# Model Simulations and Measurements on the New Chinese Solar Greenhouse

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**Abstract**: The ChineseAcademy of Agricultural Sciences is working on improvements of the widespread Chinese Solar Greenhouse. Typically this greenhouse is heated by solar energy only and is therefore a sustainable way of growing vegetable crops in the off-season period. Due to the high insulation of the covering during the night and the bright sunny days, the diurnal mean inside temperatures are around 10℃ higher than the average outside temperature. Even on dull days the diurnal mean temperature in the greenhouse remains 5 to 6℃ higher than the ambient. In the Shouguang region this means that the Chinese Solar greenhouse enables a frost-free ambient so that crops like tomato, cucumber and sweet pepper can be grown without heating.

However, the passive character of the Chinese Solar Greenhouse prohibits any control of the heating. During the day, solar heat is accumulated in the north wall and during the following night, this heat is released to the greenhouse air. This paper discusses the measurements and simulation results with a new design for the greenhouse, allowing for a controllable release of solar energy to the greenhouse. Moreover, the design comprises additional screening for a higher daytime insulation. The paper shows that some improvements can be made, but the total amount of intercepted solar radiation remains to be the limiting factor.

**Key words**: Chinese Solar Greenhouse; Active Heat Storage and Release System

## 1 Introduction

The Chinese Academy of Agricultural Sciences is working on improvements of the widespread Chinese Solar Greenhouse. Typically this greenhouse is heated by solar energy only and is therefore a sustainable way of growing vegetable crops in the off-season period. Due to the high insulationduring the night and the substantial accumulation of solar energy during the day, the diurnal mean average of the indoor temperature can be up to 20℃ higher than the diurnal mean outside temperature.

The high insulation during the night is achieved by covering with an insulating blanket at the end of the day. In the morning, after the sun has gained enough radiative strength the insulating blanket is removed. The air exchange between inside and outside of a Chinese Solar Greenhouse is typically very limited. Only when the inside temperature reaches values around 28℃, some openings are made in the covering by pulling apart two pieces of overlapping film of the covering material. If the ventilation through this opening is insufficient, additional ventilation can be achieved by opening the bottom section of the south facing covering. The photo below shows an example of the Chinese So-

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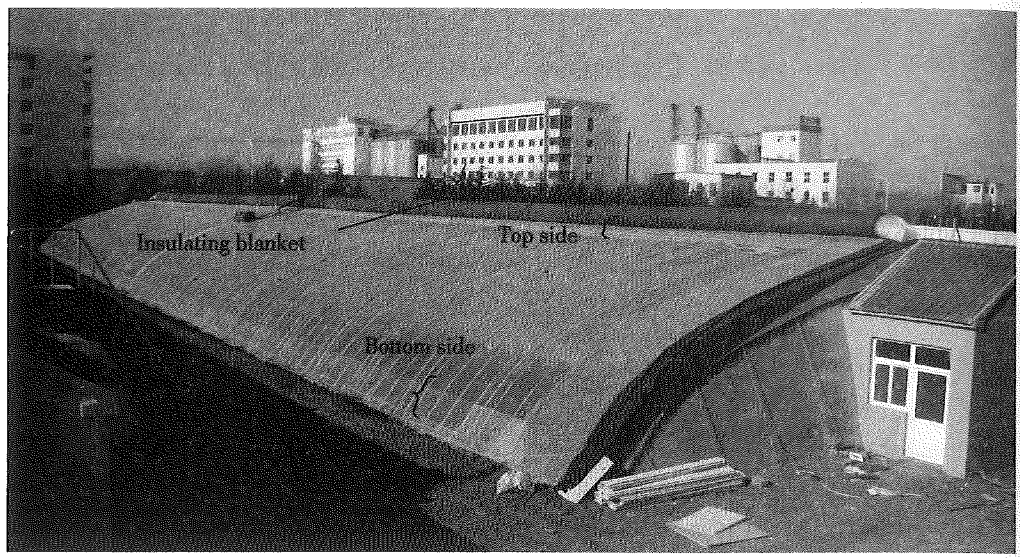
lar Greenhouse.




