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# UNIFORMITY OF AIR TEMPERATURE AND RELATIVE HUMIDITY INSIDE AND OUTSIDE THE DIFFERENT TYPES OF GREENHOUSES
# DISTRIBUCIJA TEMPERATURE I RELATIVNE VLAŽNOSTI VAZDUHA UNUTAR OBJEKATA ZAŠTIĆENOG PROSTORA RAZLIČITE KONSTRUKCIJE

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## *ABSTRACT*

*Greenhouse plant production is one of the most intensive parts of the agricultural production. In order to reduce the costs and save the energy, various greenhouse constructions and different coverings are offered to the farmers. One of the biggest problems is in winter production when additional heating and light are needed as well as in summer when intensive cooling is needed. During these period construction and coverings fully show their qualities. The aim of this research was to investigate the temperature and air relative humidity distribution in the different greenhouse constructions in the different production systems in order to see if the choice of the greenhouse construction can improve the production conditions inside the greenhouse enabling the better energy efficiency and lower energy input for heating / cooling. Air temperature and relative humidity were tracked in the open field and in the two types of greenhouses (tunnel and gutter connected type) in the lettuce and tomato production.Results show that temperature pattern and its values during the night and day depend on the greenhouse construction, plant specie that is grown and production season. Gutter connected type of construction showed more uniform production conditions inside the greenhouse. In the winter production conditions temperature oscillations were not significant and were lower compared to the values measured in the tunnel construction type greenhouse.*

***Key words**: tunnel, gutter-connected greenhouse, air temperature, air relative humidity, lettuce, tomato.*

## *REZIME*

*Proizvodnja u zaštićenom prostoru je jedna od najintenzivnijih grana poljoprivredne proizvodnje u smislu potrošnje energije i ostvarenog prinosa. Na tržištu je veliki broj pokrivnih materijala i materijala konstrukcije kojima se može uštedeti energija i time povećati energetska efikasnost proizvodnje u zaštićenom prostoru. Jedan od značajnijih problema koji se javlja kod ovog vida proizvodnje su nepovoljni temperaturni uslovi tokom zimskog i letnjeg perioda. Pravilnim izborom konstrukcije, pokrivnog materijala i orijentacije objekta nepovoljni uticaji niskih temperatura tokom zime i visokih temperatura tokom leta, se mogu ublažiti. Cilj ovog rada je bila analiza temperaturnih i uslova relativne vlažnosti vazduha u objektima zaštićenog prostora različite konstrukcije u proizvodnji salate i paradajza kako bi se videlo da li se izborom konstrukcije objekta zaštićenog prostora može uticati na ravnomernost proizvodnih uslova u objektima, i samim tim, na kvalitet proizvodnje i ostvareni prinos. Prema navedenom cilju, temperatura i relativna vlažnost vazduha su praćeni unutar objekta (njegovom dužinom i visinom) i izvan objekta, tokom proizvodnje zelene salate i paradajza. U istraživanje su bila uključena dva objekta zaštićenog prostora, i to tunel i dvobrodni plastenik. Rezultati ukazuju na postojanje razlika u rasporedu temperature i relativne vlažnosti vazduha unutar objekata različite konstrukcije. Blok objekat se pokazao kao sredina sa uniformnim rasporedom temperature i relativne vlažnosti dužinom objekta tokom čitavog dana. U zimskom periodu su oscilacije temperature bile manje značajne nego kod objekta tunel tipa.*

***Ključne reči**: tunel, blok objekat, temperatura vazduha, relativna vlažnost vazduha, zelena salata, paradajz.*

## INTRODUCTION

Factors that determine the greenhouse production system are air temperature, relative humidity of air and soil, air quality and light conditions. Tracking these micro-climatic conditions is of a great importance for the successful greenhouse production (*Ponjičan et al., 2011, Babić et a.l, 2004*, *Karadžić, 2005*).

Various types of greenhouse constructions and covering materials are available at the market and are offered to the farmer (*Dimitrijević et al., 2011)*. Purpose of tracking the greenhouse production continuously is to optimize the plant productions in the greenhouse. It is necessary to know the correlation between greenhouse construction, covering material and type of the plant production.

