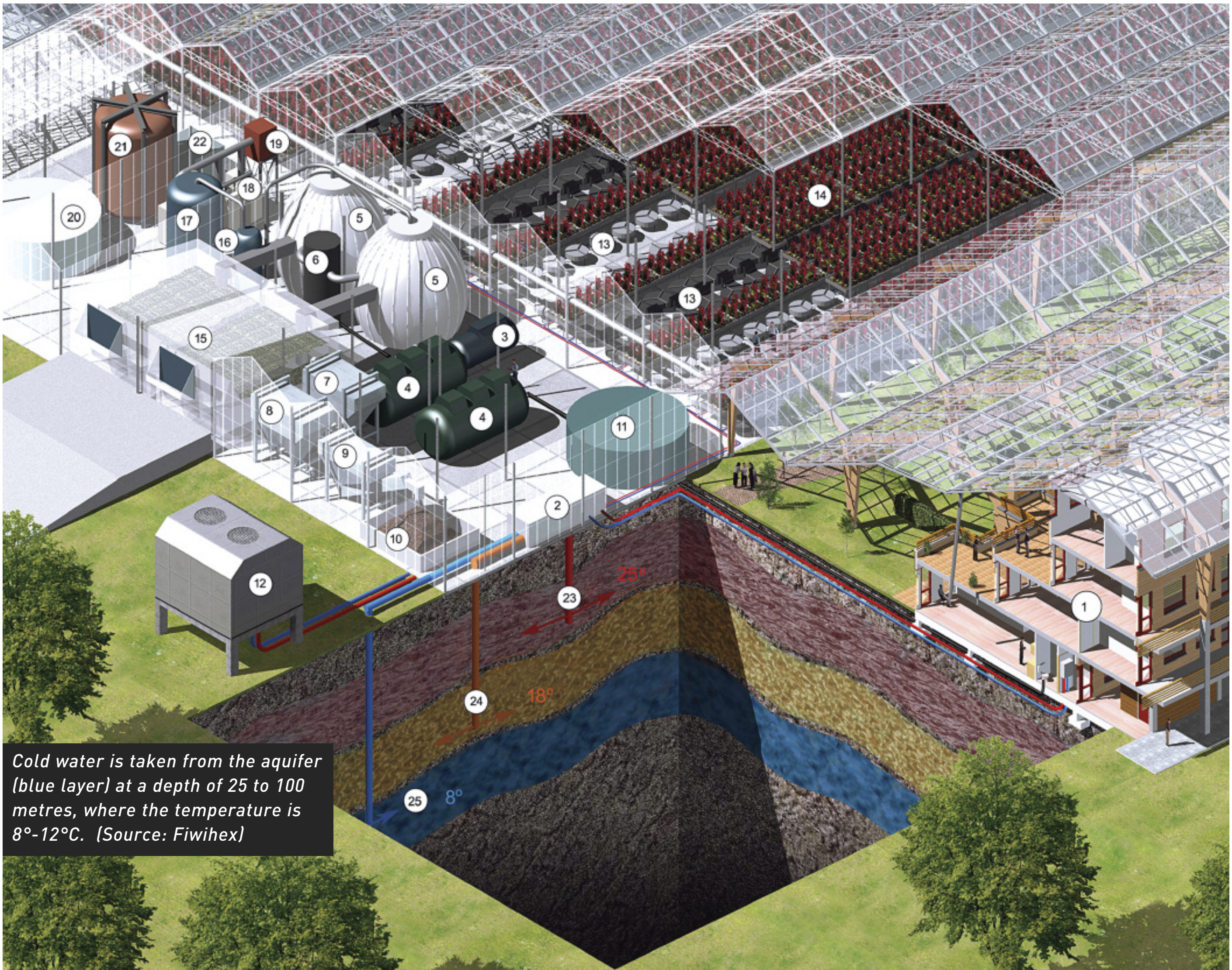


Cold water is taken from the aquifer (blue layer) at a depth of 25 to 100 metres, where the temperature is 8°-12°C. (Source: Fiwihex)

FUTURE PROOFING

Drastic improvements in growing technology in the Netherlands have achieved a large reduction in energy use and a striking increase in production.

