Final report

Project JI/Shandong Improved Greenhouses

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Acknowledgement/Preface

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Abstract

This report provides an overview of the major outcomes of the project 'JI/Shandong Improved Greenhouses'. The project has been carried out under responsibility of ECN on the Dutch side and Shouguang Municipality Agricultural Committee on the Chinese side. The ultimate Receiving Party is the Shouguang Agriculture Hightech Demonstration Park, Shouguang, Shandong Province, China. The project has been carried out in the period April 2002-August 2005.

The main project goal of this 'Activity Implemented Jointly (AIJ)' is to perform vegetable growing tests and in-greenhouse climate measurements in distinct sections of three pilot greenhouses under experimental conditions:

- to provide indications on the suitability of the distinct configurations to local circumstances; and
- to enable the determination of the most suitable configuration.

The project should lead to widespread commercialisation of feasible, low-cost new and renewable energy concepts in the horticulture sector of Shandong province with significant improvement of the quantity and quality of crop yields. In turn, this should reduce the penetration of high-tech fossil fuel-intensive glasshouse horticulture in Shandong and, at the same time, reduce emissions of GHG (greenhouse gases) by this sector.

A major achievement of the project is the demonstration of an 'enhanced sunny greenhouse' concept with locally produced Solar Water Heater collectors to provide additional heating during the winter vegetable growing season. In spite of many operational compromises deviating from the original greenhouse design, preliminary test results indicate that this concept is quite promising for Chinese horticulture. However, the project failed to deliver a credible vegetable growing experimental programme, and by implication, to bring about the immediate take-off of commercialization of project greenhouse concepts.

Given the (preliminary) test results obtained within the framework of the present project and the potential environmental and economic significance of commercialisation of a further elaborated 'enhanced sunny greenhouse', it is recommended that a follow-up demonstration project will be launched in Shandong Province led by reputable local research institutes.

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Summary

In 1997 ECN was requested to investigate the possibilities in Shandong for the application of renewable energy concepts to the local ‘sunny greenhouse’. Such application should - compared to its absence - improve in-greenhouse climate conditions for vegetable growing, reduce future demand for fossil fuels by the local and national horticulture sector and, by implication, mitigate greenhouse gas emissions in China. In 1998 ECN submitted an initial proposal idea at the Pilot Projects Programme for Joint Implementation (PPP/JI) of the Directorate-General for Development Co-operation of the Dutch Ministry of Foreign Affairs. During a mission to China the same year in the framework of the twinning relationship between the provinces of Shandong and North-Holland the project idea was further elaborated. It was envisaged that ECN, in association with SDERI and Wan Fang, a company designated by the Shouguang Municipal Government, would set up a demonstration project introducing renewable energy concepts to the local farmers and conduct experimental measurement programmes. The project was to trigger commercialisation of the project concept in which Wan Fang and the Dutch greenhouse construction company Debets-Schalke were to play a leading role. After lengthy approval procedures, the project was approved in April 2002 without a detailed work plan and rather short notification to the implementing parties. The project was scheduled to last through end of April 2004.

Project implementation proved rather challenging under a range of unexpected, adverse events. As a result, the project duration had to be extended twice until end of August 2005 eventually while only part of the project objectives could be achieved.

Major achievement of the project is the demonstration of an ‘enhanced sunny greenhouse’ concept with locally-made Solar Water Heater collectors to provide additional heating during the winter vegetable growing season. In spite of many operational compromises deviating from the original greenhouse design, preliminary test results indicate that this concept is quite promising for Chinese horticulture. However, the project failed to deliver a credible vegetable growing experimental programme, and by implication, to bring about the immediate take-off of commercialization of project greenhouse concepts.

The future will learn what societal value added the project has created. To that effect, a crucial factor is whether or not further experimentation with the ‘enhanced sunny greenhouse’ concept will take place with a critical extent of perceived ‘project ownership’ by suitable local parties. In the first stage, the emphasis should be on further research with suitable arrangements for ensuing commercialization. It is recommended to consider the Energy Research Institute of the Shandong Academy of Sciences (SDERI) and the Institute for Vegetable Research of the Shandong Academy of Agricultural Sciences (SDIVR) to lead such an effort. The former because of its proven track record on renewable energy research and commercial application and the latter for its outstanding competencies regarding vegetable growing research. Relevant Dutch research institutes and horticulture-related companies may well assist such efforts.

The following major lessons can be learnt from the less fortunate implementation of the present project:

- A well-elaborated project work plan with proper consultations of all project partners and conclusion of pro forma project procurement contracts at project start are essential.
- A good project management structure with proper provisions to bridge language and intercultural communication gaps and a critical minimum of perceived local ‘project ownership’ is essential. In order to reduce the cost for local project supervision a management-sharing relationship with a related Dutch horticulture-training project in Shandong was reached. On

hindsight, this did not prove successful. Resort to suitable Chinese project representation on behalf of ECN would most probably have been more effective.
- The project approval cycle should be suitably time-framed. Long time lapses between conceptualization and implementation increase the risks of adverse changes in critical project parameters. For example, at project start geographical priorities of the Dutch greenhouse construction company turned out to have changed with less emphasis on China. Moreover, the twinning relationship between Shandong and North Holland provinces appeared to have become less intense after a change of Governor in the latter province. Moreover, the long time lapse and difficulties in bridging communication gaps (see previous point) may have made it more difficult for the administration of Shouguang Municipality to honour promises made during the project proposal phase.

To end this summary on a positive note, all project participants have indicated their disposition to support follow-up activities. Based on the above considerations, it is deemed most appropriate that the initiative comes from the Chinese side. For financing any Dutch assistance to support such initiative, certain (limited) financing options appear to be available such as the Asia Facility for Asia (Senter) and facilities financed by the Dutch Ministry of Agriculture. Moreover, the Chinese Ministry of Science and Technology has indicated clear interest on the Chinese side in the development, with Dutch assistance enabled by e.g. the Dutch Ministry of VROM, of a relatively robust methodology to determine a baseline scenario for any commercialization activities in China of ‘enhanced low energy greenhouse’ concepts. This methodology should be deemed acceptable by the CDM Executive Board for application to potential CDM projects with enhanced sunny greenhouses.

1. Introduction

In 1997 ECN was requested to investigate the possibilities in Shandong for the application of renewable energy concepts to the local ‘sunny greenhouse’ so as to improve in-house climate conditions for vegetable growing. At the time some 200,000 hectares of ‘sunny greenhouses’ were in use in China, of which about half in Shandong province. Currently, the area covered by ‘sunny greenhouses’ appears to at least have doubled. It took quite some time from the date that the first project idea popped up to project start. Instrumental for invigoration of the efforts to get the project on stream proved to be the twinning relationship between the provinces of Shandong, P.R. China, and North-Holland, Kingdom of the Netherlands. The official signing of the agreement on the implementation of the ‘JI/Shandong Improved Greenhouses’ project took place at the Dutch embassy in Beijing on 2 April 2002.

The project is aimed at widespread commercialisation of feasible new and renewable energy concepts in the horticulture sector of Shandong province with significant improvement of the quantity and quality of crop yields. In turn, this should reduce the penetration of high-tech fossil-fuel-intensive glasshouse horticulture in Shandong and, at the same time, reduce emissions of GHG (greenhouse gases) by this sector.

Within the project framework two pilot greenhouses have been designed and vegetable growing tests have been carried out in a reference conventional ‘Sunny Greenhouse’ as well as in the aforementioned pilot greenhouses. Tests have been performed under experimental conditions controlled to the extent feasible with one type of vegetables (tomatoes). The tests have provided indications on the suitability of the distinct configurations to local circumstances and enabled the determination of the most suitable configuration.

This report presents the main project results. Chapter 2 provides an overview of the project history. Chapter 3 provides design details of the project greenhouses and measurement results on their performance. Two sets of measurement are accounted for: (i) measurements of inside- and outside-greenhouse temperature and moisture content, and (ii) measurements of harvest yields. Chapter 4 makes assessment of options for dissemination of improved greenhouses with special attention to a possible role of the CDM. Chapter 5 presents conclusions and recommendations for follow-up activities.

2. Project history

2.1 Introduction

This chapter seeks to broadly familiarise the reader with the project background by presenting a concise account of the project history. Technical details and an assessment of project results will be given in the ensuing chapters.

The chapter starts out with an explanation of the project aims (Section 2.2.). Next a review of the project history is given (Section 2.3). A brief summary concludes this chapter (Section 2.4).

2.2 Concise account of the project history

2.2.1 Project conception phase: June 1997 through March 2002

In the 1990s many horticulture-oriented Dutch companies were looking for business partnerships in China at large and more specifically in Shandong Province. Some engaged in partner matching missions in the framework of the twinning agreement between the provincial governments of the Chinese province Shandong and the Dutch province North-Holland. Dutch horticulture companies observed that yields in the traditional Chinese greenhouses - the generic type being referred to as ‘Sunny Greenhouse’ - were substandard in both quantity and quality terms. Main reason appeared to be the poor control of in-greenhouse climate conditions: large temperature volatility and at times high moisture levels. On the other hand, replacement by advanced western greenhouses would require quite high capital investments beyond the reach of ordinary Chinese farmers. Moreover, wide-scale penetration of western greenhouses would result in egregious increases in energy demand from Chinese horticulture with associated massive increases in greenhouse gas emissions.

In 1997, this resulted in a request to ECN by Mr R. Baan - at the time employed by Syngenta - to investigate the possibilities in Shandong for the application of proven renewable energy technology concepts to the local ‘sunny greenhouse’. In-house climate conditions for vegetable growing would have to be improved by integration of renewable energy concepts at affordable additional costs.

In 1998 ECN submitted the first draft proposal at DGIS to conduct a pilot project to be financed in the framework of the PPPJI programme as an Activity Implemented Jointly. The main other parties involved were:

- Debets-Schalke, a Dutch greenhouse construction company
- The Agricultural Committee of the Shouguang municipal government
- Wanfang Flower Company, the company assigned by the Shouguang municipal government as the Recipient Party
- Energy Research Institute of the Shandong Academy of Science (SDERI) in charge of the implementation of a greenhouse climate measurement programme and the delivery and installation of Solar Water Collectors.

Furthermore, the (Dutch) Foundation for Shandong - North-Holland Agricultural Co-operation (SNAC) chaired by Mr M. Sanders and with Mr R. Baan as deputy-chairman played an important advisory background role. In 1998 the ECN proposal matched perfectly the ongoing Sino-Dutch business collaboration activities in the horticultural sector in Shandong, while at the provincial level strong support existed at both sides. Moreover, representatives of the municipality of Shouguang emphatically showed their great eagerness to host the proposed project activity.

2.2.2 Project inception phase: April 2002 through July 2002

The lengthy decision process at central government levels came at a rather sudden conclusion in April 2002. The parties directly involved in the project were informed on very short notice in advance. The assignment responsibilities of the parties involved in the project were not clearly delineated in an agreement document, draft pro forma subcontracts were not yet arranged while the broad draft budget had been approved without due consultations.

Given the very difficult lines of long-distance communication not least because of the language barrier, ECN sought an affordable solution, given the project budget, to have local representation. A two-year horticultural training project in Shouguang under aegis of SNAC financed by the North-Holland Provincial Administration with a project period almost completely overlapping the present Improved Greenhouses project, offered a seemingly perfect match. It was decided that the field manager of the SNAC project would also act as field manager for the Improved Greenhouses project. At project start it could not be foreseen that the SNAC project was to be discontinued and its field manager withdrawn untimely by October 2003.

Meanwhile, Debets-Schalke gave less priority to developing the Chinese market at project start than in the early project concipiation phase. This resulted in lengthy negotiations between ECN and Debets-Schalke on the subcontract for deliveries of Debets-Schalke to the project. In July 2002 a subcontract was signed. Given the time pressure and the knowledge of Debets Schalke of the Chinese market, another greenhouse supplier was not an option. The budget allocation for the deliveries, for certain frame components of one of the pilot greenhouses had to be settled for good second-hand components. The components concerned, mainly for the construction of project Greenhouse III (the ‘Venlo-type’ greenhouse), are of a standardised nature with a long lifetime and did not embody technology on application of renewable energy and energy storage at which the project is targeted. The local party (SMAC) complained about the second-hand greenhouses on arrival, complaining that they were not consulted in this matter. However, given the time and budget pressure and the project conditions (that did not specify the need for first-hand material), the project management judged the situation such that the second-hand greenhouse would be of sufficient quality and relied on the guarantee of Debets Schalke that the design of the greenhouse was not up to present-day Dutch standards.

The subcontract issue with Debets-Schalke being solved, the next unexpected issue that took a lot of effort and negotiation time was an agreement on the principle that local project costs, unless otherwise stated in the project agreement should be borne by the Recipient Party, i.e. Wan Fang Flower corporation with a guarantee from Shouguang Municipality. This problem prevented the forwarding of the first container with goods from Debets-Schalke from Rotterdam harbour and eventually the container had to be withdrawn and returned to sender at considerable cost. Furthermore, detailed design work for manufacturing of tailor-made special components for project Greenhouse II (the ‘hybrid type’ greenhouse), had to be interrupted for several months. A solution was found for this during a mission, undertaken by Messrs. Bussink (DGIS) and Jansen (ECN) in November 2002. It was agreed that a supplementary € 2500 would be made available for customs clearing and haulage from Qingdao (port of disembarkation) to the Recipient Party on presentation of invoices, while in case of substantial unforeseen local costs accommodation by all parties would be sought. The Project recipient would inspect the consignments from Debets-Schalke in presence of the local ECN representative, Mr Vollebregt, and check and sign, if found in due order, for receipt of all goods listed on the Bill of Lading. This was, however, not done properly. Firstly, the containers were already opened and even some glass of the greenhouses was broken before Mr. Vollebregt could inspect the contents of the container. The project recipient (SMAC) repeatedly contradicted itself that the goods were not delivered properly but when Mr. Vollebregt joined the inspection, they were complete.[1]

[1] On a later visit in April 2004, a Debets Schalke representative, Mr. Quaasteniet, observed that several goods were packed in Chinese boxes and several boxes had got lost in the meantime.