Temperature conditions in the greenhouses influence the overall plant growth, yield and fruit quality. If the air temperature and relative humidity in the greenhouse are lower than optimal plants will be shorter with smaller dark green leaves. In the case of lower temperature and higher relative air humidity flowering of the plants will be delayed and the yield will be lower. Higher night temperatures cause the higher consumption of organic matter by plants which grow with the long pale green gently leaves with the lower yield and deformed fruits. It is stated (*Lazić Branka et al., 2001, Hanan, 1998, Nelson, 2003*) that night temperatures and the temperatures during the day should be 3–5° C lower compared outside temperatures during the sunny days. It is also stated that temperature variations during the day should not be more than 2 do 3° C. Literature sources (*Lazić Branka et al., 2001, Hanan, 1998, Nelson, 2003, Sengar and Kothari, 2008, Singh and Tiwari, 2000*) confirm the statement that temperature in greenhouses varies along their length, width and height. The pattern of this variation is influenced by the greenhouse type of construction and its dimensions, covering material, orientation and applied heating and venting systems.

The aim of this paper was to show how the type of greenhouse construction, production season and plant species can influence the uniformity of the micro-climatic conditions in the greenhouses.

## MATERIAL AND METHOD

For the purpose of the research a tunnel type (TUN) 5.5 x 24 m covered with 180 μm PE UV IR outside folia (Figure 1) and a gutter connected plastic covered greenhouse (GUT) 21 x 250 m and with 50 μm inner folia and 180 μm outside folia were used.

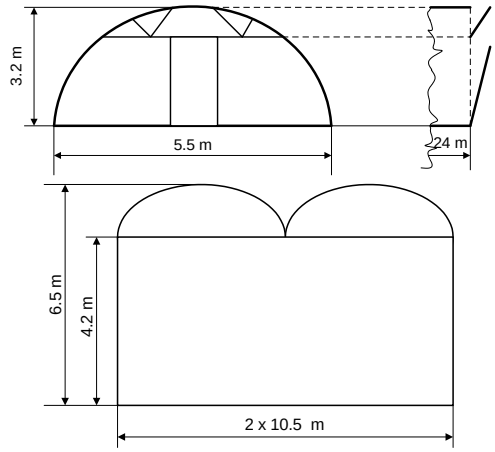



*Fig. 1. Tunnel and gutter connected greenhouses*

Production surface of the tunnel greenhouse was 132 $m^2$, covering material / production area ratio was 19.91 and its specific volume was 12.56 $m^3$/m. Gutter-connected greenhouse had the 5250 $m^2$ production surface, covering material / production surface ratio 1.62 and specific volume of 37.92 $m^3$/m. Experiment was carried out at the private property in Pancevo and at a private property near Jagodina (Serbia).

Temperature and air humidity were measured using the sets of WatchDog Data loggers 150 Temp/RH, t= 0.6 °C and RH= 3 % and a WatchDog Data Logger Model 450 – Temp, Relative Humidity - Temp/RH, t= 0.6 °C and RH= 3 %. In the tunnel greenhouse, lettuce production conditions were analysed for the October 2008 production season while tomato production conditions were analysed for the summer 2008 production season. In the gutter connected greenhouse lettuce production conditions were analysed for the winter 2008/09 production season while tomato production was analysed for the summer 2008 production season. Both of the greenhouses were without heating systems.

Statistical analysis of the results was based on variance analysis, F tests and LZD tests which were used to determine if the temperature and relative humidity are uniform along the greenhouses and if the type of construction and plant specie influence the temperature and relative humidity uniformity. Data used for the analysis represent the five days average values.

## RESULTS AND DISCUSSION

### Temperature distribution

According to some authors (*Enoch, 1978, Hanan, 1998, Nelson, 2003*) tunnel greenhouses are considered to be the simplest form of the greenhouses in which temperature and the other production parameters vary during the day significantly depending on the outside climatic parameters.

Temperature measurements in the tunnel greenhouse show that temperature varies along the greenhouse. During the night it was highest on the north side and lowest on the south side of the greenhouse (Tab. 1). In the morning hours the highest temperature was observed in the central part, while in the afternoon hours the highest temperature was measured in the south part of the greenhouse while the lowest was measured in the north part. Statistical analysis of the data showed that temperature differences along the greenhouse during the night are not significant. The LSD test (0.05 and 0.01 significant level) of the morning temperatures showed that there is a very significant difference in the temperatures along the greenhouse (Fig. 2). These values were 2.05 °C and 2.74 °C for the given levels of significance. Temperature difference of 2.63 °C between the south and the central part of greenhouses showed to be significant. Variation coefficient was 10.82 % and standard deviation 1.11 °C. Measurements in the 13h also showed variations in the temperature along the tunnel greenhouse. Temperature was highest in the south part and lowest in the north part (Tab. 1). Variance analysis confirmed that these differences are significant and based on the LSD test it was concluded that difference of 5.13 °C between south and central part was significant and that difference of 6.91 °C between south and north side was very significant (Fig. 2). Variation coefficient was 8.32 % while standard deviation was 2.93 °C.

