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Reinventing Agribusiness and Rural Areas

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Innovation-Network

InnovationNetwork develops radical new concepts in agriculture, agribusiness, food and rural areas and ensures that these are put into practice by interested parties.

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Greenhouse Village, the greenhouse-powered neighbourhood

Background

The Dutch greenhouse business is well known for it's large stake in world supply of cultivated flowers, plants and vegetables. The export of horticultural products amounts to 7 billion euro per year. In The Netherlands greenhouse cultivation largely depends on natural gas: Dutch greenhouses account for almost 10% of the national natural gas consumption. With increasing environmental awareness and rising fuel prices new methods are being developed pushing back the dependence on natural gas. The Dutch greenhouse business has a leading edge in the use of innovative technologies for energy, water and climate control. Recent developments are even ground breaking. New greenhouse designs appear in which fossil fuel dependency is largely reduced. Instead these greenhouses are transformed in sources of sustainable energy. On various locations the possibility is now considered to use such greenhouses to provide green energy to the suburban neighbourhood. InnovationNetwork is a strong catalyst in these developments.

This paper presents the results of a recent report of InnovationNetwork. It presents a design for a greenhouse-powered neighbourhood with decentralised water and wastewater facilities, named Greenhouse Village. This design is based on an innovative greenhouse that captures the excess heat from solar radiation during summer. The heat is stored in underground natural water reservoirs (aquifers) and used for warming the greenhouse at night or during the winter. Energy balances show that there is sufficient energy left to heat a large number of houses (2 ha greenhouse can heat up to 200 houses).
In addition, the greenhouse supplies tap water, treats wastewater and produces electricity. The whole complex is self-sufficient in energy and water and recycles nutrients and carbon.

New interactions between urban and rural areas

Most modern cities have lost their connection to surrounding rural areas. They consume energy and resources and produce wastes at rates that are not sustainable in the long run. Big energy and water utility companies have increased the gap between production and consumption in the urban environment. Most modern citizens are unaware of the basic agricultural processes and utility provision services that underlie their lives.

InnovationNetwerk initiated the work on Greenhouse Village in order to promote new interactions between rural and urban areas. The project is an example of a design that shows that the urban environment can be closely and visibly connected with agricultural activities. Because of the strong interdependencies and the physical integration, inhabitants will become aware of the importance of new interactions between urban and rural areas and become involved with these relations. Greenhouse Village also brings ecology to the neighbourhood by providing energy, clean water and agro products on a sustainable basis. The sun provides far more energy than

the global economy needs. Greenhouse Village shows that if it can be harvested and stored, much of the global energy problems can be solved. It even extends its harvests to natural fertilizer and fresh water that would else be wasted. In addition, the project shows that new interactions can lead to increased efficiency and lower costs for basic utilities.

Technical lay-out of Greenhouse Village

The technical design of Greenhouse Village contains four subsystems that are closely connected.

1. The energy system for climate control in the greenhouse and the connected housing block

The heat (not electricity) system for climate control of the energyproducing greenhouse has been described in detail in other publications of InnovationNetwerk (van Andel et al., 2003), see www.innovatienetwerk.org. The basic elements are (Figure 1):

- A closed greenhouse, i.e. a greenhouse that is not using ventilation windows to release excess heat
- Heat exchangers in the greenhouse
- An aquifer, which stores the hot and cold water
- An aquifer management system, consisting of pumps, flow control
- A piped heat distribution system to greenhouses and houses
- A heating and cooling system consisting of floor and ceiling pipes in the houses
- A cooling tower

The basic concept of the energy producing greenhouse is the harvesting of excess heat in the summer and its storage in the form of warm groundwater in an aquifer. Special (patented) heat exchangers can increase the groundwater temperature of 11°C to 25-27°C while maintaining the air temperature of the greenhouse at a maximum of 30°C. The use of these revolutionary heat exchangers (so called Fine Wired Heat Exchangers - FiWiHEx) is essential, as they are effective at small temperature differences. The type of aquifers which are suitable for heat storage are divided by layers of isolating sand that maintain the temperature of the water. These sandy aquifers are present in most areas in The Netherlands. The houses will have to be equipped with a heating and cooling system consisting of floor, wall and possibly ceiling pipes

Greenhouse Village provides for full air conditioning throughout the year. It delivers heat and cooling according to the demand. During summer days the system is used to cool the greenhouse and - when desired - the houses. At night or during the winter, the stored heat can be used to heat the greenhouse and a block of houses.

