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# Energy Consumption, Light Distribution and Plant Growth in Greenhouse partly insulated with non-transparent Material

## Energieverbrauch, Lichtverteilung und Pflanzenwachstum im teilweise mit lichtundurchlässigen Material isolierten Gewächshaus

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## Summary

Energy consumption for heating a separate greenhouse insulated with opaque insulating material with high reflection was reduced by 28% compared to an uninsulated single glass greenhouse. To improve light distribution across the insulated greenhouse and to obtain the same light sum in both greenhouses an algorithm for controlling the artificial light was used. The electricity consumption of the artificial light was increased by 38% in the insulated greenhouse leading to an overall reduction by 25% in energy consumption because production time was equal in both greenhouses.

*Dendranthema grandiflora* was grown at two densities of 36 and 45 plants $m^{-2}$ under short day condition. In the insulated greenhouse the plant growth was influenced by plant density and high density increase the plant height. In the uninsulated greenhouse there was a spatial variation in plant height depending of plant density and position in the greenhouse. The spatial variation in growth of *Dendranthema grandiflora* was lesser in the insulated greenhouse owing to the equalization of light conditions and higher canopy temperature in the insulated part of the greenhouse.

## Zusammenfassung

Der Verbrauch an Heizenergie in einem einzeln stehenden Gewächshaus, das mit einem lichtundurchlässigen Material mit hoher Reflexion isoliert war, war um 28% niedriger als im nicht isolierten Haus (= Kontrolle). Um die Lichtverteilung im isolierten Haus zu verbessern und die gleiche Lichtsumme in beiden Häusern zu erhalten, wurde ein Algorithmus zur Kontrolle der künstlichen Beleuchtung verwendet. Der Stromverbauch stieg um 38% im isolierten Gewächshaus an, aber insgesamt war der Energieverbrauch um 25% reduziert, weil die Produktionszeiten in beiden Häusern gleich war.
*Dendranthema grandiflora* 'Surf' wuchs in zwei Dichten von 36 und 45 Pflanzen/$m^2$ unter Kurztagbedingungen. Im isolierten Gewächshaus war das Pflanzenwachstum durch die Pflanzendichte beeinflusst, wobei hohe Dichten die Pflanzenhöhe steigerte. Im unisolierten Gewächshaus war die Pflanzenhöhe abhängig von der Pflanzendichte und dem Standort im Gewächshaus. Der Standort im isolierten Gewächshaus beeinflusste das Pflanzenwachstum weniger, weil hier die Lichtverteilung gleichmäßiger und die Temperatur höher war.

## Introduction

A glass greenhouse has a high heat transfer coefficient because of the covering material, which also makes greenhouse very sensitive to radiation. To reduce heat loss during night the shading screens are used as energy saving screen. This way of reducing energy consumption is the only one that is well established in the greenhouse industry.

Owing to the international societies demand for reduction in energy consumption and $CO_2$ emission it is a necessity for the greenhouse industry to cut down the use of energy to be environmentally compatible.

In the winter at northern latitudes sun elevation is prevailing and the direct solar radiation passes through the north facing roof and wall. Reflection from constructions parts and internal surfaces seems to be underestimated in light distribution in the greenhouse (KURATA, 1990). It has been suggest that it is possible to enhance plant growth by the use of panels which redistribute irradiance in a greenhouse (AIKMAN, 1989) or improve light conditions by the use of venetian blinds or by reflective materials (CRITTEN, 1985; LI et al., 1998).

In a preliminary experiment (JACOBSEN et. al., 1996) it was found that direct solar radiation gave a higher irradiance in the northern part of the greenhouse, when it was covered with reflective material. When the natural light is diffuse the intensity is lower in the northern part of the greenhouse, owing to no light transmission through the northern wall and roof. Diffuse light is predominant in the winter and excluding the incoming diffuse light from the north facing side of the greenhouse results in lower growth rate and skewed plants in the northern half of the greenhouse (JACOBSEN et al., 1996). On the other hand permanent insulation reduces the energy consumption by approximately 20–30% and demonstrates the potential of energy saving in greenhouses.

The aim of this experiment was to investigate the influence of using non-transparent insulating material in greenhouses and level out the difference in light conditions between insulated and uninsulated greenhouses with respect to total energy consumption and plant growth.

