The Energy-producing Greenhouse

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ABSTRACT: The glasshouse horticulture as a source of energy without being a fossil energy devourer, will sound like music to everyone's ears. The trick of the trade is a new fine-wire heat exchanger that can heat and cool air very efficiently in combination with forced air circulation. The small (1/4 ha.) first trial glasshouse has already been built. An old textile factory (spinning-mill) has been reopened to weave fine (1/10 mm) tin-coated copper wire to mats with 2 mm water pipes as weft for the innovative water/air heat exchanger. Due to the integration of closed greenhouses and heat and cold storage in the aquifer the sun has replaced natural gas as heat source. There is even a heat surplus of water of 24˚C for CO_2 neutral private-house heating. In the further phases of development which we call Greenhouse Village, the aim is to process the waste matter from the greenhouse and the private houses in a biogas fermentator. Through these closed cycles electricity from biogas can be produced and the CO_2 excess will return to the greenhouse to stimulate vegetation.
In short: 2 ha. of closed glasshouse horticulture can provide 8 ha private houses (ca. 200 families) with a very low temperature heating and make use of all the organic waste matter at the same time.

Keywords: closed ecosystems, fine-wire heat exchangers, aquifer season storage, CO_2 neutral

1. INTRODUCTION

The Dutch glasshouse horticulture as a source of energy without being a natural gas devourer is becoming a reality. The Energy-producing Greenhouse concept is attributed to the high-quality and innovative Dutch glasshouse horticulture in the moderate West European climate and thick sand/clay-layers in the Rhine delta as a substrate for seasonal heat storage. In March 2006 four municipalities have already decided together with local market gardeners' organisations to realise the Energy-producing Greenhouse.
The trick of the trade is a fine-wire heat exchanger that can heat and cool air efficiently. Year-long technical innovation has led to a fundamentally new heat exchanger, a much better climate control and so a better use of low temperatures than in the past.
The basic idea and French patent date from 1927 but were never used. In the laboratory of Akzo Nobel in Arnhem no application was found either for this fine-meshed-wire heat exchanger which has proved to be approximately 22 times more effective than plate heat exchangers.
When this renowned laboratory was dissolved, the unused patent passed into the hands of Dr. Noor van Andel (former corporate research director), who in 2001 received an honorary doctorate from the University of Amsterdam.

For many years nobody was interested in it. In their workshop housed in a former hairdresser's shop father and son Eur Van Andel tried to develop low-temperature air-heating by means of this technology.

Before all the possibilities of the new product technology and its applications have been experimented with much patience is required. Then the Innovation Network of the Ministry of Agriculture and Environment discovered the existence of this innovation concept and the realisation of the energy-producing greenhouse was accelerated. In 2002 three ministers decided together to make the experimental phase financially possible. The largest cost items were the new fine-wire heat exchangers. After serious delay due to professional deliberation on the payment of development money new weaving techniques were developed and at present there is a fully-operating factory with new weaving-looms. Meanwhile it has been calculated that the energy-producing greenhouse has a heat excess of 24˚C., a very low temperature. This temperature is too low to be able to heat adjacent greenhouses with traditional heating installations.
Newly built blocks of minimum energy houses would be more suitable to use a heat surplus. In this phase PLEA author 112 Jon Kristinsson was approached to help to think about a concept for minimum energy houses in a Greenhouse Village, besides having been the contact man between various disciplines at the start of the project. The energy department of Rabo Vastgoed (immovable property) rural bank, became also a party to this project due to their interest in the redevelopment of glasshouse horticulture areas and also in the financing of house-building.
As luck would have it (if luck exists) professor dr. Gatze Lettinga of the Agricultural University in Wageningen and his staff members, Adriaan Mels e.a. (Lettinga Associates Foundation: LeAF) were

involved in the Energy producing Greenhouses and the project acquired a new ambitious dimension by producing all materials by means of closed cycles beside raising the possibilities of heating control. The standard of attainment was raised and the Energy Producing Greenhouse project (Fig.1) changed its name and is now called (Zonneterp) the Greenhouse Village.