Dutch law states that the year-round energy balance of the aquifer should be neutral and that the temperature should not exceed 25°C to avoid the soil from slow heating or cooling. A cooling tower has been added to the design to keep this balance.

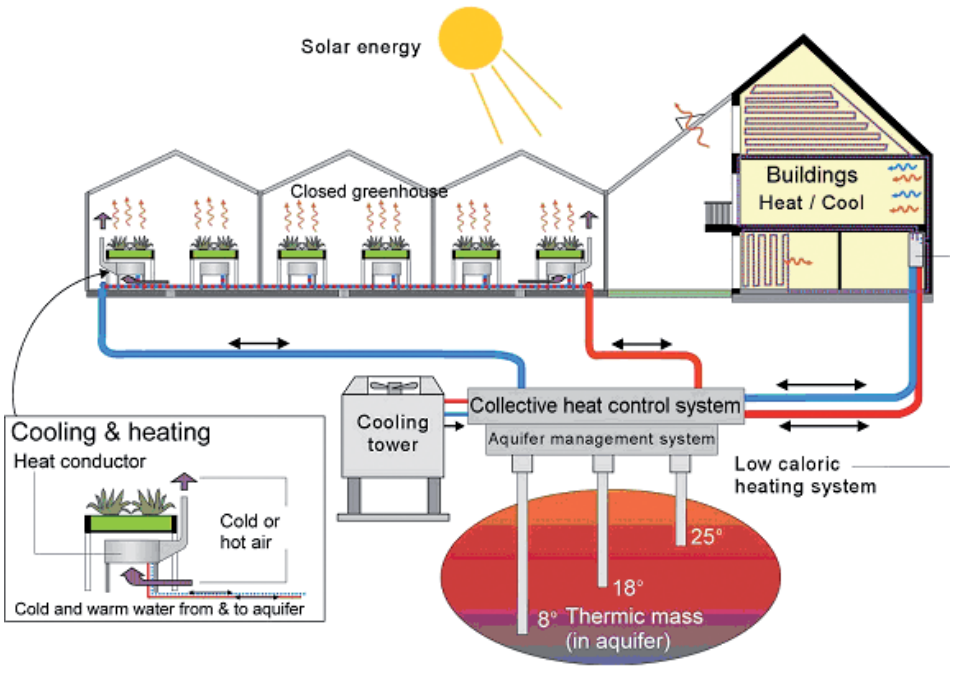

Figure 1. Climate control system of the greenhouse and the block of houses

2. The carbon cycle

Black water (faeces and urine) of the toilets and organic kitchen wastes are transported by a vacuum collection system to an anaerobic digester adjacent to the greenhouse. Residual plant material of the greenhouse and locally available organic wastes can be added to this digester as well. The combined biowaste is converted into biogas by bacteria. The biogas is combusted in a gas turbine. The combustion gases are used as CO_2 fertilizer in the greenhouse, bringing higher yields for the farmer. The combustion energy is used for power generation (electricity) and tap water heating. The biogas has a caloric value