## Materials and methods

A separated east/west orientated single glass greenhouse was insulated with 30 mm of glass wool wrapped in air

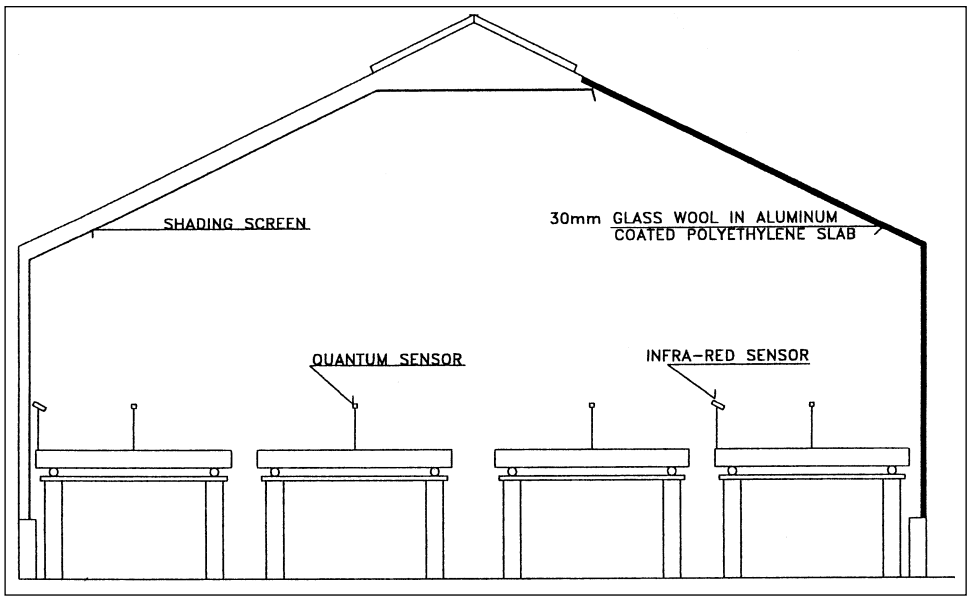



Fig. 1. Cross section of the insulated greenhouse with indication of measuring point for light and canopy temperature.
*Querschnitt durch ein isoliertes Gewächshaus mit Angabe der Messpunkte für Licht und Temperatur*

prof polyethylene film coated with aluminum. The greenhouse has a ground area of 8 × 20 m with a wall height of 2.8 m and a roof sloop of 25.8° which gives a total glass surface of 285 m². Insulating the northern wall and the entire roof from the eave to the lower edge of the roof ventilation reduces the glass area with approximately 35%. A separated single glass greenhouse of same construction and with same heating and artificial lighting system was used as reference.

The set point for heating was 19 °C and the ventilation set point was 28 °C. The $CO_2$ concentration was kept on a minimum of 600 ppm in the photoperiod. During night the shading screens were used as energy saving screens.

In a previosly experiment it was found that there was lesser light in the northern part of an insulated than in an uninsulated greenhouse at outdoors irradiance lower that 150 $Wm^{-2}$ total short wave radiation and more light over 150 $Wm^{-2}$ (JACOBSEN et al., 1996).

From the recorded data on light distribution it was possible to define an algorithm based on the relation between outside and inside irradiance in the insulated and the uninsulated greenhouse. The algorithm was implemented on a DGT/Volmatic climatic computer which allows user-written subprogram calls. The control algorithm was based on light sum and the difference in daily light sum was levelled out by calculating the deficit in light sum between the insulated and the uninsulated greenhouse. With respect to the plant species (short day plant) photoperiod in which the equalization could take place was limited to 11 hours. The set point for switching on and off with regard to outdoors condition was 60 µmol $m^{-2}s^{-1}$ for the reference greenhouse.

The period for integrating the daily light sum was from noon to noon. At noon the light sum was calculated and in the case of excess the number of hours the lighting system should run in the insulated greenhouse was calculated. The starting time for the insulated greenhouse was calculated backward from the expected light depended starting time for the artificial lighting system in the reference greenhouse. To simplify the determination the starting time from yesterday was used, because it was expected that the weather conditions were identical for the present and previous day.

The artificial lighting system was operated as a whole in both greenhouses and consisted of 2 rows with 6 luminaries of 400 W in each row providing 60 µmol $m^{-2}s^{-1}$ at plant height from high pressure sodium lamps.

The light distribution across the greenhouse was measured in four positions (designated as 1, 2, 3 and 4, where 1 is the most southern position) and the quantum sensors were placed in the middle of the greenhouses (Fig. 1).

*Dendranthema grandiflora* 'Surf' Tzvelev. (Chrysanthemum) was used in the experiment and was grown at two densities of 36 and 45 plants $m^{-2}$. The plants were pinched to three nodes before start of the experiment. No chemical growth retardant was used in the experiment. Seven times during the experiment leaf area and fresh and dry weight was determined by destructive measurements on 8 plants per plot.