Report by ELLY NEDERHOFF, ARIE de GELDER, ANJA DIELEMAN & JAN JANSE

Greenhouses with an extensive energy plant.

Energy is needed year-round for humidity control.

Energy is needed in summer for CO_2 enrichment.

Heavy-duty boilers in Canada.

Energy is needed in winter for temperature control.

Energy

Energy forms a large part of the production costs of greenhouse crops, be it for temperature control in cold winter conditions, humidity control in mild conditions, or CO_2 enrichment (by burning gas) in summer conditions. The price of gas, oil, coal and electricity increases all the time and may get even higher when the carbon tax or the CO_2 emission trading fee is added. Energy and other resources must be used as efficiently as possible, both for sustainability and profitability.

In the Netherlands, great progress has been made recently by combining a range of energy-efficient techniques that have been developed over the last decades. So-called semi-closed greenhouses and the 'future-proof' growing concept employ forced ventilation by means of Air Treatment Units (ATUs) instead of natural ventilation by means of vents in the roof. This helps to keep CO_2 inside, which increases production without requiring a lot of CO_2 injection. The spin-off from these concepts is very useful for conventional greenhouse growing methods, too.

The first half of this article is about the 'future proof' growing method. The second half describes the technology of semi-closed greenhouses.

Future-proof growing concept

Some years ago the government in the Netherlands called for a drastic reduction in energy use while growers stipulated that the production and quality should not be compromised. Dutch researchers from *Wageningen University and Research* (WUR) together with the industry then developed a new growing concept called *het nieuwe telen* (the new growing), freely translated into 'future-proof growing'. It is based a lot on the technology of semi-closed greenhouses. This future-proof concept comprises strong insulation, forced ventilation, air treatment technology, fogging, shading, optimal CO_2 enrichment, smart control and optimal plant management.

The concept was tested for cucumbers and tomatoes, and proved highly successful. This year it is being tested for a wide range of vegetable and flower crops. For each crop the implementation will be different depending on particular crop requirements. The seven steps of the future-proofing concept are listed here and explained further - the energy savings in parenthesis apply only to the Dutch situation. In other climate zones or other conditions the energy saving can be a lot higher (e.g. point 1), or lower (point 2), or the measure may not be achievable (point 7). The steps are:

1. Using dried air from outside for humidity control (15% energy saving)
2. Advanced use of screens (15% energy saving)
3. Temperature integration (5% energy saving)
4. Air movement (less diseases)
5. Fogging/humidification (increased production)
6. Active cooling (increased production)
7. Cooling by aquifer and heating with heat pump (25% energy saving).

Humidity control by concurrent heating and venting uses a lot of energy.

A lot can be improved on this basic screen as used in the early days.

A modern screen runs smoothly and closes perfectly.

A screen that only partly blocks the light can be closed in daytime for energy savings, and can also act as a shade screen in summer.

(1) Humidity control

In most greenhouses a lot of energy is spent on humidity control: trying to keep the humidity down in cold or dull conditions. In mild climates, humidity control makes up the largest part of the energy consumption. The standard method for humidity control is using minimum pipe temperature and concurrent heating and venting, which requires a lot of energy. Even more energy is used (or lost) due to flawed computer settings, as seen so often. Humidity control can be assessed by checking the computer graphs. The heating and venting lines should only cross-over when humidity is beyond a set upper limit (say, above 83% RH). But even with optimal settings, this method of humidity control requires a lot of energy.

In the semi-closed greenhouse using the future-proof growing concept, the temperature and humidity are controlled through forced ventilation by means of Air Treatment Units (ATUs). These draw air from outside or from inside the greenhouse and then warm and dry it. The treated air is blown directly into the greenhouse or spread via air ducts. The option to draw air from outside into the ATUs has the advantage of a lower absolute air humidity. The other option, that ATUs draw air from inside the greenhouse, means that no CO_2 is wasted. In Dutch conditions, humidity control by air treatment saves 15% of energy compared to conventional humidity control with heating and venting.