In order to have maximal exposure to sunlight, the ridge is east-west oriented and the transparent cover is facing south. Normally the north wall is constructed as a massive body of soil or bricks. This wall provides insulation and, what's more, thermal storage capacity. Results of Guan*et. al.* (2014) show that a brick wall with a volume of about 0.35 $m^3$ per $m^3$ greenhouse (a 0.9 meter thick wall with a height of 2.3 m at the back side of a greenhouse with a span width of 5.3 m) allowed for about 0.6 $MJ/m^3$ of solar heat captured during the day for heating during the night. Assuming a night time period of about 14 hours this means that the heating power of such a north side wall is about 27 $W/m^3$ wall on average, which comes down to some 12 W per $m^3$ greenhouse surface.

Such average heat release figures can also be found in Wang *et. al.* (2014) and Xu *et. al.* (2013).

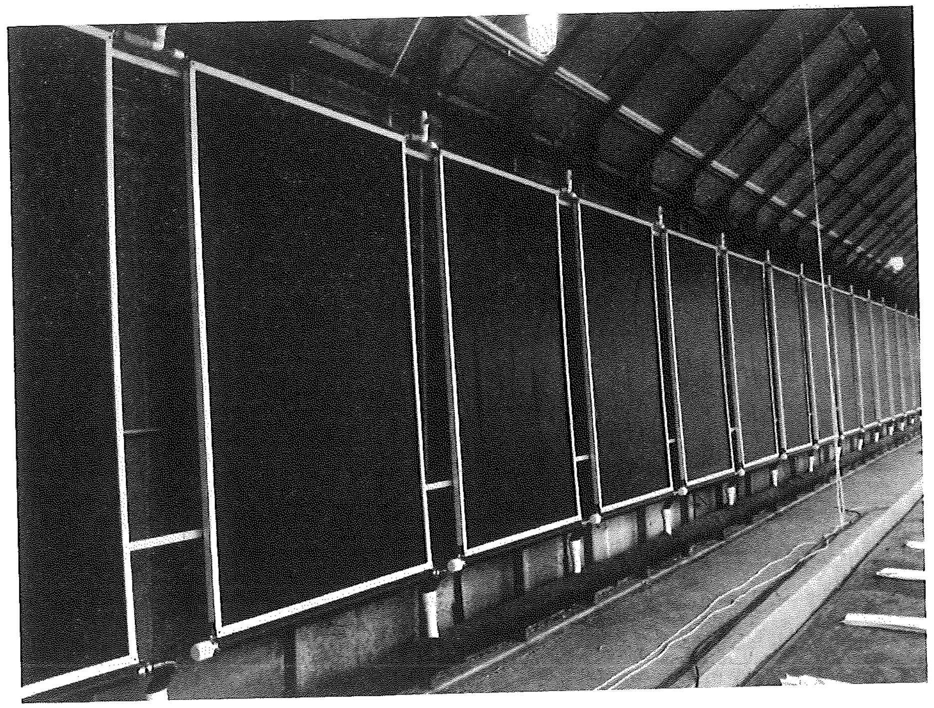
Typically, the heat release from the north wall is not controlled. This means that as soon as the sun sets and the greenhouse starts to cool down, the north wall starts torelease the accumulated heat. This system makes the greenhouse simple, robust and cheap to build, but during cold periods one would rather postpone the heat release in order to prevent the real low temperatures at the end of the night.

To introduce the possibility of a controlled application of the solar heat accumulated during daytime, the Chinese Academy of Agricultural Science has developed the Active Heat Storage and Release System. This is a system based on a simple heat collector that gathers solar energy by letting water to pass in between two sheets of black plastic foil. The foil prevents the water to evaporate. The inlet of water at the top of the panel ensures an equal distribution of the water along the full width of the panel. At the bottom, the water is collected after being heated by the solar radiation. When heating of the greenhouse is needed, the same panels are used for heat release. Then warm water flows in at the top side and cools down when traveling to the bottom side.





A large number of panels can be mounted in a parallel configuration in order to scale the capacity in accordanceto the greenhouse size. The water circulating in the system is pumped from a subsoil water tank. The tank is insulated to minimise heat losses.



Because the back wall in the New Chinese Solar Greenhouse is not needed as a heat accumulator anymore, the wall can be made from insulating panels. These allow for an easy and rapid building of the greenhouse.

In the experimental site, the on and off switching of the pump that circulates the water is performed by an ISII Greenhouse Climate Computer (Hoogendoorn). Apart from the control of the AHSRS the computer takes care of the preparation and supply of the drip irrigation system. Watering takes place in small shots of around 150 cc per $m^3$ greenhouse. The shots can be triggered by a combination of time schedules and cumulative outside radiation.

