

# Numerical Modelling of Radiation-Convection Coupling of Greenhouse Using Underfloor Heating

Yan Jia\*, Can Wang\*, Chi Zhang, Wenxiong Li

Department of Energy and Power Engineering, Inner Mongolia University of Technology, Hohhot, China

Email: \*2497331641@qq.com, 421388331@qq.com

**How to cite this paper:** Jia, Y., Wang, C., Zhang, C. and Li, W.X. (2017) Numerical Modelling of Radiation-Convection Coupling of Greenhouse Using Underfloor Heating. *Open Journal of Fluid Dynamics*, 7, 448-461. <https://doi.org/10.4236/ojfd.2017.73030>

**Received:** July 25, 2017

**Accepted:** September 25, 2017

**Published:** September 28, 2017

Copyright © 2017 by authors and Scientific Research Publishing Inc.

This work is licensed under the Creative Commons Attribution International License (CC BY 4.0).

<http://creativecommons.org/licenses/by/4.0/>



Open Access

## Abstract

Greenhouse is an important place for crop growth, and it is necessary to control the temperature of growing environment in winter. In addition, the root temperature underground also plays a decisive role for plants growth. Adopting underground heating to increase the temperature can effectively improve the yield of crops. The objective of our study was to model the heat transfer of greenhouse underfloor heating which is analyzed and simplified based on the FLUENT software by changing the several important factors that affect the temperature distribution: pipe diameter, pipe spacing, laying depth, supplied water temperature and flow rate, as boundary conditions to simulate the changes of the soil temperature field around the winter night environment. Researching the temperature distribution of the greenhouse, the soil surface and the plant root layer under the different parameters and the basic rules of the heating system are summarized. The results show that the water supply temperature, pipe spacing and diameter of the pipe has a greater impact on the ground and room temperature, and the laying depth has greater impact on the temperature uniformity of the ground, the velocity of water in pipe has little impact on the uniformity of ground temperature.

## Keywords

Greenhouse, Underfloor Heating, Radiation-Convection Coupling, CFD

## 1. Introduction

The growth temperature of plants determines the crop yield and the economic benefits of planting in winter, especially the root temperature. The temperature of the growth period is about 20°C to 22°C, which is the most suitable, and the

minimum temperature should not be less than 17°C. In northern China, temperatures in winter are often maintained at a very low level, especially temperatures at night, which can hardly meet the conditions of plant growth. In the heating of the greenhouse, the use of traditional furnace heating can cause pollution to the environment, consumption of fossil fuels, and uneven distribution of indoor temperature, and the ground temperature cannot be significantly improved. Adopting new energy instead of the traditional heating method for the new heating system is necessary [1] [2] [3].

Adopting floor low temperature hot water radiant heating can effectively solve this problem. The study of this paper is based on solar heat collection heating system, which turn the clean energy solar energy into the energy of the water of the pipes underground through the heat exchanger in daytime, and when the hot water reaches the set heating temperature, it will be carried to the pipeline of the greenhouse, which will heat the greenhouse [4] [5].

The laying of pipe, pipe diameter, water supply temperature and flow rate are important factors that affect greenhouse temperature and plant root temperature. On the other hand, outdoor real-time changes in air temperature, wind speed, soil temperature and greenhouse envelope material also affect the greenhouse temperature distribution. But these external factors are uncontrollable and the existing specific parameters are not taken as the main direction of the study. In this paper, the CFD method is adopted to study the temperature distribution under different parameters of the ground heating system by establishing a simplified greenhouse convection-radiation coupling model. Compared with the experimental method, CFD is a simpler and more intuitive method for temperature measurement and pipeline laying changes of large-scale greenhouse, which has been widely used in various horticulture and agriculture areas in recent years [6] [7] [8] [9] [10].

Many experts and scholars have used CFD method to study the various types of heating of the greenhouse microclimate. Abel Rouboa (2006) simulated the effects in the temperature and velocity fields by the introduction of hot water tubes along a greenhouse in night conditions. Three different situations are simulated: natural convection heating (A), artificial heating tubes (B), and natural ventilation (C). The numerical results are compared with experimental values. The average increase in air temperature for case A is highest. Turbulence is lower in case A, increase slightly in case B, and increase significantly in case C due to the effect of natural ventilation [11]. Mohammad Javad Izadi (2009) modeled flow of air in a 3D flow field surrounded by several walls and windows as laminar, and flow of room as turbulent in incompressible flow conditions. The variables are two models of pipes arrangements, three types of pipes, and several pipe diameters. As a result, in an underfloor heating system, the reciprocating model using the PAP pipe type of 16 mm pipe diameter are the best parameter values for a good comfortable room temperatures [12]. Chen Jiao Liao (2011) proposed optimized design of hot air pipe in greenhouse based on CFD tech-

nique. The standard K- $\varepsilon$  turbulence model and the Non-gray DO model of radiation model were applied. Compared with CFD simulation results of 8 cases, according to the air pressure distribution in the HAP, the structure is optimized by adjusting the distance of exhaust outlet to 1.05. The simulation and experiment results show that heating effect of optimized structure is better than the results of other cases [13]. Ahmed Mezrhab (2010) analyzed the effects of the radiation exchange inside a horticultural greenhouse, under winter climatic conditions, according to the number of squared heating tubes used. Results are reported in terms of isotherms, streamlines and average Nu number for Ra number of 103 - 106. As a result, the rise in the value of Ra number leads to an increase of the overall heat transfer within the greenhouse [14]. Romona-Oana Grigoriu (2015) proposed a system developed to provide heat for a greenhouse using parabolic trough collectors (GHPTC) to maintain the temperature inside the greenhouse. The proposed model consists of two parts: the greenhouse model and the collector's model. Based on the linearized model, a PID controller was tuned and used to control the internal temperature in the greenhouse. The control method is suited for the system according to the obtained stationary and transient response performances [15].