(2a) Intensive thermal screens

Thermal screens are very effective in reducing energy use and they play an important role in the future-proof growing concept. In cold climates it is worthwhile having two screens: one heavy-duty thermal screen for energy saving and one lighter screen that can be used for energy saving and shading. The first screen can be made, for instance, of XLS-18. This saves around 72% energy while closed, which is especially useful during cold nights. This screen is not suitable to be used during daytime as it transmits less than 20% light and would hinder photosynthesis too much. The second screen is made, for instance, of XLS-10. This saves about 45% energy when closed and transmits over 80% light. This screen can be used in milder nights and can stay closed (or get closed) during daytime, as it does not hinder the photosynthesis too much.

This lighter screen can also be used as a shade screen in summer. Shading prevents wilting, burning and sunburn on fruits (e.g. capsicum). Note that sunshine consists half of heat and half of light. So when the heat influx is reduced, inevitably the light influx is also reduced. Shading screens should not be closed for too long in vegetable crops like tomatoes, pepper, cucumber, as they can utilise even the highest levels of light (provided the other conditions and water supply are good). Shading is essential for shade-loving plants like many ornamental pot plants. The pros and cons of using a screen have to be weighed up. The advantages of using a screen include energy saving and keeping the plant heads warm (in winter time), and protection against excessive sunshine (in summer).

(2b) Optimal control of thermal screens

Weighing up the advantages and disadvantages of a thermal screen is done by a smart control programme (with the correct settings). The lowest temperature of the day often occurs in the early morning hours, but some growers open the screen just in those hours. This wastes a lot of energy and is very harsh on plants. Opening and closing a screen should not be based on clock-time and not even on sunset and sunrise. Optimal screen control can best be based on the prevailing climatic conditions such as humidity in the greenhouse, light and temperature outside. Local aspects, such as the price of energy should be taken into account as well.

Computer settings for Dutch conditions are given here as an example. A heavy-duty thermal screen should only be closed when it is fairly cold outside (e.g. below 10° or 12°C), and when at the same time the light intensity is fairly low (e.g. below 50 W/m^2). The higher these temperature and light settings are chosen, the more hours the screen is closed. Screen opening too must be based on temperature and radiation. At low outside temperature, the screen should be opened at a higher radiation level, or when the temperature above the screen has reached a certain level. Opening in the morning must always happen in small defined steps of a few per cent each, spread over at least half an hour. In this way the heating can adjust to the open screen.

A serious problem under a screen is high humidity. A good strategy to avoid this is the following. A certain target level of humidity is set, for instance 88% at night and 85% during the day time. When humidity reaches this limit, the screen is partly opened, creating a gap of 3%. If humidity still remains high, the vents are opened above the screen to a maximum of, say, 5%. If the humidity still stays too high for half an hour after vent opening, the screen is completely opened. In this case, priority is given to humidity control over energy saving.

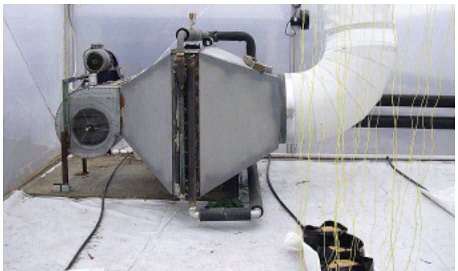
(3) Temperature integration

Opportunities for light-depending temperature control can be utilised better than they are now. The temperature can be allowed to go higher when radiation is higher (to utilise the free heat) and must then be compensated by lower temperature at night or during dull moments. The average temperature must remain at the chosen level, as that determines the rate of plant development. Advanced computers have settings for temperature integration. Temperature integration is calculated as saving 5% of energy costs in the Dutch situation.

(4) Air movement

Air movement helps create a homogeneous environment, without gradients in temperature and humidity. It helps to avoid cold spots where condensation occurs. Cold wet spots are the cradle for fungal infections and disease outbreaks. Reduced leaf wetness minimises the need for spraying and secures good production. In the future-proof growing concept, air movement comes from the Air Treatment Units. It can also be achieved by using fans (see *PH&G Nov/Dec 2008, Issue 103, pp 49-57*).

Fogging can reduce the air temperature by several degrees, especially at low air humidity.



An early version of an ATU in the 1990s in New Zealand: air is heated by hot water pipes and then spread through air ducts.

A string of Air Treatment Units (ATUs) in a large-scale semi-closed greenhouse.

