

## **PROJECT WATERGY: A CLOSED GREENHOUSE FOR MINIMIZED WATER CONSUMPTION AND OPTIMIZED SOLAR ENERGY USE**

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### **Abstract**

*Watergy project is funded by the European Community's Vth Framework in its Energy, Environment and Sustainable Development program. It consists of the development of a humid air solar collector system that follows the principle of a closed two phase thermosyphon. A combination of evaporation and condensation allows to use solar thermal energy in a much more efficient way. The main advantage is not only the reduction of costs in space cooling and heating, but the possibility of water purification, as the system can be fed with low quality water to obtain distilled water. The decentralization of heat and water supply opens the possibility of residential areas where greenhouses fed with low quality water (grey water and brackish water) could be used to produce distilled water as well as heat and fruits. The project contemplates the development of two prototypes: one application for arid climates in Southern Europe with an emphasis on water production in the context of greenhouse horticulture, and another for temperate Central European climate focused on heat and water production for sustainable architecture.*

### **1. Introduction**

The limited water resources are real challenges for the actual status of intensive greenhouse horticulture as a highly profitable technology of food production in Mediterranean areas. The intensive horticultural production system using greenhouses was shifted from Central to Southern Europe due to the increasing energy prices. The semi arid Mediterranean climate allows for a concept of passive greenhouse with considerably less additional energy demand (Stanhill 1980). However, even though the greenhouse itself is a means of saving water (compared with outside growth, greenhouse horticulture demands a third less water consumption (Stanghellini et.al. 2003)), the water scarcity associated with the areas where the greenhouses are developing is a serious handicap for the sustainability of the actual production system.

The issue of sustainable architecture is a growing one, and energy efficient buildings are being promoted by governments and private organizations. However, although solar energy is slowly being introduced in the energy balance of the buildings with the use of standard solar collectors and even means for heat storage, the aspect of water supply and purification is still subject to centralization and dependent on an existing network.

Project Watery proposes a new concept of solar collector based on a humid air circuit powered by thermal solar energy (Buchholz 2003). The collector is formed by a greenhouse connected with a solar chimney, inside of which a cooling duct contains an air-to-water heat exchanger connected to a heat accumulator.

The project contemplates two versions of the collector, developed in two different prototypes, one for Mediterranean climate with day-night loading cycles and another for Central European climate with a seasonal storage of heat.

## 2. Watery Prototyp 1 : a closed greenhouse

The first prototype has been constructed in the province of Almería, Spain, which is the region with the highest concentration of greenhouses in Europe. It was built trying to follow the constructive means of greenhouses in the Mediterranean area. With a ground surface of about 200 m<sup>2</sup>, it has a structure of galvanized steel. A very transparent three-layer material (thickness 200 µm) with a layer of low density polyethylene on the outside and two layers of anti-drip EVA on the inside was used as a cover. The tower is 10 m high and is closed with polycarbonate. The heat exchanger is made of arrays of very fine capillars of polypropylene, connected to an external heat storage of 20 m<sup>3</sup> consisting in four deposits of polyethylene filled with water. Both the heat exchanger and the storage are built in a modular way to allow several degrees of performance and capacity of the system (Buchholz et.al. 2005).

In figure 1 the princip scheme of the greenhouse prototyp is showed. The process starts with the heating of the air inside the greenhouse, which rises to the solar tower by natural buoyancy. The evapotranspiration of the plants and soil is added to the air, which becomes humid.