Subsequently, the detailed design work and manufacturing of components for project Greenhouse II could be resumed and the first container be re-forwarded to China. The first container arrived in China in April 2003, the second and last container in August 2003. Clearance of the first container was retarded by claims of costs in excess of € 2,500 by Wan Fang Flower company, while stating that Wan Fang could and would not pay for the excess costs. Later on, apparently after opening of the container in the absence of the ECN representative, Wan Fang reported that the latter could not clear the standard frame parts of Greenhouse III as these were second-hand which would be in transgression of Chinese customs procedures as it was not clearly stated on the Bill of Lading. Meanwhile, Mr Vollebregt informed ECN of the less solvent status of Wan Fang Flower company and strongly advised that a more solvent and capable Recipient Party should replace Wan Fang, while suggesting a particular local company.

Shift of Recipient Party
In August 2003 an official mission from Shandong with delegates of Shouguang municipality visited Holland. At ECN's Petten office the project situation was discussed with ECN in presence of Mr Bussink from DGIS and representatives of SNAC. The Chinese delegation reluctantly accepted the arguments that a shift of recipient Party was warranted. At the same time, the delegation was adamant on a shift to the Shouguang Hightech Agriculture Demonstration Park (SHADP) with Mr Sui as managing director, contingent on the consent of Mr Lu Xuedu of the Ministry of Science and Technology. Given strong assurances by the Shouguang official delegation of commitment at a rapid construction of the pilot greenhouses within a time period of 40 days after the aforementioned meeting, a consensus on this subject could eventually be reached.

After the August 2003 meeting at ECN Mr Vollebregt reported a lack of project co-operation on the side of SHADP and, what counted even more for Mr Vollebregt, co-operation from Shouguang Municipality on the SNAC horticulture demonstration project which ran concurrently with the Improved Greenhouse project with ECN. End October 2003 SNAC decided to retire its expatriate staff and to discontinue their project. Subsequently, Mr Yu Jiating, responsible officer of Shouguang municipality on project affairs, assured ECN that Shouguang municipality strongly endorsed continuation of the Improved Greenhouses project. ECN in consultation with DGIS and MoST continued the project, given the disposition by the local side to take much more responsibility for project management. In a bid to smoothen further project implementation, in January 2004 an unscheduled and unbudgeted five-day fact-finding mission by Mr Quaasteniet, a Debets-Schalke expert, was fielded. The latter reported that most components were stored in a less orderly, dispersed way but were still in good condition and that he had constructive talks with local parties. A planning was agreed upon for construction of the foundations of the project greenhouses, after which the Debets-Schalke expert would return for the scheduled 2-week mission for construction of the greenhouses, conform contract between Debets-Schalke and ECN. Upon return 20 March, Mr Quaasteniet reported mistakes in the construction of the greenhouse foundations, too few workers who were poorly equipped and problems with availability of an English-speaking translator. His stay was extended to 28 days but he had to return home without installation of the project greenhouses being completed. Under normal conditions, this should have been completed within two weeks. In order to speed up the installation work, an ECN mission by Ms de Coninck (replacing Mr Jansen) and Messrs Schuitema and Sijpheer (both in-house climate conditioning technology experts) were fielded. Another Agreement was signed in which Shouguang municipality promised full collaboration. In return, ECN promised to send several essential parts that got lost between the arrival of the two consignments of Dutch parts (the last one in August 2003) and the first visit of Mr. Quaasteniet. Expensive replacement parts had to be sent. In May 2004 a third mission by a Debets-Schalke expert, Mr van de Stok, was sent out who stayed for 26 days, again without being able to assist at completion of the installation works. He also reported lack of sufficient and skilled workers, slow work speed, poor construction equipment and lack of translation facilities, despite the clear promises from the side of Mr. Yu Jiating of SMAC to take care of improvement and the intentions expressed by SHADP to start planting in the greenhouses by September 2004.

2.2.3 Project extension period: July 2004 through August 2005

Mid-2004 a project extension up to April 2005 was requested and granted by the project-funding organisations. In view of the great difficulties facing the project-implementing organisations, the following adjusted project scope was approved:

a) Conduct an experimental temperature and moisture measurement programme during a key planting season.
b) Conduct an experimental planting and harvest yield measurement programme.
c) Assess and identify the most attractive greenhouse configuration.
d) Engender sufficient enthusiasm in the horticulture business sector to commercialise the identified greenhouse concept, possibly in a CDM project framework.

Meanwhile, the Chinese collector company SANGLE finished the mechanical installation work for the solar collectors on Greenhouse II(hybrid type) on June 15 2004. The local workers should finish preparations for installing pumps and controllers for the collector system. Incoming photos made clear that the local workers finished the water reservoirs, needed for the storage of heat collected from the solar system during the day, although a lid for the water reservoir still has to be made. Also the North wall of Greenhouse II should be built by the local workers. Upon complete closure of the (walls, roof etc), the final installation work could be carried out and staff of the Recipient Party trained in the due operation of the greenhouses. An additional mission by another Debets-Schalke supervisor, Mr René van de Stok, in August 2004 for a duration of some three weeks was needed for this purpose.

A subsequent mission by Messrs Zwanenburg (mission leader) and Jansen (resource person), was fielded by DGIS to make separate arrangements for conducting an AIJ baseline determination and monitoring study consistent with CDM guidelines. In the course of this mission the project was visited and a consultative stakeholders meeting was held in Shouguang. The upshot of this meeting was that an adjusted project planning for completion of the project by end of April 2004 and an adjusted division of responsibilities was agreed (Jansen, 2004b). In the meantime, ECN searched for cost-effective arrangements to bring in new external horticulture expertise. Rijk Zwaan B.V. (RZ), a prominent seed company with subsidiary offices in Qingdao and Shouguang, agreed to fill the horticultural expertise gap.

As agreed RZ delivered high-quality tomato seedlings and advice on planting procedures. Unfortunately, the required fertilizer was not administered. Consequently, the tomato seedlings became unsuitable for further experimental planting. Moreover, problems with the circulation of the SWH-heated water basin remained causing further project delays. By January 2005 SAHDP succeeded in resolving this problem with assistance of SANGLE experts. RZ agreed to deliver tomato seedlings for a second time. Yet accrued implementation delays necessitated a request for a second and final project extension until end of August 2005. This request was granted by the project financing agencies.

Regrettably no definite experimental planting results could be obtained. Due to a mishap with the boiler for water heating during a very cold February day and the late response by SHADP staff to this mishap the second consignment of RZ planting material became useless. In contrast, the in-house climate measurement programme could be implemented in part up to the moment the active mode of the SWH-heating system was discontinued by SAHDP personnel. The (preliminary) results of this measurement programme are discussed in the next chapter.

2.3 Summary

The project witnessed a succession of unexpected adverse events, negatively affecting its implementation. As a result, implementation took much longer than expected. Moreover, only part of the project work plan drawn up at project inception could be carried out.

3. Design and performance of the improved greenhouses

3.1 Introduction

This chapter describes the design and performance of the project greenhouses after completion of their construction. Moreover, some of the initial design features and other relevant technical aspects are described.

Design aspects are set out in Section 3.2. Section 3.3 gives an introduction to the research programme on in-greenhouse climatic performance. An overview of the test results obtained during the period February 2005- July 2005 is given in Section 3.4. Section 3.5 gives preliminary results of experimental tomato growing over the same period. Some key conclusions on the technical performance of the pilot greenhouses is given in Section 3.5

3.2 Design details of the project greenhouses

Section 3.2.1 describes the initial set-up and preliminary design of the project greenhouses. Upon project start a new greenhouse concept was designed based on proven technology. This design is explained in Section 3.2.2 together with the final designs of all project greenhouses. In 3.2.3 the final realisation of the greenhouses is reported. Some of the initial design features have been modified due to different operational reasons during the realisation of the greenhouses. This will be set out further below in this chapter.

3.2.1 Short introduction to the project greenhouses

The project greenhouses are numbered as type I, type II and type III. Type I is a conventional Sunny Greenhouse ubiquitously present in Shandong province and elsewhere in the eastern plains of China. Type II is an enhanced Sunny Greenhouse III a Dutch ‘Venlo’ type greenhouse. All greenhouses are approximately 600 m^2. The Type II, enhanced Sunny Greenhouse has been designed within the current project.

Type I

The Sunny Greenhouse basis is a clay wall and arches of iron and bamboo. The clay wall is the north side of the greenhouse and stretches from east to west. The wall gives stability to a construction of arches of bamboo and iron. Over the arches a plastic foil is stretched, the foil faces south. The thick clay (or brick) wall provides the greenhouse with a large thermal mass. During the day the sun typically heats the wall and the heat is stored in the wall. During the night, the wall provides the greenhouse with the heat stored during the day. To prevent large heat losses during the night, the plastic foil is covered with a straw mat. The straw mat is rolled down in the evening and again pulled up in the morning. See Figure 3.1. Most Sunny Greenhouses are dug a little into the ground for additional ‘thermal stabilization’.

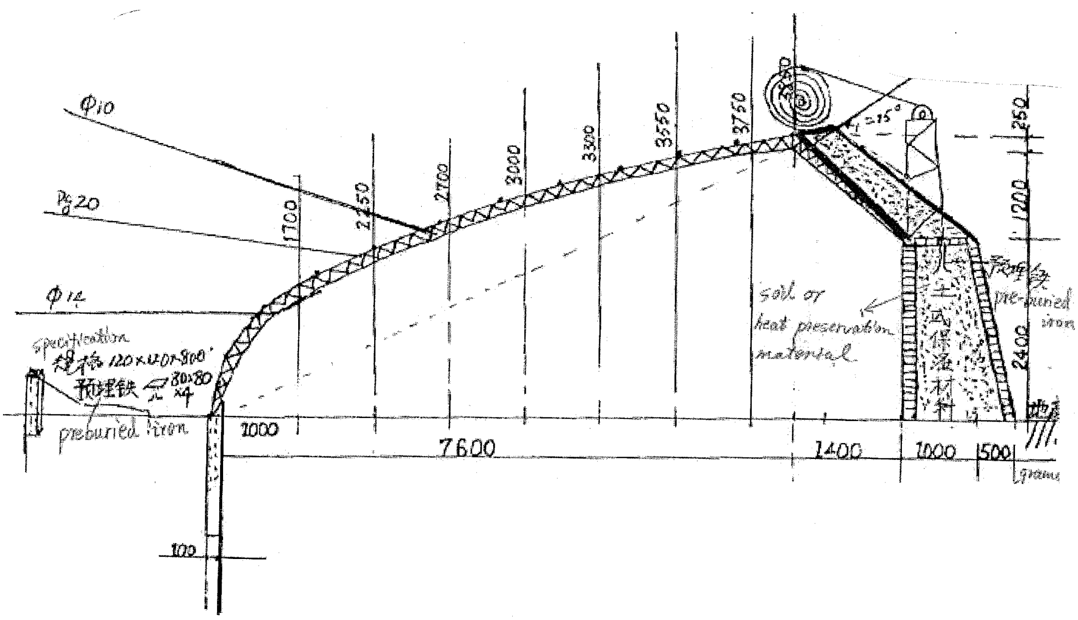


Figure 3.1 *Cross section of a traditional Sunny Greenhouse*

The Sunny Greenhouse is a relative cheap greenhouse to build/buy which is just capable of keeping the in-greenhouse temperature above 0°C during winter months. The price varies with the quality and material use from 30,000 to 50,000 RMB. A huge drawback is the poor ventilation system, resulting in an in-greenhouse climate with a very high humidity. High humidity levels make plants liable to diseases and limit the number of species able to grow.

Type II

The enhanced Sunny Greenhouse was designed during the early days of the project. Its design and shape is based on the traditional Sunny Greenhouse. The enhanced Sunny Greenhouse is constructed out of steel to make it suitable for carrying an array of thermal solar collectors. These solar collectors will produce hot water to heat the greenhouse during the night. Because of the additional heating, the wall thickness can be reduced which creates a larger crop area (~10%) within the same outside measures.

A second modification regards a better controllable ventilation method. Windows at the front side and in the roof can be opened to create an efficient ventilation stream to control the in-greenhouse humidity. An additional modification would be a ventilation system with heat recovery. The most important design criteria are 1) an increased night-time temperature by 5°C compared to the traditional Sunny Greenhouse and 2) a significantly reduced humidity level compared to the traditional Sunny Greenhouse.

The enhanced Sunny Greenhouse is made of steel joists to obtain a rigid construction to carry the solar collectors. The joists can be covered by foil or by glass. In the original design the greenhouse was partly coved with foil and partly with glass. The foil part would have a curved roof shape.

The solar heating system consists of an array of solar collectors to be placed on the roof, a water basin to store the solar heat produced during the day and a heating system of pipes. These pipes distribute the stored heat during the night in the greenhouse. A design study performed by IMAG and ECN DEGO was conducted to dimension the solar heating system and to determine the insulation level of the greenhouse and water basins. Figure 3.2 shows project Greenhouse II, the enhanced Sunny Greenhouse.

Figure 3.2 *Greenhouse II (November 2004), the far left part is covered by PC board, right is covered by glass and equipped with the solar collectors*

Type III
The third project greenhouse is an original Dutch 'Venlo' greenhouse. This greenhouse is a square 'house of glass'. The greenhouse is designed with a large and efficient useable area and it can be ventilated very well. The main greenhouse construction is made of steel, the main construction is covered by a frame of aluminum straps to which a glass coverage is mounted. The Venlo greenhouse can be heated with a standard heating system. This heating system is a standard feature for a Venlo greenhouse in the Netherlands. In the project the performance of the Venlo greenhouse will be examined. If the Venlo Greenhouse was to prove a suitable replacement for the Sunny Greenhouses, it could be considered for further dissemination instead of the enhanced Sunny Greenhouse. The advantage of the Venlo greenhouse is that it is a proven fully developed and standardised technology, while it can be produced quite easily. Furthermore, the Venlo greenhouse has a relatively low heat loss per square meter because of its low envelope area per square meter and volume ratio. Figure 3.3 shows a picture of the Venlo Greenhouse at the project site.

