LEC - GREENHOUSE

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- Abstract

The main objective of the research was to construct and test an LEC greenhouse, in regard to energy consumption, greenhouse climate and plant growth. The common denominator for the project is energy saving in greenhouse based on substitution of glass with screen materials and adaptation of a growing system based on concept that makes it possible to convert the greenhouse to almost open land. The LEC greenhouse is designed for production of plants with low temperature requirement and high tolerance to variation in air temperature. The LEC greenhouse is heated with hot water from a heat storage connected to a solar collector to diminish the use of non-renewable energy. The heating system consists of PEL tubes placed in soil and the solar collector, consisting of PEL tubes, is placed in the top of the greenhouse. As a supplement in case of exhausting of the heat storage, energy is supplied from the boiler and the heat storage works as a heat exchanger.
A standard climatic computer was modified and extended to the operation needed in the LEC greenhouse.
The LEC greenhouse is a shed roof construction with a roof slope of 5_, with a span of 10 metres. Using a shed roof construction gives 3 features, 1) the wind load on the roof screen is minimised, 2) rain runs off (screen material is water proof) and 3) the LEC greenhouse can be build as a separate greenhouse as well as in block.
The screen materials is QLS in the roof because it is most suited for a folding screen, while Solar Woven is used in the side walls because it is most suitable for a rolling screen. Both materials have an appropriate light transmission and when the screens are closed the light transmission is 60-65%. The LEC greenhouse is equipped with an aluminised energy screen, which is closed during night.
Argyranthemum frutescens, *Campanula potenschlagiana*, *Petunia hybrid*, *Osteospermum ecklonis* and *Pinus pinea* were grown in the LEC greenhouse and the growth and development was compared with plant grown in traditional way in a glass greenhouse. The plant species produced in the LEC greenhouse were grown under lower average air temperature than the plant in the reference greenhouse and the production time was increased to the double compared with the time in the reference greenhouse. The slow growth rate of the plants result in a higher dry matter content. The fluctuation in air temperature and the lower average temperature decreases stem elongation, which reduces the need for application of chemical growth retardant.
The quality of the plants produced in the LEC greenhouse is high and the plants were produced with an energy consumption of approximately 20% compared to the amount of energy used in a glass greenhouse.

The energy consumption per hour was on average 4 MJ and the average per day was 21 MJ, but with very large variation in energy consumption over the experimental period. The energy accumulated by the solar collector was on average 2.3 MJ per hour and the average per day was 49 MJ, but with very large variation in energy accumulation over the experimental period. In regard to energy the heating system is able to provide sufficient heat to keep the LEC greenhouse free of frost. The solar collector has a low efficiency, but energy accumulation could be improved by change in the design of heat storage and control system. It is not possible to improve the performance of the solar collector it self as long as it is an integrated part of the greenhouse construction.

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3. Objectives

The prime objective was to develop and test a greenhouse build of screen materials instead of glass in regard to energy consumption and plant growth and development.

The technical solutions known today do not combine the use of modern screen material as movable covering material, mainly due to lack of knowledge. Today some pot plant species are grown partly outdoor and forced in greenhouse to reach the marketable stage. The advantage of these production methods is that they require lesser energy and reduce the amount of chemical growth retardant used to keep the plant compact. The disadvantage is that production time and quality is unpredictable, and a screened outdoor area might improve quality and give a better prediction of production time.

The design and operation of a LEC greenhouse differs in many way from an ordinary glass greenhouse and the main driver for the project was a new plant production system with low energy consumption. The LEC greenhouse requires an implementation of a new strategy for climatic control in greenhouses, based on the use of renewable energy and control based on outdoor condition.

By combining the technology of greenhouse construction and computer technology with modern screen material a compliant greenhouse for production of plant with high temperature tolerance is established.

The project objectives where as follows:

- Optimisation of the LEC greenhouse shape, selection of screen material and design of hot air heat trap or solar collector
- Develop and modify soft ware for charging and discharging heat storage and extend greenhouse climatic control to fulfil new requirements specific to the LEC greenhouse
- Building a small scale LEC greenhouse
- Conduct technical and plant growth experiments

- Technical description.