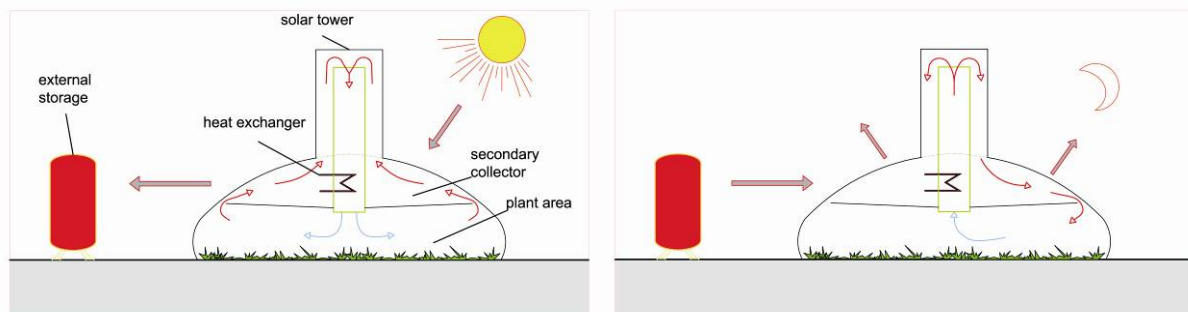


Figure 1 - Basic functioning of the greenhouse prototyp during a day cycle left and a night cycle right.

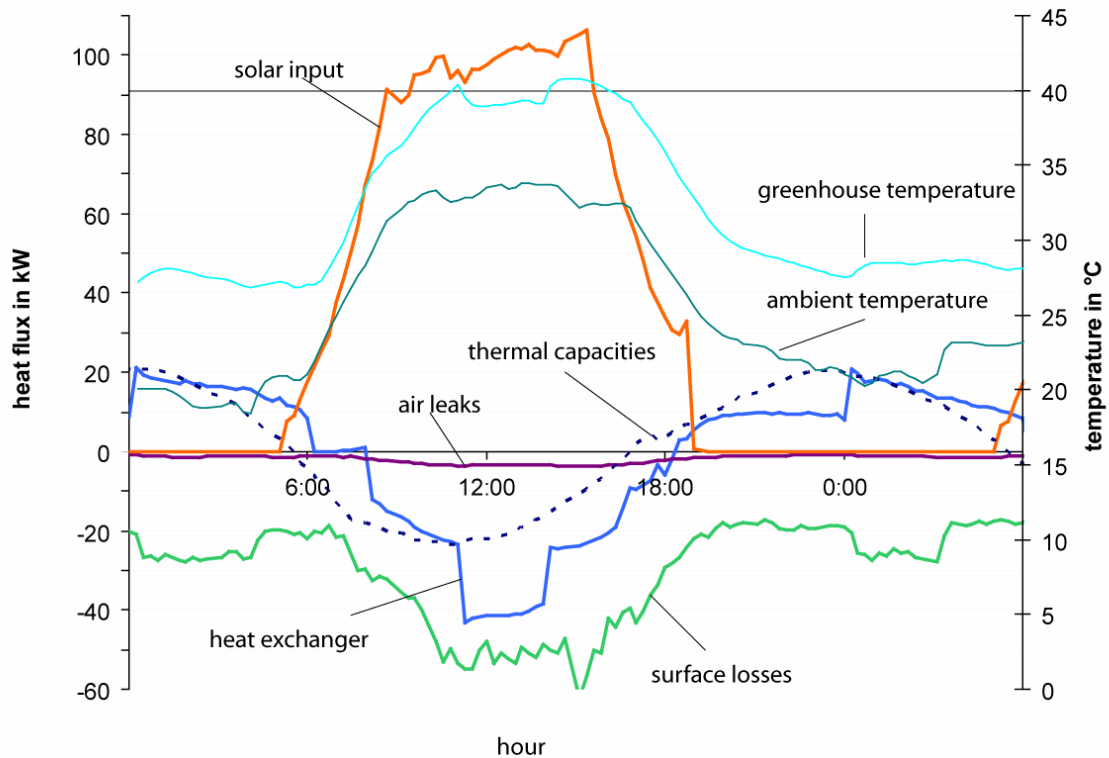
Above the greenhouse, removed from the plant area, the rising air is further heated in a secondary solar collector until it reaches the maximum temperature at the top of the solar tower. In this secondary collector, in order to saturate the rising air while it is heating, a humidification system acts as an additional evaporation source. The aim is to have very hot and humid air at the top of the solar tower. Inside the tower, a feedback duct contains a heat exchanger which cools the air. On the surface of the heat exchanger, the cooling of the humid air creates condensation, releasing additional thermal energy and distilled water. The cold and dry air falls back to the greenhouse, where it is heated and humidified starting the cycle again. During the night this cycle is basically turned around. The air inside the feedback duct is heated by the heat exchanger using the energy from the external heat storage. This air will rise to the top of the tower. There it releases the heat to the greenhouse as well as the outside cover and falls back to the plant area. From there it will return to the feedback duct.