Figure 3.3 *The Dutch Venlo Type greenhouse, Greenhouse III at SAHDP*

3.2.2 Summary of the design study of IMAG and ECN

The project focuses on the enhanced Sunny Greenhouse which design has been broadly predicated on the existing local design. It was based on a selection out of a variety of initial ideas. Because it denoted a new greenhouse concept most key parameter values had to be calculated. The pilot enhanced Sunny Greenhouse was constructed by Debets Schalke, a Dutch greenhouse construction company. It is based on the shape and functionality of the Sunny Greenhouse. To fulfil the requirements of a higher night-time temperature and a lower humidity ECN and IMAG worked together to design an ‘energy system’ for the construction design of Debets Schalke. In the design ECN focused on the energy related aspects of the greenhouse, IMAG focused on the in-greenhouse climate and growing conditions.

The following steps were made to come to the final design of the energy system.

1. Based on the in-greenhouse temperature of a traditional Sunny Greenhouse a new in-greenhouse temperature profile was made for the enhanced Sunny Greenhouse. The new temperature profile included the project aim of a night temperature increase of 5°C. Figure 3.4 shows the desired temperature profile of Greenhouse II.
2. The heat demand of the new greenhouse was calculated by IMAG, using the in-greenhouse temperature profile, the outdoor climate parameter of Shouguang and the thermal properties of the greenhouse. IMAG is specialized in greenhouse heat demand simulations.
3. Based on the calculated heat demand, ECN DEGO determined the level of greenhouse insulation (to reduce the heat demand) and the area, efficiency and capacity of the solar collectors with heat storage (to supply the remaining heat demand).

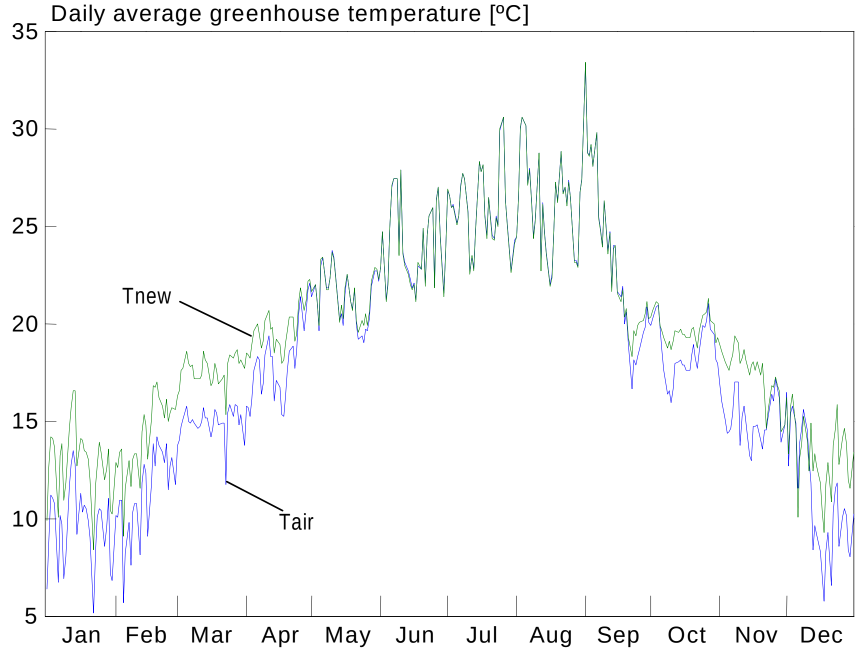


Figure 3.4 *Calculated temperature profile of the traditional Sunny Greenhouse (T-air) and the desired temperature profile for Greenhouse Type II (Tnew)*

Figure 3.5 gives the determined daily average heat demand for the enhanced Sunny Greenhouse. The maximum heating demand during the coldest night in wintertime is 68.2 W/m^2 calculated with a 1-hour time interval. The heat demand in Figure 3.5 represents the daily average values, which are lower than the peak heat demand of 68.2 W/m^2.

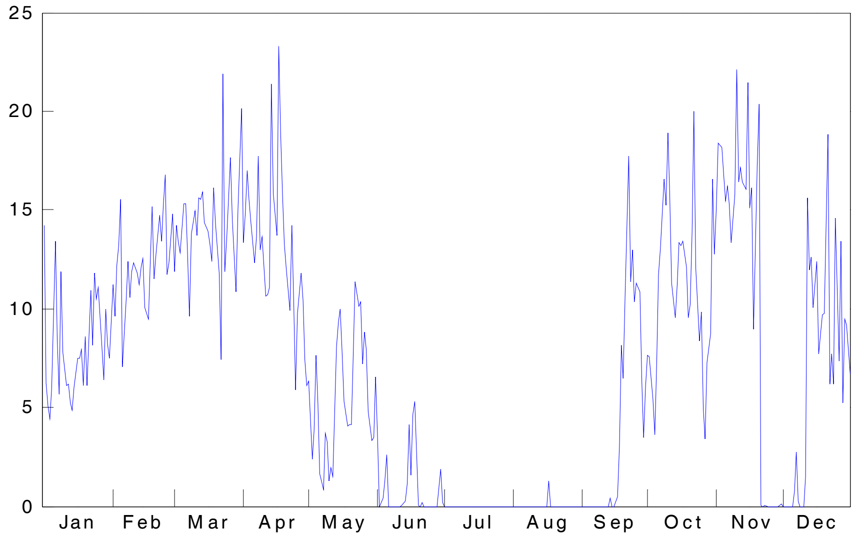


Figure 3.5 *Determined for Greenhouse II: the average heat demand per day (y-axis [W/m² floor area]) plotted throughout one year (x-axis)*

To fulfil the heat demand, evacuated tube solar collectors are used. The specifications of the definite installed collectors are given in Paragraph 3.2.3. The solar heating design is based on 3×20 m² vacuum collectors with an efficiency based on collector parameters a_0 = 0,52 a_1 = 2,3 and a mounting angle of 50°. Detailed design specifications are given in Appendix A. The Optimal water volume to store the solar heat is 30 m³. With these specifications the solar heating system can supply 80% of the heat demand, this can be seen in Figure 3.6.

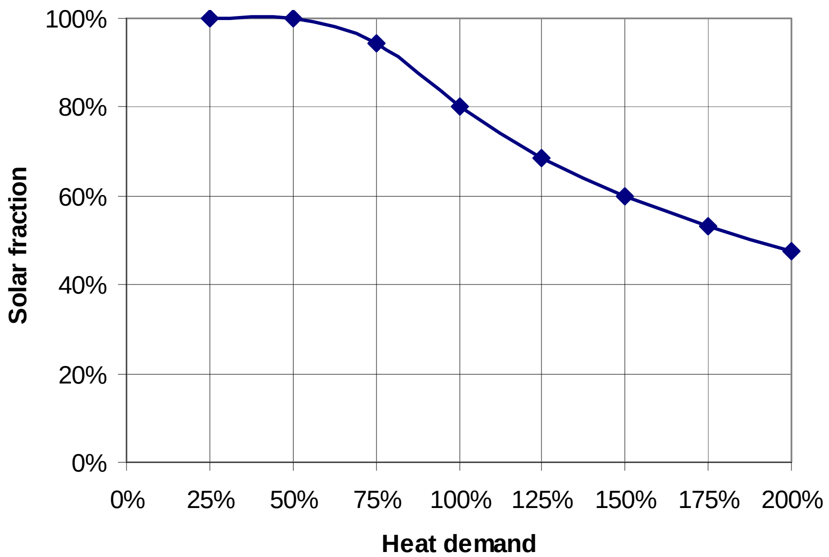


Figure 3.6 *Solar fraction of Greenhouse II. The Solar Faction is the percentage of coverage of the heat demand. The complete heat demand (100%) can be supplied for 80% by the specific solar system*

Obtaining a higher solar fraction requires an additional investment in collector area or efficiency. The last 20% of the projected heat demand is to be met by reducing the heat demand. This is done by insulation and efficient ventilation. Insulation of the back wall and foundation of the greenhouse with 20 cm EPS (EPS is polystyrene, a cheap and very effective insulation material widely available), together with heat recovery ventilation gives a solar fraction of 95%.

Only for exceptional cases, the supply will not be enough to meet the projected demand. This demand is based on a traditional greenhouse +5°C, so at any rate the temperature will at least match the traditional greenhouse. Furthermore, the greenhouse ventilation can be lowered at specific cold moments, which will directly result in a higher temperature.

The ECN DEGO and IMAG design study has yielded the specifications of the solar collectors, the level of insulation of the greenhouse and the volume of the heat storage. Details are given in Appendix A. Appendix A also lists the insulation properties of the piping and heat storage. The calculations are broadly based on common and reasonable installation techniques including normal insulation thickness.

3.2.3 Final realization of Greenhouse I, II and III

This section describes the realization and final shape of the pilot greenhouses as built at the premises of the Shouguang Agricultural Hightech Demonstration Park (SAHDP).

Greenhouse I

In the final set-up, the traditional greenhouse is not heated. Figure 3.7 shows Greenhouse I which is used for growing tomatoes in the project. The interior of a traditional greenhouse is shown in Figure 3.8.

Figure 3.7 *The traditional greenhouse (Greenhouse I) used for the experiments*

Figure 3.8 *Interior of a Traditional Sunny Greenhouse*

Greenhouse II

Project Greenhouse II is shown in Figure 3.2. The north wall is made of a single layer of bricks and is insulated with 10 cm thick Poly Styrene (EPS). The foundation is not insulated. The requirements were an insulation thickness of 20 cm and the foundations to be insulated (also into the ground). The greenhouse consists of two parts of equal size, the west part of the greenhouse is covered with “PC-board” and has a heating system connected to a central boiler house. The east part of the greenhouse is equipped with solar collectors (without back reflector). It has an outside heat storage water basin, built in three semi-separate basins. In the original design the heat storage was planned inside. The final heat storage contains a water volume of almost 60 m^3 (and 40 m^3 in a later stage) as against a volume of 30 m^3 required in the specifications document (Sijpheer, Schuitema 2004). The specifications document was discussed with and approved by SAHDP during an ECN mission in April 2004. Between 21-24 February 2005 one compartment of 20 m^3 was disconnected to reduce the volume to 40 m^3. The water basin is insulated with 10 cm of poly-styrene as against a designed thickness of 20 cm. The heating system of the east part of the enhanced Sunny Greenhouse has been connected to the water basin. Initially the greenhouse was planned to be covered with foil, the final version is covered with ‘PC board’ on the west and glass on the east side. PC board is a double layer of ridged plastic separated by canals.[2] PC board has better insulating properties than foil.

Some of the requirements from the design could not be met for different reasons. For example: due to possible wind pressure, the solar collectors are installed without reflector. Due to possible construction problems (expected by SAHDP and not acknowledged by ECN-DEGO) the heat storage is placed outside the greenhouse instead of indoors. The insulation thickness is kept 10 cm instead of the required 20 cm EPS. The greenhouse construction is not suitable for a foil covering so a solid PC board covering is realised (PC board insulates better than foil). This is poised to adversely impact the performance of the greenhouse. In the thermal (energy) related properties of Type II greenhouse are summarized.

2 In Holland PC board is known as ‘lexaan’ plates.

Table 3.1 *Thermal (system) properties of Greenhouse II*

	Original design	Final Release
Solar Collectors	60 m^2 with reflector	No reflector
Heat Storage	30 m^3 insulated by 20 cm EPS	40 m^3 insulated by 10 cm EPS
Insulation of Greenhouse	Wall and foundation: 20 cm EPS	Only back wall: 10 cm EPS
Coverage of Greenhouse	Glass (East) and Foil (West)	Glass (East) and PC board (West)

The solar collector system is described in more detail in Appendix B. Here two figures show the hydraulic circuit of the solar collectors and the water basins and a picture of the collectors itself, see Figure 3.9 and Figure 3.10.

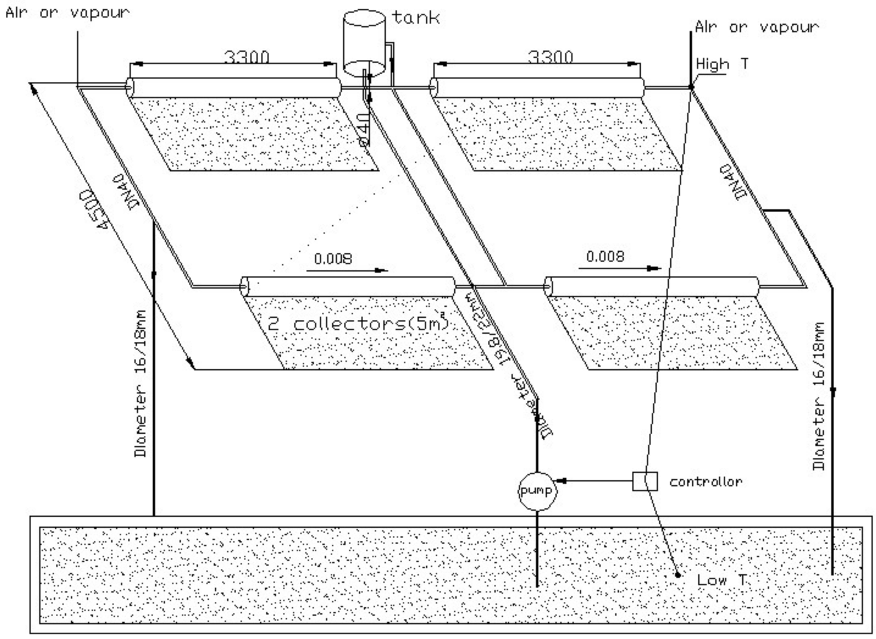


Figure 3.9 *Schematic layout of the solar collector system*

Figure 3.10 *Picture of the solar collectors at the roof of Greenhouse II*

Greenhouse III

The Venlo greenhouse has been installed in a similar way as being done in the Netherlands, also without additional insulation around its foundation. The greenhouse is covered with single layer glass. The heating system is the standard system used in Holland, it is supplied from the same central boiler house as the west part of Greenhouse II. Figure 3.3 shows a picture of Greenhouse III.

3.3 Research program/experimental set-up

The initial design envisaged splitting of Greenhouses I and II into two parts. This would make it possible to set reference situations and to compare different kind of heating and different kind of greenhouse constructions. The first half of the traditional Type I greenhouse was to be unheated, the second half heated using a traditional coal boiler. The first part of the enhanced Sunny Greenhouse was designed to be heated traditionally, like the Sunny Greenhouse, the second half of the Type II greenhouse to be heated using the solar collectors as described in (Sijpheer and Schuitema 2004). Finally the Type III Venlo greenhouse was to be heated by a conventional heating source, using the same external boiler system as for the No. II enhanced Sunny Greenhouse.