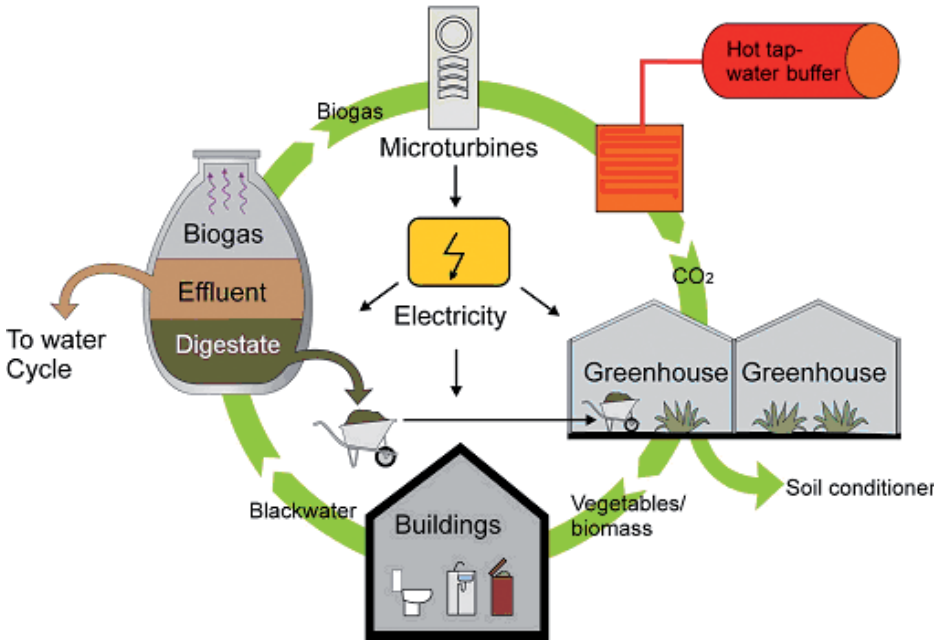

Figure 2. The carbon cycle of Greenhouse Village

of ca. 20 - 25 MJ per m^3 (60% of standard Dutch methane gas). The biogas typically consists of 67% of CH_4, 33% of CO_2 and traces of other gasses, such as H_2, the inert N_2 and the smelly H_2S. As the digester can be placed inside the closed greenhouse, odour emissions to the surroundings are minimized. In order to remove H_2S and prevent corrosion of machinery, measures such as adding trace concentrations of oxygen to the biogas might be necessary.

After digestion, the digester effluents are separated into a liquid and a solid part using a dewatering unit. The liquids are added to the grey water treatment system and eventually end up as irrigation water in the greenhouse. The solid material is composted and can be used as a peat substitute in the greenhouse. Structure providing material, such as wood chips, is added to optimize the composting process.

3. The water system

The wastewater flows from the households are collected into two separate flows:

- grey water from the shower and kitchen and
- black water from toilets.

As mentioned earlier, black water is brought to a digester to produce biogas. To reduce the size of the digester, dilution of black water by flush water is prevented as much as possible by using vacuum toilets, similar to those used in airplanes (1 liter per flush). The grey water of the households is purified in an aerobic bioreactor. Before treatment the liquid fraction of the digester, which contains the nutrients, is mixed with the grey water. After treatment, this water is used for irrigating the greenhouse. The excess sludge of the bioreactor is brought into the digesters. The treatment purpose in this bioreactor is:

- removal of oxygen consuming organic pollutants
- conversion of ammonium into nitrate (nitrification)
- partial denitrification, i.e. transformation of nitrate into gaseous nitrogen. By partial denitrification the nitrate concentrations in the irrigation water can be tailored for the specific demands of the greenhouse plants.

Greenhouse plants will evaporate the irrigation water. The vapor condenses and is collected. The collected water is of high quality. In Greenhouse Village, it can serve as a source of tap water for