### ***2.1 Climatisation***

A greenhouse can basically be seen as a solar collector. In the absence of any active climatisation in a closed greenhouse it reaches a stagnation condition. All of the solar energy which is collected during the day has to be released over the greenhouse covering. Thereby the heat transfer over the cover depends mainly on the temperature difference between inside and outside of the greenhouse. Similar to the stagnation temperature in a solar collectors for domestic hot water the temperature in the closed greenhouse reaches quite high values in order to dispose the input of solar radiation during warm summer days. Thermal heat capacities inside the greenhouse as well as the periodical heat exchange with the soil shift thermal loads from the middle of day to the afternoon or even to the night. This way they act as passive elements to reduce the maximum temperature inside the greenhouse. To use the greenhouse for an agricultural purpose this temperature reduction is not enough and further cooling is needed.

In order to analyse the performance of the climate control in the first prototype an energy balance for the whole greenhouse was conducted. The calculations could be based on the sophisticated measurement systems (temperature, air humidity and the flows of water and air). Figure 2 shows the heat fluxes over the boundaries of the watery greenhouse as well as the inside and outside temperatures of the 26th July 2006. With outside temperatures of about 35 °C over several hours this was one of the very hot days during the last summer of 2006.

The heat flux over the surface is still the major heat sink throughout the day. But it can be seen that the temperature in the greenhouse is influenced by the cooling system as well. In the morning the increase of temperature is slowed down by starting the heat exchanger circuit. If the full capacity of cooling system (40 kW so far) is used it is possible to stop the increase or even lower the greenhouse temperature. This way maximum temperature in the plant zone is limited to about 40 °C even during the hottest periods of the day.



**Figure 2 - Heat fluxes over the boundary of the greenhouse and temperature in the plant zone as well as the ambient temperature on the 26th of July 2006**

## 2.2 Food Production

In a closed greenhouse carbon dioxide will be consumed by the plants. Therefore an active fertilization is needed to control the level of carbon dioxide. Unlike in open greenhouses this can be done in a very efficient way and concentration could constantly be kept at about 1000 p.p.m. during daytime. This raises the optimal temperature for the plants and enhances their photosynthetic activity. Also, no use of pesticides was required at any time.

Since the construction of the prototype several crop cycles have been carried out. The crop cycles and the results of production are summarized in table 1.

In autumn 2004 the first crop of French beans was planted in the greenhouse with a density of 2 plants/m<sup>2</sup> which is higher than the standard of the area. Beans grow fast and provide a high leaf area index. Therefore the evapotranspiration rate is high which contributes to the functioning of the watery principle. During this cycle the relative humidity in the north side was generally above 90%. Despite this permanent near-saturation, no fungal diseases appeared and the production was 1,5 kg/m<sup>2</sup>. In the south side with more radiation and better humidity conditions production was 3 kg/m<sup>2</sup>, which is slightly higher than that of a standard greenhouse for this crop and season.