Besides control, the ISII Computer gathers and stores the greenhouse climatemeasurements and the outside weather conditions.

A third actuator the ISII computer controls, next to the AHSRS-pump and the fertigation unit, is the opening and closing of an internal energy screen. Contrary to the insulating blanket at the outside of the greenhouse, an energy screen can be made of a transparent material, allowing for an extra insulation on dull days while still having light entering the greenhouse to promote crop growth. The picture below shows the construction of this thermal screen. It consists of three sections of the Ludvig Svensson Luxous screen, running along the full length of the greenhouse and sliding up and down along pulling wires. One motor drives the three sections together.

The measurements in this experimental set-up have to show to which extent the AHSRS is capable to apply the heating in a more controlled way and to what extent the thermal screen helps to prevent too low temperatures during the coldest days. Analysis and results will be based on measurements and model computations.

## 2 Materials and Methods

The results discussed in this paper are based on the experiments in440 $m^3$ test facilities in Shouguang, Shandong Province in China (37°N; 119°W). These test facilities were only recently finished so there are no data yet on the performance in winter. Therefore, a simulation model is tuned in order to describe the behavior of the New Chinese Solar Greenhouse in the first 40 days. Having learned the parameters, the model is used to run some comparative cases for the period from September through April.

Thesimulation model used is relies on the Greenhouse Process model (KASPRO). This model is developed as a research tool by Wageningen UR Greenhouse horticulture and extended with modules that describe the behavior of the AHSRS and the outdoor insulation blanket. This extension could seamlessly be integrated since the model is entirely constructed from modules describing the physics of mass and energy transport in the greenhouse enclosure, and a large number of modules that simulate the customary greenhouse climate controllers. Thus, the model takes full account of mutual dependencies between greenhouse characteristics and its climate control. Full details of the





model can be found in "Analyzing energy-saving options in greenhouse cultivation using a simulation model" (de Zwart, 1996).

The simulation of the greenhouse physical processes comprises the energy and mass fluxes in the enclosure. These fluxes result in a transient course of temperature, humidity and $CO_2$ concentration.

All processes are parameterized according to their physical characteristics like optical parameters in the visible and infra-red wavelengths, their inertia and physical limitations (e. g. maximum ventilation capacities, leakage etc. ).

To mimic the control of the New Chinese Solar Greenhouse, the simulation model switches on the AHSRS pump whenever the solar collector is heat up by the sun and whenever the greenhouse temperature drops below the lower boundary temperature, which is set to 14℃. When switched on, the model computes an energy exchange between the collector and the heat storage vessel, based on a water circulation rate of 3. 6 $m^3/h$. The vessel is modelled as a perfectly mixed tank of 5 $m^3$ water per 440 $m^3$ greenhouse, so having a capacity of 0. 0475 MJ/K. The tank has some heat loss to soil. The exchange coefficient is modelled as being 0. 05 W/K per $m^3$ greenhouse.

Apart from a module that simulates the behavior of the AHSRS, the model can also mimic the traditional Chinese Solar Greenhouse. In that casethe north wall is simulated as three capacities in series. Just like the model described by Xu et al. (2013), the first surface is modelled as a 10 cm layer of rock-like material. This layer absorbs the direct solar radiation and passes the heat partly directly to the greenhouse and partly to the inner thermal capacity of the north wall. This inner capacity is modelled as a 0. 8 m thick soil volume, exchanging heat with the first layer and with the third layer. This third layer is coupled to the outside temperature by means of a 2 W/ ($m^3$ K) heat exchange coefficient to contribute for heat losses from the wall.

In the model computations the greenhouse has a very low leakage [1 $m^3$/ ($m^3$ · h) on average]. Only when the greenhouse temperature exceeds 25℃, the greenhouse is going to be ventilated to carry off the heat excess.

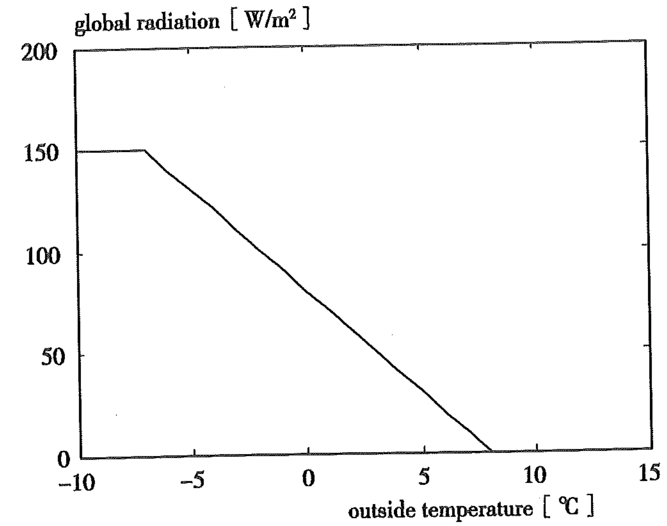
The light transmissivity of the covering is set to 65%.

