of mean daily outdoor temperature on the daily temperature inside the greenhouse.

Table 1. Maximum temperatures in the different greenhouses (°C). (10-days mean)

Building type	Roof cover	November 1979			December 1979			January 1980			February 1980			March 1980			April 1980		
		1–10	11–20	21–30	1–10	11–20	21–31	1–10	11–20	21–31	1–10	11–20	21–29	1–10	11–20	21–31	1–10	11–20	21–30
Sharsheret	Glass	30.8	30.7	29.2	23.7	21.2	21.6	21.9	22.0	22.6	22.1	22.0	25.4	23.9	25.6	26.0	30.2	26.3	29.3
Sharsheret	P.E.	29.5	29.4	28.2	21.8	20.9	20.7	20.7	21.4	21.7	22.0	22.8	25.7	24.5	28.4	28.3	25.9	25.4	27.4
Sharsheret	P.C.	30.3	30.3	28.0	22.3	19.9	19.8	20.1	20.3	19.7	20.1	20.8	24.8	24.4	24.7	24.8	28.8	23.1	27.4
Sharsheret	F.G.	30.7	30.7	28.5	22.7	20.1	20.0	20.1	20.0	20.3	20.9	21.1	24.4	23.7	25.4	25.9	30.3	25.8	28.3
Venlo	Glass	31.9	31.8	29.4	22.8	21.3	21.0	22.8	21.3	22.3	23.2	22.3	25.8	25.8	23.4	2.80	33.5	23.2	30.2

Table 2. Minimum temperatures in the different greenhouses (°C). (10-days mean)

Building type	Roof cover	November 1979			December 1979			January 1980			February 1980			March 1980			April 1980		
		1–10	11–20	21–30	1–10	11–20	21–31	1–10	11–20	21–31	1–10	11–20	21–29	1–10	11–20	21–31	1–10	11–20	21–30
Sharsheret	Glass	14.8	18.8	13.8	10.8	9.3	8.2	7.8	8.4	7.4	8.4	8.8	8.7	8.2	9.5	12.7	13.5	11.8	13.9
Sharsheret	P.E.	14.3	18.5	13.3	10.4	8.5	8.1	8.9	8.1	8.9	7.8	8.1	8.5	8.4	8.8	12.8	12.8	10.8	13.8
Sharsheret	P.C.	15.5	18.9	14.5	10.8	9.8	9.1	7.8	8.8	7.7	8.4	9.6	10.0	7.7	10.1	13.6	13.8	12.1	14.4
Sharsheret	F.G.	14.3	18.1	13.8	11.5	9.1	8.9	7.3	8.6	7.8	8.1	8.3	8.3	8.6	9.3	12.5	13.4	10.9	13.2
Venlo	Glass	14.8	18.5	13.7	9.8	8.8	8.7	7.7	8.2	7.2	7.8	9.2	8.3	8.8	9.1	12.7	13.5	11.3	13.7