In each greenhouse two replications per plant density was used for each of the four benches given a total of 32 plots.

Canopy temperature was measured by infrared sensors on *Ficus pumila* in the northern and southern part of both greenhouses.

The floor and wall/top heating system was cascade coupled and energy consumption was measured separately for each system.

The running time for the artificial lighting system was recorded and included in the calculation of the whole energy consumption under the assumption that all electric energy is converted to heat.

## Results

In the insulated greenhouse the total energy consumption was reduced by 25% compared to the uninsulated greenhouse, however the electricity consumption increased by 38% owing to the control strategy. The biggest reduction in energy consumption was obtained

Tab. 1. Energy, light and temperature data for insulated and uninsulated greenhouse in the period of December 7 1996 to March 10 1997
*Energieverbrauch, Licht und Temperatur im isolierten und nichtisolierten Gewächshaus zwischen 7. Dezember 1996 und 10. März 1997*

| | Insulated | Uninsulated |
|---|---|---|
| Energy consumption (MJ) | | |
| Floor heating | 95725 | 99447 |
| Wall/top | 63058 | 122524 |
| Electricity (artificial light) | 16654 | 12108 |
| Light sum (mol $m^{-2}$) | | |
| Position 1 | 493.3 | 472.3 |
| 2 | 511.3 | 472.5 |
| 3 | 380.1 | 411.6 |
| 4 | 475.6 | 477.9 |
| Running time for artificial lighting system (hours) | 657 | 479 |
| Average temperature (°C) | | |
| Air | 19.8 | 19.4 |
| Canopy (south) | 17.8 | 17.8 |
| Canopy (north) | 18.1 | 16.8 |

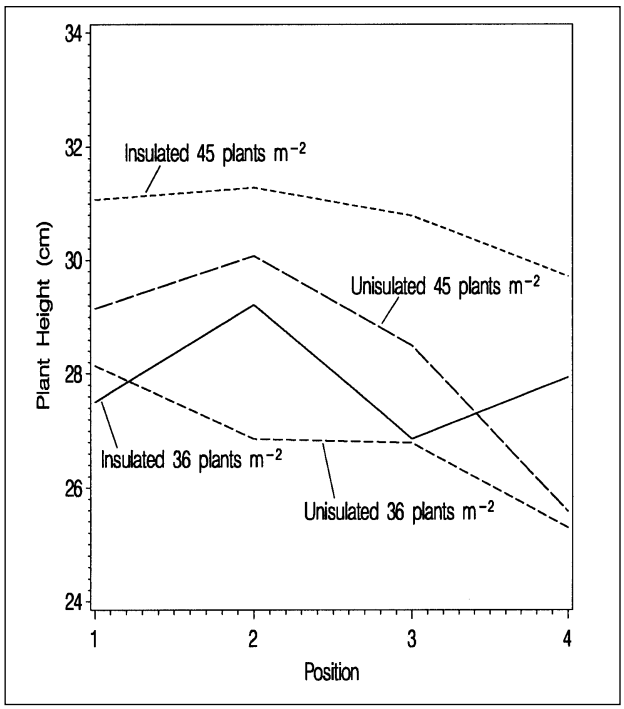



Fig. 2. The influence of insulating the northern wall and roof on spatial plant height of Dendranthema grandiflora 'Surf'. Position 1 is south
*Einfluss der Isolierung von Nordwand und Dach auf die Pflanzenhöhe von Dendranthema grandiflora 'Surf'. Position 1 ist Süden*

for the wall/top heating system by 49% (Table 1). The energy consumption of the floor heating system is equal in the two greenhouses, but the energy consumption of the wall/top heating system was 94% higher in the uninsulated greenhouse.

The light level across the greenhouse was very similar in the four positions in the uninsulated greenhouse resulting in nearly the same light sum. In the insulated greenhouse the light sum has larger variation, however the light sum in the most southern and northern position was similar in both greenhouses (Table 1).

The light sum in position 1 and 2 was higher in the insulated greenhouse and position 3 is remarkable lower, but a similar tendency found was for the same position in the uninsulated greenhouse. The control strategy for adjusting the daily light sum resulted in a compensation by 75 to 100% in 84% of the experimental period in the insulated greenhouse in position 1 and for 16% of the experimental period an overcompensation occurred. In position 3 a compensation lesser than 50% was obtained in 16% of the experimental period. In 78% of the experimental period a compensation between 50 to 100% was obtained and in 6% of the experimental period a compensation with more than 100% was obtained.