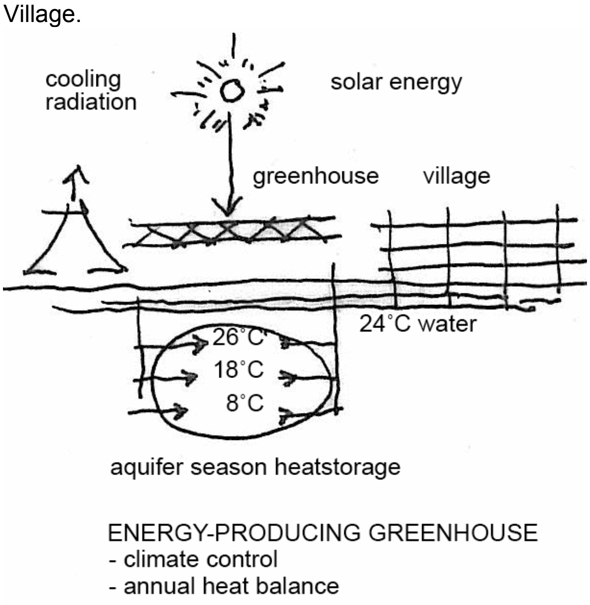


Figure 1: Sketch shows the energy producing greenhouse plan as concept

2. CLOSED CYCLES

2.1 The symbiotic existence of greenhouses and village houses

The former, lost symbiosis between the town and the surrounding country can be partly regained, although it is no longer the greengrocer who with a horse-drawn cart brings the season's vegetables around and the waste-food collector who collects kitchen waste for his pigs. There is a balance between the sunlight radiation towards the earth during the day and the permanent radiation from the earth towards a clear sky. When the greenhouse is double glazed the radiation from the sun is 7x the radiation from the earth.

The greenhouse must get rid of its excess heat. The surrounding houses need to be heated. The aquifer under the greenhouse has minimum dimensions, otherwise the marginal loss will be too great.

There is a reasonable energy balance between 2 ha. greenhouse (150x150 m) and 7 to 8 ha. residential area with 200 houses.

This appears a simple and complete story, but ask any heating installer to heat your house with water at 24˚C and he will seriously scratch his head.

The present home radiators are set at 90˚ and 70˚C discharge temperature. Heating houses with water of 23 to 24˚C is therefore a new challenge to finish this paper with. First of all there are the possible material cycles, which form the most important symbiosis on a clear scale.

This test case is important indeed. It is wishful thinking to expect that soon all metropolitan citizens start thinking in cycles, but one day it will happen.

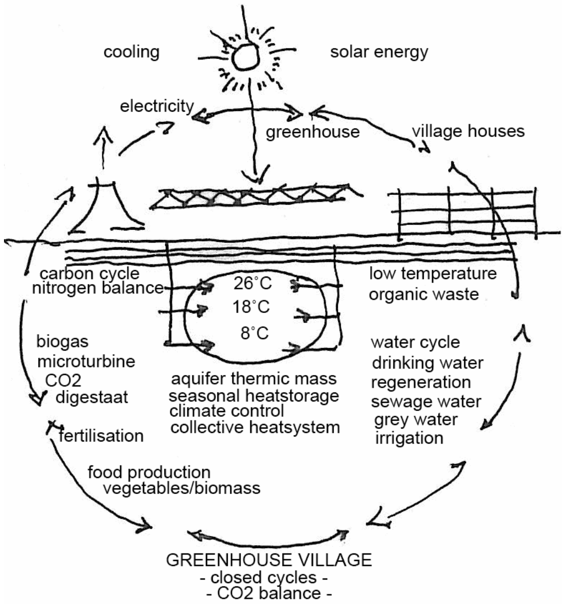


Figure 2: Concept of a sustainable greenhouse and dwellings with their closed cycles, based on the Dutch Zonneterp Greenhouse Village

If we do not achieve a sustainable society humanity will be finished in a hundred years' time. The basic type of heating and cooling from this aquifer in the Minimum Energy Houses is radiation heating supplemented with fine-wire air heating. The problem of the necessary ventilation in super-insulated draught-proof houses is solved by using "breathing windows" and is also based on fine-wire heat exchange technology.

2.2 The greenhouse village

The realisation of the Greenhouse village, an ecological residential area as a further development of the Energy-producing greenhouse, is a new demonstration project for closed material cycles (Fig.2). Beside the climate controlled heating and cooling such as the energy-producing greenhouse, the Greenhouse village concept has four more closed material cycles.

Food production, drinking water purification, irrigation water regeneration and organic waste management for biogas production.