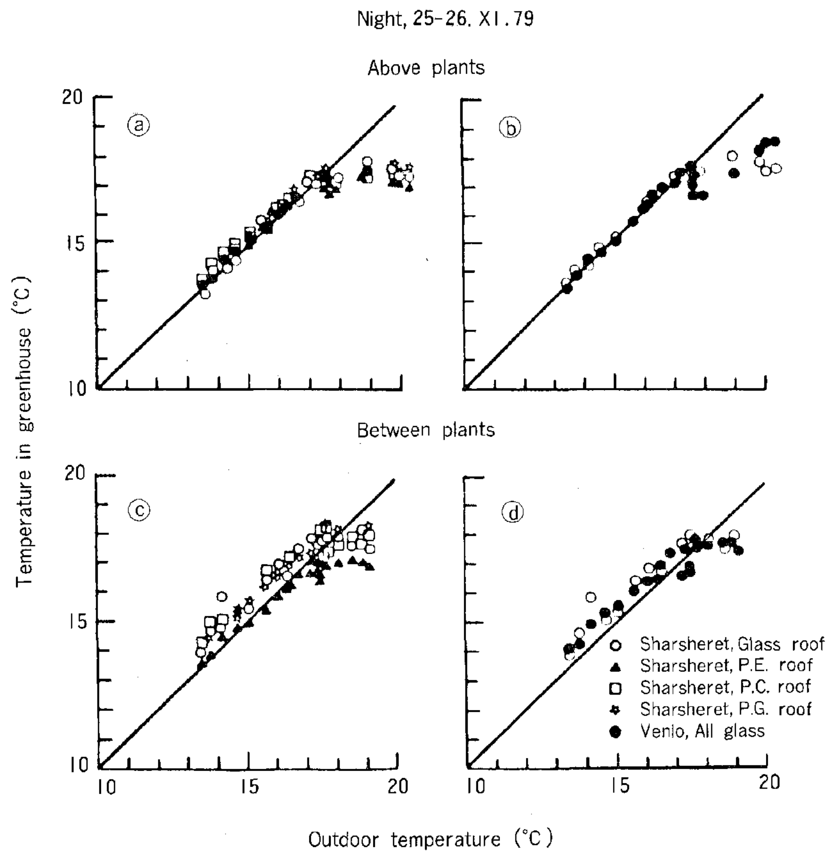

Fig. 2. A comparison between night temperatures outdoors and the simultaneously measured temperatures inside the greenhouse above and between the plants.

between plants were lower and in the P.C.-covered one they were higher than in the control. The differences between the greenhouses were more pronounced in the measurements taken among the plants than above them (Fig. 2).

The relative humidity in the closed greenhouses usually reached 100%. Water condensation on the leaves and fruit occurred in all the greenhouses, mainly close to the walls, but not on all nights. In the P.E.-covered greenhouse, water condensation on the leaves was more common than in the others. On most nights, water condensed on the polyethylene and polycarbonate sheets and dripped on the plants. In the other greenhouses, water dripped mainly under the gutter.

Table 3 summarizes the relations between radiation intensities measured inside the greenhouses and those measured outside. In the P.C. greenhouse, radiation levels were 10% lower than in the other greenhouses. Also, in the Venlo type, low radiation levels were recorded, especially because of the dust covering the roof. In January the dust was washed away and penetration of radiation into the greenhouse improved. In general, radiation levels inside the greenhouses were 50–60% lower than those outdoors.

Table 3 also summarizes the relations between global and photosynthetically active radiation outside and inside the greenhouses. For all greenhouses, the

Table 3. Some transparency characteristics in the different greenhouses (means of 2–3 days of measurements)

Building type	Cover material	Remarks	b/a	c/a	d/b	Date of measurement
Sharsheret	Glass		0.618	1.91	2.11	Nov.–Dec 1979
Sharsheret	P.C.		0.504	1.91	2.00	Nov.–Dec. 1979
Sharsheret	Glass		0.631	1.84	2.06	Dec. 1979
Sharsheret	P.C.		0.504	1.84	2.05	Dec. 1979
Sharsheret	Glass		0.608	1.95	2.38	Dec. 1979
Sharsheret	F.G.		0.586	1.95	2.15	Dec. 1979
Sharsheret	Glass		0.637	1.88	1.96	Jan. 1980
Sharsheret	P.E.	Double layer	0.625	1.88	2.03	Jan. 1980
Sharsheret	Glass		0.627	1.94	2.08	Dec. 1979
Venlo	Glass	Old house	0.554	1.94	1.81	Dec. 1979

a=global radiation outside (W m^{-2}).
b=global radiation inside (W m^{-2}).
c=photosynthetic radiation outside (μE m^{-2} s^{-1}).
d=photosynthetic radiation inside (μE m s^{-1}).

Table 4. Daily mean evaporation (mm) from a class-B pan in the different greenhouses

		Month											
		November		December		January		February		March		April	
Building type	Roof cover	Mean	S.D.	Mean	S.D.	Mean	S.D.	Mean	S.D.	Mean	S.D.	Mean	S.D.
Sharsheret	Glass	2.6	0.21	1.3	0.10	1.6	0.10	1.8	0.14	2.9	0.17	5.1	0.25
Sharsheret	P.E.	2.8	0.44	1.2	0.09	1.4	0.11	1.8	0.14	2.7	0.18	4.6	0.22
Sharsheret	P.C.	2.9	0.31	1.1	0.12	1.3	0.10	1.4	0.13	2.0	0.15	3.8	0.29
Sharsheret	F.G.	2.7	0.27	1.2	0.08	1.4	0.10	1.6	0.13	2.2	0.15	3.7	0.21
Venlo	Glass	2.7	0.27	1.5	0.14	1.3	0.08	1.4	0.12	2.1	0.12	3.8	0.22