Construction

Foundation

The foundation for the greenhouse consists of a cheap and simple point foundation. In a drilled hole the concrete is poured down and prefabricated concrete pillars are mounted in the wet concrete. The pillars have a connection part in the top, which fits into a connection part in the bottom of the steel column.

To make a separation from the soil inside the greenhouse and soil outside the greenhouse, the use of prefabricated concrete panels are both cheap and convenient. On the other hand one can also use a part of the fabric from the lower permanent screens and put it in a dug trench and in that way save a good deal of money.

It is very much up the grower or builder to decide which solution is the best for him. The last mentioned method is by far the cheapest. The slope of the roof also gives a possibility to have a vertical ventilation, when several houses are built in blocks. This is very important when talking ventilation during raining, to avoid wet plants and leaching of nutrition from the pots.

Steel construction

The construction of the LEC-greenhouse is made of hot galvanised steel, which is normal for greenhouse building today. Aluminium is also a very good and light material in stead of steel, but it is rather expensive and the prices for aluminium is very dependent of the aluminium market, which is resulting in very unstable prices.

The construction consists of columns at a distance 3,654 metres, which is suitable for the width of the covering system. Between each two columns there is a system of steel girders with a roof angle of 5 degrees. The 5 degrees are determined from the fact that the rain must have a possibility to get away from the roof without being pushed upwards, due to hard wind. Furthermore the load on the screening system will be too strong if the angle is lower than 5 degrees. From girder to girder there is a system of galvanised steel bars, which are transporting the forces from the roof to the earth. In the gable ends are mounted a steel structure to which the covering material is fixed.

Stability

Stability in the length of the building is obtained by the mounting of wind braces in the roof and in the sidewalls. Stability in the other direction is obtained by the solid connection between the girders and the columns.

Heating system

In the LEC-greenhouse the energy supply comes from a heat storage and the heat storage is loaded from a solar collector. The water temperature in the heat storage does not exceed 50_ C therefore thin tubes with high ratio between volume and surface should be used. In the LEC-greenhouse the heating system is placed near the plants because of the low inlet temperature.

The dissemination efficiency of the heat distribution system is dependent on the temperature difference at every point of the tube and the air movement on the tube surface. The experiment is carried out to simulate greenhouse conditions thus the tubes are exposed to solar radiation.

Solar radiation influences the energy dissemination from the PEL-tube, because the PEL-tube absorbs the radiated energy. If the heating system is placed beneath the plant canopy, the influence of solar radiation on energy dissemination is with out significance and the energy dissemination depends only on inlet temperature, flow rate and ambient air temperature.

Screen material

A LEC-greenhouse differs from glass greenhouses owing to the removable covering material that diminish the requirement of high light transmission. The cover of the LEC-greenhouse is closed during night and when the weather conditions are poor e.g. low irradiances, high wind speed, rain, frost and snow. Under this condition plant growth is limited more by temperature than irradiances.
A LEC-greenhouse consists at least of two layers of covering materials which are able to fold up.
In greenhouse construction are used several different covering materials from simple polyethylene film to aluminised screens and many combinations are possible to obtain a high insulating efficiency.

Owing to the possibility of opening the greenhouse cover, transmission in the photosynthesis wavelength range of 400-700 nm (photosynthesis active radiation) of the covering material is of lesser importance than for an ordinary greenhouse.

The light transmission and scattering of light depends on the thickness of the plastic film. Increasing the thickness from 25 to 225 _m decreases the light transmission by 12% and increase light scattering by 40%.