2.3 Climate control

The energy exchange between the sun and the earth and between the planet earth and the universe, finds a balance in our climate via the day/night cycle and the seasons. To determine the order of magnitude of this energy balance we assume that the solar radiation during daytime and the radiation from the earth during 24 hours are almost the same. If not we will have a problem of very fast global warming.

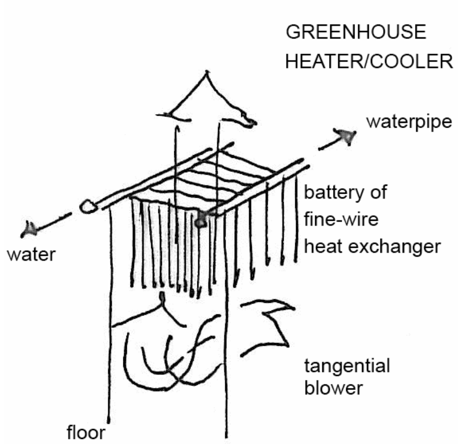


Figure 3: The woven fine-wire heat exchanger is an air/water heat exchanger for heating and cooling. The woven type has a warp of tinned copper wire and a weft of 2 mm water pipes, connected by means of supporting water tubes.

The heating of the greenhouse is not our problem. The design works with a double polycarbonate [zig-zag] glazing developed by General Electric Bergen op Zoom, with a heat transfer of 3.5 W/m^{2}K. When we want to heat the greenhouse in winter to 19˚C, and it is freezing -11˚C outside, we have a temperature difference of 30˚C, and should heat with 30*3.5 = 105 watts per m^2. For cooling purposes, we should cool away 600 W/m^2 however when the sun shines maximally in June and it is hot outside. Therefore we install minimally 55 W/m^2K heat exchangers to cool this heat away with ground water from 10 rising to
26˚C. When heating with 105 W/m^2, we need water of 105 / 55 = 2 degrees higher in temperature than the
19˚C we want to reach in heating: 21˚C. But we produce water of 26˚C when cooling, store it under-ground, and expect a half year later still a temperature of 23˚C.It really comes down to a few degrees, but we are sure that it will work. The aquifer takes 2 years however to reach this performance, so in the first year we have to use a supplement of natural gas for heating. (In existing non-airtight greenhouses a heat-pump is a good solution).

At a peak load of 1500 W/m$_2$ on a summer day and clear sky radiation cooling of 300 W/m$_2$ during a winter night, the thermal mass of the seasonal storage has to solve the problem of the difference between the maximum greenhouse temperature of 28˚C and the minimum one of 15˚C. Wind and precipitation we leave aside. However, if the short-waved sunlight falls through a greenhouse roof and touches a plant or the floor, the wavelength changes into the IR-radiation which will be radiated again in some measure via the glass. Throughout the year 7 times more solar heat will enter the greenhouse than the greenhouse with double glazing will give off as transmission loss.
The essential difference between present greenhouses and the energy-producing greenhouse is that the latter is closed, will not be cooled by opening roof windows and furthermore it can be built low-rise compared to modern glasshouses.
The excess heat at 25˚C is absorbed by 50 W/m2K fine-wire heat exchangers on the greenhouse floor and carried off to a heat and cold aquifer storage at 30m depth.
These 2 m long heat exchangers which have the structure of an open car battery, have tangential blowers for the forced air circulation. (Fig. 3) In anticipation of the description of the houses in the Greenhouse Village we can already reveal that there are two types of fine-wire heat exchangers: a. the woven water/air heat exchanger and b. the winding air/air heat exchanger (Fig. 4).

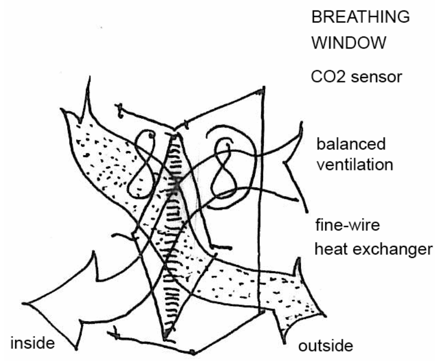


Figure 4: The air/air fine-wire heat exchangers are made of winding 0.1 mm pure copper wire glued on 0.5 mm nylon thread with 15 mm distance in between. The dimensions of the 26 winding, airtight, glued mats are w x d x h: 200 x 16 x 400 mm respectively.