Air Treatment Units (ATUs) of Fiwihex are placed here between the tables at Huisman.

An Air Treatment Unit (ATU) of Goedhart is an effective heat exchanger.

This Air Treatment Unit (ATU) blows treated air overhead.

Copper pipes in the Goedhart Air Treatment Units (ATU).

(5) Fogging/humidification

Fogging is very effective to reduce temperature on a warm sunny day. Fogging works better when the air humidity is lower. The small water droplets evaporate and this lowers the air temperature. Due to the lower temperature, the vents can stay closed for longer in a semi-closed greenhouse. This helps maintain a high CO_2 concentration, which helps increase photosynthesis and production.

Fogging can have a downside too. Humid conditions (especially if combined with low light) lower the transpiration and hence reduce the uptake of nutrients. This leads to nutrient deficiencies in leaves and buds, making plants vulnerable. Warm conditions are beneficial for pests and diseases, and high humidity is especially favourable for many diseases. The combination of these conditions can result in an infection by diseases or an infestation by insects. Also, humid growing conditions make plants 'lazy' (i.e. weaken the roots and water transport channels). As a result the plants may wilt in a sudden spell of sunshine if shading and fogging are not activated in time.

Hence, the use of shading and fogging should be controlled carefully by weighing up the pros and cons. This requires a good computer control programme and the right settings. Check the results by studying the graphs and change the settings when necessary.

(6) Active cooling

Active cooling with Air Treatment Units (ATUs) is now common practice in the many semi-closed greenhouses in the Netherlands. ATUs cause forced ventilation that replaces natural ventilation by vents in the roof. In semi-closed greenhouses the roof vents can open as a safety net, when the temperature rises too far. So, effective air treatment by ATUs help to keep the vents closed. This allows a higher CO_2 concentration to be maintained, which increases production. Active cooling at night reduces the 24-hour temperature, which is a method of improving plant balance. Both pathways will increase production. The technicalities of ATUs are discussed later.

(7) Cooling water, aquifer and heat pump

The final step in the future-proof growing concept is using cold water for cooling, and also storing heat from one season to another. The way this is solved in the Netherlands is by using the aquifer, which is a layer of water at 25 to 100 metres below ground level. It is relatively easy to access (compared to other countries), but the drilling is extremely expensive. An additional heat pump is necessary for effective heating in winter (see explanation that follows). Making use of an aquifer and heat pump can save 25% on energy use. This is by far the most expensive step in the concept, but is not achievable everywhere. Modified versions of this approach, for instance using another source of cooling water, might be useful for other locations.

Some details of Closed and semi-closed greenhouses

It may be interesting to write a bit more about technologies such as forced ventilation, ATUs (air treatment units) and the use of an aquifer. These were developed for 'closed greenhouses' and are now common practice in the many 'semi-closed greenhouses' in the Netherlands.

A closed greenhouse has no vents in the roof and is completely reliant on mechanical cooling. The first commercial closed greenhouse in the Netherlands was built in 2004 by the company Themato. This greenhouse is still operational, proving the concept works. However, the cost of cooling in a fully closed greenhouse was very high. Hence, other companies chose a modified system, with less cooling capacity and with the option to open vents at peak temperatures. And so the first semi-closed greenhouses were built in 2005. A semi-closed greenhouse does have roof vents that are opened when other cooling systems can't keep the greenhouse temperature low enough.

Closed and semi-closed greenhouses are cooled by Air Treatment Units (ATUs). Although these can also be used for heating, in practice heating is often done by the standard pipe heating system. This is because the gas-fired boiler is running anyway for the production of CO_2, or the gas-fired co-generator is running for the production of electricity and CO_2. A boiler or co-generator produces heat at the same time, which is then utilised for heating with conventional heating pipes.

Air Treatment Units (ATUs)

ATUs are heat exchangers consisting of copper pipes and plate fins with water flowing through them, and a fan blowing greenhouse air over the pipes. In summer they are fed with cold water to cool the greenhouse air. The cold air is spread via large air ducts under crop gullies or under benches. Similarly, in winter the ATUs can be fed with warm water to heat the greenhouse.