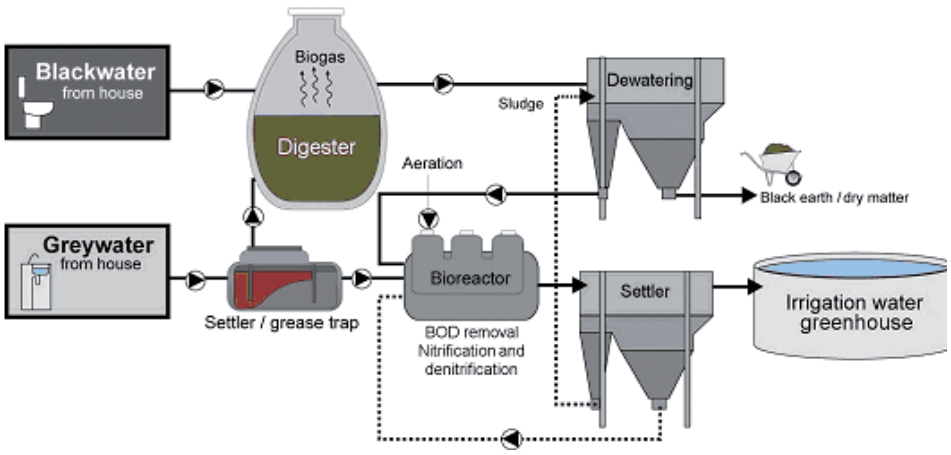

Figure 3. Seperate collection and treatment of black and grey water in Greenhouse Village