The cooling of the greenhouse from the bottom of the aquifer is equal to its solar heating. The cold "battery" in the ground of app. 8˚C is charged in wintertime. There is also a cooling tower on at night. The first generation of the greenhouse as a source of energy, such as in Huissen in the Netherlands, satisfies these prior conditions. The glasshouse horticulture can become CO_2 neutral.
Whereas the Energy producing Greenhouse can function independently by means of a thermostatically controlled temperature annual programme, the Greenhouse Village is interactive through the participation of the occupants, who profit by it also economically (Fig. 5).

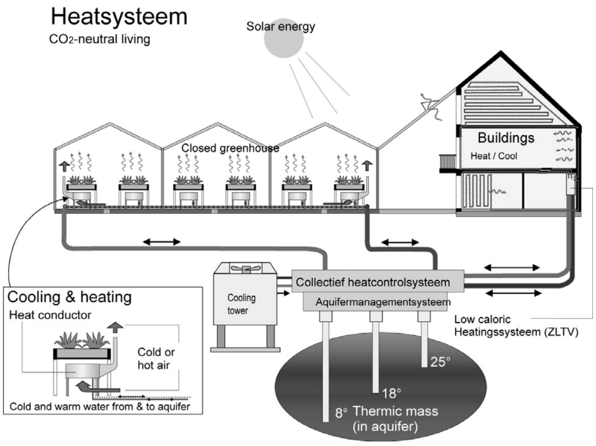


Figure 5: Heating system, CO_2-neutral living

2.4 Organic waste

Technically and socially the organic cycle near home is hard to imagine. We were born and bred in a society with water closets and GFT containers which are collected and emptied on payment.
Vacuum toilets, crushed kitchen garbage, separated urine and vegetable waste processing in a biogas fermentator is an inevitable ecological process.
By processing in a central fermentator all the organic waste matter from the greenhouses and the private houses, including grey and black waste water (faeces + urine), biogas can be gained, which can operate a diesel engine for the production of electricity for the private houses.

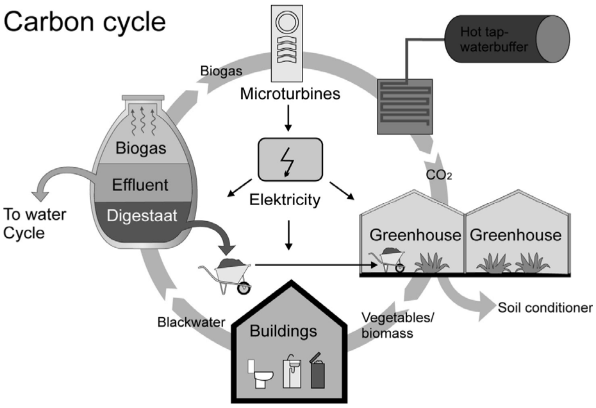


Figure 6: The carbon cycle

The waste matter is manure that, among other things, can be used as a substrate in the greenhouses as well as the CO_2 that the plants need in daytime in a concentration of 1000 ppm. (Fig. 6) Raising CO_2 from 500 to 1000 ppm yields roughly a 20% larger crop. Due to the fact that the greenhouse is closed there are fewer troublesome insects and the fact that 85% relative humidity is maintained does not cause any problems.
Biogas exists of approximately 2/3 methane (CH_4), 1/3 CO_2, some H_2 and inert N_2 and, the weak link, a little stinking sulphurated hydrogen H_2S. The village of 200 households is too small, we need about 50% more biomass (Fig. 7) Garbage from a hotel kitchen would be very welcome.

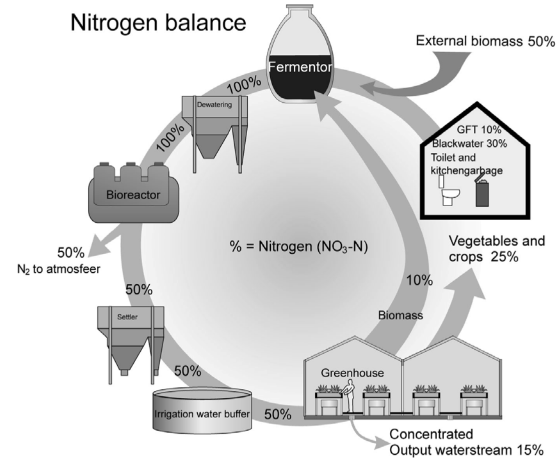


Figure 7: The nitrogen balance

2.5 Three water systems

Inside the closed greenhouse, which has also to be cooled to keep the temperature below 28˚C, a special inside climate arises, even apart from the CO2 content and the condensation produced by drinking water.
This condensed water lacks the flavour of minerals and is not permitted in the Netherlands as drinking water. (Fig. 8)