The canopy temperature was higher in the northern part of the insulated greenhouse than in the uninsulated, however the canopy temperature was equal in the southern part (Table 1). The plant height as average for the whole greenhouse was slightly higher in the insulated greenhouse, but the plant height was more influenced by the plant density (Table 2). The plant height across the greenhouse was affected by the insulation and plant density, even though that the number of nodes were equal (Fig. 2). The plant height decreased from south to north in both greenhouses, but in the uninsulated greenhouse there was no difference between plants grown at 36 and 45 plants $m^{-2}$ in the northern part.

No differencies were found between number of flower buds and production time for the two greenhouses.

The increase in dry weights depends on the position in the greenhouse and are most pronounced for plants grown at 36 plants $m^{-2}$.

The highest increase in dry weight was obtained in the southern side and the lowest in the northern side independent on insulation (Fig. 3).

Plants grown at 45 plants $m^{-2}$ in the northern side of the uninsulated greenhouse ended up with the lowest dry weight. In the insulated greenhouse the increase in dry weight was identical in both the northern and southern side. The dry weight became the same for plants grown in the southern side of the greenhouse and was independent of insulation (Fig. 4).

Plants grown at 36 plants $m^{-2}$ in the northern side of both greenhouses ended up with same dry weight as plants grown at 45 plants $m^{-2}$ grown in the southern side of the greenhouse.

## Discussion

The heat loss from the greenhouse is restricted by the permanent insulation and the demand for heating is lower but electrically energy consumption increases. Electricity is a high value energy source which requires other energy sources to be produced. Changing energy consumption from low to high value energy locally does not reflect the global consequences on the environment. Electricity produced on a coal-burning power plant not connected to district heating has only an efficiency of 30%, where as electricity produced in a combined heat and power system has an efficiency up to 80%.

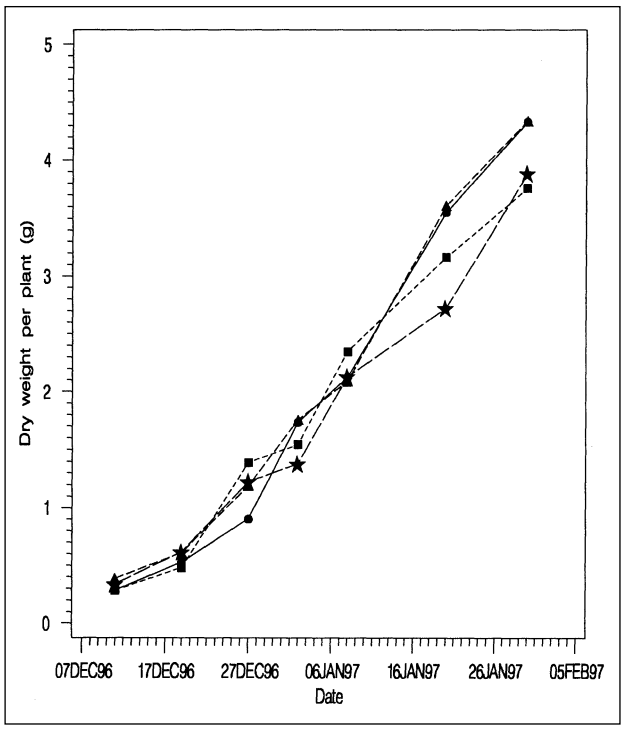



Fig. 3. Increment in dry weight of *Dendranthema grandiflora* 'Surf' at a plant density of 36 plants per m². Uninsulated: south (▲), north (✷); insulated: south (●), north (■)
*Zunahme der Trockensubstanz von Dendranthema grandiflora 'Surf' bei einer Pflanzendichte von 36 Pflanzen/m². Nichtisoliert: Süd (▲), Nord (✷), isoliert: Süd (●), Nord (■)*