A spring cycle with French and Bush beans in inter-planting led to no production due to high peaks of temperature reached during the flowering stage (flowers fade above 35°C). The reason for this was a limited performance of the cooling system, as the sprinkling on the heat exchanger during the night, which enhances the heat release, was not fully operative until mid-July. During the summer, as the high temperatures outside (the average of the maximum temperatures is about 30 °C) make it impossible to keep the closed greenhouse in a thermal level below the tolerance limit of most species, a photosynthetic C4

plant is required. Okra, which has a rapid growth comparable to beans, was chosen. The crop grew healthy during all the summer. Production was not taken into account because the emphasis was put on vegetative growth to enhance transpiration and on testing the behaviour of the plants inside the greenhouse to obtain agronomical experience on a completely new species in the area.

After the summer 2005 Bush beans were sown in two alternate cycles. At this stage, problems with the anti-dripping property of the plastic led to a distinct reduction of light transmission. Despite this decrease of radiation input, production was about 2 kg/m<sup>2</sup> (an effect of the CO<sub>2</sub> enhancement), very satisfactory for local growers' standards on that season.

In the beginning of 2006, the plastic cover of the greenhouse was changed to a new anti-dripping one and a new crop cycle was started. First, Bush beans were sown at the end of February, trying different cultivars. A similar procedure was carried out with okra half a month later, following the technique of inter-planting, which combines two different species inside the same greenhouse at different cycles, in order to guarantee a constant presence of developed plants inside. As indicated in Table 2, the production of Bush beans of the "Strike" variety was 1.5 kg/m<sup>2</sup>. This is a very remarkable figure considering that the cycle ended a bit sooner than expected due to the summer heat starting than expected earlier on 2006. The estimated price of these fruits in the local market is between 3 and 5 €/kg, maybe larger considering that they are "ecological" production. As for the okra, up until the middle of July the production reached 0.5 kg/m<sup>2</sup> for the most productive variety. The crop continued the rest of the summer, but the subsequent harvesting was not accounted for in these results. No figures are available of the price of these fruit in the local market. However, in the U.S.A. markets the price is about 1.5-2 \$/kg. Considering that the European market of okra is only served by importing from Africa, Asia or America, a much higher price can be expected for selling okra in countries as the United Kingdom or Germany.

**Table 1 – Summary of the crop cycles performed in the closed greenhouse.**

Dates	10/9/04 - 7/12/04	4/3/05 - all through summer	30/9/05-3/1/06 19/10/05 - 24/1/06	24/2/06 - 1/6/06	13/3/06 - 17/7/06
Crop	French beans (cv "Donna") (high density)	Frenche beans and Bush beans and Okra (interplanting)	Bush beans (cv "Parker") alternate cycles	Bush beans (variety trail)	Okra (variety trail)
Production (in kg/m <sup>2</sup> )	3	Faild or not harvested	2	cv "Strike" 1,2	cv "Red Burgundy":0,44 cv "Cajun Delight":0,49 cv "Green Velvet":0,31 cv "Star of David":0,16
Observation	Optimum only in south (too much density shadowed the north canopy)	Performance of cooling not 100 % (incomplet night heat deloading)	Optimum despite 50% reduction in transmissivity (anti-drip property of plastic faded)	Heat wave shortened cycle	Production continued rest of summer

### **2.3 Water Upgrading**

One important feature of the Watergy greenhouse is the rational use of water. By collecting the condensate and the drainage from the soil about 75% of the irrigation water is recovered. So far, the recovery of irrigation water by condensation and drainage has been close to 75%. This figure is still subject to improvements with further technical adjustments, especially concerning the collection of the condensation which takes place at night on the inner side of the plastic cover. The greenhouse is designed so that this condensation slides down to gutters for collection. However, some of the condensation leaks outside the gutters. Also, better performance is obtained with a good anti-drip plastic, where tenso-active additives force the condensation to take place in the form of a thin continuous film which slides down easily. This avoids the formation of drops of water which not only reduce the transmission of radiation through the plastic, but can be evaporated again or lost by precipitation to the ground. Unfortunately, the anti-drip property of the plastic dissipates with time as the additives are washed out by the condensation.