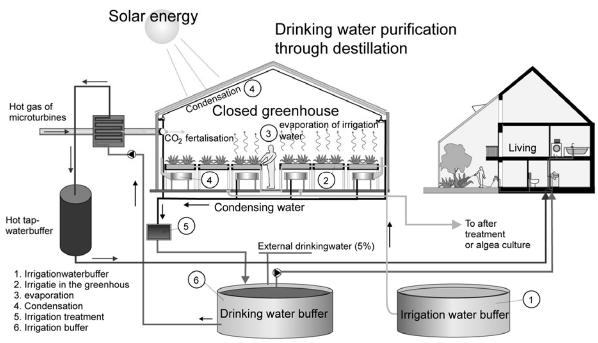


Figure 8: Three water systems: condensed (drinking) water, grey waste water and rainwater used for irrigation

2.6. Irrigation

If the grey waste water from the private houses can be kept apart, irrigation water can be won from it. Very little irrigation water is needed in a closed greenhouse which is not ventilated. Closed ecosystems within the built environment are professional installations. (Fig. 9)
They are entirely dependent on the willingness of the occupants and their guests not to disturb the short closed cycles.

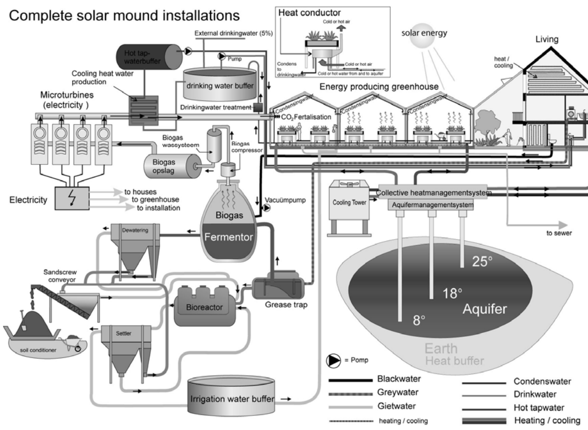


Figure 9: Complete greenhouse installation

2.7. Food production

The Greenhouse is commercially productive. Who should be the owner has not yet been settled. Neither has been settled the relationship between work and joint use by the occupants of the area around the greenhouse which could be used for facilities such as a school, local coffee house and pub or swimming-pool. The greenhouse itself must be able to create an added value for the participating occupants, as a supplier of food, employment, income guarantee and low recurring household expenses. The greenhouse can also have an educational value showing how the bio-industry can be sustainable. The technical installation space needed for a greenhouse of 2 ha. is about 10% - (15x15m) of the greenhouse surface. The cooling tower is a new visible element that gives some shade. The cooling tower forms the skyline profile of a greenhouse village.

2.8 The village houses

The very-low-temperature energy houses are by far the most expensive parts of the Greenhouse Village. The investment for 200 houses is almost 10 times the cost of the greenhouses with their fine-wire heat control and the seasonal storage in the aquifer.
The list of requirements for the new village contains regulations for various measurements and building costs of cheap houses for young couples, one-family houses, houses for senior citizens and eventually houses suitable for every age.
Division of land charges from hereditary tenure to property offers many possibilities. The very low water temperature from the aquifer is a challenge. Some technical innovations are needed in these minimum energy houses.
This extremely low temperature heating is floor/wall radiation heating of 20 to 22˚C, which may be too low for bathrooms and old chilly people sitting near a large window.
As there is little experience with regard to very low temperature heating, air heating of 23 to 24˚C is locally added.

You may already have guessed that we are thinking of small convectors, based on the heating and cooling of greenhouses. This big switch to a self-supplying energy system is the second generation of "greenhouse-heated houses". (Fig. 10)
These minimum energy houses with EPC (Energy Performance Coefficient) ≤ 0.5 appear to have about as much loss of heat through transmission as through ventilation and chinks. When these super-insulated houses are also detailed and built draught-proof, they will get decentralized breathing-window (BW) ventilation.