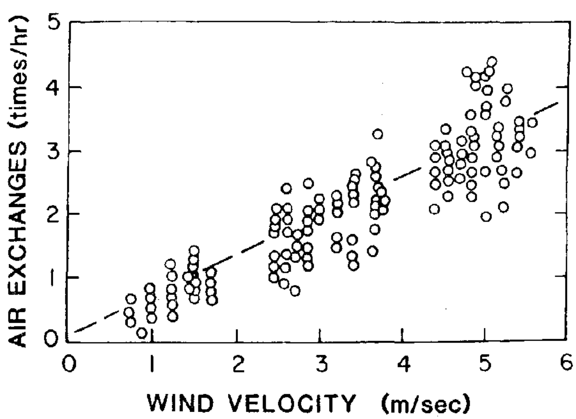

Fig. 3. Effect of wind velocity on air exchange rates in a glass-covered, Sharsheret greenhouse.

Table 5. Air exchange rates in closed greenhouses (wind velocity 4–5 m s^{-1})

Building type	Cover material	Air exchanges per hour	Compared with control
Sharsheret	Glass	2.1	1.0
Sharsheret	P.E.	0.8	0.38
Sharsheret	P.C.	1.3	0.61
Sharsheret	F.G.	1.3	0.61
Venlo	Glass	2.9	1.38

fraction of the photosynthetic radiation was higher inside than outside.

Table 4 presents the monthly average values of class B pan evaporation rates as well as the ratio of the values measured in each greenhouse to the ones measured in the control. Evaporation rates were highest in the glass (reference) and P.E.-covered greenhouses and usually lowest in the P.C.-covered greenhouse. The Venlo had lower values than the control. The differences between the greenhouses were more pronounced toward the end of the season (March–May).

Evaporation rates outside the greenhouses were usually 1.4 times higher than inside.

Figure 3 presents the influence of wind velocity on air exchange rates in the reference (glass-covered Sharsheret greenhouse) and Table 5 presents air exchange rates in the different, closed greenhouses as measured on a typical day, when wind velocity was 4–5 m s^{-1}. A greenhouse in which one wall was left opened, even partially, had very high air exchange rates: more than 10–13 per hour. At such rates the measuring technique is not sufficiently sensitive to detect differences between the greenhouses.

DISCUSSION

The different roof covers used on the Sharsheret greenhouses did not cause significant differences in maximum temperatures reached inside (Table 1). There is no indication that a certain greenhouse had a consistently lower or higher temperature compared with the other buildings. This uniformity in maximum temperatures is caused by the ventilation practice of the greenhouses, according to which the vents are maintained open during most hours of the day (usually from 07: 30 until 16: 00). In the Sharsheret greenhouses ventilation is applied by rolling up the southern and eastern walls. On clear days or when external temperatures are high, the sliding windows at the tops of the gables are opened as well. The ventilation regime applied in this experiment was identical for all the constructions tested and was determined daily according to the specific weather conditions. Such ventilation regime causes high air exchange rates and enables a very rapid heat exchange, mainly by mass transfer, with the external air. Thus rather similar maximum temperatures are maintained in the greenhouses, regardless of the material used as a roof cover. This happens in spite of the differences in transparency between the materials used (Table 3). The influence of air exchange rates on temperature inside the greenhouses was found to be very significant also in the relatively well closed greenhouses maintained under European conditions (*1*).

The effect of construction type or of roof cover material on temperature was difficult to detect also because of the plants grown inside. Shading, evapotranspiration and the heat capacity of the plants all influence temperature directly, as the plants are a buffering mass to changes in temperature. The soil in the greenhouses is partly isolated from the effect of the construction by the intermediate layer of the plants and therfore cannot store much energy (*4*).

The effect of the plants on climatic conditions inside the greenhouse during the day can be detected by comparing temperatures measured above the plants with those measured among them (Fig. 1). In spite of the high air exchange rates during the day, air temperatures are higher above the canopy than within it, as a result of shading and evapotranspiration.

The plant populations in all greenhouses were similar (age, developmental stage, agrotechnical activities, etc.) and could not cause any significant differences in temperatures in the different constructions.