*Table 1. Temperature variation inside and outside the greenhouses in the lettuce production*

| | Time of the day | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | 1h | | 7h | | 13h | | 19h | |
| | TUN | GUT | TUN | GUT | TUN | GUT | TUN | GUT |
| INSIDE | | | | | | | | |
| North side | 9.21 | 0.85 | 9.15 | 2.46 | 32.32 | 15.05 | 13.18 | 1.79 |
| Centre part | 8.88 | 1.31 | 11.78 | 2.69 | 34.10 | 15.67 | 12.10 | 2.35 |
| South side | 8.87 | 3.41 | 9.85 | 3.36 | 39.23 | 13.12 | 12.55 | 4.88 |
| Average | 8.99 | 1.86 | 10.26 | 2.84 | 35.22 | 14.61 | 12.61 | 3.01 |
| OUTSIDE | 8.66 | -2.63 | 10.28 | -2.25 | 22.84 | 14.64 | 15.46 | -1.52 |
| Inside/outside difference | 0.33 | 4.49 | -0.02 | 5.09 | 12.38 | -0.03 | -2.85 | 4.53 |

Measurements in 19h (Tab.1) show that the north part had the highest temperature and the central part had the lowest temperature. Variance analysis showed that these are significant differences and the LSD test showed that the difference of 1.08 °C was significant between north and central part. Coefficient of variation was 3.49 % and standard deviation 0.44 °C. It can be concluded that in the case of lettuce production in the tunnel greenhouse one could expect significant temperature variation along its length during the day.

Statistical analysis for testing the mean values showed that there are differences between inside and outside temperature in the tunnel structure and that these differences are very significant in the afternoon hours (Fig. 3). This means that during the night and early morning hours one should not expect significantly higher temperatures inside the greenhouse compared to the outside temperatures.

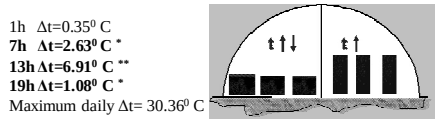



*Fig. 2. Temperature variation significance in the tunnel lettuce and tomato production*

In the winter vegetable production the most critical are the temperatures during the night. Temperature measurements in the gutter-connected greenhouse in lettuce production show variations during the day and along the greenhouse. The lowest temperature was observed during the night in the north part of the greenhouse (Tab. 1). Statistical analysis showed that temperature does not vary significantly along the greenhouse in the night.

Variation coefficient was 59.68% while standard deviation was 1.11 °C. The same situation was observed for all other measuring periods (Fig. 4). This means that in the gutter-connected greenhouse temperature does not vary significantly along its length which means that in the case of winter lettuce production more uniform temperature conditions can be expected in the gutter-connected greenhouses compared to the tunnel structures. Concerning the fact that both type of greenhouses had the same covering material, with the same period of exploitation the reasons for these differences in the temperature uniformity distribution can be searched in the type of construction, its volume and orientation. Tunnel greenhouse is a single span type of greenhouse with the specific volume of 12.56 $m^3$/m and covering material / production surface ratio of 1.91 while gutter-connected greenhouse is a type of multi-span greenhouse with the specific volume of 37.91 $m^3$/m and covering material / production surface ratio of 1.62. It is stated *(Nelson, 2003, Hanan, 1998)* that the smaller is the ratio covering material / production surface the smaller is the surface of the greenhouse that is exposed to the weather and thus are the heating requirements lower because the temperature conditions in the greenhouses are more uniform. The other parameter that can be responsible for the temperature oscillation is the greenhouse orientation. Single span greenhouses in this region should be orientated north-south but in this case the orientation was east-west.

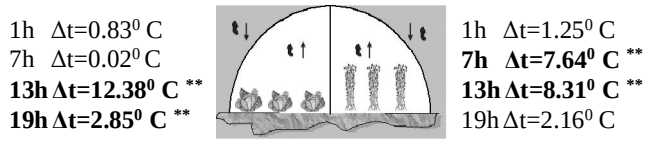



*Fig. 3. Outside / inside tunnel temperature differences in lettuce and tomato production*

Measurements of the outside temperature (Tab. 1) showed that the temperature in the greenhouse was significantly higher compared to the outside during the day as well as during the night (Fig. 5). During the night temperature was up to 5.47 °C higher compared to the temperature outside the greenhouse. During the days these differences are even higher (up to 18.83 °C at 13h). When inside and outside temperature patterns are analysed it can be concluded that the gutter-connected greenhouse is well thermally balanced. Inside temperature is stabile and does not vary much during the day and along the greenhouse length enabling to all the plants in the greenhouse to have the same production conditions.