In the just described design situation, the difference between an unheated and heated No. I Sunny Greenhouse can be extracted. The heated Sunny Greenhouse can be used as a reference for heated enhanced Sunny Greenhouse. For the enhanced Sunny Greenhouse (no. II) it can be determined if the solar heated part can meet the performances of the coal heated part. Finally the performance of the Venlo greenhouse would yield an answer to the question whether or not Type I and/or Type II 'low energy' greenhouses were more appropriate than western technology Venlo greenhouse under Chinese conditions.

SHADP decided to make available to the project a type I traditional greenhouse without splitting it into two compartments nor with access to heating. Hence, in the tomato growing experiment the traditional Sunny Greenhouse was left unheated (and unsplit). This way the performance of the unheated Sunny greenhouse has to be compared directly to that of the heated enhanced greenhouse. This makes it harder to single out the performance of the (unheated) greenhouses as such from the effect of additional heating. Nonetheless, comparison of (i) performance of (unheated) Type I with the performance of the solar water heater (SWH)-heated Type II and (ii) of performance of SWH-heated Type II with that of boiler-house-heated Type II under good experimental conditions could still yield quite meaningful project results.

Two complementary programmes to determine the performance of the greenhouses have been implemented. The vegetable growing programme set out to conduct experimental vegetable (tomato) growing and to compare the growing results for the different greenhouse configurations. The second greenhouse climatic measurement programme set out to record the temperatures and humidity at different places in the distinct greenhouse parts. Hence the project design envisaged that during a growing season in the winter:

- tomato plants were to be planted,
- the plant development and the yield of the harvest monitored, and
- temperature and humidity recordings made to monitor the in-greenhouse climate of the different greenhouses.

The monitoring system is described in Appendix C in detail, below a short summary is given.

Data recording modules are placed at three places inside the greenhouses and the air temperature of the greenhouse and its distribution is recorded accordingly. Moreover, for each (part) of the greenhouses, the relative humidity is recorded. Furthermore, the temperatures of the different heating flows are recorded; this data gives a clue for each greenhouse (part) about the amount of heating. Finally the solar collector temperature, the water basin temperature and the outdoor temperature are recorded.

SDERI placed the recording devices and was responsible for collecting the recorded data. SDERI programmed in addition a very useful computer tool to have a quick look at the recorded data. With this computer tool, the data can be plotted in graphs, can be extracted to different file formats and be related to a map with the sensor locations. Figure 3.11 shows one of the boxes with two data recording devices. Figure 3.12 gives a screen shot of the computer program (made by SDERI) to view the data.

Figure 3.11 *Data recording devices as installed in the project Greenhouses*

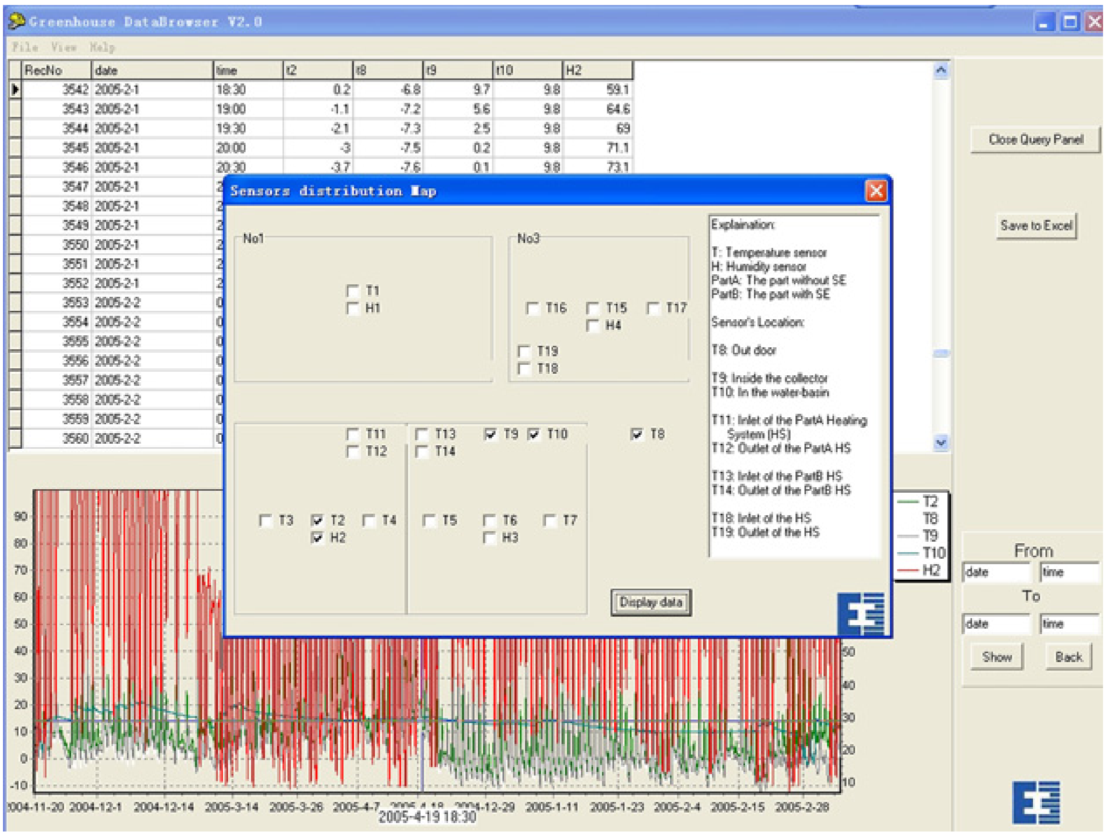


Figure 3.12 *Screenshot of the data view program produced by SDERI as support tool to read the monitoring data*

Greenhouse performances
By measuring the harvest of the tomato plants and by measuring the temperature and humidity in the different greenhouses, the performances of the different greenhouses can be measured, the different greenhouses can be compared to each other and conclusions can be drawn about the possibilities of the greenhouses to be introduced in China.

3.4 Preliminary results of the greenhouse climatic measurement programme

3.4.1 Greenhouse management

Greenhouse management is needed to ensure the proper conditions for the plants. Generally, the greenhouse farmer provides this management; in the project setting SAHDP is in charge. For Greenhouses II and III the management consist of operating the windows, the screens and the heating.

Table 3.2 gives an overview of the general management during the tomato-growing period of the project.

The windows of the greenhouses were kept closed during the cold period while the heating was turned on. After the heating period, the greenhouse windows were opened during the day from 10:00 till 14:00. The screens in the greenhouses were used to prevent heat losses during the night, they are closed at night from 17:00-08:00.

Table 3.2 *General operating schemes of the project greenhouses*

Greenhouse	IIA (boiler heated)	IIB (solar heated)	III
Planting tomatoes	March 5 2005	March 5 2005	March 5 2005
Start heating period	February 21 2005	March 5 2005	February 21 2005
End heating period	April 25 2005	April 30 2005	April 25 2005
Heating times during the day	16:00-04:00	17:00-08:00	16:00-04:00
Windows during heating period	Closed	Closed	Closed
Windows after heating period	Open 10:00-14:00	Open 10:00-14:00	Open 10:00-14:00
Screens	Closed 17:00-08:00	Closed 17:00-08:00	Closed 17:00-08:00

Two specific occurrences had a great impact on the results of the greenhouse climatic measurement programme:

- Between 21 and 24 February 2005 the capacity of the water basins was reduced to have a better match with the solar collector capacity. This modification had to take place because the water basins appeared to be larger than the original design.
- The final batch of tomato plants was planted on 5 March 2005. Around the same day, the solar collector system started and had a final check by SDERI staff. From the date of planting, the heating system of the boiler heated part of Greenhouse II and of Greenhouse III was started. In principle the heating systems have been operated up to 30 April 2005. However, the solar collector system was stopped before 30 April by SAHDP staff because in their opinion it did not supply enough heat to the greenhouse.

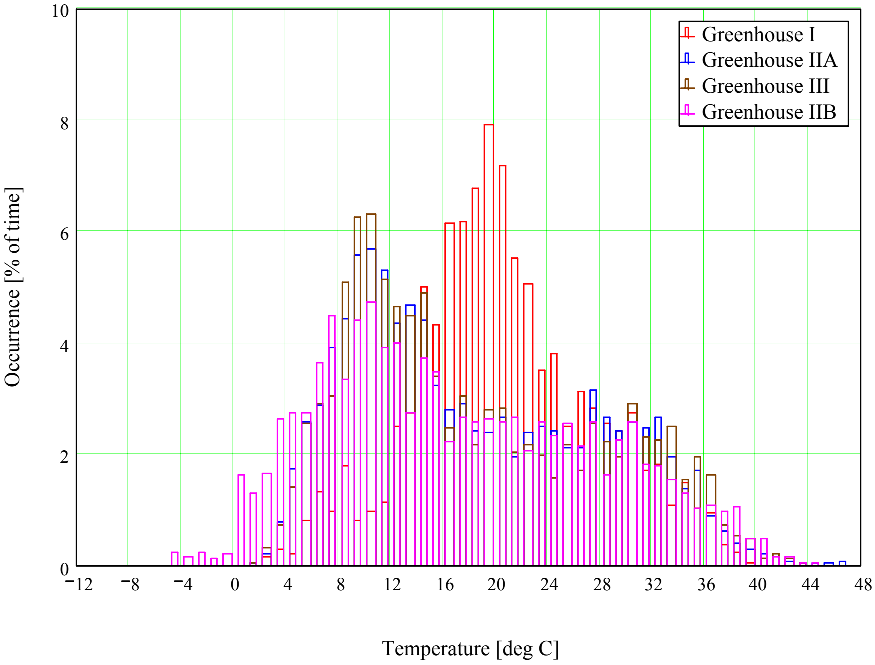
In general, it appears that the management of the total energy system has not always been very efficient. The main indication for this statement is the loss of many tomato plants due to a defected heating pump, causing many plants to be frozen during the following night. Also the monitored data provide evidence that the solar collector system has been out of operation for many days. Adequate management would have reduced the number of days the system is out of operation.

3.4.2 Analysis of the measured temperature and humidity in Greenhouse I, II and III

As described, in all the greenhouses the temperature and relative humidity was measured. These measurements yielded data on in-greenhouse climate in the greenhouse for the period of December 2004 - June 2005. For Greenhouse II and III the temperature and humidity were measured at different positions in the greenhouses. The data shows a good comparison, this means the climate through the greenhouses is rather uniform. Therefore the average value of the different locations is taken as measure for the temperature and humidity.

The total monitoring period from December 2004 until June 2005 is separated in periods related to the management in the greenhouses (see Table 3.2).

For the heating period mentioned in Table 3.2 (5 March 2005 till 25 April 2005), a frequency plot has been made of the temperature and humidity. In a frequency plot the percentage of occurrence of a specific temperature range is given. For example in Figure 3.13 can be seen that a temperatures of 20°C occurred 8% of the time in Greenhouse I.



Greenhouse IIA is conventionally heated.

Greenhouse IIB is solar heated.

Figure 3.13 *Temperature distribution during the heating period (5 March 2005-25 April 2005), all greenhouses*

This graphic presentation gives the possibility to compare the different greenhouse in an easy way. In Figure 3.13 all greenhouse temperature distributions are plotted in one graph, to have some more overview, the same temperature distributions are plotted separate in Figure 3.14. The plotted temperatures are measured during the heating period from 5 March 2005 till 25 April 2005. Greenhouse I shows a higher average temperature (the highest peak is more right wards than the others) although Greenhouse I is not heated. *It is important to mention the heating system has not always been working during the stated period*. This will be further explained in the next section. Greenhouse I has better passive heating properties and will function better when the heating is turned off, this is mainly shown in Figure 3.13 and Figure 3.14. Especially the solar heating system has been shut down for a long period, this has resulted in the few temperature measurements below 0°C (pink bars on the left in the figures).

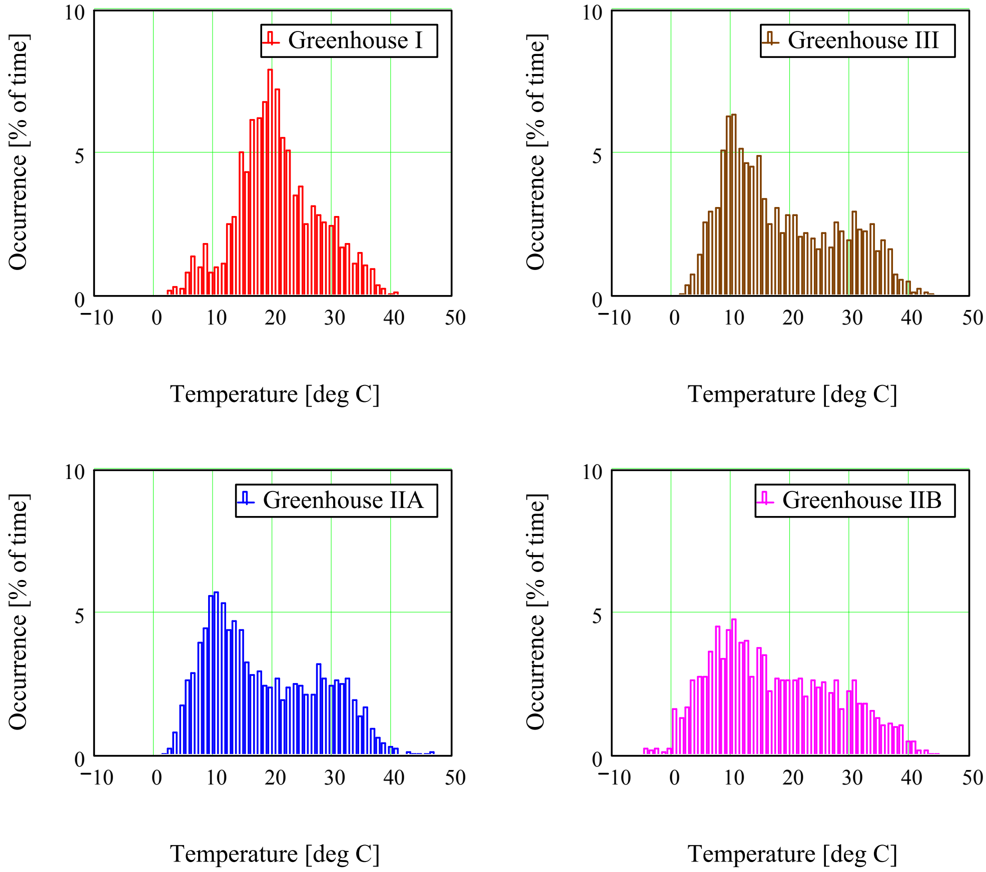


Figure 3.14 *Temperature distribution during the heating period (5 March 2005-25 April 2005), separate per greenhouse*

In the next figure (Figure 3.15) the distribution of the relative humidity is plotted for the same heating period. The graphs are read the same way as the temperature distributions. It can be seen that a RH of 100% occurred more than 1/3rd of the time in Greenhouse I. So the humidity is over 16 hours a day at its absolute maximum. Greenhouses II and III show a much better humidity figure, their humidity is distributed quite flat during the time. For the boundary value of 85% humidity, Greenhouse I has a humidity higher than 85% for 60% of the time. While Greenhouse III and II (east) have a humidity over 85% only 30% of the time and Greenhouse II (west) even 25% of the time.