The quality of the water is optimal for reuse in irrigation. The periodical analysis of the collected water show a very good quality both chemically (residual chlorine less than 0,05 mg/l) and biologically (absence of legionella and undetectable presence of E. coli bacteria, i.e., less than 3 colonies forming in 100 ml), with a high presence of aerobic bacteria (in occasions more than 30000/ml) which does not jeopardize its use for plant irrigation (Zaragoza et. al.2006).

The remaining water losses (due to defaults in the collection system and leakage of humid air) can be compensated with the volume of natural rainfall collected on the used surface (designed for rain water collection on additional gutters outside). The average annual rainfall in the region over the past 30 years is 240 l/m<sup>2</sup>. Considering that a normal greenhouse demands about 700 l/m<sup>2</sup> for irrigation, and the closed greenhouse requires less (as the evapotranspiration is diminished in a confined space), these figures indicate that water autarky plant production can be achieved, even at an arid climate as that of the south-east of Spain (Buchholz et.al.2006).

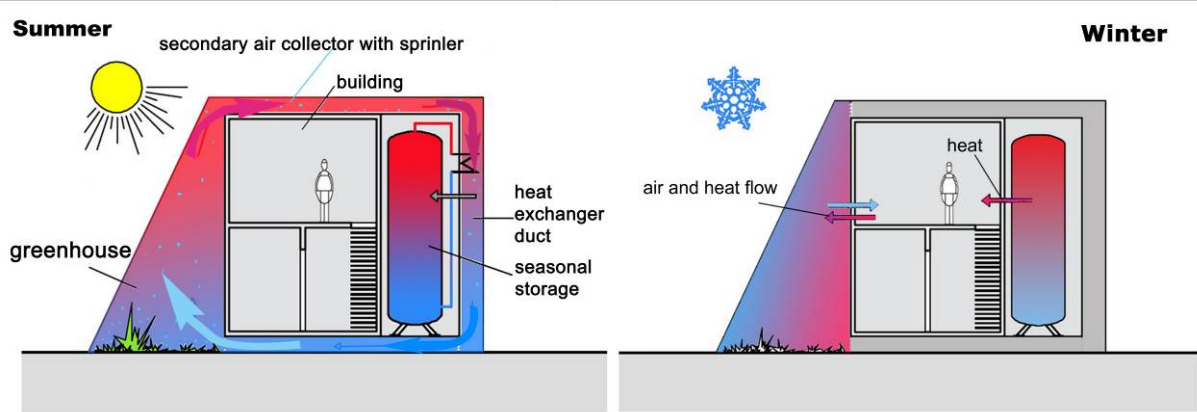
### **3. Watergy Prototyp 2 : a sustainable building**

The second prototyp has been constructed in the city of Berlin. It follows the concept of a standard passive house with an attached closed tropical greenhouse. The building is a two storey wood walled construction, 6 m high with a surface of 120 m<sup>2</sup>. The greenhouse covers the complete south facade of the building. It is a metal structure covered with a double membrane of transparent ETFE foil. The surface of the greenhouse is 40m<sup>2</sup>. As solar radiation is lower in this Central European location the secondary collector was installed on the rooftop. The greenhouse plants will not be shaded this way and the efficiency of the secondary collector can be raised by using high absorbing materials.

The main aim of this second prototyp is to produce heat which is used to load a seasonal heat storage of about 35 m<sup>3</sup> capacity inside the building. The heat losses of the storage tank are reduced by a 60cm layer of cellulose insulation. Since the storage is in a central position of the building, heat losses first contribute to the heating of the building and then

be released to the environment. Figure 3 shows the scheme of the heat collection during the summer and the heat release during the winter.