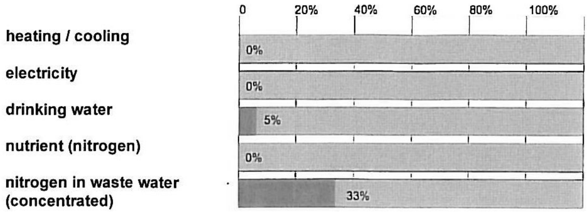


Figure 10: Consumption of public utilities as a standard consumption percentage of a greenhouse and private houses

The detailed drawing and building of the apartments requires close attention. One easily tends to use triple glazing, insulating window frames and outside sun-blinds.

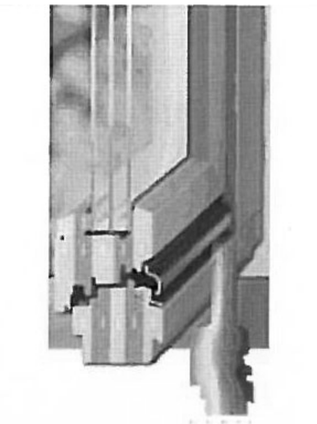
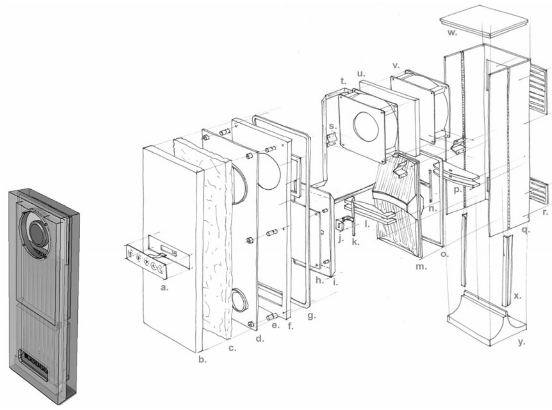


Figure 11: German 'passiv Haus' – window
Ewitherm = 0.8 W / m^2K

2.9 Breathing Window

The breathing window (BW) is an innovative balanced ventilation system in the outer wall of private houses and offices with a 90 to 95% heat recovery. (factor 20)
The air/air heat exchanger is based on the same principle as the water/air fine copper-wire heat exchanger in the greenhouses. This is in an advanced phase of development.
The measurements of the BW as for depth, width, height = 250 x 270 x 660 mm. The fine-wire heat exchanger in the breathing window consists of a stack of 26 mats of copper wire with a total length of 15 km. The depth of this air/air heat exchange is no more than 16 mm. and has the unexpected property that the air current (which appears for only for a split second) hardly condenses nor freezes. (Fig. 12)



a = display - CO_2 meter control
c = acoustic board/noise reduction
i = dust filter
t = inside fan
u = insulation
m = fine-wire heat exchanger
v = outside fan

Figure 12: The latest design 2006 (left) and exploded view (right). The dimensions are d x w x h: 250 x 270 x 660 mm.

Due to the use of breathing-window ventilation a 35 to 40% energy saving in private houses is plausible. The two ventilators per BW use together 8 Watts at a flow rate of 50 m^3/hour. The breathing window has a CO_2 sensor and will react on the quality of the inside air if the occupant forgets to control it.

Each house needs 3 to 6 BWs, dependent on the number of rooms.
The development of the BW is a separate subject, independent of the Greenhouse Village concept.

3. CONCLUSION

Living in a Greenhouse Village has the disadvantage of being unknown as a new way of living. (Fig. 13) The advantages are evident: no dormitory towns as a living environment, no commuter traffic. Mainly biological food and small-scale living around a village green. The recent know-how to gain low-temperature solar heat and store it as seasonal heat has never before been possible on a large scale. Solidarity is certainly required, but without a joint responsibility for a sustainable living environment within an urban area, our western culture will crumble away very soon.
The fine-wire heat exchangers may be small, but can have great world-wide energy-saving consequences, both for heating/cooling and for ventilation devices in all types of buildings.

Figure 13: Senior Greenhouse apartments at Hengelo, the Netherlands. Architecten- en Ingenieursbureau Kristinsson BV
photograph: J. Kristinsson

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