Low-density polyethylene (LDPE) have a transmission better than 80% in the wavelength range 500-1000 nm, but lower between 400 and 500 nm, at 400 nm only 56%. Thermal polyethylene (TPE) has the same characteristics. Ethylene vinyl acetate (EVA) has a transmission of 90% in the wavelength range of 400-1100 nm. Coloured films based on polyvinylchloride (PVC) are equal in transmission over 700 nm and have a transmission better than 70%. The transmission between 400 and 700 nm depends on the colour of the film but the transmission varies between 20 to 60%. Polyvinyl diflorid film (PVDF) with a thickness of 130 _m has a transmission of 90% in the wave length range of 400-700 nm.
Most information on light transmission of plastic films is based on dry film, but light transmission is also influenced by drop formation on the film. Owing to the optical properties of a hemi-spherical droplet the light is reflected out of the greenhouse. Reduction in light transmission depends on the density of the droplets and can reduce the transmission with up to 50%. To overcome this problem surface active agents are used and instead of droplets is a thin water film formed. Film treated with surface active agents are named anti-fog or anti-condensation, where the last term is misleading because condensation occurs on the film if the surface temperature is lower than the dewpoint.
A water film reduces the light transmission with approximately 10%.

The light transmission depends on the greenhouse construction, but is seldom a consideration in the decision of covering material. Light intensity measured near the roof and at plant canopy gave a decrease by 7% under glass and 33% under double layer of polyethylene.

Properties in the infrared wavelength range

Glass transmits radiation in the visible and near infrared wavelength range of 300-3000 nm and absorbs radiation over 3000 nm. Radiation from plant and soil surface in the infrared wavelength (over 3000 nm) is absorbed in the glass. Polyethylene is transparent to infrared radiation and has a transmittance of approximately 60%. Thermic polyethylene has an infrared transmittance of between 20 and 40% and polyfloride approximately 25% and polyvinyldifloride 2%.

Stability/longevity

The longevity of plastic films is difficult to determine owing influence of many factors. The different quenches (UV, anti-drop e.g.) is leached from the film, but also pesticides reduces the chemical stability.
Mounting of the material is essential, because mechanical abrasion and heating occurs in contact with the greenhouse construction.

Screen material properties for a LEC greenhouse

From a photosynthesis active light transmission point of view the available plastic films for greenhouse covering are suitable as covering material for a LEC-greenhouse.
Plastic films have a heat transmission coefficient of approximate same size as glass, but more sensitive to changes in the physical environment.
To reduce energy loss by infrared radiation the material should be opaque to infrared radiation or have a low transmission. Therefore it is an advantage if a thermic agent is added to the material in combination with an anti-drop agent because a thin water film makes the material opaque to infrared radiation.
The energy performance of the LEC-greenhouse is improved by implementing an energy saving screen that is partly or fully aluminised.

Climatic control

Climatic control in greenhouses is today controlled by digital technology that handles all required functions in modern plant production. At northern latitudes heat is supplied by a boiler or district heating. The capabilities and flexibility of existing climatic computers cover the demand for control in the LEC-greenhouse except handling of charging and discharging of the heat storage. A few changes in actuators and controllers are required to control some of the features in the LEC greenhouse, but the extensions can be adapted to existing interfaces.

Heating and ventilation

Climatic control for heating and ventilation in a LEC greenhouse differs from the methods use in ordinary glass greenhouses. The usual climatic control is based on one set point for heating and one for ventilation and to maintain the desired minimum and maximum PID control is used for heating and ventilation. Outdoors condition is only use to a lesser extent in the climatic control and mainly in the control of the vents in case of rain or high wind speed.

The LEC-greenhouse is designed for production of plants with low temperature requirement and high tolerance to variation in air temperature. The crop produced is able to withstand shorter periods with air temperatures below freezing point, but are sensitive to root zone temperatures below freezing point especially when the air temperature is above 0_ C. However, plant production in the LEC-greenhouse is considered to be flexible and non frost resistant plants may be produced in periods with frost.
The plants produced are potted crops and the soil temperature is measured in the pots. If the air and canopy temperature is above 2_ C and the soil temperature is lower than 0_C the plant is exposed to drought because the leaf transpires but water uptake is limited. If this condition runs for a longer period the plant wilts due to low root activity in combination with no liquid water available.

