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The response of pot plants to reduction of energy consumption peaks in greenhouses

Potteplanters reaktion på udjævning af energiforbrugs spidser i væksthuse

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Summary

This experiment was started to avoid difficulties in energy supply, when big areas of greenhouses were connected to district heating. The aim of the experiment was to find ways to reduce energy consumption peaks at dawn and at dusk by means of simple techniques. This paper reports on the results of an experiment where five different pot plants were grown by a temperature control strategy based upon low day and high night room temperature set points (14°/22°C) combined with reduced opening speed of the mixing valves.

In general it may be concluded that it is possible to produce *Chrysanthemum, Begonia, Kalanchoë, Hedera* and *Ficus* with a temperature control strategy which reduces energy consumption peaks at dawn and at dusk without affecting the plant quality. However, it is necessary to apply growth retardants to *Chrysanthemum* and *Kalanchoë* to secure a good quality.

The production time is reduced for *Kalanchoë,* increased for *Chrysanthemum* and *Hedera* and unchanged for *Begonia* and *Ficus.*

Key words: Greenhouse, night temperature, pot plants, district heating.

Resumé

Denne forsøgsserie blev begyndt for at undgå nogle af de vanskeligheder, der opstår med varmeforsyningen, når store arealer med væksthuse tilsluttes fjernvarme. Det er især kraftige stigninger i energiforbruget om morgenen og om aftenen, der volder problemer. Et klimaprogram baseret på rumtemperatur setpunkter på 14°C dag og 22°C nat, kombineret med et »arbejdstidpause« relæ, der ændrer motorventilernes åbningstid fra 4 til 140 minutter, er tilstrækkeligt til at undgå energispidserne om morgenen og om aftenen.

Resultaterne af de biologiske undersøgelser viser, at det er muligt at producere *Chrysanthemum, Begonia, Kalanchoë, Hedera* og *Ficus* i dette klimaprogram, uden at kvaliteten forringes. Dog er det nødvendigt at behandle *Chrysanthemum* og *Kalanchoë* med vækstretarderende midler for at opnå en god kvalitet. For *Chrysanthemum* og *Hedera* må man være indstillet på nogen forlængelse af produktionstiden. Produktionstiden for *Kalanchoë* blev derimod reduceret ved lav dagtemperatur/høj nattemperatur. Forsøgsbetingelserne havde ingen signifikant effekt på kulturtiden af *Ficus* og *Begonia.*

Nøgleord: Væksthus, nattemperatur, potteplanter, fjernvarme.

Introduction

On initiative of the Danish Ministry of Energy a working group was formed to look into some of the problems which arise when heat for large numbers of greenhouse nurseries is supplied by district heating. The main difficulty lies in a simultaneous and very steep rise in energy consumption at dawn and at dusk (1), which cannot be supplied by the power plants. The best way to avoid the energy consumption peaks is an environmental control strategy which reduces the energy demand at the critical hours.

The experiment was divided into a biological and a technical section. The results from the technical experiments showed that heat consumption peaks at dawn and at dusk can be avoided by low day and high night room temperature setpoints (14°/22°C) in combination with a reduction in the opening speed of the mixing valves.

A change in the heat supply has an effect upon the environment and consequently upon plant growth. It is therefore important that the suggested technical solution is followed by experiments with plants.

Many authors have reported upon beneficial results on plant production, obtained by high night temperatures and low day temperatures (3, 4, 6, 7).

For many pot plants a reduction in production time and better qualities were found. The quality improvement was mainly due to shorter internodes which may reduce the demand of growth retardants.

This paper reports on the biological results. The results of the technical experiments are presented separately (2).

Methods

Research facilities

The experiment was carried out in two identical east-west orientated greenhouses (8×21.5 m^2), clad with single glass.

Screens

The greenhouses are equipped with top going shading screens (Ludvig Svensson, No. 15) which reduced irradiation by 55 per cent. The screens are also applied during the night as thermal screens.

Benches and irrigation

Four movable benches 18×1.6 m of the same type were installed in each greenhouse. The benches were lined with perforated polythene film and on the top of this a capillary mat (Vattex) was placed. The mat was covered with a perforated polythene film. Below the mat five capillary tubes per m^2 were evenly distributed to supply the benches with a diluted nutrient solution of 0.88 per thousand.

The water supply was activated by an evaporimeter which released 0.8 mm whenever 1 mm was evaporated. In addition to that irrigation took place whenever needed.

Carbon dioxide

The plants were supplied with pure carbon dioxide. The concentration was controlled at 800 cm^3/m^3 and started one hour before sunrise and stopped one hour before sunset. The supply was stopped whenever the vents were open.