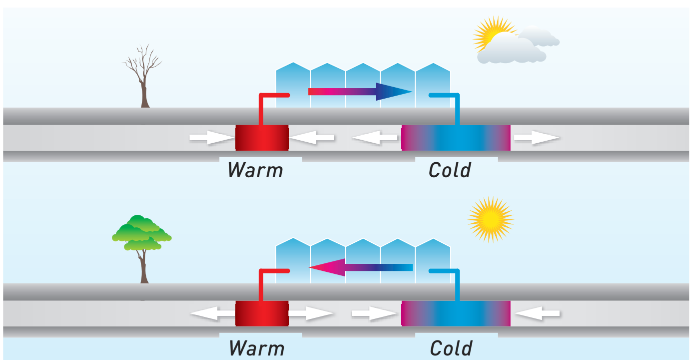
However, the greenhouse is not always heated by ATUs (see earlier remarks). An ATU draws air either from outside or from inside the greenhouse, for instance, from the top of the greenhouse. In this way no CO_2 is wasted. Several brands are used (e.g. Fiwihex and Goedhart).

The cooling capacity required in a closed greenhouse depends on the weather conditions at a given moment, especially sunshine and outside temperature. Peak radiation in the Netherlands is around 1000 W/m^2 and occasionally higher. About 70% of this enters the greenhouse. This means that the peak heat load is over 700 W/m^2. This is then the required cooling capacity for a completely closed greenhouse. In practice, a lower cooling capacity of 600 or even 550 W/m^2 proved to be sufficient to keep the greenhouse closed nearly all the time.

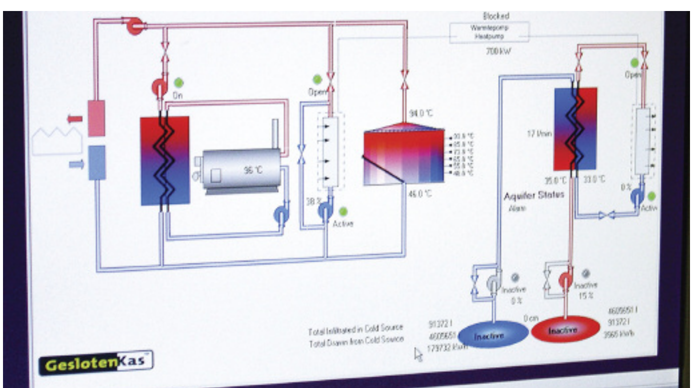
Cooling capacity depends on the number and quality of ATUs, the water temperature, water flow rate and air flow rate. Unfortunately, a cooling capacity of 600 W/m^2 requires a lot of ATUs, and is very expensive in terms of investment and running costs. This peak capacity is only required in a small number of hours per year. Therefore, most growers opt for a semi-closed greenhouse, with fewer ATUs, with a capacity of, say, between 200 and 400 W/m^2. The vents in the roof are opened when the air temperature exceeds a certain threshold level, for instance 26°C. Semi-closed greenhouses have now become the norm for new greenhouse projects in the Netherlands.

An 'open' greenhouse (left) cooled by natural ventilation and 'the closed greenhouse' (right) cooled by forced ventilation.

Air ducts spreading cold air in a semi-closed greenhouse.



In summer, cold water from the aquifer is used for cooling. The water warms up and is stored. The tepid water can be used for heating in winter. (Source: Wageningen UR)



A computer screen depicting the heat and cooling of 'the closed greenhouse'.

Aquifer

The ATUs need cold water for cooling. In the Netherlands there are now many greenhouse projects where cold water is pumped up from the aquifer. This is a water layer at 25-100 metres underground. Drilling bores into the aquifer is expensive, and is only cost-effective for mega-projects. It only works if the geological conditions and legal requirements allow using the aquifer.

The aquifer has a constant temperature of about 8° or 12°C. This cold water is pumped through the ATUs where it absorbs a part of the heat from the greenhouse air. This lowers the air temperature by some degrees and raises the water temperature to, for instance, 23°C. The tepid water is pumped back into the aquifer. In winter, the tepid water stored in the aquifer is still at about the same temperature, say 22°C. This is too cold to be used directly for heating, but it is an excellent heat source for a heat pump. So a heat pump uses this tepid water as input to produce water of a much higher temperature to be used in heating pipes.