The above references are all about the temperature field changes within the greenhouse and the optimization based on the temperature inside the greenhouse. In contrast, this paper considers the temperature distribution within the soil that meets the plant's growth needs. In this paper, a simplified greenhouse convection-radiation coupling model is established by CFD method, using RNG K- $\varepsilon$  turbulence model and DO radiation model. This paper sums up the basic rules of the heating system and obtains the solution which is suitable for the optimization of the heating system in the greenhouse by changing the factors that influence the temperature distribution, the diameter distribution, the pipe spacing, the laying depth, the water supply temperature and the water flow rate, and researching the temperature distribution of the greenhouse, the soil surface and the plant root layer under the different parameters of the geothermal heating system.

## 2. Methods

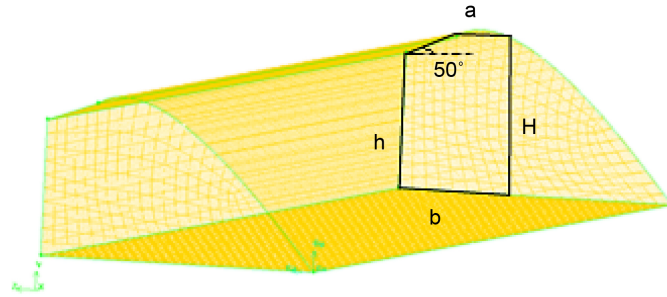
### 2.1. Thermal Modeling

The general structure of the solar greenhouse in the north is 50 m long, the span of which is 8m, the back wall of which is 3 m, the ridge height of which is 4.7, and the rear slope is about 50°, and the front roof is covered with plastic film, as shown in **Figure 1**. Using heating pipes in greenhouse is a complex heat transfer process, in which radiation and convection are two main ways of heat transfer.

The convective heat transfer coefficient of the floor surface is given by the follows:

$$Nu = 0.11(Gr \times Pr)^{1/3} \quad (1)$$

$$h = 1.18(T_p - T_n)^{1/3} = 2.17(T_p - T_n)^{0.31} \quad (2)$$



**Figure 1.** The structure of the greenhouse.

The integrated heat transfer per unit floor surface is given by the follows:

$$q_{ch} = q_d + q_f = 2.17(T_p - T_n)^{1.31} + 4.98 \times 10^{-8} \left[ (T_p)^4 - (T_n)^4 \right] \quad (3)$$

where  $T_p$  is the average temperature of the floor surface, K;  $T_n$  is the average temperature of the indoor air, K;  $q_d$  is the convection heat transfer per unit floor, W/m<sup>2</sup>;  $q_f$  is the radiation heat radiation per unit floor, W/m<sup>2</sup>.

The heating pipe wall and hot water heat transfer equation is:

$$Q = GC_p(t_g - t_h) = q_l \times l \quad (4)$$

The heat transfer per unit length pipe is:

$$q_l = \frac{t - t_w}{\frac{1}{\pi d_1 h} + \frac{1}{2\pi \lambda_1} \ln\left(\frac{d_2}{d_1}\right)} \quad (5)$$

The pipe wall temperature is:

$$t_w = t - \frac{Q}{L} \left[ \frac{1}{\pi d_1 h} + \frac{1}{2\pi \lambda_1} \ln\left(\frac{d_2}{d_1}\right) \right] \quad (6)$$

where  $Q$  is the total indoor heat load, W;  $W$  is the hot water flow rate in the heating pipe, kg/s;  $t$  is the average temperature of the return water, K;  $h$  is the convective heat transfer coefficient, W/(m<sup>2</sup>·K),  $L$  is the length of the heating pipe, m;  $\lambda_1$  is the thermal conductivity of the pipe wall, W/(m·K).

## 2.2. Mathematical Modeling

When the temperature of the greenhouse gas increased due to heating, the gas will flow. The Boussinesq hypothesis is usually adopted to deal with the buoyancy term which is caused by the temperature difference. Under these assumptions, the viscous dissipation in the fluid is neglected, and the physical properties other than the density are considered constant, and the density only takes the terms relates to momentum equation and the volume into account.

When doing the natural convection calculation in the closed large space, determine the laminar flow and turbulence by the Ra number, the flow is called turbulent flow when Ra is greater than 1010. Because of the larger size of the greenhouse, the result got from the research of related literature contains  $Ra = 2 \times$

1013 and other data, and it is realistic to use the turbulence model to calculate. In this paper, the RNG K- $\varepsilon$  model with high accuracy and accuracy is adopted, and the standard wall function method is used to deal with the low Reynolds number motion near the wall. In the simulation conditions of this paper, the air radiation absorption rate is very low, and coupling heat transfer calculation is needed, so discrete radiation coordinates (DO) model is chosen to solve the problem.

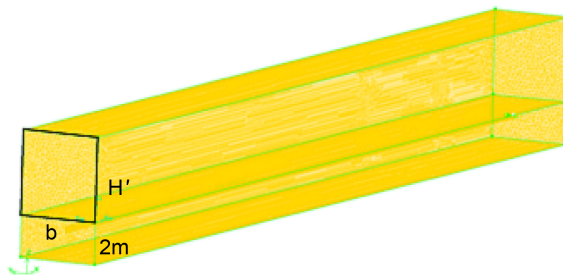
The fluid follows the mass, momentum and energy conservation equations, and the most commonly used is SIMPLE (Semi-implicit method for pressure-linked equations) algorithm proposed by Patanka currently. That is, using the mass conservation equation to make the assumed pressure field be continuously improved with the iterative process. The general form of SIMPLE algorithm adopted in this paper is as follows:

$$\frac{\partial(\rho\varphi)}{\partial t} + \text{div}(\rho v\varphi) = \text{div}(\Gamma_{\varphi} \text{grad}\varphi) + S_{\varphi} \quad (7)$$

where  $S$  is a general variable;  $\Gamma_{\varphi}$  is the effective exchange coefficient corresponding to  $\varphi$ , dimensionless;  $v$  is the velocity vector, m/s;  $S_{\varphi}$  is the source term corresponding to  $\varphi$ , including the generator term and dissipation term, J.