Experiment

Environmental control was based on analog equipment (DGT Lumix Combi LC 21):

Room temperature minimum setpoints day/night:

1. Experiment treatment: 14°/22°C.
   Reduced opening speed (140 minutes from closed to open) of mixing valves.
2. Reference treatment: 18°/18°C.
   Normal opening speed (4 minutes from closed to open) of mixing valves.

Change in room temperature setpoints was controlled by natural day length.

Ventilation at 28°C room temperature.

Relative air humidity control at 92 per cent RH.

Shading screens applied at an irradiation higher than 300 W/m^2.

Shading screens applied at night at irradiation lower than 5 W/m^2.

Plant species

The experiment was performed with five species of important pot plants: *Chrysanthemum* (*Dendranthema grandiflora* 'Garland'), *Begonia* (*Begonia elatior*-hybrid 'Schwabenland'), *Kalanchoë* (*Kalanchoë blossfeldiana* 'Pollux'), *Hedera* (*Hedera helix* 'Susanne') and *Ficus* (*Ficus benjamina* 'Cleo'). The three flowering species were treated with or without growth retardant.

The plants were propagated in commercial nurseries and used in the experiment as rooted cuttings.

The winter experiment was started in week No. 45 1987 and included *Chrysanthemum* and *Kalanchoë*. The experiment was repeated once in 1988. In the spring experiment the different plant species did not start at identical dates: *Begonia* and *Chrysanthemum* in week No. 4, *Hedera, Ficus* and *Kalanchoë* in week No. 6. The experiments were terminated in week No. 18.

Plant density

The final plant density for *Hedera* was 59 plants per m^2, *Chrysanthemum* and *Kalanchoë* 45 plants per m^2, *Ficus* 36 plants per m^2 and *Begonia* 20 plants per m^2. In the beginning of the experiment the plant density for *Begonia* was 50 plants per m^2 and for *Hedera* 89 plants per m^2.

Growth regulation

During the experiment *Kalanchoë* and *Chrysanthemum* were sprayed twice with daminozide 2.55 g/l a.i. (Alar 85). *Begonia* was sprayed once with chlormequat-chloride 0.69 g/l a.i. (Cycocel extra).

To observe the effect of 14°/22°C on plant height the flowering species were replicated without growth retardants.

Production time

The production time is expressed by the 95 per cent quantile found by a Weibull distribution function of the date where each plant reached the criterion for sale. The criterion for sale is defined for each plant species as follows. *Chrysanthemum:* Second ring of disc-florets open. *Begonia* and *Kalanchoë:* Two open flowers. *Hedera:* Three vines longer than 20 cm. *Ficus:* Plant height 45 cm.

Recordings

Whenever a plant had reached the criterion for sale, different observations were made. Plant height from the pot rim and quality were recorded for all plant species.

Quality at time of sale was an assesment due to a visual impression of the whole plant. Furthermore, following specific recordings were made.

Chrysanthemum – number of flowers and buds showing colour. The number of nodes on the longest stem was used for computing the internode length.

Begonia – height of inflorescences and leaf damages.

Kalanchoë – height of inflorescences.

Hedera – number of leaves on the second longest vine was used for computing the internode length.

Ficus – number of laterals and leaf damages.

Energy consumption per plant

Energy consumption is related to each plant species and is a result of temperature control and production time. It expresses the amount of energy which is used in a particular treatment during a particular period.

Statistics

Only the two benches in the middle of the greenhouse were used for experimental purposes. Each bench was divided into two equal sections which acted as replicates. Thus, there were four replicates per greenhouse. Each section contained eight plots, which were randomized. The pattern of the plots was identical in the two greenhouses. Each plot contained 50 plants and ten plants in each plot were used for recording.

From a statistical point of view, the experiment suffers from certain restrictions. Because only one greenhouse per treatment was available, the effect of greenhouse and locality cannot be separated.

Results

Production time

The effect on production time depends on the plant species. 14°/22°C increases the production time of *Hedera* and *Chrysanthemum* (Table 1).

The production time of *Kalanchoë* is reduced by 16 days in the winter experiment and 4 days in the spring experiment.

There is no significant difference in production time for *Begonia* and *Ficus*.

Room temperature

As can be seen in Table 1, the mean room temperature in the winter experiment is from 1.3°C to 1.7°C higher at 14°/22°C. This is due to natural irradiation which raises the room temperature above 14°C. Only small differences in mean room temperature between the two treatments were observed in the spring experiment.

Table 1. Production time, plant height, quality (1–5, 5 best), energy consumption and mean room temperature.