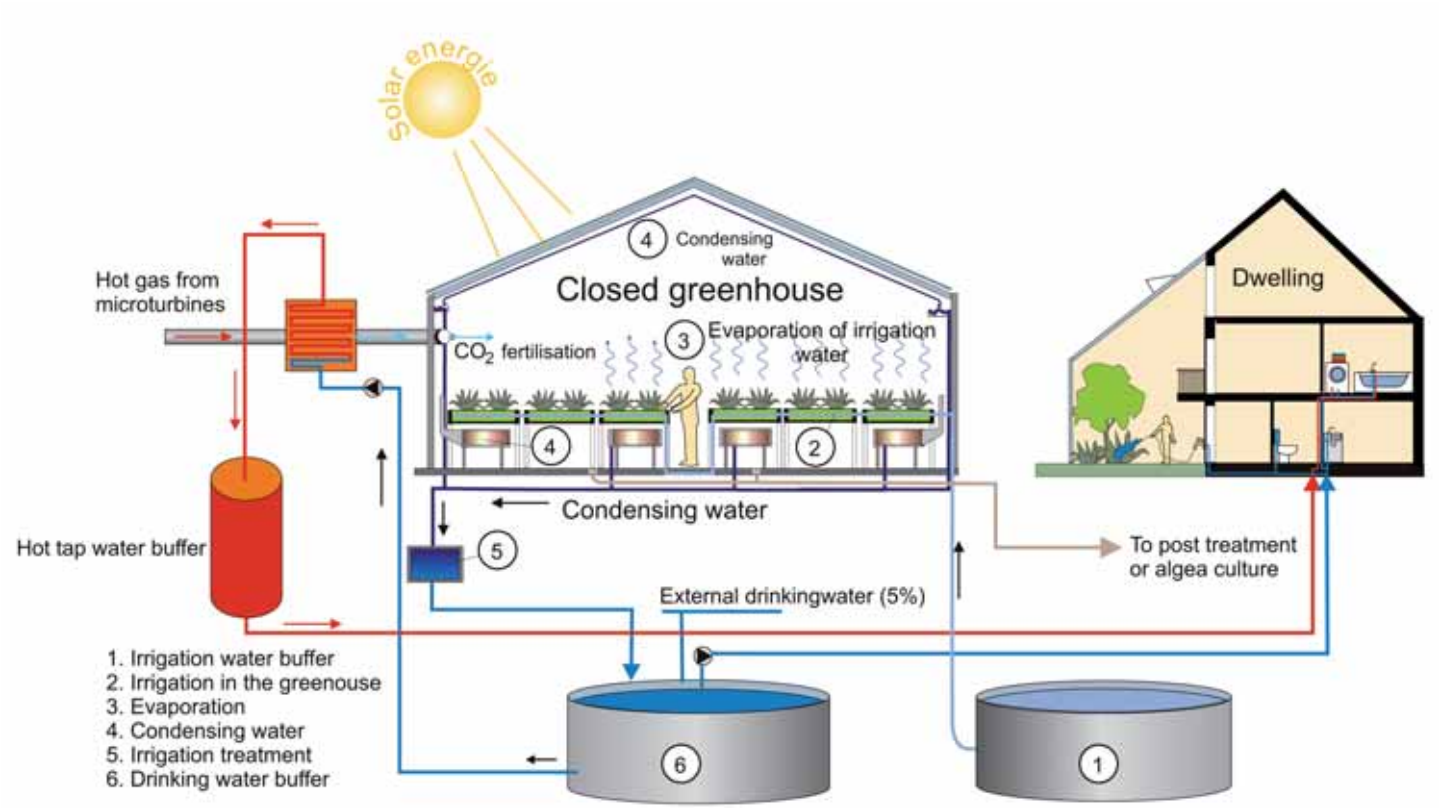

Figure 4. The water system of Greenhouse Village

the households after some steps:
- filtration through activated carbon
- addition of $CaCO_3$ (chalk), since pure distilled water is too low in salt content for human consumption
- quality monitoring.

Small volumes of drained irrigation water (approximately 15%) will have to be discharged to keep the salt concentrations at a low level and from affecting the crop yields negatively. As a result, Greenhouse Village may require small volumes of external water for which rain water can be used.

4. The nutrient system

The liquid fraction of the digester is rich with nutrients. The most important are nitrogen, phosphorous and potassium. These minerals are essential for plant growth and are elementary components of plant tissues. Therefore, they are used in the greenhouse by adding the digester liquid to the grey water before treatment in the bioreactor.

Figure 5 shows the nitrogen balance of Greenhouse Village. The nitrogen in the digester liquid is mainly

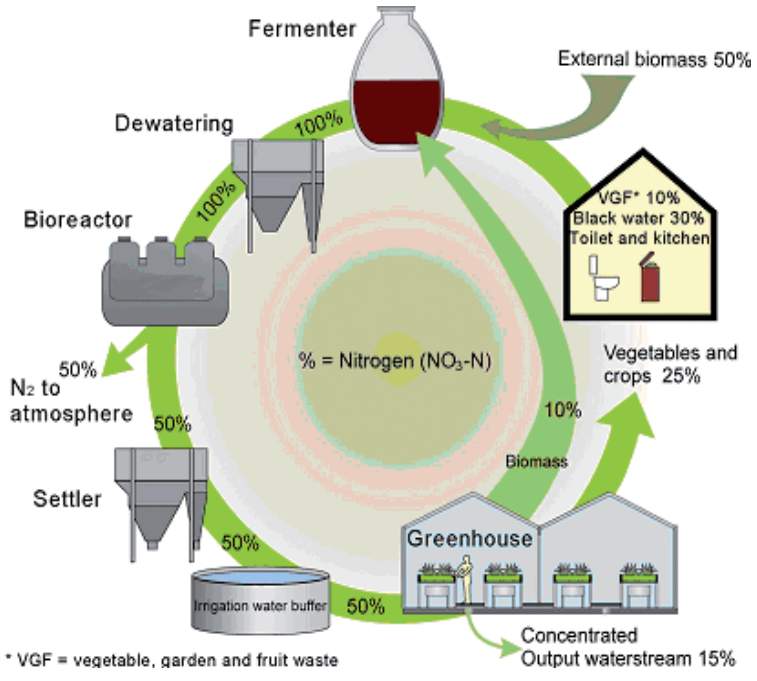

Figure 5. The nitrogen balance of Greenhouse Village

available in the form of ammonium (NH_{4+}). Plants have a preference for nitrate (NO_{3-}) and therefore ammonium is converted into nitrate (nitrification). For soil cultures, ammonium can be dosed directly, because natural nitrification will take place in the soil. However, when plants grow on an artificial substrate, which is often the case in Dutch greenhouses, the nitrogen is made available as nitrate. (back page)

Figure 6 (see back page) shows the overall technical lay-out of Greenhouse Village.