The LEC-greenhouse is heated with hot water from a heat storage connected to a solar collector. As a supplement in case of exhausting of the heat storage energy is supplied from the boiler or direct hot air heating. The heating system consists of PEL-tubes that restrict the inlet temperature. The heating system acts also as a solar energy collector for the heat storage.
The climatic control system should be able to handle both loading and unloading (heating of the greenhouse) and switching to alternative heat supply. In the following is listed modification for adapting a standard computer to a LEC-greenhouse.

Temperature control

The difference in the control of a LEC-greenhouse and an ordinary greenhouse is that the ventilation set point is based on outdoors air temperature. However, it should be possible to control ventilation by air temperature in the greenhouse. When the air temperature outdoors is higher than the set point, the screens open progressively without any consideration to the air temperature in the LEC-greenhouse. The only thing that influences the action is a timer function to delay opening and closing when the air temperature is close to the set point and the temperature control for ventilation is overruled by rain.

The set point for heating is based on a combination of soil (root zone) and air temperature in the LEC-greenhouse. If the soil temperature is 0_ C or higher heating depends on the air temperature in the greenhouse.
If soil temperature falls below 0_ C heating depends on soil temperature, even if the air temperature is above 0_C.

Temperatures below 0_ C may have hazardous influence on equipment and other installations and can course frost cracks of the PEL-tubes. Methods for preventing frost injury should be considered.

Inner screen - Thermal screen

To reduce heat dissemination of energy from the LEC-greenhouse it is equipped with a thermal screen. The thermal screen is closed during night and is controlled by irradiances.
The thermal screen has a lower ultimate tensile strength as the covering screen and must not be closed when the outer screen is open.

Shading screen

Some plant species requires shading to obtain right quality and shading is optional in the climatic control. Shading is controlled by irradiances and the screens close when the set point is reached and open when irradiances is below the set point. A delay secures that variation in irradiances prevents frequent opening and closing of the shading screens. The shading screen fabric is in general a light material with high permeability and low ultimate tensile strength. High wind speed easily damages the shading screen and overrules control of shading.

Hot water-heating system

The hot water heating system consists of PEL-tubes placed near the plants and the PEL material is the limiting factor for the maximum inlet temperature. The temperature in the heat storage is expected not to be higher than the maximum temperature the PEL-tubes can endure. In the situation where hot water from the boiler is used the inlet temperature must be limited to the maximal allowable temperature. As an alternative, hot water from the boiler heats the water in the heat storage through a heat exchanger.

Rain

Rain is a minor problem but can cause leaching of nutrient from the pot and problems with fungal attack could be initiated when the plants are wet. At rain the screens should be closed and the action overrules temperature control for ventilation.

Wind speed

The LEC-greenhouse is a light construction made of screen materials and high wind speed could damage the covering material and devastate the construction. At a predetermined wind speed the control system should close the screens to reduce the risk of devastation. The action overrules maximum temperature control.

Humidity control

The requirement for humidity control is present after rain or days with high transpiration when the screens close. Depending on the air change rate of the LEC-greenhouse (e.g. wind speed) the humidity might increase.
A possible way of controlling humidity is air circulation by fans, which starts when the RH is over the desired set point.
Opening of the screens overrules the control of the fans.

Charging and discharging the heat storage

Two possibilities for charging the heat storage have been discussed; one where the strategy is to maximise the water temperature and the other to maximise energy state.

In both situations the heat storage is charged as long as the outlet temperature from the solar collector is equal or higher than the highest (top layer) water temperature in the heat storage. To maximise the water temperature the heat storage is only charged when the outlet temperature from the solar collector is higher than a desired set point.
To avoid continuously circulation of water in the solar collector, circulation is stopped at low difference between inlet and outlet temperature of the solar collector.

Discharging of the heat storage is based on the heat requirement of the greenhouse and discharge occurs as long as the outlet temperature is high enough to maintain the desired minimum air temperature in the greenhouse. In situations where the outlet temperature from heat storage is unable to maintain the temperature in the LEC-greenhouse, alternative site specific heat sources are introduced.