Plant species		Treatment	Production time		Plant height		Quality		Energy consumption	Mean room temperature
		Day/night	Days	LSD	cm	LSD		LSD	MJ/plant	°C
Winter experiment										
Chrysanthemum	+	18°/18°C	59	1.6	17	ns	4.6	0.2	13.9	18.1
		14°/22°C	63		17		4.3		15.4	19.8
	–	18°/18°C	58	ns	27	1.7	3.0	ns	13.7	18.1
		14°/22°C	60		25		3.0		14.7	19.8
Kalanchoë	+	18°/18°C	125	6.0	12	ns	4.5	ns	31.4	18.1
		14°/22°C	109		13		4.8		26.8	19.4
	–	18°/18°C	118	4.6	17	1.2	4.8	0.3	29.6	18.1
		14°/22°C	102		22		3.1		25.1	19.5
Spring experiment										
Chrysanthemum	+	18°/18°C	63	3.0	16	1.3	4.9	ns	16.8	18.3
		14°/22°C	68		18		4.9		15.7	18.5
	–	18°/18°C	61	2.4	31	ns	3.0	ns	16.5	18.3
		14°/22°C	69		30		3.1		15.8	18.5
Kalanchoë	+	18°/18°C	81	2.1	17	0.6	5.0	ns	17.3	19.3
		14°/22°C	77		18		4.9		15.0	19.3
	–	18°/18°C	81	3.9	23	ns	3.2	0.2	17.3	19.3
		14°/22°C	77		25		3.0		15.0	19.3
Begonia	+	18°/18°C	84	ns	15	ns	3.7	ns	30.4	18.9
		14°/22°C	83		15		3.7		26.7	18.9
	–	18°/18°C	80	ns	22	ns	4.1	ns	29.6	18.7
		14°/22°C	79		22		4.2		26.0	18.8
Hedera		18°/18°C	53	3.9	–		4.5	ns	8.8	18.4
		14°/22°C	57		–		4.6		8.2	18.5
Ficus		18°/18°C	73	ns	–		4.4	ns	20.9	19.0
		14°/22°C	78		–		4.1		19.5	19.2

+: Sprayed with growth retardant. –: No growth retardant.

Energy consumption

The energy consumption per plant for *Chrysanthemum* was larger at 14°/22°C in the winter experiment. This is due to a higher energy consumption in this greenhouse in November 1987 (2) in combination with a longer production time (Table 1).

For all other plant species the energy consumption was lower in the greenhouse with 14°/22°C. This is true even for *Hedera* and *Chrysanthemum* in the spring experiment, where the production time was longer in this treatment.

Growth regulation
14°/22°C did not show the expected reduction of plant height for non sprayed plants (Table 1).

Plant height
There is no significant difference in plant height for growth retarded plants between the two temperature treatments in the winter experiment (Table 1).

Growth retarded *Chrysanthemum* and *Kalanchoë* were slightly lower at 18°/18°C in the spring experiment.

Number of flowers
Chrysanthemum plants had a significant higher number of flowers and buds at 14°/22°C (Fig. 1).

Further, spraying with daminozide increased the number of flowers in the darkest time of the year (winter experiment).

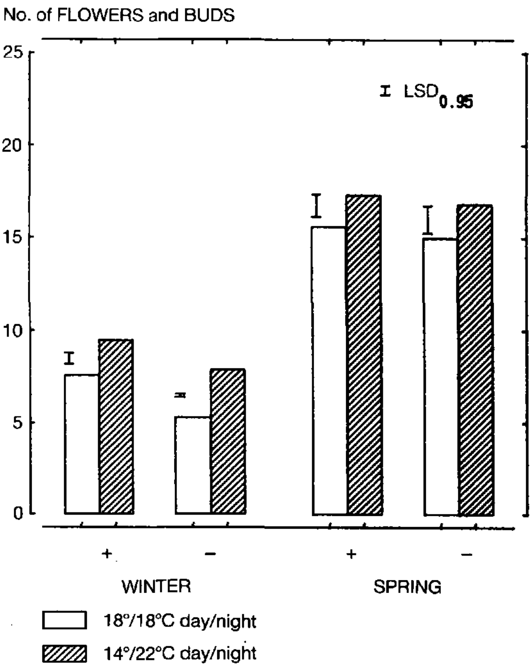

Fig. 1. Number of flowers and buds on Chrysanthemum.
+: sprayed with growth retardant.
−: no growth retardant.

Leaf damages
There was no significant difference in the number of plants with leaf damages for growth retarded *Begonia* but the number of plants with leaf damages was high and this resulted in plants of poor quality (Table 1).

There was no leaf drop or leaf damages at all for *Ficus* in any of the treatments.

Length of internodes
There was no difference in internode length for retarded *Chrysanthemum* (Table 2). However the internode length of *Hedera* was significantly shorter at 14°/22°C.

Number of laterals
The average number of laterals longer than 1 cm for *Ficus* was identical (11.1) for both treatments.

Plant quality
14°/22°C had no great effect upon plant quality in general (Table 1). However the quality of the non growth retarded *Kalanchoë* in the winter experiment was very bad as compared to 18°/18°C.