In this way, a closed or semi-closed greenhouse 'harvests' heat in summer, then stores it in the aquifer over autumn, and uses it for heating in winter. Considerably more heat can be harvested in summer than what is needed for greenhouse heating in winter. The surplus heat can be used for domestic heating.

CO_2 enrichment

The benefit of this concept comes from lower energy use (in fact heat is produced rather than used). It also comes from a lower need for CO_2 gas for enrichment. The biggest benefit is a considerable higher production due to higher CO_2 levels. The effect is most clear on sunny days. Even when the vents then have to open quite a bit, they still open much later and much less than in a standard 'open' greenhouse. Hence, it is easy to maintain a much higher CO_2 level than in an open greenhouse.

It is known that plants under a higher CO_2 level do better at a higher temperature level. So the more closed the greenhouses is, the higher the CO_2 level is, and the higher the temperature can be chosen. The difference can be some degrees during parts of the day. The optimal temperature is determined by accurate 'plant reading' as is done with crop registration (see *PH&G Jan/Feb 2009, Issue 104 and Mar/Apr 2009, Issue 105*). So in a semi-closed greenhouse, the high CO_2 level generates a considerable production gain. In addition, the somewhat higher growing temperature also increases production.

Comparing open and closed greenhouse

In an experiment with tomatoes in 2008 by WUR in Bleiswijk, a standard or 'open' greenhouse was compared to three semi-closed greenhouses (with 150 to 350 W/m^2 cooling capacity) and one closed greenhouse with 700 W/m^2 cooling capacity. More mechanical cooling meant less natural venting, which allowed a higher CO_2 concentration. The CO_2 concentration was about 600 ppm in the open greenhouse, and about 1100 ppm in the closed greenhouse during daytime in midsummer.

The results were remarkable: the more closed the greenhouse was, the higher the production. The difference was up to 11%, from 55 kg/m^2/year in the open greenhouse to 61 kg/m^2/year in the semi-closed greenhouse with 350 W/m^2 cooling. The completely closed greenhouse produced the most, until a severe *Botrytis* infection struck and affected the end result. Otherwise this greenhouse would have had markedly more than 11% higher production than the open greenhouse.

The higher production had three components: increased rate of flowering and increased rate of fruit ripening due to higher temperature, and increased fruit weight due to higher CO_2 level. Even more striking were the results in energy balance and in CO_2 consumption. The open greenhouse used $31m^3$ gas per m^2, whereas the semi-closed greenhouses yielded (instead of costed) the equivalent of 3 to $26m^3$ gas per m^2, and the fully closed greenhouse yielded the equivalent of $45m^3$ gas per m^2. Energy yield means that more energy was 'harvested' in summer than was used in winter. CO_2 usage was reduced from 55 kg/m^2/year in the open greenhouse down to 14 kg/m^2 in the closed greenhouse. Experiments with cucumber were equally successful.

Pros and cons

Experiments have shown that the future-proof growing concept can save 40% on energy (compared to the Dutch general standard) by using advanced screens, forced ventilation, air treatment, fogging, shading, optimal CO_2 enrichment, smart control and optimal plant management. Moreover, the production is considerably higher and CO_2 consumption a lot lower.

It is even achieved to harvest and store much more heat in the aquifer than what is needed for greenhouse heating in winter. The surplus heat can be used to heat other greenhouses or nearby buildings, such as care homes and houses. This is already a reality and new projects are on the drawing board.

Growing conditions in summer are slightly different in a semi-closed greenhouse compared to in a standard 'open' greenhouse. Further experiments are needed to find out whether it makes a difference if the heat is released under or above the crop, and how to adjust plant management.

The biggest hurdle for closed greenhouses is the cost. ATUs with air ducts are far more expensive than standard heating pipes. A source of cold water is needed for cooling. Not in all countries can an aquifer be used to obtain cooling water and for seasonal storage of warm water.

Due to economies of scale, modern greenhouse complexes are mega-large: many tens of thousands of hectares. They often have a very complex heating set-up that can consist of one or more of the following items: co-generator, boiler, connection to an aquifer, heat pump, heat storage tank (buffer), pipe heating system, and in the greenhouse many small ATUs (heat exchangers). It requires a special skill to manage the energy park.

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