Environmental profits of Greenhouse Village

Greenhouse Village does not require external energy supply, neither for heating, cooling nor for its electricity. Moreover, all of the energy used is coming from renewable energy sources (solar and biomass). Only low volumes of external water are needed (for which rain water can be used) and wastewater and green wastes are locally treated and reused. Both the carbon and the nutrient cycles are closed. As a consequence, the environmental benefits are significant. As shown in Figure 7 Greenhouse Village hardly needs external utilities for energy, water and wastewater and the people living in this neighbourhood will benefit from reduced environmental costs.

Dimensions of Greenhouse Village

An important question is how to dimension the different parts of Greenhouse Village: houses, greenhouse, and installation. Through an energy balance it is calculated that 2 hectares of greenhouse can provide sufficient energy for heating 200 houses. These dimensions are also indicative for the minimal economical size. Cost calculations have shown that the integrated system could be cost-effective at this scale. The extra investments that have been taken into account are the closed greenhouse, the heat exchangers, the heat and cold storage in the aquifer, the anaerobic digester and the equipment needed for treatment of grey water. The savings include the costs for energy supply (gas and electricity), water supply, wastewater treatment and transport and the processing of green wastes. The given size is a minimum size, practical application could be at a much larger scale. A feasibility study is currently done for a location (Zuidplaspolder) to establish 400 ha of glasshouses and 20,000 houses.

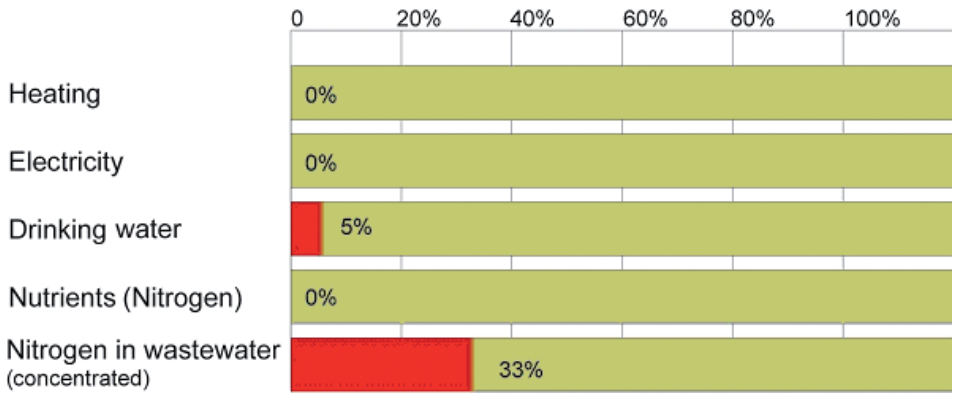

Figure 7. Environmental costs and benefits of Greenhouse Village

Spatial segregation, a certain distance between the greenhouse and the settlement, reduces the potential benefits of Greenhouse Village. E.g. heat cannot be distributed cost effectively further than 2-3 kilometres. Practical implementation of the design will therefore have to account for spatial and organisational integration. This, of course, raises questions as to which extent integration of greenhouse and urban areas is possible and whether citizens find this attractive.

Interdependences within Greenhouse Village

The concept of Greenhouse Village can only be developed within a strong interdependence of the energy-producing greenhouse(s) and a surrounding neighbourhood. This will require new forms of interdependences between the various stakeholders that are involved For practical applications of Greenhouse Village, the design team foresees three potential forms of interdependence between the owner and / or user of the energy-producing greenhouse and the inhabitants of the surrounding settlement. The three forms have decreasing levels of integration and mutual profits.

Integration

Integration is the highest form of organisational and spatial interdependence. The greenhouse serves the settlement and vice versa.