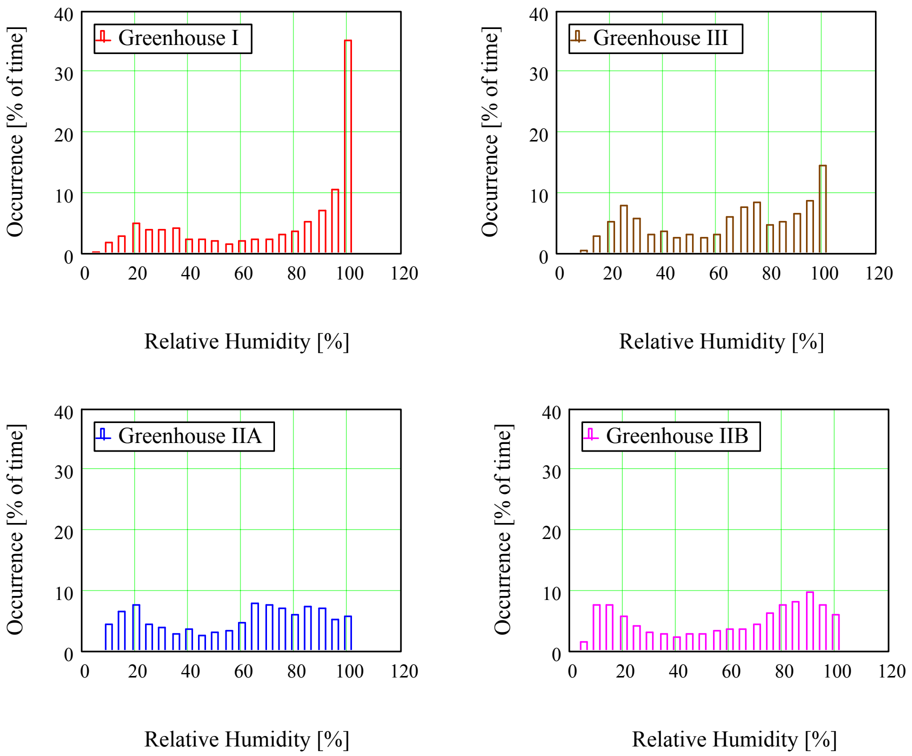


Figure 3.15 *Relative humidity distribution during the heating period (5 March 2005-25 April 2005), separate per greenhouse*

The aim of the enhanced greenhouse is to have a 5°C higher temperature during the night and a relative humidity smaller than 85% most of the time. From the previous presented figures can be seen that this is not completely reached. Although the humidity is reduced significantly, the temperature in the greenhouses II and III is not improved as much as desired. The next section will discuss the reasons.

3.4.3 Functioning of the heating system in IIb

The measurement system (described in Appendix C) measures the temperature of the water in the heating system. For each greenhouse the temperature of the hot water flow towards the greenhouse and the flow returning from the greenhouse was measured. The signals received yield a measure of the amount of heat delivered by the tubes of the heating system in the greenhouses. They also indicate the moments the heating is turned on and off.

During Heating period from 5 March 2005 till April 25 2005 the heating has been turned on only 12.5% of the time. Related to the outside temperature, it would have been preferable to have the greenhouses heated the whole period during the nights.

Like the heating system, the solar collector temperature and the water basin temperature have been measured. These temperatures are an indication of the amount of heat collected by the solar collector and stored in the water basin. From the data can be derived which periods the solar collector is active and loading the water storage. The solar collector has been operating only partly during the winter months. Due to the short period of operations, the water basin is not been loaded up to high temperatures. This is one reason for the poor heating performances in Greenhouse IIb, together with the heating switched off.

Figure 3.16 shows the temperature rise of the water basin. Each day the solar collector is heating the water storage. During the night there is a small heat loss or can be a larger heat loss if the heat is used for the greenhouse.

Surprisingly the water inside the water basins is not heated up to 50°C or more, while the solar collector is producing water at least up to 50°C (when turned on).

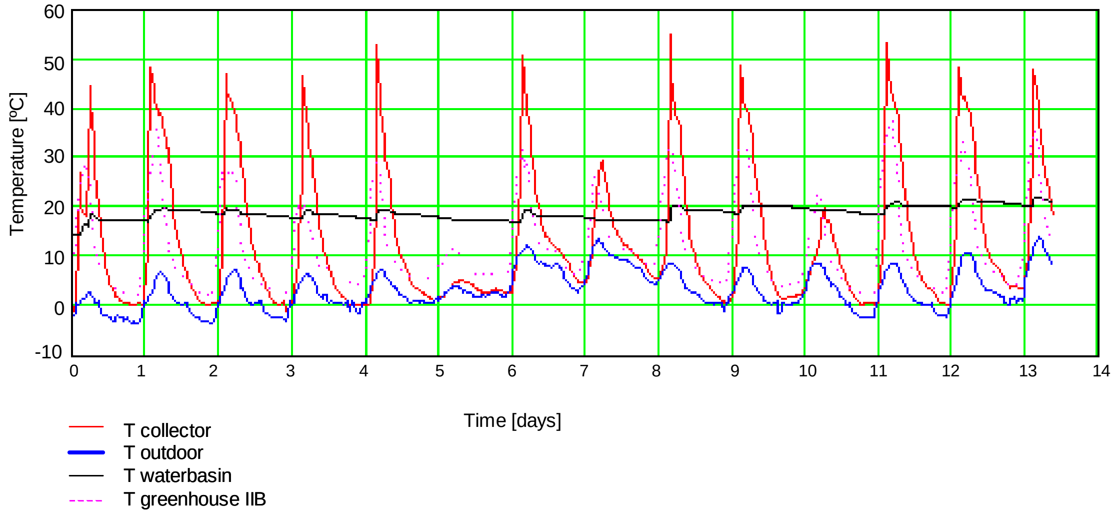


Figure 3.16 *Loading water basin, 26 November 2004 till 9 December 2004*

3.4.4 Conclusions

In short:

- The Solar heating system has proven to be an alternative system for greenhouse heating, warranting further experimentation.
- The water basin is the main problem in the project for a more successful demonstration of the solar heating system.
- The greenhouses itself, IIA, IIB and III should be better insulated
- With better and more management the system could have performed significantly better.
- Greenhouses II and III have performed better on keeping a low humidity, this is an important improvement in greenhouse climatic conditions for vegetable growing.

3.4.5 Improvements for the future

Improvements to the current system to let it operate with low investments

- Using all three water basins, now with a high insulation and absolute waterproof heat resistant foil.
- Improvement of the greenhouse insulation, an insulation around the foundation which is dug into the ground. Shielding of the heating pipes along the wall/glass
- Optimisation of flow speed of the collector system and of the heating system

It is noted that implementing these measures under direct control of a supervisor familiar with the situation is essential.

Improvements in general, towards better greenhouses using the same solar heating concept.

- Integrated and integral design of the collector capacity, the storage capacity and the heat demand of the greenhouse.
- More and better effort in reducing the heat demand of the greenhouse.
- Better ventilation without heat losses (heat recovery system).

- Water basin inside the greenhouse.
- Research on possibilities of using a water tank instead of a water basin.
- Solar collector with a backside reflector (efficiency will increase 10%).
- One array of collectors instead of a double row.
- The use of high efficient screens on the inside, in combination with dehumidity systems (condensation and drainage). Otherwise re-introduction of the classical straw mat on the outside.
- Re-introduction of a back wall with heat storage capacity.
- System with less shading to other greenhouses.
- System without pumps below ground level.

3.5 Preliminary results of experimental tomato growing

As mentioned in Section 3.3 tomatoes are used to compare the actual growing properties of the greenhouses. The experiments started with the final batch of planted tomatoes just after Chinese New Year (see Section 3.4.1). The final batch of tomatoes was planted on 5 March 2005.

After several trials to start tomato grow in the Greenhouses, new tomato seedlings were planted just after Chinese New Year at 5 March 2005.

The last trial to start up, has a quite strong impact on the final results. During one night at the end of February, due to a technical problem with a heating pump and a very late response to this, 60% of the original delivered seedlings by RZ had to be replaced Greenhouses II and III.

Figure 3.17 *Tomatoes inside Greenhouse II*

3.5.1 Background information

The Dutch seed company Rijk Zwaan has provided tomato plants to be planted in the greenhouses. After some delays due to several reasons, around Chinese New year the tomato plants were planted in the greenhouses. A previous batch of tomato plants had been planted at the end of 2004, but due to delays in the heating systems, the planting of these plants did not match the required conditions and a new batch of plants had to be raised.

The second batch is planted in February after Chinese New Year, unfortunately one of the heating pumps in the system broke and during a very cold night, many tomato plants in Greenhouse

II an III suffered severe freezing damage. To 'restore' the damage as much a possible, SAHDP immediately replaced the frozen plants by new ones. Important to mention is that the new plants where not from the same brand and race as the Rijk Zwaan plants (!). This makes it more difficult to compare the different yields of the tomato plants. Greenhouse I was not affected by the broken heating system and no plants were frozen in Greenhouse I.

In Greenhouse I 1800 Rijk Zwaan plants are grown. Greenhouse II has 960 plants of which 2/3 are replaced after the freezing problems. Greenhouse III has 1225 plants from which 800 are replaced by non-Rijk Zwaan plants.

Furthermore SAHDP has chosen to use two kinds of 'soils' for planting the tomatoes. Some of the plants are planted directly into the greenhouse ground (referred to as 'soil'), some of the plants are planted in a special soil like substance of dried rice plant materials (referred to as 'soil replacement'). Figure 3.18 shows the soil replacement, which is put on plastic sheets on top of the normal ground.

The areas of the greenhouses are more or less comparable, but due to the heating tubes and the different divisions inside, different effective areas result. This is taken into account in the final analysis of the harvests.

Figure 3.18 *Soil replacement material (shredded rice plant?) put on top of a foil to keep the roots separated from the soil underneath. Water dripping system is also visible*

3.5.2 Results

Table 3.3 shows the results of the tomato harvest experiments. Greenhouse II and III have been heated until the end of April 2005, so during the first two months of experimental growing additional heating has been applied in Greenhouse II and III. Greenhouse I witnessed a little faster growth and the harvest started at 30 May 2005. In Greenhouse II and III the first picking started at 10 June 2005.

The actual picked amount of tomatoes (measured in kilograms) is show in the first row of Table 3.3. The amount of picked tomatoes is averaged over the amount of days in which the tomatoes are picked. Furthermore the planted area is taken into account. This results in a number of average kilogram tomatoes per day and per square meter greenhouse (Row 5).

A second way to be able to compare the tomato yield is to determine the amount of kilograms per plant per day. These figures are denoted in Row 6. One complicating factor is the fact that not all tomatoes in Greenhouse II and III where already picked. An estimation is done how many kilogram is left at the plants. This gives the total amount of kilograms produced over this growing period (independent of the days). This is called the total yield over the full harvest period. To compare the individual greenhouses, again the number is taken per square meter greenhouse area and secondly per plant. These results are found in the last two rows of the table.

Table 3.3 *Overview results tomato harvest in the different greenhouses*

Greenhouse	Greenhouse I		Greenhouse II		Greenhouse III	
Heating:	Unheated	Normal	East Solar heated	West Boiler heated	Boiler heated	Normal
Used soil:	Soil replacement	Soil	Soil replacement	Soil replacement	Soil replacement	Soil
Total yield [kg] till 2 July ‘05	1045.2	2283.3	530.5	371.5	850.7	254.3
Harvest period [days]	23	28	21	20	22	22
Planted area [m^2]	133.3	453.4	206.7	206.7	420.0	106.7
Approximate amount of tomato plants [-]	410	1400	490	490	970	250
Average yield [kg/day m^2]	0.34	0.18	0.12	0.09	0.09	0.11
Average yield [kg/day per plant]	0.11	0.06	0.05	0.04	0.04	0.05
Average weight of one tomato [gram]	-	-	98	76	85	159
Total yield over full harvest period [kg]	1045.2	2283.3	895.1	782.4	1067.5	392.2
Total yield over full harvest period [kg/m^2]	7.8	5.0	4.3	3.8	2.5	3.7
Total yield over full harvest period [kg/plant]	2.5	1.6	1.8	1.6	1.1	1.6

3.5.3 Conclusions

The results show that Greenhouse I gives (at soil replacement) a yield which is 2 to 3 times higher than Greenhouses II and III. But also the yield of Greenhouse I for the soil planted tomatoes is higher than for the heated greenhouses.

It depends a little on the ‘normalization’ method (yield per square meter or yield per plant) but in general Greenhouse I is performing better. As soon as the heating is not working properly, Greenhouse I will be in advantage because its ‘heating’ principle is much more passive and functions continuously, at least at a low level. There is not much difference between Greenhouse IIA, IIB and III, although Greenhouse II is heated in two ways.

In Greenhouse I the soil replacement performs better than the original soil, but in Greenhouse III it is just the other way around.