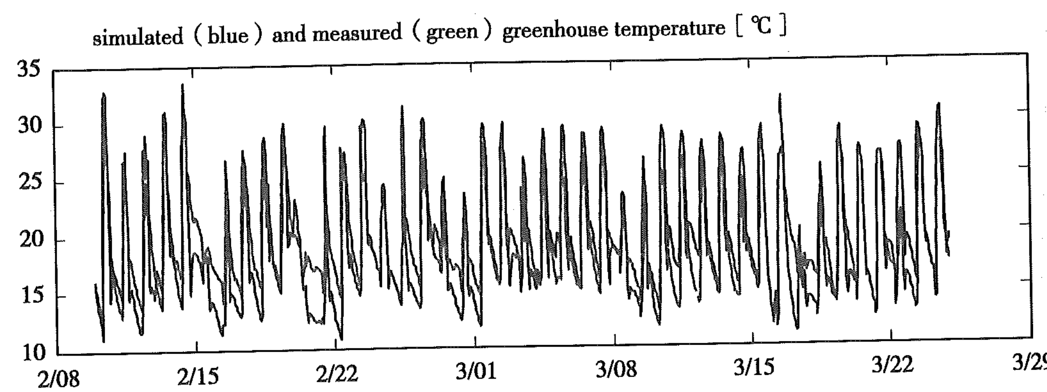
The simulation results are compared with the data obtained by the ISII Climate computer. When calibrating the model, the control of the AHSRS is not governed by the simulation model, but by the actual control as it has been imposed by the ISII. The manual actions of the grower are not known so therefore an estimation had to be made. With respect to the outside insulating blanket it is assumed that the blanket is closed when the outside radiation drops below a certain threshold. This threshold is dependent on the outside temperature according to the graph alongside.

## 3 Results

When running the model for the period from February 10$^{th}$ till march 24$^{th}$, after having imposed the model to the outside weather conditions as measured in Shouguang, the comparison between model and measured data gives the following result.

The dynamics are simulated quite well but there are a lot of days with quite large differences be-




tween measured and simulated data. However, the data set as available at the moment is still too small to improve the matching of data.

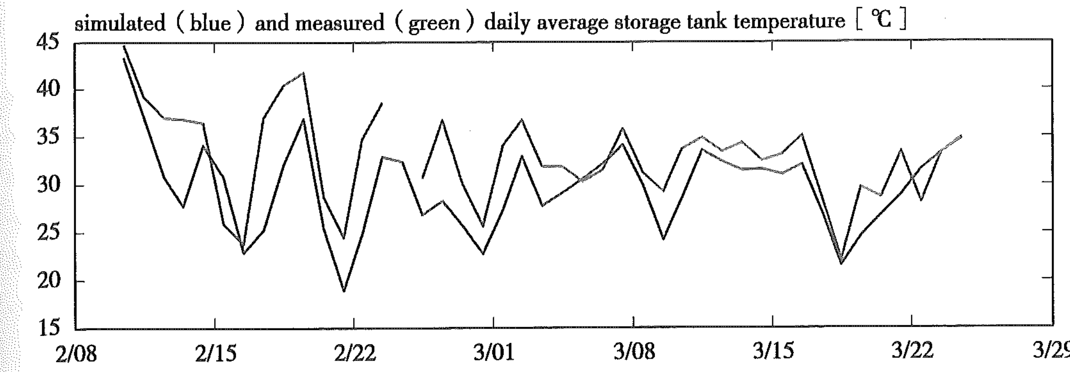
The average temperature of the storage tank that accumulates and releases the energy harvested from the sun is simulated quite well. The graph below shows the daily average temperature of the tank as it is measured and simulated.

There are differences, of course, but the general trend is considered to be good enough to allow for a preliminary answer on the question of the AHSRS works in order to postpone heat release at the beginning of the night for the benefit of heating the greenhouse in the coldest period of the day, which is the early morning.