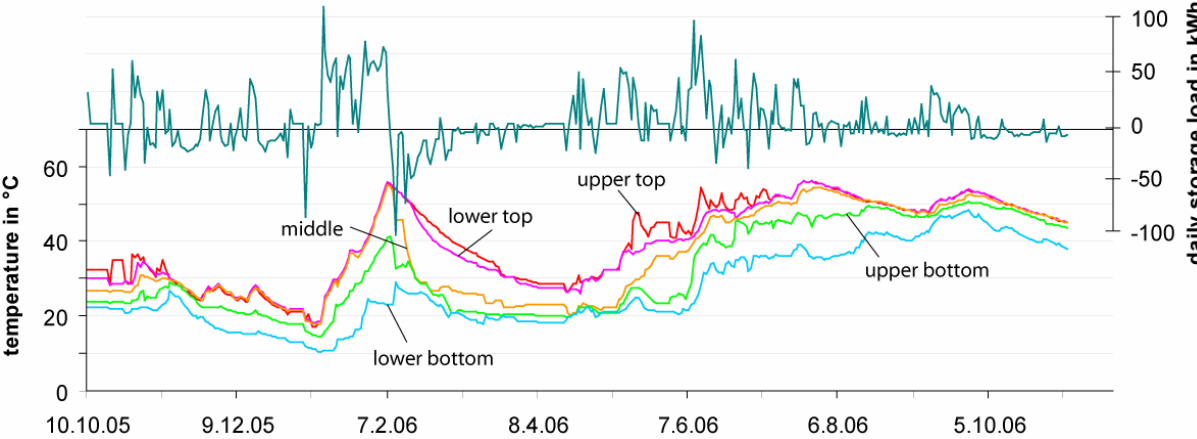
Beside its function as a solar collector, the greenhouse is fed with grey water, organic waste and even used air from the building, producing distilled water, heat and food for it. The construction of this prototype was finished at the end of the summer in 2005. The first loading cycle could start in the summer of 2006.



**Figure 3 - Principel functioning of the Prototyp 2. Heat collection in the summer left and heat release during the winter right.**

Figure 4 shows the course of temperatures in different heights inside the storage tank as well as the daily head load to the storage during the first year of functioning.

After the installation of storage tank insulation in the beginning of 2006 the tank was heated artificialy for testing reasons. The storage temperatures reached at the end of the sommer 2006 remained under the expected values. This was due to several system adjustments as well as extensive test during which the storage loading had to be stopped. Furthermore a automatic system control still has to be developed and implemented.



**Figure 4 - Course of temperature in different hights of the storage tank and daily storage loads during the first year of function.**

Still the rather low level of stored energy could be enough to heat the building during the cold season. Experiences from last winter showed that the building (passive house standart) consumes only little heat energy. On sunny winter days the system will collect even more heat than needed due to the transparent south facade.

#### **4. Summary and conclusions**

The Watergy project proposes two prototypes for application of a novel humid-air solar collector. The first is a closed greenhouse for solar thermal energy capture, water recycling, water desalination and advanced horticultural use. It is already constructed in Estación Experimental de Cajamar in Almería (Spain), and functioning since the fall of 2004. The system allows controlling the climate inside the closed greenhouse as well as closing the water cycle with the recovery of all the evapotranspiration from the plants. This opens a very interesting possibility for sustainable management of water in intensive horticulture, as the greenhouse irrigated with grey water becomes a means of producing not only of fruits but also clear water. Alternatively, if grey water is left out of the system, the greenhouse can reduce greatly its water consumption with the reuse of the recovered distilled water.

The second prototype is constructed in Berlin (Germany), and it is a building with an autonomous supply of heat and also of clear water. In this case, the closed greenhouse is connected to the building and purifies its residual grey water. Beside its main function as solar collector and water distiller, the greenhouse provides fruits and can be fed with residual air from the building. The more efficient collection of solar thermal energy in the system and its seasonal storage allow for a passive climatization of the building. In the context of sustainable architecture, the Watergy system means that this concept of zero energy is complemented with that of water autarchy.

#### **5. Acknowledgements**

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