A relatively small but consistent difference exists between the Venlo and the Sharsheret greenhouses in relation to maximum temperature, with the maximum temperature usually higher in the former than in the latter. The ventilation regime in the Venlo greenhouse was identical to the other greenhouses, but as this construction is lower, its heat storage capacity is smaller and temperature increases faster than in the Sharsheret greenhouse. If a similar air exchange rate is assumed when vents are open, higher temperatures can be expected in the Venlo as the relation: (air exchange rate)/(temperature increase rate) is higher in this greenhouse than in the Sharsheret types.

During the night the greenhouses were maintained closed and no heating was applied. The minimum temperatures reached in the greenhouses were similar in both types of construction and under all the roof cover materials tested (Table 2). The use of a certain material as a roof cover or a certain construction could mostly affect the decrease rate of the temperature inside the greenhouse, according to the thermal conductance properties of each material, the temperature differences between inside and outside, and the air exchange rates. However, ultimately all greenhouses reached similar minimum night temperature values, which were approximately 1°C higher than the minimum external temperature. In Fig. 2 this is shown clearly. The drawn line represents the 1 : 1 slope. At the beginning of the night the temperature decrease rate in the Venlo (Fig. 2b) was greater than the reference (glass-covered Sharsheret), probably due to a larger heat capacity and better isolation properties because of a lower air exchange rate in the latter, leading to a slower temperature decrease rate. The decrease of the external temperature during twilight hours is rapid while that of the greenhouses is relatively slow. During the day, small amounts of heat accumulate in the greenhouses, especially because of the plants which separate the energy source from the soil, which is the main heat capacitor in the greenhouse (*4*). The small amounts of heat stored in the soil during the day are released into the greenhouse's atmosphere during twilight hours. Thus, a large reduction in outdoor temperature is accompanied by only a slight decrease inside, a situation shown clearly in Fig. 2 for outdoor temperatures higher than 17°C.

Later in the night, internal and external temperatures reach similar values, so that there is always a steady state reached between them (Figs. 2a and 2b). Within the canopy, the temperature is about 1°C higher than the external values measured simultaneously, probably due to the interference of plants with the heat transfer.

Observing the whole night temperature regime, differences between the greenhouses can be detected. The night temperature in the P.E.-covered greenhouse (Fig. 2a and 2c), which is penetrable by long-wave radiation, was usually lower than in the other houses. The polycarbonate is not penetrable by long-wave radiation, like glass, but as it has air spaces and fewer air exchanges (Table 5), its heat isolation properties are better than those of glass, and night temperatures under this covering material are higher.

A similar phenomenon can be detected regarding the minimum temperature reached inside the greenhouses on some winter days. In the P.E.-covered greenhouse most of the minimum temperature values were lower, but in the P.C.-covered greenhouse they were higher than elsewhere (Table 2). This phenomenon is not repeated consistently throughout all the winter as the conditions for night-reflected radiation were not similar on different nights.

The small differences detected between the greenhouses in pan evaporation measurements may be explained by the differences in radiation intensity and air exchange rates rather than in relative humidity. Thus, for example, low radiation levels prevailed under the P.C. roof and the pan evaporation values there were usually lower than in other greenhouses.

There were differences between the roof covers regarding radiation levels inside the greenhouses (Table 3). In the P.C. greenhouses radiation levels were lowest, probably due to the multilaminar structure of the material. In winter, radiation levels are low and the roof cover reduces the penetrating radiation to 50%–60% of the outside levels so that plant production is limited in most cases (*6*). Under such conditions, the differences in transparency may be significant to plant growth and development. The fraction of the photosynthetic radiation was larger under the covers, but not to such an extent that could compensate for the 40%–50% decrease in global radiation.

The results of this study indicate that the use of different materials as roof covers, or of different constructions, did not cause significant differences in climatic conditions inside the greenhouses, mostly due to the commonly used management practice applied. It is clear that under such circumstances, the effect of a certain construction on plant growth conditions should be evaluated by measuring plant parameters, e.g. yield, quality, plant development etc. An evaluation based on climatic measurements, as done in this work, may lead to erroneous conclusions.

The effect of the different constructions and roof cover materials on plants will be presented elsewhere (*2*).

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