### 2.3. Meshing and Boundary Conditions

Due to serpentine symmetrical distribution of the pipes, in order to facilitate the analysis, this paper selected the latter half of the greenhouse as a research object, in the case of ensuring the volume being equal, the rectangular height got is  $H' \approx 4$  m, simplifying which to  $50 \times 4 \times 4$  rectangular space. The roots of general greenhouse crops are in the length of 20 - 35 cm, so the laying depth of the pipe should be set within 60 cm, which is appropriate. So select the indoor  $50 \text{ m} \times 4 \text{ m} \times 4 \text{ m}$ , and rectangular space 2 m deep in the soil layer 2 m as the calculation domain. The solar greenhouse calculation model established using Gambit is shown in **Figure 2**. Divide the fluid area which takes air as the medium as 1, and the solid area which takes soil as the medium as 2, and the fluid area which takes water as the medium as 3 when establishing. Because of the complexity of the shape of the internal underfloor pipe in the greenhouse model, adopting the



**Figure 2.** The solar greenhouse model established using Gambit.

unstructured grid can be more efficient, and the paper divide the three area into 1,175,723 grids by adopting tetrahedral meshing method.

The factors affecting the temperature distribution in the greenhouse are shown in **Table 1**.

In the junction surface between the fluid region and the solid region, the surface is set to the wall type, and the shadow surface is automatically generated in the fluent software. The boundary condition is set as coupling, and the interaction and influence of heat conduction, convective heat transfer and radiation are also considered. Soil boundary is set to constant temperature wall. The envelope boundary is set to convective radiation coupling heat transfer. Detailed boundary condition parameters are shown in **Table 2**.

### 3. Result and Discussion

Floor temperature of the greenhouse not only affects the growth environment of the entire plant, but also has a great impact on human comfort. The temperature which makes people feel fit in winter is 22°C - 25°C, for the area like the greenhouse that people stay for a short time, keep the temperature around 20°C can meet the demand. While the plant root needs higher temperature to grow, maintain the temperature at 20°C - 22°C can meet the growth conditions of ordinary vegetable crops.

The greenhouse ground temperature distribution when the pipe spacing is 0.5 m, 1 m, 1.5 m is shown in **Figure 3**.

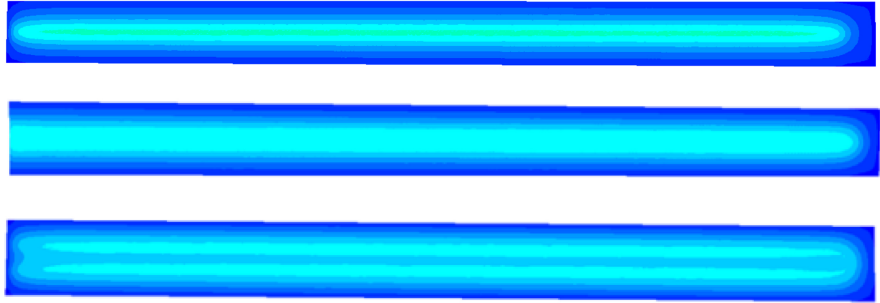
The greenhouse temperature distribution in the depth of 30 cm under the ground when pipe spacing is 0.5 m, 1 m, 1.5 m is shown in **Figure 4**.

**Table 1.** The factors affecting the temperature distribution in the greenhouse.

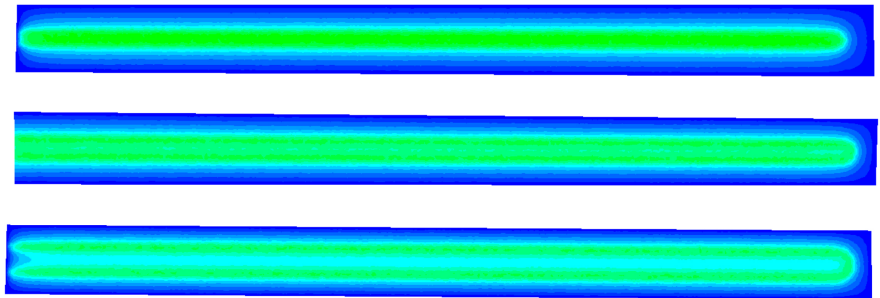
Influencing factors	Parameter value		
Pipe spacing (m)	0.5	1	1.5
Laying depth (m)	0.4	0.5	0.6
Inlet temperature (K)	313	318	323
Diameter (mm)	160	200	
Water flow rate (m/s)	0.6	0.8	

**Table 2.** Detailed boundary condition parameters.

Boundary name	Boundary condition type	Material	Temperature	Others
Enclosure	WALL	Brick	$T = 288 \text{ K}$	$H = 21 \text{ W}/(\text{m}^2 \cdot \text{K})$
Soil layer	WALL	soil	$T = C = 278 \text{ K}$	—
Water inlet	Velocity-inlet	—	$T = 313 \text{ K}$	$V = 0.6 \text{ m/s}$ , $0.8 \text{ m/s}$
Water outlet	Pressure-outlet	—	—	$P = 101,326 \text{ Pa}$
Pipe	WALL	PE pipe	—	—



**Figure 3.** The greenhouse ground temperature distribution when pipe spacing is 0.5 m, 1 m, 1.5 m.



**Figure 4.** The temperature distribution in the depth of 30 cm under the ground when pipe spacing is 0.5 m, 1 m, 1.5 m.