The first priority is to maximise the efficiency and profits of the complex as a whole. The various entities are placed under a common management and are physically, organisationally and functionally connected. In this situation the water, nutrient and carbon cycle will be fully closed.
The project management will have to involve the various stakeholders (project developer, future house owners, greenhouse companies, local authorities, etc.) from the start of the project. This intense form of integration will be challenging, because house owners and greenhouse owners are different parties in most practical situations. However, if a group of house owners is able to unite in a very early stage or if a project developer is willing, the project can be developed and owned by one entity. In this situation the owner could rent parts of the facilities to other stakeholders, e.g. the greenhouse to a farmer and / or the houses to inhabitants.

Coexistence
The key driver in Coexistence is mutual profit. The owner of the greenhouse and the owners and / or inhabitants of the settlement both take advantage of the presence and activities of each other. The stakeholders are and remain separate entities with a separate economy and management. The project management will have to look for the mutual and conflicting interests and will have to make arrangements and rules to ensure the functioning of the complex as a whole. In this situation the economical and / or organisational optimum does not necessarily comply with the ecological optimum and it is possible that the water, nutrient and carbon cycles will not be completely closed.

Segmentation
The primary starting points of Segmentation are freedom of choice and individual interests. Only some elements of the design of Greenhouse Village are used, for example the energy supply or the tap water production. These individual elements are exploited by independent entities, for example a local utility company for energy.
The specific interactions between the greenhouse, a local utility company and the houses are organised based on rules and individual interests. In Segmentation the interaction between the energy supply and the closing of water, carbon and nutrient cycles are separate goals and will probably not both be fully accomplished.

Future perspective

Implementation of Greenhouse Village in The Netherlands
The vision and approach of Greenhouse Village has proven to be a remarkable success. Farmers and farmers' organisations have enthusiastically welcomed the development. Various city councils are currently considering the feasibility of greenhouses to provide for energy- and waste water services, in new urban developments. Greenhouse areas are now widely promoted as energy source for surrounding offices and dwellings.

The first energy-producing greenhouses have been established this year. They received a lot of media covering and attracted the attention of members of Dutch parliament. The results are above expectations: the energy-producing greenhouses showed an increase of vegetable harvests by 20% and reduction in use of fossil fuels of 100%. It is largely expected that the energy-producing greenhouses will revolutionize the entire greenhouse business. This will turn the horticultural sector from a natural gas consumer into sustainable energy provider.
The core technology of the greenhouse climate control system is in an advanced stage of development. Production plants are scaled up to increase volumes and to lower costs. The coming years research and development investments will be directed to improve the electricity production. Aim is complete self-sufficiency in electricity supply, based on local waste and biomass production.

International developments
Although Greenhouse Village was originally developed for The Netherlands, it offers solutions for energy and water services that are globally applicable. In areas with strong seasonal temperature changes it provides for a water source or heating and / or cooling (provided a suitable aquifer is available). In dry areas Greenhouse Village presents a potential solution for water-scarcity, since it can provide for a reliable supply of high quality tap water. In addition it provides for wastewater treatment and irrigation water supply. The applied technologies are relatively simple and it is expected that when the adequate heat exchangers can be produced at large scale the costs will be relatively low.

In many developing countries centralised energy, water and

waste services are absent or poorly functioning. In these situations Greenhouse Village enables a complete decentralised solution for energy and water supply, waste and wastewater treatment and recycling of nutrients.
The Greenhouse village was nominated for the prestigious French Altran Award. This brought it to the international stage, resulting in the first leads to international expansion. At this moment local and national governments in France, Turkey and China have expressed their interest in Greenhouse Village. In Shenzen, China, a first international demonstration project is under development.