The quality was high for growth retarded *Chrysanthemum*, growth retarded *Kalanchoë*, *Hedera* and *Ficus*.

Table 2. Length of internodes.

Plant species		Treatment Day/night	Length of internodes cm	LSD
Winter experiment				
Chrysanthemum	+	18°/18°C	1.2	ns
		14°/22°C	1.3	
	−	18°/18°C	1.9	0.1
		14°/22°C	1.7	
Spring experiment				
Chrysanthemum	+	18°/18°C	1.1	ns
		14°/22°C	1.2	
	−	18°/18°C	2.0	ns
		14°/22°C	1.9	
Hedera		18°/18°C	2.2	0.2
		14°/22°C	1.8	

+: Sprayed with growth retardant. −: No growth retardant.

Discussion and conclusion

Growth regulation

The treatment 14°/22°C did not result in a pronounced reduction of plant height for plants not treated with growth retardants. Therefore it is necessary to apply growth retardants to *Chrysanthemum* and *Kalanchoë* to obtain adequate quality.

Chrysanthemum

The production time of *Chrysanthemum* was increased when the plants were grown at 14°/22°C (Table 1).

In similar experiments (5) a reduction in production time of *Chrysanthemum* 'Garland' was found when the plants were grown at 14°/22°C day/night as compared to 18°/18°C. However, on an average of seven cultivars the same authors found the shortest production time at 18°/18°C. The experimental conditions were not identical.

It has been shown that the average temperature determines the time until flowering (3). In our experiments, the higher mean room temperature at 14°/22°C did not lead to a reduction in production time.

The plant height of non growth retarded *Chrysanthemum* was lowest at 14°/22°C in the winter experiment. The lower plants at 14°/22°C of non growth retarded *Chrysanthemum,* resulted in slightly shorter internodes. This is in agreement with results of other authors (3, 5, 8). *Chrysanthemum* produced more flowers at 14°/22°C. Other authors (3) reported the same at a night length of 8 hours and a mean room temperature of 15°C.

It may be concluded from this experiment that it is possible to produce *Chrysanthemum* with a temperature control strategy which reduces energy consumption peaks at dawn and dusk. Plant quality will not be affected provided growth retardant are applied to secure a good quality. A delay of about four days in production time must be accepted.

Kalanchoë

The production time of *Kalanchoë* was reduced by 4 to 16 days when the plants were grown at 14°/22°C (Table 1). The greatest reduction was found in the winter experiment and it may be a mixed effect of 14°/22°C and a higher mean room temperature (1.3°C). There was no difference in mean room temperature in the spring experiment and the reduction in production time was only four days. The mean room temperature appears to be the most important factor in reducing the production time of *Kalanchoë.* A similar reduction in production time was reported, when *Kalanchoë* was grown at 17°/21°C day/night as compared to 17°/17°C (6).

The height of inflorescences of non growth retarded *Kalanchoë* was increased against all expectations at 14°/22°C in the winter experiment (Table 1). This resulted in plants of poor quality in contrast to 18°/18°C. The mean room temperature was 1.3°C higher here as compared to 18°/18°C (Table 1). This may be the reason for the increased stem elongation. However, the high night temperature 17°/21°C did not affect the plant quality in similar experiments (6).

There was no significant difference in the height of inflorescences of non growth retarded *Kalanchoë* in the spring experiment and the plants were very tall. As a consequence the quality was poor in both treatments.

There was no significant difference in plant quality of growth retarded *Kalanchoë* and both treatments produced excellent plants in the winter and spring experiment.

It may be concluded from this experiment that it is possible to produce *Kalanchoë* with a temperature control strategy which reduces energy consumption peaks at dawn and at dusk. Plant quality will not be affected provided growth retardant are applied to secure a good quality. A considerable reduction in production time may be expected.

Begonia

There was no significant difference in production time, plant height, number of leaf damages and quality for *Begonia.* The quality was bad in the growth retarded *Begonia* due to a high number of leaf damages.

It may be concluded from this experiment that it is possible to produce *Begonia* with a temperature control strategy which reduces energy consumption peaks at dawn and at dusk. Plant quality and production time will not be effected.

Hedera

The production time of *Hedera* was increased by four days when the plants were grown at 14°/22°C.

There was no significant difference in the plant quality but the internode length of the plants were shorter at 14°/22°C.

It may be concluded from this experiment that it is possible to produce *Hedera* with a temperature control strategy which reduces energy consumption peaks at dawn and at dusk. Plant quality will not be affected but a delay of about four days in production time must be accepted.

Ficus

There was no significant difference in production time, number of side shoots and quality of *Ficus*.

It may be concluded from this experiment that it is possible to produce *Ficus* with a temperature control strategy which reduces energy consumption peaks at dawn and at dusk. Plant quality will not be affected and no significant delay in production time may be expected.

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