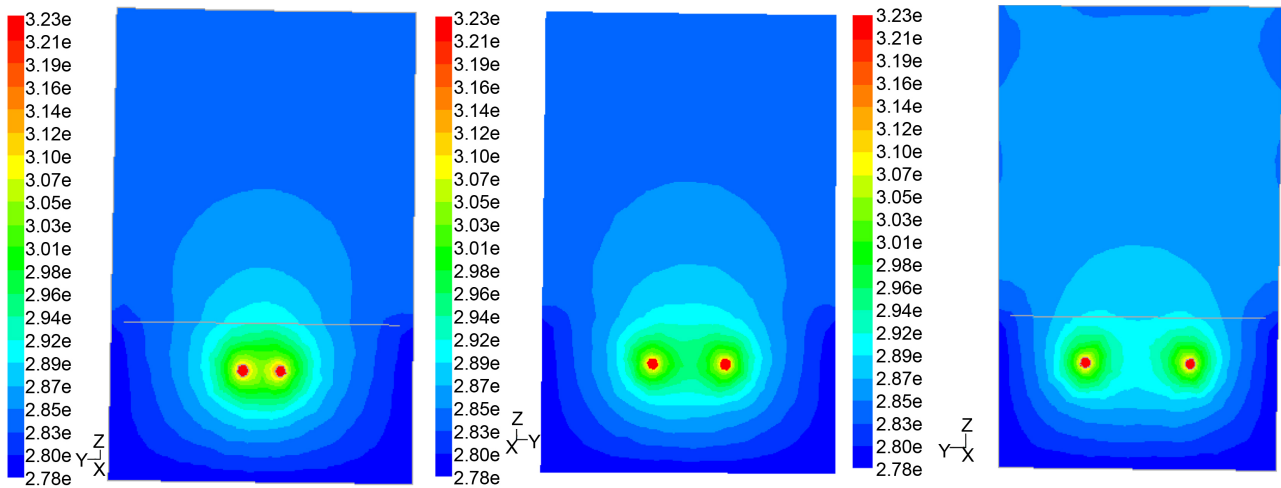
The temperature distribution inside the greenhouse when pipe spacing is 0.5 m, 1 m, 1.5 m are shown in **Figure 5**.

The difference of the average temperature of ground temperature with different pipe spacing is 285.8 K, 286.3 K and 286.7 K respectively, which is not too significant. The maximum local temperature of the ground is 293.8 K, 291.5 K, 291.5 K respectively. The average heat flux of the floor is  $13.4 \text{ W/m}^2$ ,  $16.1 \text{ W/m}^2$ ,  $11.2 \text{ W/m}^2$ . The difference of the average temperature in root of different pipe spacing is not significant, which is 287.4 K, 288 K, 288.3 K respectively. The maximum local temperature of the roots is 300.5 K, 298.3 K and 298.3 K respectively. The average room temperature is 284.1 K, 284.3 K, 285.4 K, the 2 m high temperature of the room is 287 K. It can be seen from the data that the distribution is more uneven when the spacing is 0.5 m, and the difference of both the average temperature and local temperature is very large, and the heat flux density is small when the spacing is 1.5 m, and the distribution is the most even when the spacing is 1 m, and the High temperature range close to the pipe is also larger. After integrated consideration, the pipe spacing being 1 m is the most reasonable.

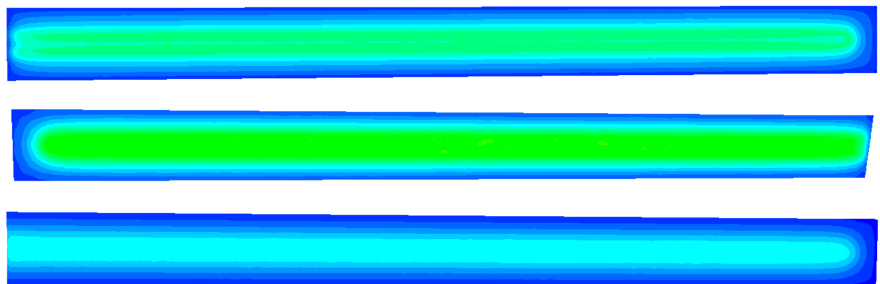
The greenhouse ground temperature distribution of when the laying depth is 0.4 m, 0.5 m, 0.6 m is shown in **Figure 6**.

The greenhouse temperature distribution in the depth of 30 cm under the ground when the laying depth is 0.4 m, 0.5 m, 0.6 m is shown in **Figure 7**.

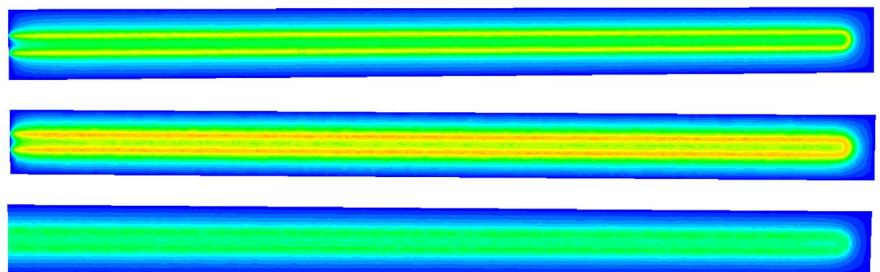
The temperature distribution inside the greenhouse when the laying depth is