5. Results and Conclusions

Energy

Stratification of temperature in heat storage

The heat storage consists of a 3 m^3 insulated steel tank with a diameter of 1.1 m and a height of 3.25 m. To obtain a high efficiency of the heat storage, a good stratification in the heat storage is necessary. The water temperature was measured in three positions, in the top, middle and bottom. As an average there was 7°C between the water temperature in the top and middle of the heat storage. Between the top and the bottom and the middle and the bottom was on average 10 and 3_ C respectively.
At heating of the LEC greenhouse the difference between the water temperature in the top and the middle of the heat storage decreases, while the difference between the middle and the bottom increases.
The supply of external heat at exhaustion of the heat storage courses the water temperature in the top of the heat storage increases to a high level and the temperature difference between top and middle could reach difference higher than 30_ C. The maximum water temperature in the heat storage reached over 60_ C when external energy was supplied.

Consumption

Over long periods the heating system was not activated owing to an outdoor air temperature over the heating set point. When the heating system was running the average running time was 5.5 hours and the maximum running time was 11 hours.
The energy consumption per hour was on average 4 MJ and the average per day was 21 MJ, but with very large variation in energy consumption over the experimental period.

Accumulation

The energy accumulated by the solar collector was on average 2.3 MJ per hour and the average per day was 49 MJ, but with very large variation in energy accumulation over the experimental period.
Over long periods the solar collector was not in function either due to low solar radiation and air temperature or high temperature in the top of the heat storage. In the experimental period the solar collector was only running 13 times and the average running time was 4.6 hours with a maximum running time of 7 hours.
The control of the solar collector was based on the difference between the outlet temperature from the solar collector and the water temperature in the top of the heat storage. To maximise the energy accumulation the outlet temperature from the solar collector should be equal or higher than the water temperature in the top of the heat storage. External energy supply by hot water from the boiler increased the water temperature in the top of the heat storage much more than the solar collector was able to due. The maximum outlet temperature measured from the solar collector when the heat storage was charge was 32_ C. The average outlet temperature from the solar collector, when it was running was 23.7_ C. In nights where external energy was supply, the solar collector was not running the next day or days owing to the high temperature in the top of the heat storage.

On days with low irradiances and low outdoor air temperature the outer screen is closed which and the water temperature in the solar collector increases very slowly. The outer screen reduced the irradiance that reaches the solar collector and convection also influences the temperature of the solar collector.

Climate

Air temperature

The average air temperature is slightly higher than the outdoor air temperature, which is due to the heating of the LEC greenhouse. Air temperature lower than the heating set point is observed and can be explain by a slow reacting heating system or an exhausted heat storage. When the heat storage is exhausted, the external heat supply starts. The heating coil is placed in the top of the heat storage, which increases the time response to comply with the heat demand.
The average air temperature near the solar collector in the top of the LEC greenhouse is higher than the air temperature near the plant canopy. This is owing to a closed outer screen and the buoyancy effect where the warmer air raises to the top of the LEC greenhouse. The air temperature near the solar collector becomes the same as the outdoor air temperature when the outer screen opens.

Pot and soil temperature

The temperature in the pot and the soil in the LEC greenhouse are nearly identical and as average higher than the air temperature. The PEL heating tubes is placed in the soil and the floor in the LEC greenhouse acts as the heating surface. Owing to higher heat capacity, the change in soil and pot temperature is slower and heat conduction from the soil keeps the temperature in the pot when the LEC greenhouse is heated.

Humidity

High relative humidity promote attack of fungal diseases e.g. grey mould (*Botrytis cinerea*) and the optimal conditions for sporulation is a relative humidity over 90% and a temperature between 16-24_ C over a period of approximately 8 hours. In the LEC greenhouse the relative humidity has been higher or equal to 90% relative humidity for 4 to 8 hours 18 times and 4 times for more than 8 hours. The longest continuous period recorded with relative humidity of 90% relative humidity was 26.8 hours. The relative humidity of 100% (saturation) is lesser frequent and due to decrease in air temperature. The longest continuous period recorded with relative humidity of 100% relative humidity was 28.3 hours. Relative humidity of 100% for 4 to 8 hours occurred 22 times and a period longer than 8 hours occurred 5 times. No fungal diseases were observed in the experiment, this could be do to no combination of high relative humidity and optimal temperature for sporulation.