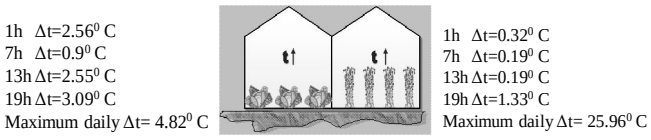



*Fig. 4. Temperature variation significance in the gutter-connected lettuce and tomato production*

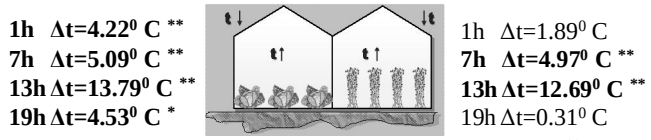



*Fig. 5. Outside / inside gutter-connected temperature differences in lettuce and tomato production*

In the summer greenhouse vegetable production it is important to have good ventilation systems that will lower the temperature in the greenhouses and that will eliminate parts of the greenhouses with high temperature. Temperature measurements in the tunnel and gutter-connected greenhouse show that the temperature varies during the day (Fig. 2 and Fig. 4), being the lowest in the night and the highest in the noon, as well along the greenhouses (Tab. 2) being in most of the cases the highest in the central part of the greenhouses.

*Table 2. Temperature variation inside and outside the greenhouses in the tomato production*

| | Time of the day | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | 1h | | 7h | | 13h | | 19h | |
| | TUN | GUT | TUN | GUT | TUN | GUT | TUN | GUT |
| INSIDE | | | | | | | | |
| North side | 15.80 | 17.67 | 22.87 | 22.42 | 37.26 | 42.55 | 25.35 | 24.86 |
| Centre part | 16.63 | 17.99 | 23.05 | 22.54 | 38.56 | 43.63 | 27.97 | 23.50 |
| South side | 16.10 | 17.84 | 24.13 | 22.35 | 36.26 | 42.44 | 26.20 | 23.51 |
| Average | 16.07 | 17.83 | 23.32 | 22.44 | 37.36 | 42.87 | 26.51 | 23.96 |
| OUTSIDE | 14.93 | 17.83 | 15.71 | 17.46 | 29.05 | 30.18 | 24.35 | 23.95 |
| Inside/outside difference | 1.14 | 0 | 7.61 | 4.98 | 8.31 | 12.69 | 2.16 | 0.01 |

The exception was the tunnel structure in the morning hours where south side was with the higher temperature and the gutter-connected greenhouse in the afternoon hours where north part of greenhouse had the higher temperature.

As for the differences in the greenhouses inside and outside temperatures the results have the similar tendencies for the tunnel and gutter-connected greenhouse. In both cases temperature differences appear to be significant in the early morning hours and in the noon (Fig. 3 and Fig. 5). In case of tunnel greenhouse the temperature difference in the 7 h was up to 11.07 °C and statistical analysis showed that these differences were very significant. The similar results were obtained for the measurement in 13h. The differences were up to 13.18 °C and, after statistical analysis, showed to be very significant. In the gutter-connected greenhouse similar results were obtained. Temperature differences during the night and in the evening were not statistically significant. Measurements in 7 h showed that temperature in the greenhouse was up to 11.35 °C higher compared to the outside temperatures. Statistical analysis showed that the differences of 3.37 °C can be considered as very significant. Measurements in 13 h show that temperature inside the greenhouse was up to 22.16 °C higher compared to the outside temperature. Statistical analysis showed that temperature difference of 5.02 °C can be considered as very significant.

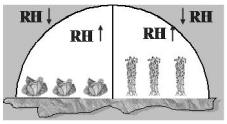
In this way it can be concluded that in the summer tomato production in the tunnel and gutter-connected greenhouse temperature conditions in the greenhouses do not vary much along the greenhouse length. Significant differences were only observed in the inside and outside temperatures in both greenhouses in the early morning hours and at noon. Concerning the temperature values, these oscillations can be considered as acceptable.

## Relative humidity distribution

Relative humidity is a very important factor of plant growth and development because it influences plant transpiration, photosynthesis and disease risks. Different plants have a different demand concerning the air relative humidity. Optimal relative humidity for cucumber is very high (90 - 95%) while for the tomato it is 50 - 65%. Literature (*Lazić Branka et al., 2001, Hanan, 1998, Nelson, 2003, Sengar and Kothari, 2008, Singh and Tiwari, 2000*) states that air humidity varies during the day and along the greenhouse length and height. It is stated that the pattern of variation depends on greenhouse type of construction its dimensions, covering material and the plant specie that is produced in the greenhouse.