It cannot be claimed a priori that a poor heating system is the reason for the low performance of the heated greenhouses. The reason is that in the heated greenhouses 2/3 of the original tomato plants are replaced by a different kind. These plants have a later start in growing and might have been of lesser quality. Furthermore, at 15 July 2005 the plants in the heated greenhouse were still carrying fruits while the plants in Greenhouse I where already removed. The remaining fruits have been taken also into account in the last row of the table. But even then Greenhouse I is performing better. But once again, other reasons than the heating system of the greenhouses may have brought this about.

3.6 Final observations

The heating system based on a solar collector and heat storage both turned out to function. The enhanced greenhouses have a much lower humidity, which is very good for the in-greenhouse vegetable growing climate. The main problem in continuing the current system is the poor way the system is built and operated. The concept has been proven, although the actual realization is not optimal.

It turned out problematic to draw inferences on the performance of the technologies on the basis of the vegetable growing experiments conducted, because of some interfering external factors. *The measurements of the indoor temperatures and climate provide the most relevant information for drawing conclusions on technology performance.* In spite of a number of sub-optimal installation compromises, the solar heating system has proven to be a promising alternative heating system for greenhouses, warranting further experimentation.

4. Possible project follow-up

The project has not conclusively triggered the commercialisation take-off of 'enhanced sunny greenhouse' concepts envisaged at project start. Nonetheless, the project has proved - for the first time to our knowledge - that solar heating systems can function quite reliably. Considering, that:

- The need for additional heating in horticulture in Shandong and more northern Chinese regions is structurally increasing as a result of higher land pressure, higher wages, and surging demand for high-quality vegetables and flowers in in-land and export markets.
- With currently more than 400,000 hectares of greenhouses in place, the structurally increasing additional heat demand by Chinese horticulture is poised to have a very notable energy demand and consequential environmental impact in the absence of mitigating measures.
- Western greenhouse technology is on the one hand more productive than Chinese sunny greenhouses, but also incomparably more energy-intensive and capital-intensive.
- The current project has proven that 'enhanced sunny greenhouse' concepts can both deliver additional heating without recourse to fossil fuels and substantially improve plant growing conditions by reducing humidity.
- From a global perspective, China has long track record and a quite pronounced comparative advantage in manufacturing of solar water heating systems.

Continued experimentation with enhanced sunny greenhouse concepts is strongly recommended.

Follow-up demonstration project activities can integrate several more renewable energy supply and storage features that were envisaged at project design but proved not feasible to install in the current project prototypes for project operational reasons. Given the lessons learned during current project implementation and the potential benefits for Chinese society, follow-up activities should have a strong sense of Chinese project ownership.

In the first stage of follow-up activities, the emphasis should be on further research with suitable arrangements for ensuing commercialization. It is recommended to consider the Energy Research Institute of the Shandong Academy of Sciences (SDERI) and the Institute for Vegetable Research of the Shandong Academy of Agricultural Sciences (SDIVR) to lead such an effort. The former because of its proven track record on renewable energy research and commercial application and the latter for its outstanding competencies regarding vegetable growing research. Relevant Dutch research institutes and horticulture-related companies may assist such efforts. For financing any Dutch assistance to support such initiative, certain (limited) financing options appear to be available such as the Asia Facility for Asia (Senter) and facilities financed by the Dutch Ministry of Agriculture.

Moreover, the Chinese Ministry of Science and Technology has informally indicated clear interest on the Chinese side in the development of a methodology acceptable for the CDM executive board to determine a baseline scenario for any commercialization activities in China of 'enhanced low energy greenhouse' concepts. The Dutch Government, including its Ministry of Housing, Spatial Planning and the Environment (VROM), may well consider supporting such an effort that may help to arouse further interest on the Chinese side in harnessing - from a global perspective - the quite promising greenhouse gas reduction technology at stake.

For the record two proposals for follow-up, made by SAHDP, are shown in Annex D. As it does not concern follow-up activities in the strict sense, no further comment is given here but interested Dutch parties may contact SAHDP directly.

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Abbreviations and acronyms

AIJ	Activities Implemented Jointly, preparing for introduction of the CDM
CDM	Clean Development Mechanism, a Kyoto Protocol flexible instrument
DS	Debets-Schalke B.V., greenhouse construction company, Monster, The Netherlands
ECN BS	ECN, unit Policy Studies
ECN DEGO	ECN, unit Renewable Energy in the Built Environment
ECN	Energy research Centre of The Netherlands, Petten, The Netherlands
IMAG	Instituut voor Milieu en AGrotechniek (Institute for Environment and Agricultural Technology), Wageningen, The Netherlands
NRG	Nuclear Research and consultancy Group, Petten, The Netherlands
RZ	Rijk Zwaan B.V., a seed company, De Lier, The Netherlands
SAHDP	Shouguang Agriculture Hightech Demonstration Park, Shouguang, China
SDERI	Energy Research Institute of the Shangdong Academy of Sciences, Jinan, China
SANGLE	Manufacturing company of solar energy technology equipment, Jinan, China
SMAC	Shouguang Municipality Agricultural Committee, Shouguang, China
SNAC	Shandong North-Holland Agricultural Co-operation, Den Haag, The Netherlands
SWH	Solar water heater
SYN	Syngenta, a seed company based in Enkhuizen, The Netherlands, incorporated in Switzerland
SDIVR	Institute for Vegetable Research of the Shandong Academy of Agricultural Sciences, Jinan, China
WFC	Wangfang Flower Company, Shouguang, China.

Appendix A Solar heating system specifications

Specification of the Solar Heating System as result of the ECN DEGO and IMAG design studies.

A.1 Energy system of Greenhouse Type II

The energy system consists of the following elements:
- solar collectors on the roof
- water basins for heat storage
- heating tubes for heating the greenhouse
- ventilation system with heat recovery
- water piping and pumps
- ventilation ducts
- additional mounting equipment and required electrical connections
- additional insulation to be applied around the greenhouse.

A.2 Requirements for the solar collectors

Table A.1 *Collector requirements*

	Type II
Total number of collectors on roof of greenhouse	12
Amount of hydraulic circuits	3
Total collector area on roof of greenhouse	60 m^2
Collector area of one collector	5 m^2
Collector coefficients ($\eta = a_0 - a_1T$)	$a_0 = 0{,}52$ $a_1 = 2{,}3$

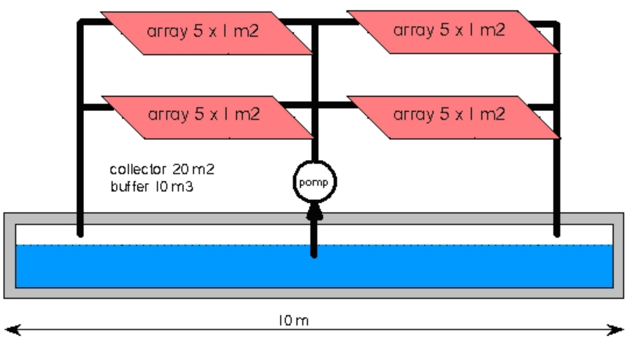

Figure A.1 *Schematic overview solar collectors and heat storage*

Table A.2 *Mechanical mounting requirements*

	Type II
Mounting angle in respect to the horizon	50°
Mounting direction	South
Additional support for collectors	Each 4 meter

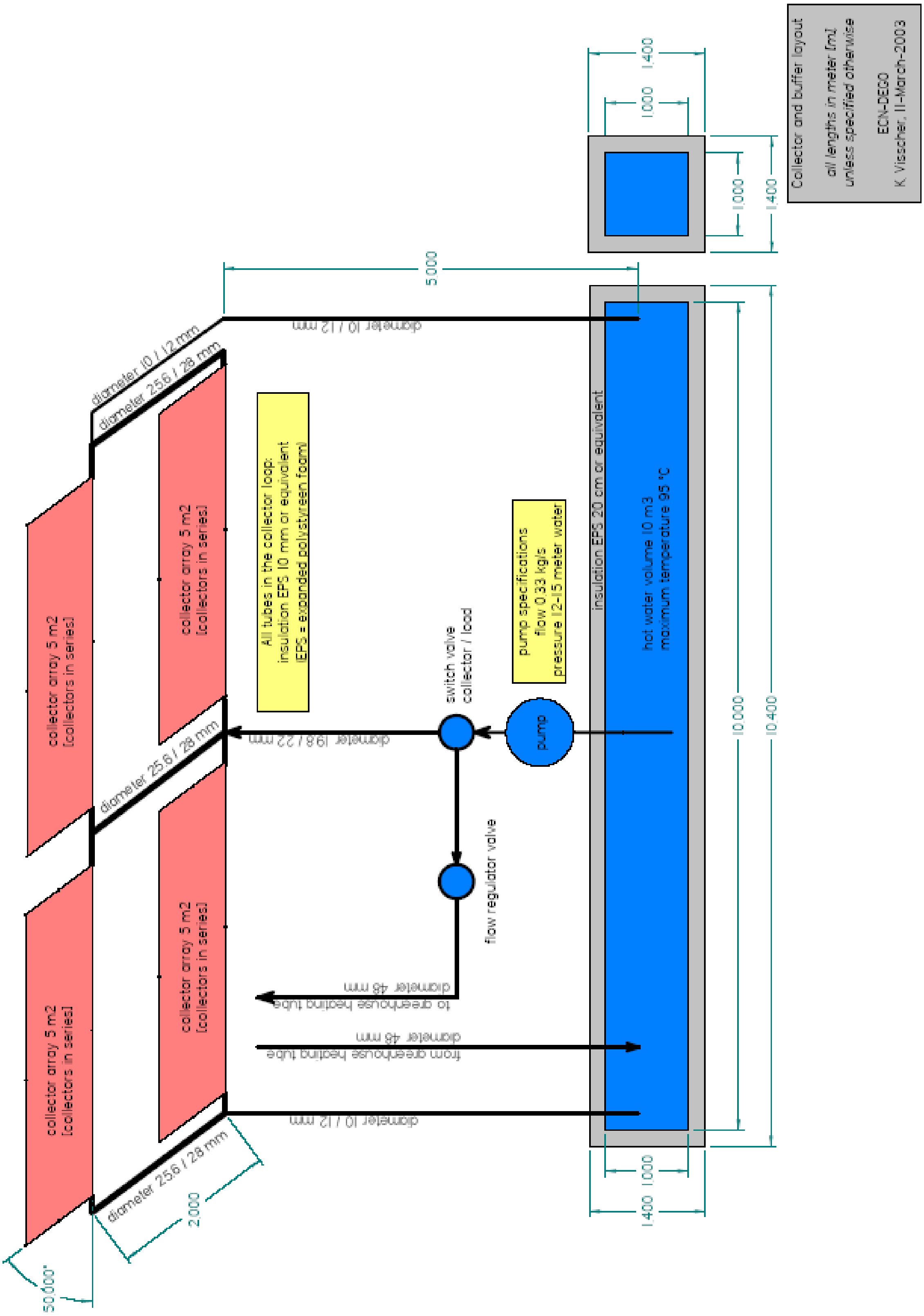

Figure A.2 *Scheme of heating system*

Table A.3 *Hydraulic mounting requirements*

	Type II
Type and thickness of piping insulation	10 mm EPS
Piping diameter	See Figure A1 and A2
Position of the pump	See Figure A1 and A2
Position of the 3-way valve	See Figure A1 and A2
Mounting scheme of the system.	See Figure A1 and A2

A.3 Requirements for the heat storage basins

Table A.4 *Building technical requirements*

	Type II
Minimal volume of *one* basin	10 m^3
Waterproof for temperatures up to	100°C
Insulation material	Polystyrene
Minimal insulation thickness	20 cm

All water basins must be *watertight*. The lid must be strong enough to walk upon and should prevent that dirt can fall in the water basins.

A.4 Requirements for the heating system

Table A.5 *Technical requirements*

	Type II
Number of strings per hydraulic system	1
Total strings per Greenhouse	3
Length of one heating string/tube	Depends on standard heating system
Type of tube	Thin-walled/good conducting
Preferable diameter	48 mm
(Possible) layout between the plants	Circular/Spiral
Flow	0.33 kg/sec

A.5 Requirements for the pumps and valves

Table A.6 *Specifications of the pumps*

	Type II
Pump pressure	0,12 ... 0,15 bar
Flow through pump	0,35 liter/sec
Number of pumps for each hydraulic circuit	1
Location of pump	See Figure A1 and A2
Location of valves	See Figure A1 and A2
Type of valve	2-way
Mounting diameters	See Figure A1 and A2
Mounting scheme	See Figure A1 and A2

A.6 Requirements for the ventilation system

Table A.7 *Specifications for the ventilation system*

	Type II
Position of ventilation unit	High at the wall, in the middle of the Solar heated part (IIb)
Mounting	With iron Bar and screws to the wall
Air connections	
Electrical connection	

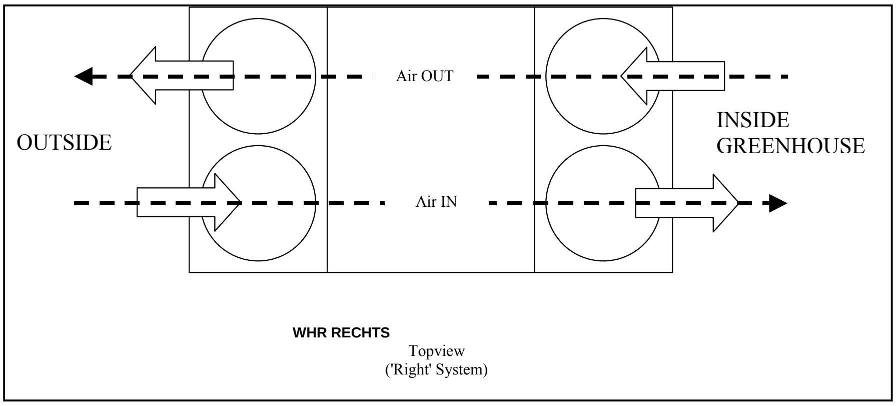

Figure A.3 *Requirements for Additional parts/equipment*

Table A.8 *Electrical connection requirements*

	Type II
Electrical connection for pump	Depending on applied pump
Electrical connection for ventilation device	?

A.7 Requirements for insulation (as far as not specified for the building of the Greenhouse)

- Insulation of the wall (see building requirements of the greenhouse)
- Insulation of the piping, mentioned at other places in this document.