Light transmission

The light transmission expressed as photosynthesis active radiation (PAR, 400-700 nm) is for a glass greenhouse between 40-60% depending of construction, covering material and age. In the LEC greenhouse the light transmission is reduced by the outer screen and when closed the light transmission is 60-65%. With the outer screen open the light transmission is 85-90% depending on cloud cover and light scattering.

CO_2

The CO_2 concentration is approximately 5% lower when the outer screen is closed. The small difference in CO_2 concentration with and without the outer screen closed could be explained by low irradiance and low air temperature when the outer screen is closed. In this situation the photosynthesis is low and the CO_2 uptake low and the natural air change rate keeps up the CO_2 concentration.

Plant production

Plant species

The plant species used in the experiment were *Argyranthemum frutescens*, *Campanula potenschlagiana*, *Petunia hybrid*, *Osteospermum ecklonis* and *Pinus pinea*. All the plant species except Petunia hybrid were half grown at the start of the experiment. *Petunia hybrid* was produced by seed and potted just before the start of the experiment. *Argyranthemum frutescens*, *Pinus pinea* and *Osteospermum ecklonis* were grown with a plant density of 40 plants per m^2; *Campanula portenschlagiana* at 30 plants per m^2 and *Petunia hybrid* at 70 plants per m^2.
In the LEC Greenhouse was established 7 blocks and each block contained one parcel of each of the plants species to reveal climatic variation. The parcels were randomly distributed within the block. In the reference greenhouse was used 3 blocks of parcels and the plant parcels were randomly distributed within the block. The experiment was started on April 9 2001.
For all plant species were fresh and dry weight recorded at the beginning and at termination of the experiment. The quality of the plants was judged according to marked standards when they reached the marketable stage. Data were recorded on 4 plants per parcel in the LEC greenhouse and 5 plants per parcel in the reference greenhouse.

In the LEC Greenhouse the plant was grown on capillary mats with irrigation based on ground level trickle hoses, while the plants in the reference greenhouse was grown on flood-drainage benches.

The plant species produced in the LEC greenhouse were grown under lower average air temperature than the plant in the reference greenhouse. The differences in average air temperature between the plants species is owing to the production time and subsequently the weather condition.

The plants were produced with an energy consumption of approximately 20% compared to the amount of energy used when produced in the Reference greenhouse.

Energy consumption in MJ for the whole production period of each plant species in the LEC and Reference greenhouse. Energy consumption is expressed for the whole greenhouse (160 m^2).

Energy consumption (MJ)

Plant species	*LEC Greenhouse*	*Reference greenhouse*
Argyranthemum frutescens	*2683*	*15318*
Campanula portenschlagiana	*2629*	*13874*
Osteospermum ecklonis	*1836*	*8503*
Petunia hybrid	*2312*	*12906*

For all plant species the production time was increased, and in most cases double as long as production time in the reference greenhouse.

The slow growth rate of the plants result in a higher dry matter content. The fluctuation in air temperature and the lower average temperature decreases stem elongation, which reduces the need for application of chemical growth retardant.

The quality of the plants produced in the LEC greenhouse is high and is obtained without the use of chemical growth retardant.

Individual plant parameters and production time.