**Figure 5.** The temperature distribution inside the greenhouse when pipe spacing is 0.5 m, 1 m, 1.5 m.



**Figure 6.** The greenhouse ground temperature distribution when the laying depth is 0.4 m, 0.5 m, 0.6 m.

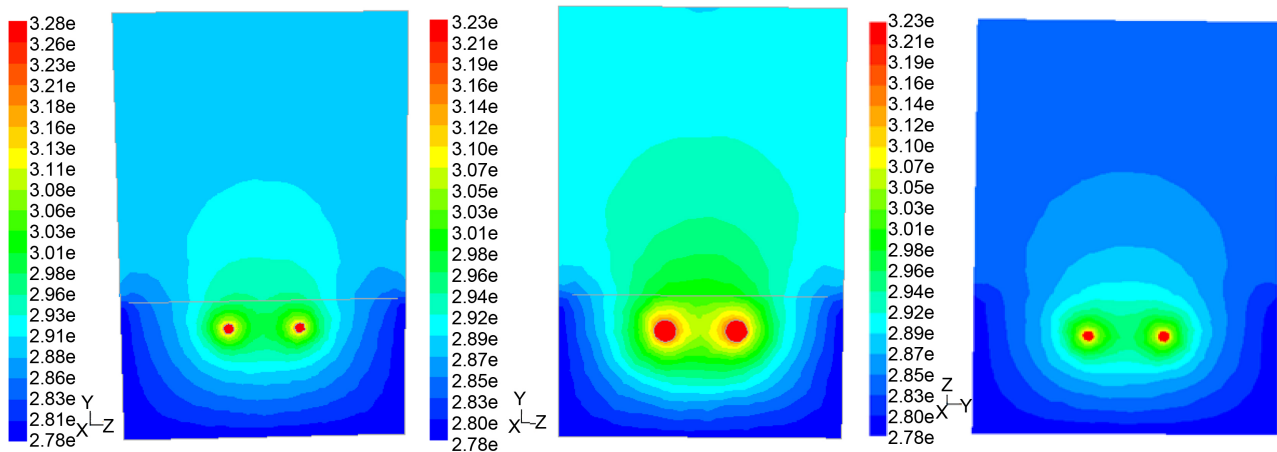


**Figure 7.** The greenhouse temperature distribution in the depth of 30 cm under the ground when the laying depth is 0.4 m, 0.5 m, 0.6 m.

0.4 m, 0.5 m, 0.6 m is shown in **Figure 8**.

The average temperature of the ground with different laying depth is significantly different, which is 290.2 K, 292.3 K and 286.7 K respectively. The maximum local temperature of the ground is 298.0 K, 300.5 K, 291.5 K respectively. The average heat flux of the floor is 7.9 W/m<sup>2</sup>, 15.3 W/m<sup>2</sup>, 16.1 W/m<sup>2</sup>. The difference average temperature of the root of different depths is also significant, which is 292.5 K, 295.3 K, 288.3 K, respectively. The maximum local temperature of the roots is 313 K, 311.7 K, 298.3 K respectively. The average temperature of the room is 289.8 K, 291.3 K, 284.3 K respectively, the temperature of the





**Figure 8.** The temperature distribution inside the greenhouse when the laying depth is 0.4 m, 0.5 m, 0.6 m.

room at height of 2 m is 293 K, 293.7 K, 287 K respectively. It can be seen from the data that the temperature at depth of 0.5 m is higher than other depth in the various parts of the greenhouse, and it can be seen from the figure that the distribution is more even, which is considered the most appropriate laying depth.

The greenhouse ground temperature distribution when supplied water temperature is 40°C, 45°C, 50°C is shown in **Figure 9**.

The greenhouse temperature distribution in the depth of 30 cm under the ground when supplied water temperature is 40°C, 45°C, 50°C is shown in **Figure 10**.

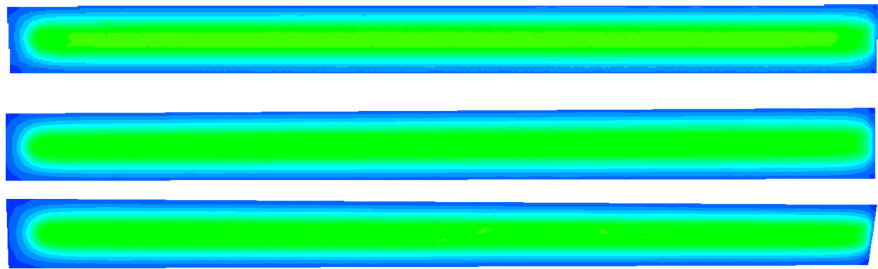
The temperature distribution inside greenhouse when supplied water temperature is 40°C, 45°C, 50°C is shown in **Figure 11**.

The average temperature of ground with different supplied water temperature is 290 K, 291.3 K, 292.3 K respectively. The maximum local temperature of the ground is 279.3 K, 298 K, 300.5 K respectively. The average heat flux of the floor is 7.7 W/m<sup>2</sup>, 12 W/m<sup>2</sup>, 15.3 W/m<sup>2</sup> respectively. The average temperature of the root with different supplied water temperature has a small change, which is 291.7 K, 293.5 K, 295.3 K respectively. The maximum local temperature of the roots is 304.3 K, 306 K, 311.7 K, respectively. The average temperature of the room is 289.6 K, 290.4 K, 291.3 K respectively, the temperature of the room at 2 m high is 292 K, 292 K, 293.7 K respectively. It can be seen from the figure that the temperature distribution of different supplied water temperature is very similar, the homogeneity is very high, and the temperature of each part is higher when  $T = 50^\circ\text{C}$ , which can just meet the temperature requirements of the human and the plant.