In the tunnel lettuce production, relative humidity measurements showed that there are differences between outside and in-

side values as well as differences in the greenhouse during the day. Results show that relative air humidity inside the greenhouse is higher through the day if compared to the outside. Statistical analysis showed that differences between inside and outside relative air humidity were very significant in the early morning hours, in the evening and in the night (Fig. 6). In the early morning the differences were up to 68.97% and 52.69% difference was considered to be very significant. In the evening the difference of 53.2% was considered as very significant. In the night the average difference was 55.71% and was considered to be very significant.




**1h ΔRH=55.71% ****
**7h ΔRH=52.69% ****
13h ΔRH=2.49%
**19h ΔRH=53.2% ****

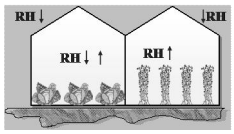
**1h ΔRH=29.4% ****
**7h ΔRH=22.81% ****
13h ΔRH=2.44%
**19h ΔRH=31.61% ****

*Fig. 6. Outside / inside tunnel air relative humidity differences in lettuce and tomato production*

This result was expected taking into account the plant respiration that, as a consequence, has production of heat, water and $CO_2$. Since no ventilation was applied, because of the temperature uniformity, the relative humidity in the tunnel was growing higher up till early morning hours.

Measurements of the relative air humidity in the gutter-connected greenhouse show that great care must be taken into account when choosing the type of greenhouse construction. Like in the case of tunnel construction, air relative humidity in the greenhouse show variations compared to the outside relative air humidity. Statistical analysis of the obtained data shows that these differences are not significant (Fig. 7). During the night hours air relative humidity was even lower inside the greenhouse. In average it was 6.52% lower. In the early morning hours air relative humidity was higher inside the greenhouse. In average the difference was 3.68% higher and it was considered not to be significant. Measurements show that in 13h relative air humidity was higher outside the greenhouse. Again, in the afternoon, air in the greenhouse had higher relative humidity.

1h ΔRH=6.52%
7h ΔRH=3.86%
13h ΔRH=2.56%
19h ΔRH=3.24%




**1h ΔRH=31.59% ***
**7h ΔRH=25.49% ****
13h ΔRH=1.5%
**19h ΔRH=24.92% ***

*Fig. 7. Outside / inside gutter-connected greenhouse air relative humidity differences in lettuce and tomato production*

Gutter-connected greenhouse has showed to be beneficial in the case of tomato production since tomato plants are not adjusted to the higher values of air relative humidity. In the tunnel greenhouse air relative humidity was higher through the day and night compared with the outside air relative humidity. Statistical analysis of the obtained data (Fig. 7) shows that these differences were all very significant except in the midday period. During the night the differences in the air relative humidity were up to 37.4%. In the early morning hours these differences were up to 31.3%. In the middle of the day the differences were the lowest and were up to 3.29%. In the afternoon hours air relative humidity inside the tunnel rose and the differences were up to 43.99%. In the gutter-connected greenhouse there was the same tendency but the differences between inside and the outside air relative humidity were smaller. Again the differences were significant in the afternoon hours and during the night. In the early morning hours the differences were the highest (up to 39.33%) and were, statistically, considered to be very significant.

## CONSLUSION

Obtained results show that micro-climatic conditions in the greenhouse vary during the day and along the greenhouse length. The variation pattern depends on the greenhouse type of construction, its orientation, plant production season and type of plant production. Generally it can be concluded that regarding the both lettuce and tomato production tunnel greenhouse construction can not be recommended as an optimal choice. Its specific volume was 12.56 $m^3/m$ while covering material / production surface ratio was 1.91. In the winter it does not provide significantly higher temperatures inside the greenhouse. Also the temperature conditions inside the greenhouse are not uniform and stabile. In the summer production higher air relative humidity brings the risk of introduction of plant diseases. On the other side gutter-connected greenhouse, having the specific volume of 37.92 $m^3/m$ and covering material / production surface ratio of 1.62, in the winter production conditions provides more uniform temperature inside the greenhouse and provides significantly higher temperatures during the day. In the summer production variation of the temperatures were observed only in the midday section. Relative humidity inside the greenhouse was higher but the differences were much lower compared to the differences obtained in the tunnel structure.

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