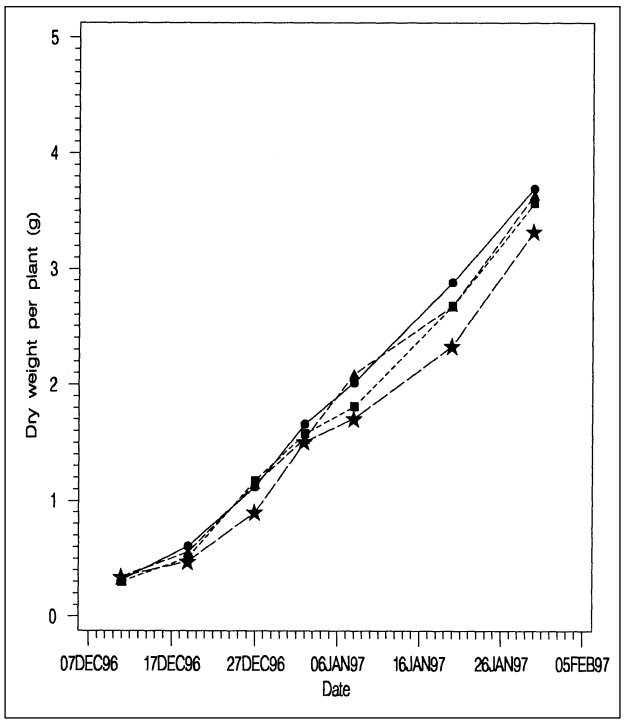



Fig. 4. Increment in dry weight of *Dendranthema grandiflora* 'Surf' at a plant density of 45 plants per m². Uninsulated: south (▲), north (✷); insulated: south (●), north (■)
*Zunahme der Trockensubstanz von Dendranthema grandiflora 'Surf' bei einer Pflanzendichte von 45/m². Nichtisoliert: Süd (▲), Nord (✷), isoliert: Süd (●), Nord (■)*

The permanent insulation influences the light distribution in the greenhouse, however artificial lighting is able to compensate for the deficit even though that the plant species is a short day plant which limits the number of hours where it is possible to compensate.

With the artificial lighting system operated as a whole an overcompensation occurs in the southern part of the greenhouse owing to no reflection from the insulated roof and wall. In the northern part of the insulated greenhouse reflection of both natural and artificial light in addition to increased running time of the artificial lighting system results in nearly equal light sum as in the uninsulated greenhouse. The only part in the greenhouse which receives significantly lesser light is the area just north of the middle of the greenhouse.

Tab. 2. Growth of Dendranthema grandiflora 'Surf' in insulated and uninsulated greenhouses. Average of positions, S.D. in brackets
*Wachstum von Dendranthema grandiflora 'Surf' im isolierten und nichtisolierten Gewächshaus. Mittelwerte von Pflanzenhöhe, Blütenzahl und Produktionszeit. (Standardabweichung in Klammern)*

| | Plants $m^{-2}$ | Insulated | Uninsulated |
|---|---|---|---|
| Plant height | 36 | 27.9 (1.2) | 26.8 (1.6) |
| (cm) | 45 | 30.7 (1.8) | 28.3 (2.1) |
| No. of flower | 36 | 15.1 (2.2) | 15.5 (1.7) |
| buds | 45 | 13.8 (2.5) | 14.8 (2.2) |
| Production | 36 | 61 (1.1) | 61 (1.2) |
| time (days) | 45 | 62 (1.6) | 63 (1.6) |

A similar reduction but lesser pronounced is also found in the uninsulated greenhouse, but is amplified by the permanent insulation. This might be due to the angle of the roof which only reflects direct light at low solar position and that there is no reflection of artificial light from the insulated wall and roof at this area of the green-house.

The overall plant production in the greenhouses is only slightly influenced by the insulation of the greenhouse, however the spatial plant height is influence more by air temperature and plant density than irradiance.

At similar light sum the plants are smaller in the uninsulated greenhouse. This might be due to air flow near the wall where cold air is passing down and reduce canopy temperature by convection or lower heat loss by radiation.

The northern facing part of a greenhouse intercepts lesser irradiance than the southern and in situations were the heating system is not in use spatial temperature differences occurs.

In the north part of the insulated greenhouse the heat loss is lower and long wave radiation reflected by the insulation causes lesser convective cooling of the plant canopy resulting in a higher canopy temperature.

The low dry weight for plants grown at a density of 45 plants $m^{-2}$ in the north side of the uninsulated greenhouse must be a result of an interaction between light and temperature. More internal shade owing to high plant density and a lower temperature reduces the photosynthetic activity.

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## Literature

AIKMAN, D. P., 1989: Potential increase in photosynthetic efficiency from the redistribution of solar radiation in a crop. Journal of Experimental Botany 40: 855–864

CRITTEN, D. L., 1985: The use of reflectors in venetian blinds to enhance irradiance in greenhouses. Solar Energy 34: 83–92

JACOBSEN, P., O. F. NIELSEN and H. E. K. JENSEN 1996: Energibesparende dækkematerialer til væksthus. Technical report nr 01/1996, pp. 28.

KURATA, K. 1990: Role of reflection in light transmissivity of greenhouses. Agri. For. Meteo. 52: 319–331.

LI, S., K. KURATAand T. TAKAKURA 1998: Solar radiation enhancement in a lean-to greenhouse by use of reflection. J. agric. Engng Res. 71: 157–165.

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