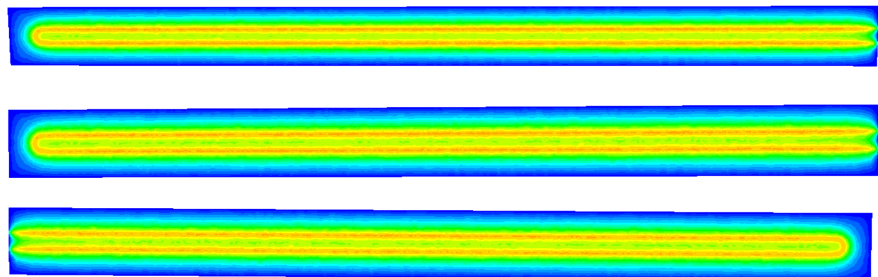
The greenhouse ground temperature distribution when pipe diameter is 160 mm, 200 mm are shown in **Figure 12**.

The greenhouse temperature distribution in the depth of 30 cm under the ground when pipe diameter is 160 mm, 200 mm is shown in **Figure 13**.

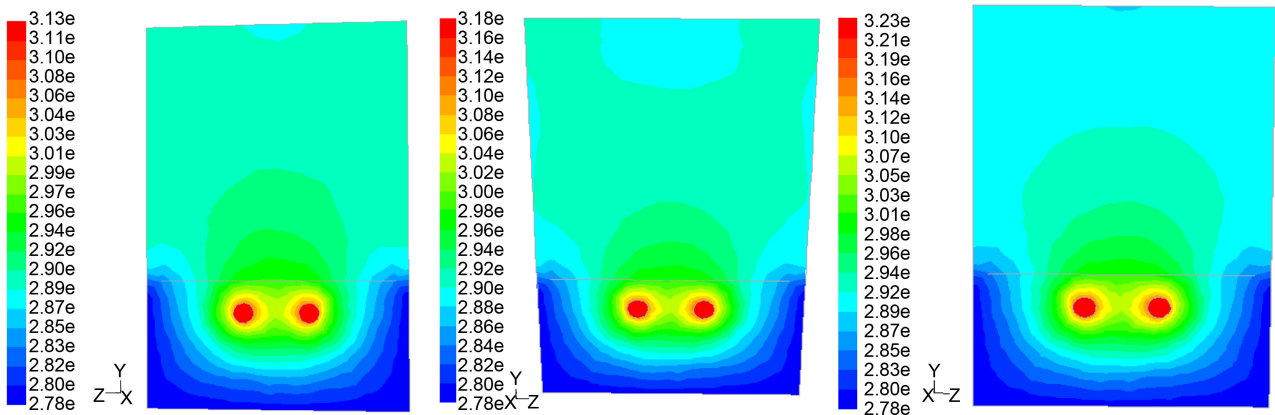
The temperature distribution inside the greenhouse when pipe diameter is 160 mm, 200 mm is shown in **Figure 14**.



**Figure 9.** The greenhouse ground temperature distribution when supplied water temperature is 40°C, 45°C, 50°C.

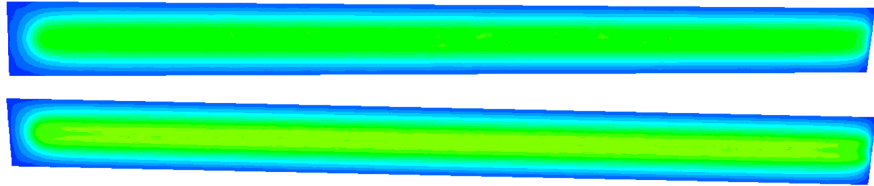


**Figure 10.** The greenhouse temperature distribution in the depth of 30 cm under the ground when supplied water temperature is 40°C, 45°C, 50°C.

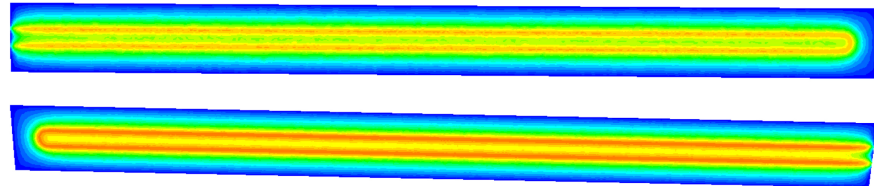


**Figure 11.** The temperature distribution inside greenhouse when supplied water temperature is 40°C, 45°C, 50°C.

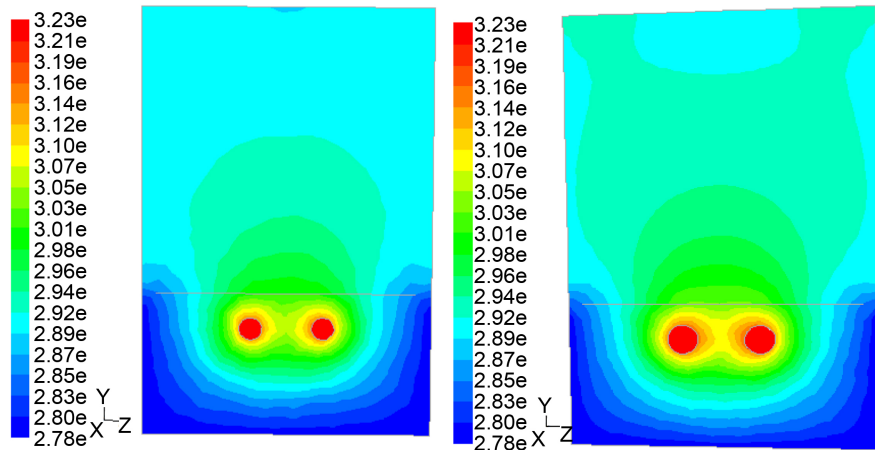
The average ground temperatures of different diameters are 292.3 K and 294.6 K respectively. The maximum local temperature of the ground is 300.5 K and 305 K respectively. The average heat flux of the floor is 15.3 W/m<sup>2</sup>, 20.7 W/m<sup>2</sup>. The difference of average temperature of root in the condition with different pipe spacing is also significant, which is 295.3 K, 297.5 K respectively. The maximum local temperature of the root is 311.7 K, 316.3 K respectively. The average temperature of the room is 291.3 K, 292.1 K, and the temperature at height of 2 m of the room is 293.7 K, 296 K. It can be seen from the figure that the temperature distribution is more uniform when  $D = 160$  mm, and the temperature range is reasonable, and the local temperature is too high when  $D = 200$  mm, and the average temperature also exceeded the optimal temperature for



**Figure 12.** The greenhouse ground temperature distribution when pipe diameter is 160 mm, 200 mm.



**Figure 13.** The greenhouse temperature distribution in the depth of 30 cm under the ground when pipe diameter is 160 mm, 200 mm.