Insulation around the greenhouse area
- Location of insulation (see Figure)
- 20 cm thick polystyrene.

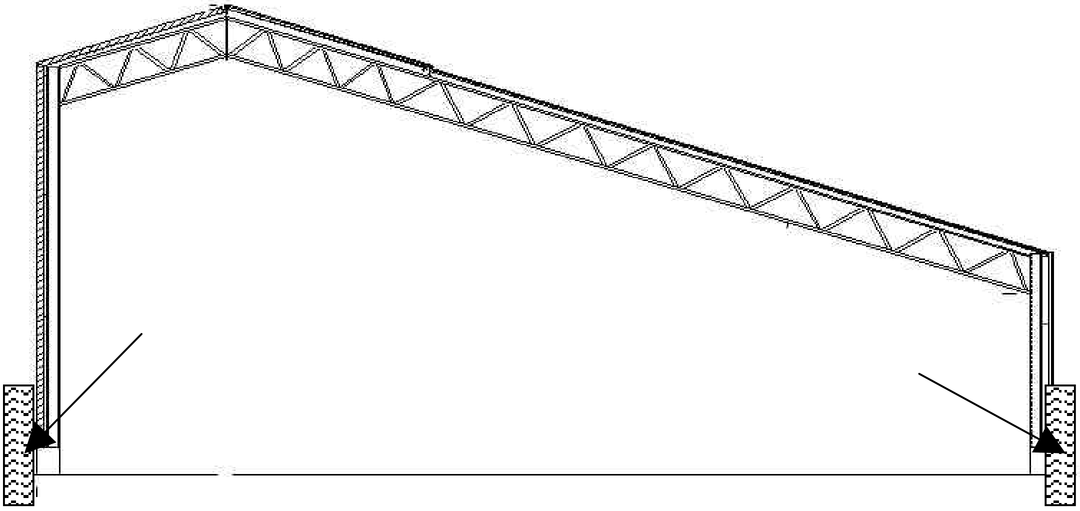

Figure A.4 *Insulation around the greenhouse*

Appendix B Details of the solar collector system

B.1 Solar energy circulate system

The structure and principle of the solar energy system are shown in Figure B1 and B2 below.

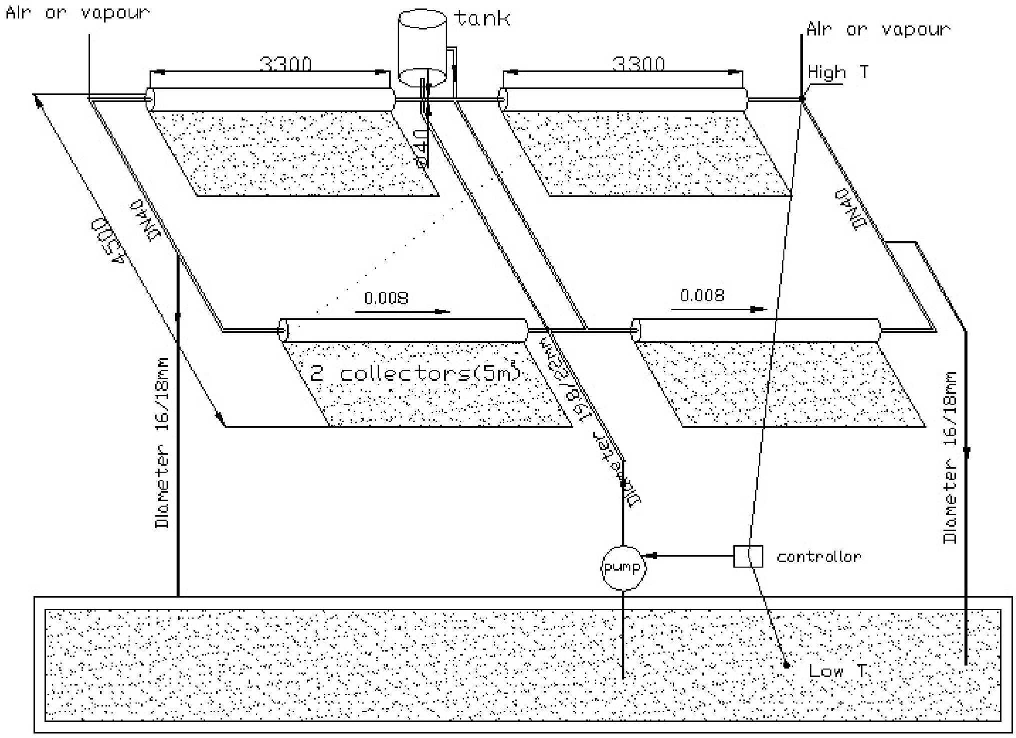

Figure B.1 *Solar energy circulate system*

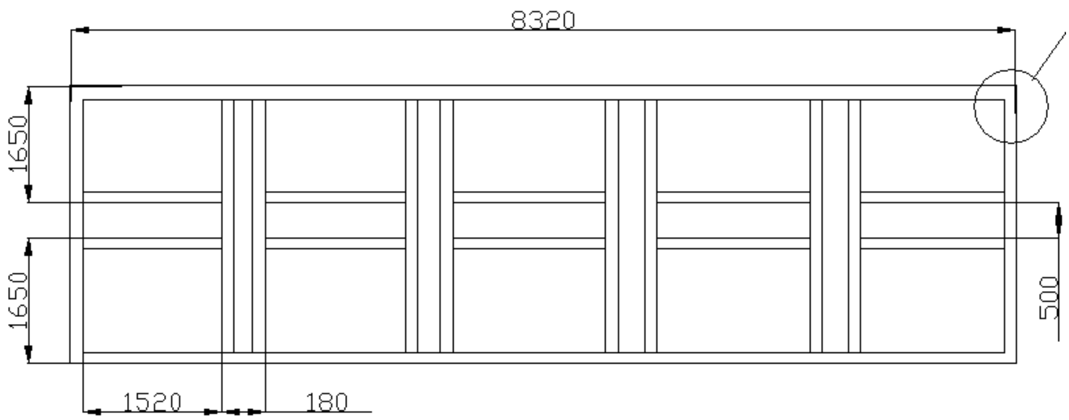

Figure B.2 *Bracket*

Figure B1 shows one of the three independent solar collector systems, water from the storage is pumped up to the collectors. It flows parallel through the four panels and the heated water is fed back to the heat storage. The controller controls the pump for starting and stopping the system.

Figure B2 shows the design of the additional frame to designed and built by SDERI. Since mounting angle and the system is not a standard design a special frame is made.

Table B.1 *The collector parameters are shown in the following table*

Total number of collectors on roof of greenhouse	12
Amount of hydraulic circuits	3
Total collector area on roof of greenhouse	60 m^2
Collector area of one collector	5 m^2
Collector coefficients ($\eta = a_0 - a_1T$)	a_0 = 0,52 a_1 = 2,3

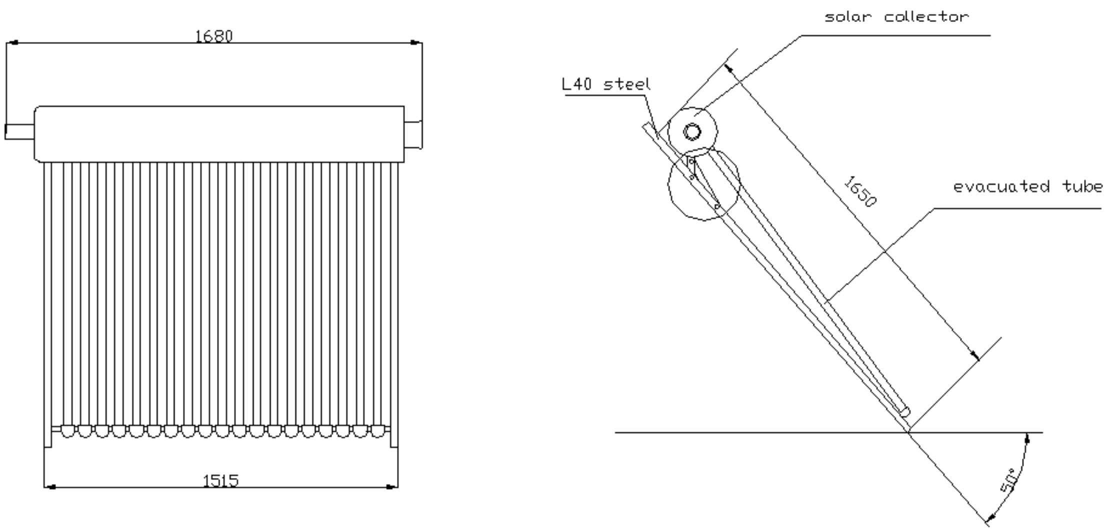

Figure B.3 *Collector*

B.1.1 Collector tubes

The main characteristics of the collector tube are shown in the following table:

Table B.2 *Main characteristics of the collector tube*

Material	Special glass just like PYREX
Length	1500 (mm) ± 5 mm
Outer diameter	47 (mm) ±0.6 mm
Inner diameter	37 (mm) ± 0.6 mm
Film structure	Al-N-C/Al selective absorber coating
Solar absorber efficiency	>0.92 (AM=1.5)
Energy emission efficiency	<0.86 (80℃)
Average heat loss efficiency	<0.86 (80℃)
Vacuum capacity	$<5\times10^{-3}$
Pressure bearing	0.6 Mpa
Thermal shock endurance	No problem after three times hot and cold water touch (>90℃ or <25℃)

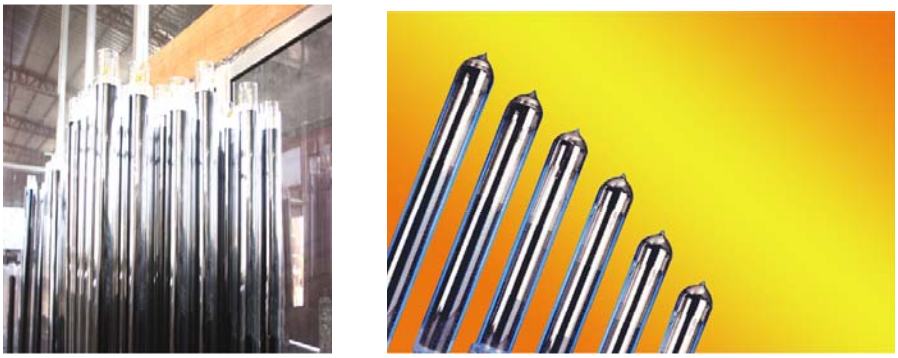

Figure B.4 *Pictures of the applied vacuum tubes*

B.1.2 Pumps

Table B.3 *Specifications of the solar collector circulation pumps*

Model	RS-15/6
Power supply	220V/50Hz
Output power	37W
Flow rate	3.3 t/h
Outer diameter	25 mm
Inner diameter	15 mm
Weight	2.1 kg

B.1.3 Control algorithm

We use the 'intelligent controller' to fulfil the control algorithm by controlling the pump.

Followed form show the parameters about the controller.

Table B.4 *Specifications of the controller*

Model	Controller C
Power supply	220V/50Hz
Electric shock protection type	I
Working environment	
Temperature	-15 ºC-45 ºC
Relative humidity	<85%
Outer diameter	25 mm
Inner diameter	15 mm
Weight	2.1 kg

Characteristics about the controller:

- Display the temperature of the collectors and the temperature of the water basin at one time
- Circulated by the difference in temperature: When the difference between the collector's temperature and water basin's temperature is 15ºC, then the water pump will start; If the difference is equal to 3ºC, the pump will stop.

Appendix C Measurement System supplied by SEDRI

(Contributed by SDERI)

C.1 Recorder

We chose the data-recorders, which produced by the Zhejiang University electric equipment factory for recording the temperature and humidity in the three kinds of greenhouses in Shouguang. And we designed a box to contain the recorders that made the recorder safer and not easy to be damaged.

The parameters about the recorder are shown in the following table.

Table C.1 *Specifications of the data recorder*

Temperature measurement range	-40~100 ºC
Humidity measurement range	0~100%RH
Accuracy:	
Temperature	0.2 ºC
Humidity	±3% RH
Resolution ratio:	
Temperature	0.1 ºC
Humidity	1% RH
Sample rate (second)	1800
Storage capacity	8000

Figure C.1 *Left: two data recorders; right: two times the protection box in which the data recorders are placed*

Left shows the data recorders inside their protection box, right upper shows the measurement box inside Greenhouse I and right lower shows the measurement box in Greenhouse II.

C.2 Sensors distribution

The sensors distribution map is shown followed, which we designed many time to ensure that all the sensors are in the right position to record the climate of the whole greenhouse.

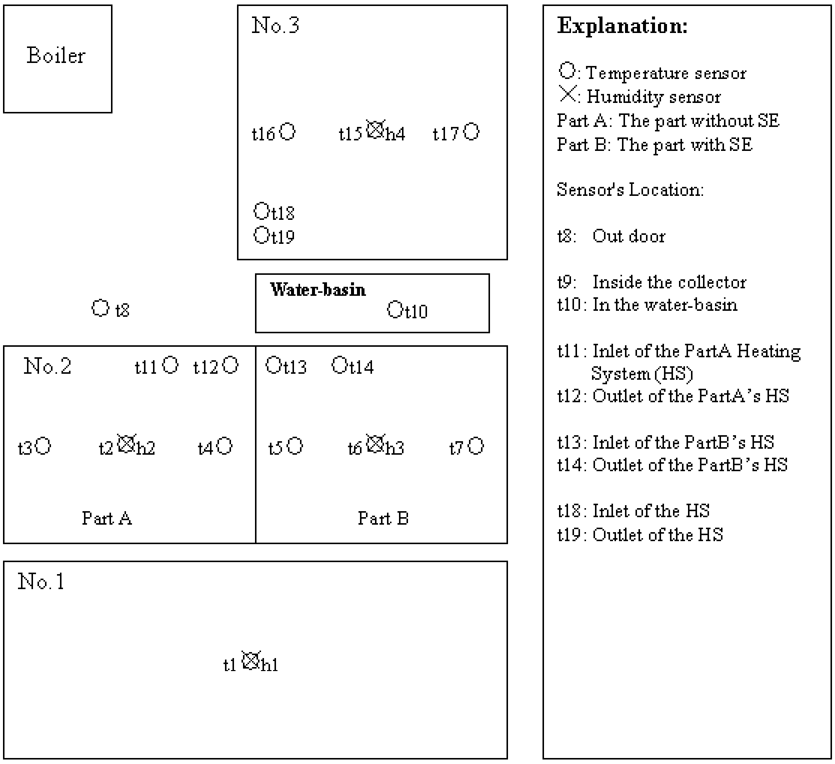

Figure C.2 *Schematic overview of the positions of all data recorders*

C.3 Data view software

We used 12 data recorders in the three greenhouses; every recorder has two channels, and every channel record one temp or humidity value every 30 minutes. So the data that recorded by the recorders are very plentiful. Although we save the data file as excel files, it is still difficult for people to see the data in the curve way by their mind.