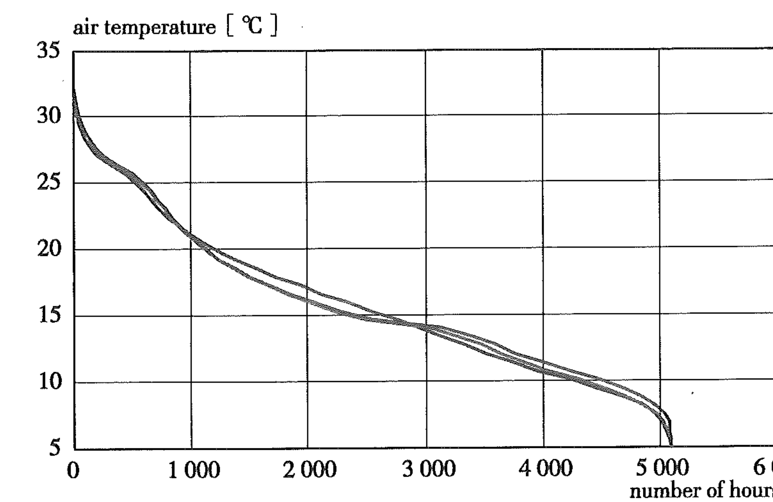
To get an answer on this question, the model is used to predict the temperatures during a cultivation cycle starting at September 15th and ending in April 15th. When comparing the cumulative frequency duration curves of a greenhouse with a traditional thick north wall, a greenhouse with the AHSRS, and a greenhouse with AHSRS and an additional Svensson Luxous screen, the results








shown in the following graph were obtained. The simulation was run with all parameters equal to the parameters found during the tuning on the measured data. The weather data for Shouguang were not available for this period so therefore the weather data from Qingdao International airport were used.




The cumulative frequency distribution curve tells for how many hours a certain value was surpassed. The graph*f. i.* tells that for all cases, the greenhouse was warmer than 14℃ during about 2 900 hours and that it was warmer than 10℃ for 4 250 hours in the cases without the energy saving Luxous screen. With the screen, the greenhouse stayed was 4 550 hours warmer than 10℃. From the data followed that with the Luxous screen, the greenhouse temperature never reache 5℃, whereas both other cases had 5 hours below 5℃.

The ‘shift of temperatures’ around 14℃ is the effect of the controlled heat release. Due to the fact that the pump of the AHSRS can be switched on and the New Chinese Solar Greenhouse has a somewhat smaller number of degree-hours below 14℃ compared to the traditional greenhouse. Since the energy budget received from the sun is equal, the shift of energy to the real low temperatures runs at the expense of greenhouse temperatures above 15℃.

## 4 Conclusion

Although the simulation of greenhouse temperatures still shows quite some shortcomings, the simulation of the AHSRS seems to go reasonably well. When using the model as it could be tuned on the limited amount of data currently available for the simulation of a winter cultivation of tomato, it can be concluded that the AHSRS can indeed bring solar energy for moderately low temperature conditions to real low temperature conditions. An improved insulation of the tank, in combination with an increased size and a more sophisticated strategy, *f. i.* a strategy that includes weather forecasts, could further enlarge the potential.

Theaddition of an energy screen to the New Chinese Solar Greenhouse is also likely to reduce the number of hours with real low temperatures.

## 5 Acknowledgements

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**Literature Cited**

Guan, Y., Chen, C., Han, Y., Ling, H., & Yan, Q. (2014). Experimental and modelling analysis of a three-layer wall with phase-change thermal storage in a Chinese solar greenhouse. Journal of Building Physics

Junwei Wang, Shuhai Li, Shirong Guo, Chengwei Ma, Jian Wang, Sun Jin, Simulation and optimization of solar greenhouses in Northern Jiangsu Province of China, Energy and Buildings, Volume 78, August 2014, pp: 143 ~ 152

Xu, F., S. Li, C. Ma, S. Zhao, J. Han, Y. Liu, B. Hu, S. Wang, 2013, Thermal Environment of Chinese Solar Greenhouses: Analysis and Simulation, American Society of Agricultural and Biological Engineers, Vol. 29 (6): 991 ~ 997

H. F. de Zwart, 1996, Analyzing energy-saving options in greenhouse cultivation using a simulation model. PhD-Thesis Wageningen University, The Netherlands