**Figure 14.** The temperature distribution inside the greenhouse when pipe diameter is 160 mm, 200 mm.

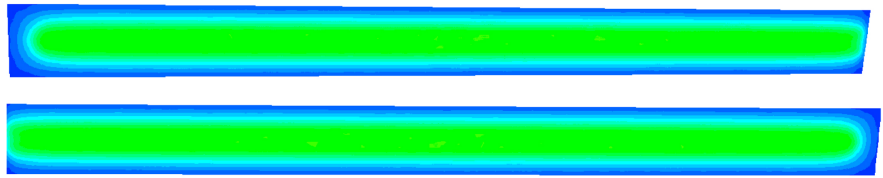
plant growth.

The greenhouse ground temperature distribution when flow rate is 0.6 m/s, 0.8m/s is shown in **Figure 15**.

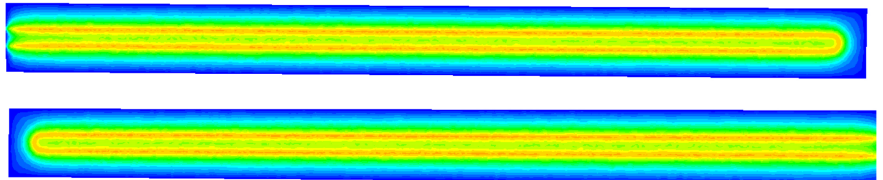
The greenhouse temperature distribution in the depth of 30 cm under the ground when the water flow rate is 0.6 m/s, 0.8 m/s is shown in **Figure 16**.

The temperature distribution inside the greenhouse when flow rate is 0.6 m/s, 0.8 m/s is shown in **Figure 17**.

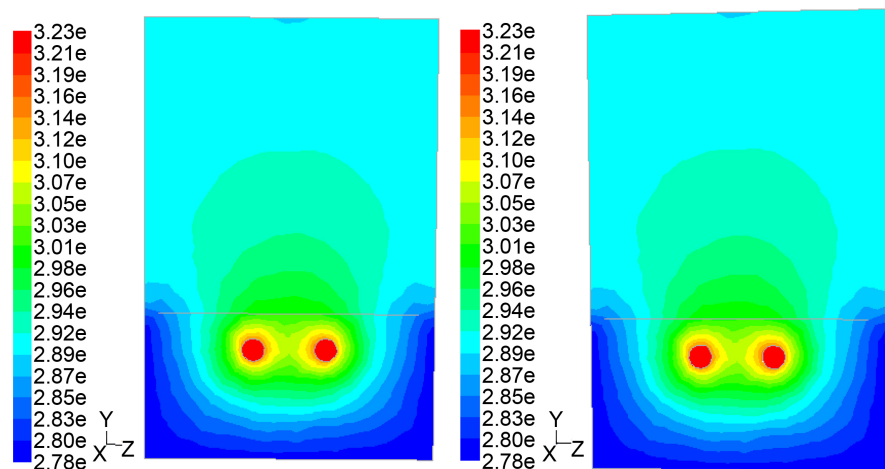
The average temperature of the ground at different flow rates has only slight changes, which is 292.3 K, 292.8 K respectively. The maximum local temperature is 300.5 K. The average heat flux of the floor is 15.3 W/m<sup>2</sup>, 15.4 W/m<sup>2</sup>. The average temperature of the root of different pipe spacing is almost the same, 295.3 K, 295.4 K respectively. The maximum local temperature of the roots is 311.7 K and 311.8 K respectively. The average temperature of the room is 291.3 K, and



**Figure 15.** The greenhouse ground temperature distribution when flow rate is 0.6 m/s, 0.8 m/s.



**Figure 16.** Temperature distribution in the depth of 30 cm under the ground when the water flow rate is 0.6 m/s, 0.8 m/s.



**Figure 17.** The temperature distribution inside the greenhouse when flow rate is 0.6 m/s, 0.8 m/s.

the temperature at the height of 2 m of the room is 293.7 K, 293.8 K respectively. It can be seen from the figure that the temperature distribution in the greenhouse at different flow rates is similar and the homogeneity is very high, and the increase of the flow rate will increase the overall temperature slightly.

#### 4. Conclusion

In this paper, FLUENT software is used to calculate the convective-radiation coupled heat transfer model of underfloor pipes of greenhouse. After having analyzed the Temperature Field in the greenhouse with different pipe spacing, laying depth, supplied water temperature, pipe diameter and water velocity, the local highest temperature and the indoor average temperature on ground and underground 30 cm is obtained, and also the average heat flux of the floor. The simulation results show that the average temperature inside the greenhouse in-

creases and the uniformity decreases with the increase of pipe spacing. This is due to that the reduction of heat source distance resulting in heat transfer within a certain range is limited, but the total heat does not change, so the local temperature near the ground rises. With the increase of laying depth, the local maximum temperature decreased significantly, but the average temperature was the highest at 0.5 m, indicating that the rest of the laying depth led to a large non-uniformity. The temperature distribution with different water supply temperature is very similar and the homogeneity is very high. With the increase of water supply temperature, the average temperature in the greenhouse obviously increased. The increase in diameter leads to a significant increase in the average temperature in the greenhouse and the in-homogeneity of the temperature distribution. The increase in water velocity also contributes slightly to the increase in temperature in the greenhouse, but does not change the uniformity of the temperature distribution. In summary, the water supply temperature, pipe spacing and diameter of the pipe has a greater impact on the ground temperature and the temperature of the room, and the laying depth has greater impact on the temperature uniformity of the ground, the velocity of water in heating pipe has little impact on the uniformity of ground temperature, but increase of the flow rate can increase the temperature of ground and the room. The pipe spacing being 1 m, laying depth being 0.5 m, diameter of pipe being 160 mm, the supplied water temperature being 50°C, flow rate being 0.6 m/s is the most suitable heating parameters for the study of greenhouse in the paper.