Thereby we designed this data browser, which is easily seeing the curve data about the greenhouses' climate.

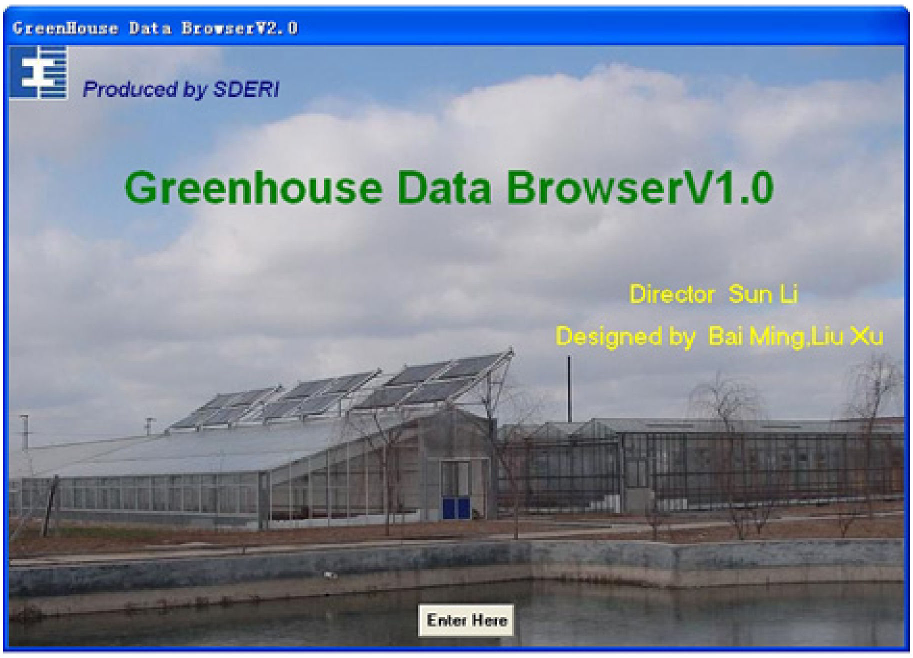

Figure C.3 *Startup screen of the data browser*

Choose the sensors in the distribution map, and then click the 'display data' button as the following picture.

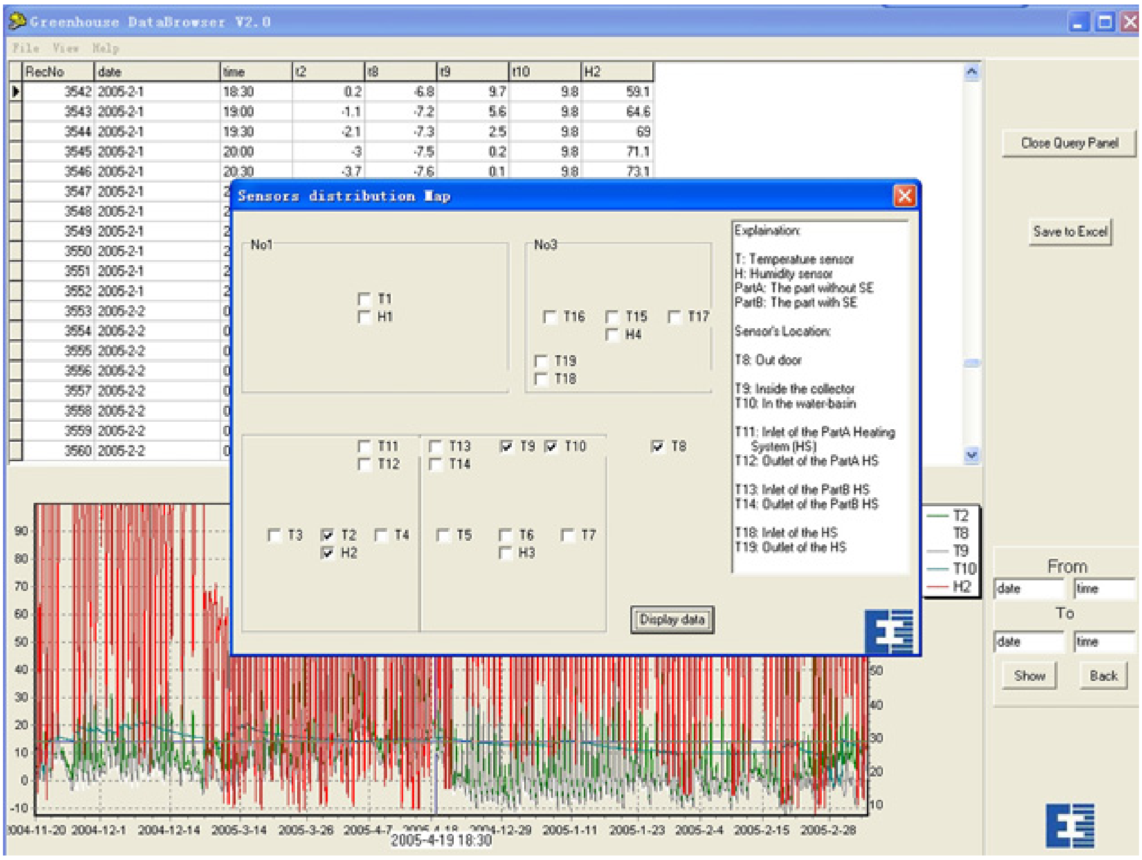

Figure C.4 *Screenshot of the data browser*

Then the data are shown in the grid, and the corresponding curves are in the chart below as the picture followed:

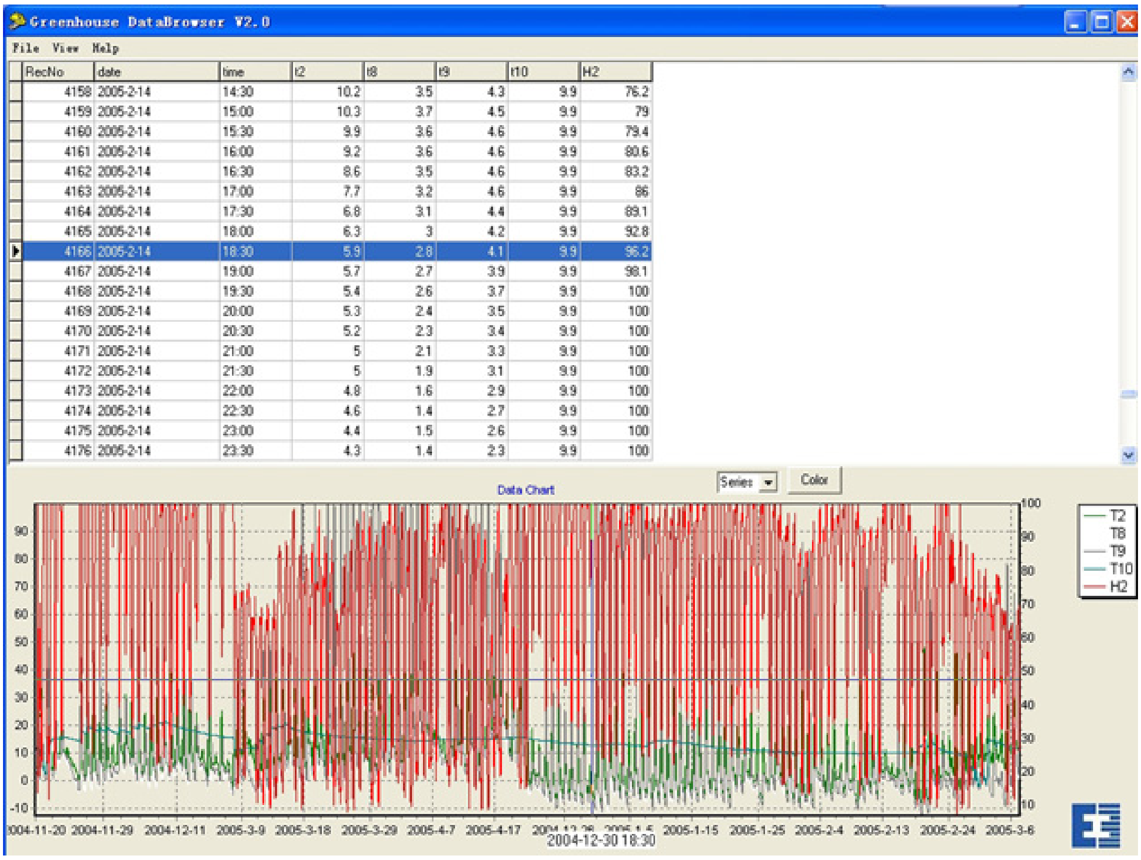

Figure C.5 *Screenshot of the data browser*

There are many powerful functions of the chart view part, such as zoom in and zoom out with the left key of mouse; drag and move with the right key of mouse.

You can also choose any part of curve in any period of time to show in the chart; you can save the current data that in the grid to a new Excel file.

Appendix D Suggestions for project follow-up by Shouguang Agriculture Hightech Demonstration Park

This appendix presents two proposals submitted by SAHDP. Please note that the original proposals have not been edited, to ensure that the authors' intent remains unaltered.

D.1 The favorable conditions of introducing different varieties of flowers from Holland

Shandong Province is situated in the lower reaches of Yellow River and on the western shore of Bohai Sea and Huanghai Sea. It lies in the North Temperate Zone, under the influence of semi-humid monsoon climate, characterized by a warm climate and distinctive seasons. The average annual temperature is 11 to 14 degrees centigrade, and annual rainfall 550 to 950 millimeters. In the coastal land area the frost-free period in one year can reach about 180 days and in the inland area about 200 days.

Shouguang lies in the east longitude of 118º 32' -119º 10', north latitude of 36º 41' -37º 19', and with a total area of 2180 km^2. It lies in the North Temperate Zone, characterized by a warm climate and distinctive seasons. The average annual temperature is 12.4 degrees centigrade, and the annual rainfall 608 millimeters. The frost-free period in one year is about 195 days.

Shouguang City and even Shandong Province is suitable for growing all kinds of flowers. Although the history of the flowers industry in China is not very long, the flower cultivation in China has a very long history, and also China is the original county of many kinds of flowers. From all above we can see that the climate of China is suitable for growing different kinds of flowers.

The advantageous location of Shandong province can promote the flower sales. With the improvement of people's life, the demand for fresh flowers is more and more, especially in the Chinese neighboring countries Japan and South Korea, the demand for fresh flowers has great potential, while Shandong Province has the advantageous location to export the flowers to them.

The greenhouse facilities of Shouguang city can provide the basic conditions for growing flowers all year around. In Shouguang the land suitable for growing is 800 thousand Chinese mu, but the same varieties of vegetable growing in the same place influence the output of vegetable, so the farmer want to find another plant with high economic value to replace vegetable and the flowers is right the plants.

Holland is famous in the world for its flower production and export. The growing technologies of flowers in Holland are advanced in the world, which can provide good experiment for the flowers grown in Shandong peninsula and Shougluang City. If the flowers of Holland can be introduced to China with the help of the Holland Energy Research Institute, which will give the flowers industry of Shouguang City a tremendous push.

D.2 A feasibility report about introducing potatoes with high starch for processing fried food & producing seed potatoes

According to the statistics in 2001, the total planting area of potatoes in China is about 60 million Chinese mu, and with the annual output of about 60 million tons. The main plantation area lies in northeast part of China, Inner Mongolia Autonomous Region and Ningxia Hui Autonomous Region etc., however the potatoes planted in Shandong Province mainly supply for the fresh food stuffs and exporting, and now most of the varieties in China contain a little starch, so introducing the potatoes from Holland is very important to promote the potatoes industry as well as the related industry.

The average content of starch and dry substance of potatoes now available in China is 13 to 19 percent, but the content is 17 to 18 percent and 22-23 percent respectively in German and America. And the varieties of Atlantic and fovoylta introduced from abroad have a lot of diseases. Now the potatoes with high output, quality and high starch is very popular in China and besides the cooperation in potato industry is tally with the state industry policies.

The demand for potatoes with high starch has great potential. According to the statistics, if the potatoes are processed into denatured starch, the value can increase by 165 percent. In 2001 the demand for denatured starch is 400 thousand tons in different fields, but in 2010 the demand will reach up to 90-100 million tons, besides the chain stores like McDonald's and KFC Corporation etc. will achieve 5000 to 10000 in China, by then 200 thousand tons potatoes will be needed and the plantation area of potatoes will be 600 million square meters.

One of the very important measures to improve the output of potatoes is to develop the production of the depoisonous technologies of seed potatoes, but now most of the seed potatoes available in China are the overgeneration, whose output only can occupy one third or on second of the output of depoisonous seed potatoes. By the year of 2001 the plantation area of potatoes was 348.9 million hectares. If per hectare needs the seed potatoes of 1.8 tons, 13 thousand tons of seed potatoes are needed, and if per hectare can produce seed potatoes of 26.25 tons, the land of 240 thousand hectares is needed. All above proves that the production of seed potatoes has great potential in China.

With the tissue culture center of 4400 square meters and two computer greenhouses of 1200 square meters cooperated with Holland, Shandong Shouguang Vegetable Hi-tech Demonstration Garden has the capacity of yearly output of depoisonous seedlings of 20 million. All above can provide the basic conditions for the project.

Holland is the largest country to export seed potatoes, with yearly output of 500 thousand tons and of which the 450 thousand tons are exported to more than 60 countries. Avebe Group is the top enterprise in producing the potato starch, with output of 660 thousand tons. IF the technologies of potato producing and processing can be introduced to China, which will give the potatoes industry and related industry of China a tremendous push.