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The design of Greenhouse Village (Zonneterp in Dutch) is made by a consortium consisting of six parties. The report and this article are written by:

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- Prof. Jón Kristinsson, Kristinsson Architects and Technical University of Delft (architecture and temperature control system)
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A pdf-file of the report is downloadable at http://www.zonneterp.nl/zonneterp.pdf. More information about InnovationNetwork can be found at: http://www.innovatienetwerk.org

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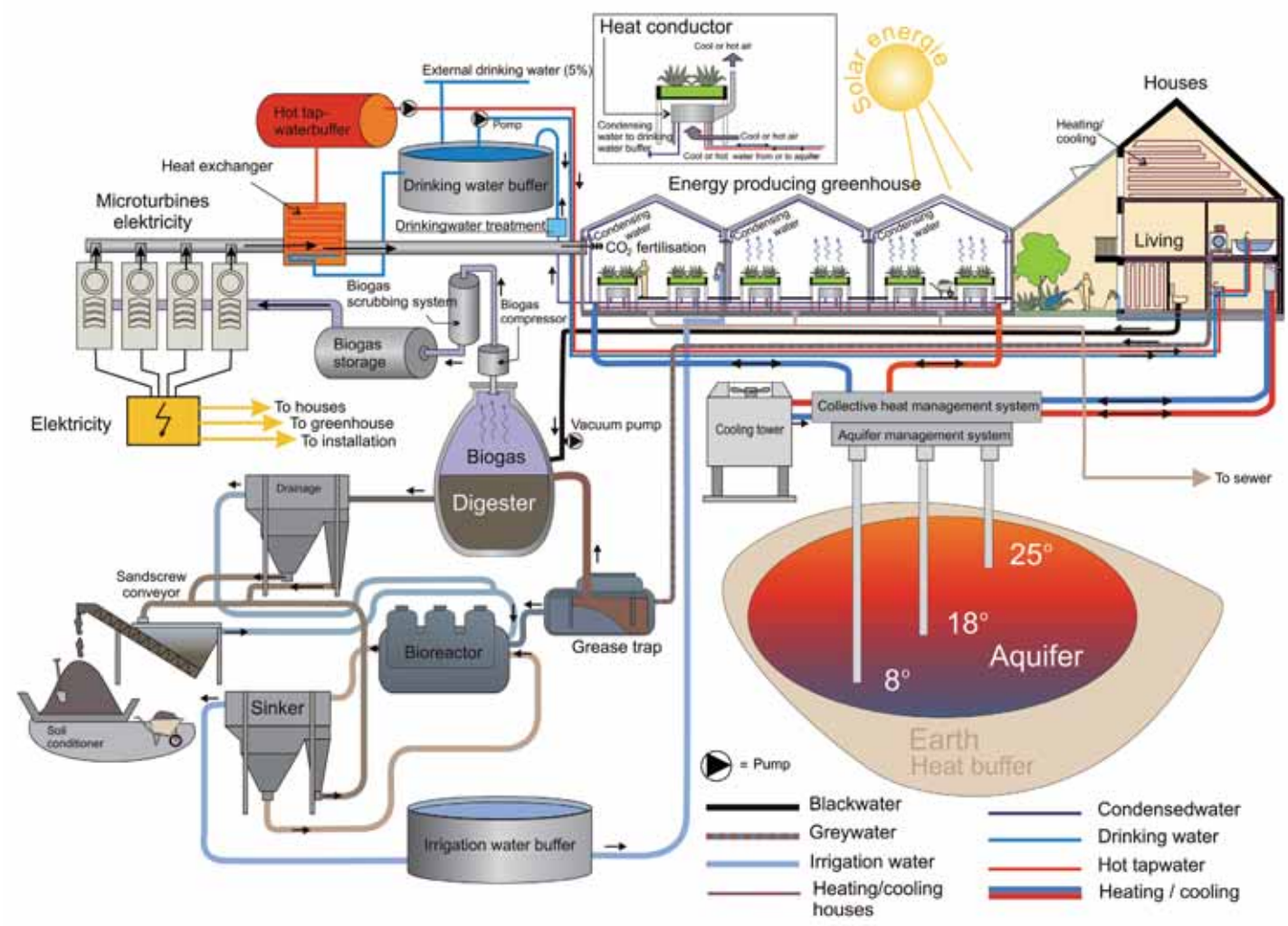

Figure 6. Technical lay-out of Greenhouse Village