## Acknowledgements

The author would like to acknowledge the following projects for financial support. Science & technology plan projects in Inner Mongolia (ZD2012MS0703). And Wind and solar energy utilization technology of Inner Mongolia University of Technology key laboratory open fund project authorized by China's ministry of education: Wind Speed Prediction Research Based on Geographic Information System.

## References

- [1] Chen, Y. and Athienitis, A.K. (1998) Three-Dimensional Numerical Investigation of the Effect of Cover Materials on Heat Transfer in Floor Heating Systems. *Ashrae Transactions*, **104**, 1350-1355.
- [2] Dragomir, F. and Dragomir, O.E. (2012) Improvement of Energy Consume from Hybrid Systems Integrating Renewable Energy Sources. *Advanced Materials Research*, **512-515**, 1147-1150.  
<https://doi.org/10.4028/www.scientific.net/AMR.512-515.1147>
- [3] Arghira, N., Hawarah, L., Ploix, S. and Jacomino, M. (2012) Prediction of Appliances Energy Use in Smart Homes. *Energy*, **48**, 128-134.
- [4] Stamatescu, G., Stamatescu, I., Arghira, N., Fagarasan, I. and Iliescu, S.S. (2014) Embedded Networked Monitoring and Control for Renewable Energy Storage Systems. *International Conference on Development and Application Systems*, Romania, 15-17 May 2014, 1-6.

- [5] Tong, Y., Kozai, T., Nishioka, N. and Ohyama, K. (2010) Greenhouse heating Using Heat Pumps with a High Coefficient of Performance (COP). *Biosystems Engineering*, **106**, 405-411.
- [6] Sase, S., Okushima, L. and Kacira, M. (2004) Optimization of Vent Configuration by Evaluating Greenhouse and Plant Canopy Ventilation Rates under Wind-Induced Ventilation. *Transactions of the ASAE*, **47**, 2059-2067. <https://doi.org/10.13031/2013.17803>
- [7] Boulard, T. and Wang, S. (2002) Experimental and Numerical Studies on the Heterogeneity of Crop Transpiration in a Plastic Tunnel. *Computers & Electronics in Agriculture*, **34**, 173-190.
- [8] Molina-Aiz, F.D., Valera, D.L. and Álvarez, A.J. (2004) Measurement and Simulation of Climate inside Almería-Type Greenhouses Using Computational Fluid Dynamics. *Agricultural & Forest Meteorology*, **125**, 33-51.
- [9] Li, Y., Li, B., Li, Z. and Ding, T. (2004) CFD Simulation of a Naturally Ventilating Cooling Process for a Venlo Greenhouse in Summer. *Journal of China Agricultural University*, **9**, 44-48.
- [10] Fatnassi, H., Boulard, T., Poncet, C. and Chave, M. (2006) Optimisation of Greenhouse Insect Screening with Computational Fluid Dynamics. *Biosystems Engineering*, **93**, 301-312.
- [11] Rouboa, A. and Monteiro, E. (2007) Computational Fluid Dynamics Analysis of Greenhouse Microclimates by Heated Underground Tubes. *Journal of Mechanical Science and Technology*, **21**, 2196-2204. <https://doi.org/10.1007/BF03177480>
- [12] Izadi, M.J. and Makaremi, K. (2009) CFD Simulation of Temperature Distribution in a Room with Various under Floor Heating System Models. *ASME 2009 Fluids Engineering Division Summer Meeting*, Vail, Colorado, 2-6 August 2009, 2319-2329. <https://doi.org/10.1115/FEDSM2009-78545>
- [13] Chen, J., Xu, F., Yang, J. and Ai, Q. (2011) Optimized Design of Hot Air Pipe in Greenhouse Based on CFD Technique. *International Conference on New Technology of Agricultural Engineering, IEEE*, Zibo, 27-29 May 2011, 441-445.
- [14] Mezrhab, A., Elfarh, L., Naji, H. and Lemonnier, D. (2010) Computation of Surface Radiation and Natural Convection in a heated horticultural Greenhouse. *Applied Energy*, **87**, 894-900. <https://doi.org/10.1016/j.apenergy.2009.05.017>
- [15] Grigoriu, O.R., Voda, A., Arghira, N., Calofir, V. and Iliescu, S.S. (2015) Temperature Control of a Greenhouse Heated by Renewable Energy Sources. *Aegean Conference on Electrical Machines and Power Electronics*, Antalya, 2-4 September 2015, ACEMP.

**Submit or recommend next manuscript to SCIRP and we will provide best service for you:**

Accepting pre-submission inquiries through Email, Facebook, LinkedIn, Twitter, etc.

A wide selection of journals (inclusive of 9 subjects, more than 200 journals)

Providing 24-hour high-quality service

User-friendly online submission system

Fair and swift peer-review system

Efficient typesetting and proofreading procedure

Display of the result of downloads and visits, as well as the number of cited articles

Maximum dissemination of your research work

Submit your manuscript at: <http://papersubmission.scirp.org/>

Or contact [ojfd@scirp.org](mailto:ojfd@scirp.org)