Plant species	*Parameter*	*LEC*-Greenhouse	*Reference house*
Argyranthemum frutescens	*Height (cm)*	*30.2*	*30.1*
	No. of flowers	*41.2*	*85.9*
	Fresh weight (g)	*42.8*	*75.8*
	Dry weight (g)	*9.8*	*10.1*
	Dry matter (%)	*23.2*	*13.2*
	Production time (days)	*64*	*33*
Campanula portenschlagiana	*Height (cm)*	*11.1*	*10.6*
	Diameter (cm)	*22.2*	*24.5*
	Fresh weight (g)	*40.7*	*40.5*
	Dry weight (g)	*8.0*	*6.4*
	Dry matter (%)	*19.6*	*16.0*
	Production time (days)	*61*	*29*
Osteospermum ecklonis	*Height (cm)*	*16.3*	*20.6*
	Diameter (cm)	*17.4*	*19.2*
	No. flowers	*37.0*	*27.0*
	Fresh weight (g)	*71.4*	*72.5*
	Dry weight (g)	*9.6*	*6.5*
	Dry matter (%)	*13.5*	*9.0*
	Production time (days)	*40*	*19*
Petunia hybrid	*Height (cm)*	*11.7*	*30.1*
	No. of flowers	*16.4*	*9.1*
	Diameter (cm)	*15.7*	*29.9*
	Fresh weight (g)	*37.2*	*57.6*
	Dry weight (g)	*3.7*	*3.2*
	Dry matter (%)	*10.2*	*5.6*
	Production time (days)	*53*	*27*
Pinus pinea	*Height (cm)*	*11.8*	*22.0*
	No. branches	*9.3*	*16.0*
	Fresh weight (g)	*5.8*	*15.0*
	Dry weight (g)	*1.8*	*3.7*
	Dry matter (%)	*31.6*	*24.6*

The heating system in the LEC greenhouse reacts slowly and natural changes in air temperature occur rapidly. The slow reaction is more due to a low inlet temperature to the heating surface than to the incline in opening of the mixing valve. From a plant production point of view, the demand for keeping a constant air temperature is of lesser importance. It is more important that the pot temperature not becomes lower than 0_ C because it would damage the root system. The heat conduction between the soil and the pot is high owing to the heating pipes in the soil, which minimise the risk for low temperatures in the pot.

Using the heat storage as a heat exchanger for external energy supply reduces the possibility to accumulate energy from the solar collector. To improve the accumulation of solar energy a heat exchanger should be placed in the outlet from the heat storage instead of a heating coil in the top of the heat storage.

The solar collector is not able to provide high water temperature, which limits the number hours that accumulation occurs. To improve the performance of the system a control system based on the energy state of the heat storage should be developed instead on a system based on temperature differences.

It is more difficult to improve the efficiency of the solar collector, because it is not possible to add an absorber. The reduction in light transmission and formation of deep shadow from the absorber influences the plant growth.

The light transmission of the LEC greenhouse with the outer screen closed is at the same level as a modern glass greenhouse. In regard to energy the heating system is able to provide sufficient heat to keep the LEC greenhouse free of frost. The solar collector has a low efficiency, but energy accumulation could be improved by change in the design of heat storage and control system. It is not possible to improve the performance of the solar collector it self as long as it is an integrated part of the greenhouse construction.

The plant species produced in the LEC greenhouse were grown under lower average air temperature than the plant in the reference greenhouse (table 2). The differences in average air temperature between the plants species is owing to the production time and subsequently the weather condition.

The slow growth rate of the plants result in a higher dry matter content. The fluctuation in air temperature and the lower average temperature decreases stem elongation, which reduces the need for application of chemical growth retardant.
The quality of the plants produced in the LEC greenhouse is high and is obtained without the use of chemical growth retardant.
Production of plants in a LEC greenhouse results in plants with higher dry matter content. The plants produced were more compact and with a quality as good as plants produced in glass greenhouse with high technical standard. The plants in the LEC greenhouse were produced with out chemical growth retardant and with a much lower energy consumption than plants produced by traditional production methods.

6. Plans for exploitation

Our plans for exploitation of the results are undergoing a great deal of consideration. On one hand all the components in the project are well known, (but not tested in this very connection), only the way the things are connected to each other, is different from the way things are done today. The whole construction is giving us a feeling of being inventing new ways of construction and erection of a greenhouse construction. The most spectacular thing about the whole LEC project is the recirculating of hot water, collected from the upper part of the greenhouse, and the returned to the plants whenever needed, in the lower part of the greenhouse, where the plants are situated. In conjunction to that, the climatic control and regulation system must also be seen as something new, where known technology is given a new and different approach. The simplicity of the climatic computer is going new ways, where simplicity is first priority instead of complexity.

The partners have decided to do their own marketing of the LEC-Green-house, based on the results of the project and common experiences.

7. Photographs

The LEC-Greenhouse with screens closed